CAPE CANAVERAL AIR FORCE STATION, LAUNCH COMPLEX 39, THERMAL PROTECTION SYSTEM FACILITY
(John F. Kennedy Space Center)
North of the Orbiter Towway, East of Kennedy Parkway North
Cape Canaveral
Brevard County
Florida

HAER No. FL-8-11-L

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
U.S. Department of the Interior
100 Alabama Street, SW
Atlanta, GA 30303

HISTORIC AMERICAN ENGINEERING RECORD

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HAER No. FL-8-11-L

Location:	North of the Orbiter Towway, east of Kennedy Parkway North John F. Kennedy Space Center Cape Canaveral Brevard County Florida U.S.G.S. 7.5. minute Orsino, Florida, quadrangle, Universal Transverse Mercator coordinates: 17.533715.3162079
Date of Construction:	1986-1988
Architect:	Jacobs Engineering Group, Lakeland, Florida
Builder:	Holloway Construction, Titusville, Florida
Present Owner:	National Aeronautics and Space Administration (NASA) Kennedy Space Center, FL 32899-0001
Present Use:	Aerospace Facility-manufacturing spacecraft thermal protection systems
Significance:	The Thermal Protection System Facility (TPSF) is considered eligible for listing in the National Register of Historic Places (NRHP) in the context of the U.S. Space Shuttle program (1969-2010) under Criterion A in the area of Space Exploration. Because it has achieved significance within the past 50 years, Criteria Consideration G applies. The TPSF is significant as one of only two NASA-owned assets constructed exclusively to house the manufacture and repair of the space shuttle's thermal protection and thermal control systems, essential to the success of the Space Shuttle program. Additionally, the TPSF is considered a contributing resource to the NRHP-eligible Orbiter Processing Historic District.
Project Information:	The documentation of the Cape Canaveral Air Force Station, Launch Complex 39, Thermal Protection System Facility was conducted in 2010 for the John F. Kennedy Space Center (KSC) by Archaeological Consultants, Inc. (ACI), under contract to Innovative Health Applications (IHA), and in accordance with KSC's Programmatic Agreement (PA) Regarding Management of Historic Properties, dated May 18, 2009. The

field team consisted of architectural historian, Patricia Slovinac (ACI), and photographer, Penny Rogo Bailes. Assistance in the field was provided by Shannah Trout, IHA's Cultural Resource Specialist. The written narrative was prepared by Ms. Slovinac; it was edited by Joan Deming, ACI Project Manager; Elaine Liston, KSC Archivist; Barbara Naylor, KSC Historic Preservation Officer; and Ms. Trout. The photographs and negatives were processed by Bob Baggett Photography, Inc.

The Scope of Services for the project, which was compiled based on the PA, specifies a documentation effort following HAER Level II Standards. Information for the written narrative was primarily gathered through informal interviews with current NASA and contractor personnel and research materials housed at the KSC Archives Department. Selected drawings were provided by KSC's Engineering Documentation Center, which serves as the repository for all facility drawings. The available drawings for the TPSF included the "as-built" drawings, as well as those depicting major modification to the facility, or any small modifications that required a set of drawings (such as changes to the electrical or mechanical systems). KSC does not periodically produce drawings of their facilities to show current existing conditions.

Report Prepared by: Patricia Slovinac, Architectural Historian
Archaeological Consultants, Inc.
8110 Blaikie Court, Suite A
Sarasota, Florida 34240

Date: April 2011

LIST OF ACRONYMS

CCAFS	Cape Canaveral Air Force Station
ET	External Tank
F	Fahrenheit
FIB	Flexible Insulation Blanket
FRCI	Fibrous Refractory Composite Insulation
FRSI	Felt Reusable Surface Insulation
HRSI	High-Temperature Reusable Surface Insulation
ISS	International Space Station
JSC	Johnson Space Center
KSC	Kennedy Space Center
LC	Launch Complex
LRSI	Low-Temperature Reusable Surface Insulation
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NRHP	National Register of Historic Places
OPF	Orbiter Processing Facility
OV	Orbiter Vehicle
RTV	Room-Temperature Vulcanizing (silicon adhesive)
SIP	Strain Isolator Pad
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
STS	Space Transportation System
TCS	Thermal Control System
TPS	Thermal Protection System
TPSF	Thermal Protection System Facility
TUFI	Toughened Uni-piece Fibrous Insulation
U.S.	United States
VAB	Vehicle Assembly Building

HISTORICAL INFORMATION

NASA's John F. Kennedy Space Center

The John F. Kennedy Space Center (KSC) is the National Aeronautics and Space Administration's (NASA) primary Center for launch and landing operations, vehicle processing and assembly, and related programs in support of manned space missions. It is located on the east coast of Florida, about 150 miles south of Jacksonville, and to the north and west of Cape Canaveral, in Brevard and Volusia Counties, and encompasses almost 140,000 acres. The Atlantic Ocean and Cape Canaveral Air Force Station (CCAFS) are located to the east, and the Indian River is to the west.

Following the launch of Sputnik I and Sputnik II, which placed Soviet satellites into Earth's orbit in 1957, the attention of the American public turned to space exploration. President Dwight D. Eisenhower initially assigned responsibility for the U.S. Space Program to the Department of Defense. The Development Operations Division of the Army Ballistic Missile Agency, led by Dr. Wernher von Braun, began to focus on the use of missiles to propel payloads, or even a man, into space. The United States successfully entered the space race with the launch of the Army's scientific satellite Explorer I on January 31, 1958 using a modified Jupiter missile named Juno I.[1]

With the realization that the military's involvement in the space program could jeopardize the use of space for peaceful purposes, President Eisenhower established NASA on October 1, 1958 as a civilian agency with the mission of carrying out scientific aeronautical and space exploration, both manned and unmanned. Initially working with NASA as part of a cooperative agreement, President Eisenhower officially transferred to NASA a large portion of the Army's Development Operations Division, including the group of scientists led by von Braun, and the Saturn rocket program.[2]

NASA became a resident of Cape Canaveral in 1958 when the Army Missile Firing Laboratory, then working on the Saturn rocket project under the direction of Kurt Debus, was transferred to the agency. Several Army facilities at CCAFS were given to NASA, including various offices and hangars, as well as Launch Complexes (LC) 5, 6, 26, and 34. The Missile Firing Laboratory was renamed Launch Operations Directorate and became a branch office of Marshall Space Flight Center (MSFC). As the American space program evolved, the responsibilities of the Launch Operations Directorate grew, and NASA Headquarters separated the Directorate from

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[1] Charles D. Benson and William B. Faherty. *Gateway to the Moon. Building the Kennedy Space Center Launch Complex* (Gainesville, University Press of Florida, 2001), 1-2.
[2] Benson and Faherty, *Gateway*, 15.

MSFC, officially designating it an independent field installation called the Launch Operations Center.[3]

In May 1961, President John F. Kennedy charged NASA and the associated industries to develop a space program that would surpass the Soviet program by landing a man on the Moon by the end of the decade. With the new, more powerful Saturn V rocket and the accelerated launch schedule, it was apparent that a new launch complex was required, and CCAFS, with twenty-two launch complexes, did not have the space for new rocket facilities. Merritt Island, an undeveloped area west and north of the Cape, was selected for acquisition, and in 1961 the Merritt Island Launch Area (which, with the Launch Operations Center, would become KSC) was born. In that year, NASA requested from Congress authority to purchase 80,000 acres of property, which was formally granted in 1962. The U.S. Army Corps of Engineers acted as agent for purchasing the land, which took place between 1962 and 1964. NASA began gaining title to the land in late 1962, taking over 83,903.9 acres by outright purchase, which included several small towns, such as Orsino, Wilson, Heath and Audubon, many farms, citrus groves, and several fish camps. Negotiations with the State of Florida provided submerged lands, resulting in the acquisition of property identified on the original Deed of Dedication. Much of the State-provided land was located south of the Old Haulover Canal and north of the Barge Canal.

The American program to put a man in space and land on the Moon proceeded rapidly with widespread support. In November 1963, the Launch Operations Center and Merritt Island Launch Area were renamed John F. Kennedy Space Center to honor the late President.[4] The space program was organized into three phases: Projects Mercury, Gemini, and Apollo. Project Mercury, initiated in 1958, was executed in less than five years. Begun in 1964, Project Gemini was the intermediate step toward achieving a manned lunar landing, bridging the gap between the short-duration Mercury flights and the long-duration missions proposed for the Apollo Program.[5]

Apollo, the largest and most ambitious of the manned space programs, had as its goal the landing of astronauts on the Moon and their safe return to Earth. Providing the muscle to launch the spacecraft was the Saturn family of heavy vehicles. Saturn IB rockets were used to launch the early unmanned Apollo test flights and the first manned flight, Apollo 7, which carried astronauts on a ten-day earth orbital mission.[6]

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[3] Benson and Faherty, *Gateway*, 136.
[4] Harry A Butowsky. *Reconnaissance Survey: Man in Space* (Washington, D.C.: National Park Service, 1981), 5; Benson and Faherty, *Gateway*, 146.
[5] Butowsky, 5.
[6] Butowsky, 5.

Three different launch vehicles were used for Apollo: Saturn I, Saturn IB and Saturn V; and three different launch complexes were involved: LC 34 and LC 37 on CCAFS, and LC 39 on KSC (only LC 39 is still active). Altogether, thirty-two Saturn flights occurred (seven from LC 34, eight from LC 37, and seventeen from LC 39, including Skylab and the Apollo-Soyuz Test Project) during the Apollo era. Of the total thirty-two, fifteen were manned, and of the seven attempted lunar landing missions, six were successful. No major launch vehicle failures of either Saturn IB or Saturn V occurred. There were two major command/service module failures, one on the ground (Apollo 1) and one on the way to the Moon (Apollo 13).[7]

The unmanned Apollo 4 mission, which lifted off on November 9, 1967, was the first Saturn V launch and the first launch from LC 39 at KSC. On July 20, 1969, the goal of landing a man on the Moon was achieved when Apollo 11 astronauts Armstrong, Aldrin, and Collins successfully executed history's first lunar landing. Armstrong and Aldrin walked on the surface of the Moon for two hours and thirty-one minutes, and collected 21 kilograms of lunar material. Apollo 17 served as the first night launch in December 1972. An estimated 500,000 people viewed the liftoff, which was the final launch of the Apollo Program.[8]

Skylab, an application of the Apollo Program, served as an early type of space station. With 12,700 cubic feet of work and living space, it was the largest habitable structure ever placed in orbit, at the time. The station achieved several objectives: scientific investigations in Earth orbit (astronomical, space physics, and biological experiments); applications in Earth orbit (earth resources surveys); and long-duration spaceflight. Skylab 1 orbital workshop was inhabited in succession by three crews launched in modified Apollo command/service modules (Skylab 2, 3 and 4). Actively used until February 1974, Skylab 1 remained in orbit until July 11, 1979, when it re-entered Earth's atmosphere over the Indian Ocean and Western Australia after completing 34,181 orbits.[9]

The Apollo-Soyuz Test Project of July 1975, the final application of the Apollo Program, marked the first international rendezvous and docking in space, and was the first major cooperation between the only two nations engaged in manned space flight. As the first meeting of two manned spacecraft of different nations in space, first docking, and first visits by astronauts and cosmonauts into the others' spacecraft, the event was highly significant. The Apollo-Soyuz Test Project established workable joint docking mechanisms, taking the first steps toward mutual rescue capability of both Russian and American manned missions in space.[10]

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[7] NASA. *Facts: John F. Kennedy Space Center* (1994), 82.
[8] NASA. *Facts*, 86-90.
[9] NASA. *Facts*, 91.
[10] NASA. *Facts*, 96.

On January 5, 1972, President Nixon delivered a speech 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."[11] The Space Task Group, previously established by President Nixon in February 1969 to recommend a future course for the U.S. Space Program, presented three choices of long-range space plans. All included an Earth–orbiting space station, a space shuttle, and a manned Mars expedition.[12] Although none of the original programs presented was eventually selected, NASA implemented a program, shaped by the politics and economic realities of its time that served as a first step toward any future plans for implementing a space station.[13]

During this 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 to the Manned Spacecraft Center (now known as the Johnson Space Center [JSC]) in Houston, Texas, based on the Center's experience. MSFC in Huntsville, Alabama was responsible for development of the Space Shuttle Main Engine (SSME), the SRBs, the ET, and for all propulsion-related tasks. Engineering design support continued at JSC, MSFC and NASA's Langley Research Center, in Hampton, Virginia, and engine tests were to be performed at NASA's National Space Technology Laboratories (later named Stennis Space Center) in south Mississippi, and at the Air Force's Rocket Propulsion Laboratory in California, which later became the Santa Susana Field Laboratory.[14] NASA selected KSC as the primary launch and landing site for the Space Shuttle program. KSC, responsible for designing the launch and recovery facilities, was to develop methods for shuttle assembly, checkout, and launch operations.[15]

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

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[11] Marcus Lindroos. "President Nixon's 1972 Announcement on the Space Shuttle." (NASA Office of Policy and Plans, NASA History Office, updated 14 April 2000).
[12] NASA, History Office, NASA Headquarters. "Report of the Space Task Group, 1969."
[13] Dennis R. Jenkins. *Space Shuttle, The History of the National Space Transportation System. The First 100 Missions* (Cape Canaveral, Florida: Specialty Press, 2001), 99.
[14] Jenkins, 122.
[15] 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.

assembly of this orbiter had started more than two years earlier in June 1974 at Air Force Plant 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 aimed at checking out both the mating with the Boeing 747 Shuttle Carrier Aircraft (SCA) for ferry operations, as well as the orbiter's unpowered landing capabilities.

The first orbiter intended for spaceflight, *Columbia* (OV-102), arrived at KSC from Air Force Plant 42 in March 1979. Originally scheduled for liftoff 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 Launch Pad 39A before finally lifting off on April 12, 1981. Flight No. 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 (EAFB) in California. This launch demonstrated *Columbia's* ability to fly into orbit, conduct on-orbit operations, and return safely.[16] *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 percent of its objectives accomplished. After the end of the fourth mission, President Reagan declared that with the next flight the Shuttle would be "fully operational."

By the end of the Space Shuttle program, a total of 135 missions will have been launched from KSC. 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 Space Shuttle program has launched a number of planetary and astronomy missions including the Hubble Space Telescope, 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.[17] The first Spacelab mission, carried aboard *Columbia* (Flight No. STS-9), began on November 28, 1983. Four Spacelab missions were flown between 1983 and 1985. Following a stand-down in the aftermath of the *Challenger* disaster, the next Spacelab mission was not launched until 1990. In total, twenty-four

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[16] Jenkins, 268.
[17] NASA. *NASA Shuttle Reference Manual* (1988).

space shuttle missions carried Spacelab hardware before the program was decommissioned in 1998.[18] In addition to astronomical, atmospheric, microgravity, and life sciences missions, Spacelab was also used as a supply carrier to the Hubble Space Telescope 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* was launched in February 1986 and remained in orbit until March 2001.[19] 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). 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*. In 1995, Dr. Norman Thagard was the first American to live aboard the Russian space station. Over the next three years, six more U.S. astronauts served tours on *Mir*. The shuttle served as a means of transporting supplies, equipment and water to the space station in addition to performing a variety of other mission tasks, many of which involved earth science experiments. It returned to Earth experiment results and unneeded equipment. The Shuttle-*Mir* program served to acclimate the astronauts to living and working in space. Many of the activities carried out were types they would perform on the ISS.[20]

On December 4, 1999, *Endeavour* (STS-88) launched the first component of the ISS into orbit. 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."[21] STS-96, 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 Space Shuttle program.

The Space Shuttle program suffered two major setbacks with the tragic losses of the *Challenger* and *Columbia* on January 28, 1986 and February 1, 2003, respectively. Following the *Challenger* accident, the program 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 Space Shuttle program, concluded "that the drive to declare the Shuttle operational had put enormous pressures on the system and stretched its resources to the limit".[22] In addition to mechanical failure, the Commission noted a number of

[18] STS-90, which landed on 3 May 1998, was the final Spacelab mission. NASA KSC. "Shuttle Payloads and Related Information." KSC Factoids. Revised 18 November 2002.
[19] Tony Reichhardt (editor). *Space Shuttle, The First 20 Year.* (Washington, D.C.: Smithsonian Institution, 2002), 85.
[20] 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.
[21] Williamson, 191.
[22] Columbia Accident Investigation Board. *Report Volume I* (August 2003), 25.

NASA management failures that contributed to the catastrophe. As a result, among the tangible actions taken were extensive redesign of the SRBs; upgrading 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 Space Shuttle program. NASA moved the management of the program from JSC to NASA Headquarters, with the aim of preventing communication deficiencies.[23] 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.[24] In 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.[25] The launch of *Discovery* (STS-26) from KSC Pad 39B on September 29, 1988 marked a Return to Flight after a thirty-two-month stand-down 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, which determined that both technical and management conditions accounted for the loss of the orbiter and crew. According to the Board's 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.[26] NASA spent more than two years researching and implementing safety improvements for the orbiters, SRBs and ET. Following a two-year stand-down, the launch of STS-114 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. . .*[27]

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[23] CAIB, 101.
[24] Cliff Lethbridge. "History of the Space Shuttle program." (2001), 4.
[25] Lethbridge, 5.
[26] CAIB, 9.
[27] The White House. "A Renewed Spirit of Discovery – The President's Vision for Space Exploration." (January 2004).

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.[28] As part of this initiative, NASA will continue to use the space shuttle to complete assembly of the ISS. The Shuttle will not be upgraded to serve beyond 2010 and, after completing the ISS, the Space Shuttle program will be retired.

[28] NASA Headquarters. "The Vision for Space Exploration." (February 2004).

Development of KSC's LC 39 and VAB Areas

Today, KSC maintains operational control over 3,800 acres, all located in Brevard County. The major facilities are located within the Industrial Area, the LC 39 Area, the VAB Area, and the Shuttle Landing Facility Area. The LC 39 and VAB Areas were developed primarily to support launch vehicle operations and related launch processing activities. They contain the VAB, the Launch Control Center, the OPFs, the two Launch Pads, A and B, and other support facilities.

Following completion of the Apollo-Soyuz Test Project in 1975, the facilities at KSC were modified to support the Space Shuttle program. KSC was originally one of three possible launch sites evaluated, along with Vandenberg Air Force Base in California and the White Sands Missile Range in New Mexico. Compared with the other two locations, KSC had the advantage of approximately $1 billion in existing launch facilities. Thus, less time and money would be needed to modify existing facilities at KSC rather than to build new ones at another location. The estimate of $200 to $400 million to modify the existing KSC facilities was roughly half the cost of new construction. In addition, only KSC had abort options for a first revolution return of the low cross-range orbiter.[29]

To help keep costs down, beginning ca. 1976, KSC engineers adapted and modified many of the Apollo launch facilities to serve the needs of the Space Shuttle program. Among the key facilities undergoing change were the VAB, the Launch Control Center, and LC 39 Pads A and B. New facilities were constructed only when a unique requirement existed. The major new structures included the Shuttle Landing Facility and the OPFs. Multi-million dollar contracts for design and construction were awarded to both national and local firms, including Reynolds, Smith and Hills of Jacksonville, Florida; the Frank Briscoe Company, Inc. of East Orange, New Jersey; Algernon Blair Industrial Contractors, Inc. of Norcross, Georgia; the Holloway Corporation of Titusville, Florida; and W&J Construction Corporation of Cocoa, Florida.

Alterations to the VAB included modification of two of the four high bays for assembly of the space shuttle vehicle, and changes to the other two high bays to accommodate the processing and stacking of the SRBs and ET. The north doors were widened by almost 40' to permit entry of the towed orbiter. Work platforms shaped to fit the shuttle configuration were added to High Bays 1 and 3 where shuttle assembly takes place, and internal structural changes were also made to High Bays 2 and 4, where the ETs are processed.

Major changes were made to LC 39, Pads A and B. Modifications were completed in mid-1978 at Pad A and in 1985 at Pad B. With the exception of the six fixed pedestals which support the Mobile Launcher Platform, all of the structures on the hardstands of each pad were removed or relocated. Fuel, oxidizer, high-pressure gas, electrical, and other service lines were rerouted.

[29] Jenkins, 112.

New hypergolic fuel and oxidizer support areas were constructed at the southwest and southeast corners, respectively, of the pads; the Saturn fuel support area was removed, a new Fixed Service Structure was erected using an original Apollo-era Launch Umbilical Tower, a Rotating Service Structure was added, the Saturn flame deflectors were replaced, and a Payload Changeout Room and a Payload Ground Handling Mechanism were added. A sound suppression water system was installed on the pads to reduce the acoustical levels within the orbiter's payload and thus, to protect it and its payloads from damage. A related system, the Overpressure Suppression System, was installed to reduce the pressure pulse at SRB ignition.[30]

Additional changes were made to Pad A and Pad B in the aftermath of the 1986 *Challenger* accident; other modifications followed the Return to Flight in 1988. Among the modifications were the installation of new weather protection structures to supplement the Rotating Service Structure; improvements in temperature and humidity controls for the Payload Changeout Room; upgrades to the emergency exit system, including the addition of two slidewire baskets; installation of new elevators on the Rotating Service Structure; and improvements to the pad communications system. Changes were first made at Pad B, followed by identical changes at Pad A.

The Thermal Protection System Facility

The Thermal Protection System Facility (TPSF) is considered to be individually eligible for listing in the NRHP under Criterion A in the area of Space Exploration, as a contributing resource to the Historic Cultural Resources of the John F. Kennedy Space Center multiple property submission in the context of the U.S. Space Shuttle Program (ca. 1969-2011). Because it has achieved significance within the past 50 years, Criteria Consideration G applies. In addition to its individual eligibility, the TPSF is considered a contributing resource to the Orbiter Processing Historic District. The period of significance for the TPSF is from 1988, the date of its completed construction, through 2011, the designated end of the Space Shuttle Program. The TPSF is significant as one of only two NASA-owned assets constructed for the exclusive purpose of manufacturing and repairing elements of the Space Shuttle's thermal protection and thermal control systems, which include tiles, gap fillers, and insulation blankets, as well as coatings and adhesives.

A major emphasis of the Space Shuttle program was cost effectiveness through the reusability of vehicle elements. The TPS protected the orbiter vehicle upon reentry into the Earth's atmosphere, when its surface temperatures could reach as high as 3,000 degrees Fahrenheit, as well as the extremely cold conditions experienced during the night phase of each orbit.[31] As with

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[30] Wallace H. Boggs and Samuel T. Beddingfield. "Moonport to Spaceport. The Changing Face at KSC." *Astronautics & Aeronautics,* July-August 1982, 28-41.
[31] NASA. *NASA Facts: Orbiter Thermal Protection System*. FS-2004-09-014-KSC. September 2004.

any repeatedly used item, the different TPS components were subject to "wear and tear," especially due to the harsh conditions to which the vehicle was subjected, as well as impact damage from debris and other materials. The TPSF provided a facility at KSC where a TPS component could be repaired, or if necessary, its replacement could be manufactured.

The Thermal Protection System for the Space Shuttle Orbiters

A spacecraft's reentry in the Earth's atmosphere creates very large heat loads and aerodynamic forces that could compromise the structural integrity of a spacecraft (as with the *Columbia* accident in February 2003). NASA's first space programs, Mercury, Gemini, and Apollo, used ablative heat shields, which by their nature, were not reusable. By 1970, with development of the space shuttle underway, NASA sought a type of heat shield that would be reusable. One of the alternate reusable heat shields under consideration was known as reusable surface insulation (RSI), which led directly to the development of thermal ceramic tiles.

Lockheed-Martin's research center in Palo Alto, California, had undertaken research and development for this type of thermal protection shield, beginning in the early 1960s. By 1970-1971, they had a functioning plant to manufacture silica-based RSI tiles. Experimentation for improved tile materials continued, and in late 1972 NASA ran a series of tests at several of its centers. At JSC, Lockheed's tiles were the only ones that survived the final series of thermal-acoustic tests.[32] Thus, Rockwell International, the prime orbiter contractor, awarded Lockheed the subcontract for producing most of the shuttle's TPS. Manufacturing of the tiles for the space shuttle began at Lockheed's Sunnyvale, California, plant in 1976, with the first shipment in early 1977. In the mid-1980s, Rockwell took over the manufacture of TPS materials in Palmdale, California.

Since the orbiter's Approach and Landing Test program occurred entirely within the Earth's atmosphere, Rockwell used Styrofoam tiles on the *Enterprise*, as was acceptable for the spacecraft's role as a test vehicle. Therefore, *Columbia* was the first shuttle to be fitted with the new thermal tiles. Since the tiles were extremely fragile, each was fitted with a Strain Isolator Pad (SIP), which would be placed against the skin of the shuttle. During tile installation, NASA encountered major challenges in the tile adhesive process, with many tiles not passing the required "pull test," meant to ensure that they would not fall off the vehicle during launch. A TPS team was created, with the single purpose of solving the tile-bonding problem. Their solution was the development of a slurry coating, which was applied to the underside of the tile; the process became known as "tile densification."[33]

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[32] Jenkins, 237-238; Joan Lisa Bromberg. *NASA and the Space Industry* (Baltimore: Johns Hopkins University Press, 1999, 100.
[33] George Diller. "Reyes' team met tile challenges." *Spaceport News* (40, 8), April 12, 2001: 3.

As initially designed, *Columbia's* TPS was comprised of over 33,000 tiles that covered most of the structure, with some Felt Reusable Surface Insulation (FRSI) blankets over portions of the upper wing surfaces and mid-fuselage. NASA testing and evaluation of the tiles, as well as other forms of thermal protection, continued through the 1970s, especially at the Ames Research Center in California. Following the initial delivery of *Columbia* and the assembly of *Challenger*, a newer blanket called Advanced FRSI, or Fibrous Insulation Blanket (FIB), was used generously as a replacement for LRSI tiles on *Discovery* and *Atlantis*. By the time *Endeavour* was assembled, its TPS contained roughly 26,000 tiles.

Presently, the space shuttle orbiter's TPS system is comprised of three base components: Reinforced Carbon-Carbon panels, insulation tiles, and "softgoods." Reinforced Carbon-Carbon is used to protect areas subjected to extreme temperatures (more than 2300 degrees Fahrenheit [F]), as well as high aerodynamic forces during launch and reentry. Such areas include the nose cap, the wing leading edges, and the area around the forward orbiter/ET structural attachment.

The insulation tiles on the orbiter take four different forms, High-Temperature Reusable Surface Insulation (HRSI) tiles, Low-Temperature Reusable Surface Insulation (LRSI) tiles, Fibrous Refractory Composite Insulation (FRCI) tiles, and Toughened Uni-piece Fibrous Insulation (TUFI) tiles. HRSI tiles, which protect against temperatures less than 2300 degrees F, are typically used on the underside of the orbiter and portions of the forward fuselage, vertical stabilizer, orbital maneuvering system pods, body flap, and elevons. Some areas of the orbiter that were originally fitted with HRSI tile, are now shielded with FRCI tile, which is about 10 percent lighter in weight; TUFI tiles have replaced HRSI tiles on areas such as the body flap and base heat shield.[34] All three of these tile types are painted black for maximum heat loss during reentry. LRSI tiles are used on select areas of the forward, mid-, and aft fuselages, as well as portions of the orbital maneuvering system pods, vertical tail, and upper wing surfaces, all of which are areas where temperatures are less than 1200 degrees F. These tiles are painted white to provide thermal control for the vehicle while it is in orbit.

All of the tile materials arrive at KSC in the form of a large block, known as a production unit. HRSI and LRSI tiles are made from a slurry of silica glass fibers and water, and have a density of either 9 pounds per cubic foot or 22 pounds per cubic foot; only 10 percent of the total volume is solid material. This material was developed by Lockheed Missiles and Space Company in Sunnyvale, California; the company still manufactures the production units. FRCI tiles are composed from a slurry made with silica glass fibers, Nextel, and water, and have a density of 12 pounds per cubic foot.[35] TUFI tiles are made of the same base materials as the HRSI and LRSI tiles, but use a stronger surface coating that actually permeates the core of the tile. Both FRCI

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[34] NASA, *Thermal Protection System.*
[35] Nextel is the trademark name for an alumino-boro-silicate fiber developed by the 3M Company.

and TUFI were developed by NASA's Ames Research Center, and the production units are manufactured at Lockheed's Sunnyvale plant.

In the language of TPS, the term "softgoods" is used to refer to TPS insulation blankets, gap fillers, thermal barriers, and thermal control blankets. There are two different styles of TPS insulation blankets: FRSI blankets and FIBs, which are also known as Advanced FRSI blankets. FRSI blankets, like SIPs, are comprised of Nomex felt[36] that is then coated with a silicone rubber paint; they are used on the upper surfaces of both the payload bay doors and the wings. FIBs are made by placing a core of pure silica felt in between a layer of silica fabric (outer side) and a layer of glass fabric. These blankets, which range in thickness from 0.33" to 2.04", are used on the sides and upper wing surfaces of the orbiter, as well as portions of the upper forward fuselage. They are considered a replacement for LRSI tiles.[37]

Due to the different thermal expansion properties of the orbiter's airframe and TPS tiles, gaps are left in between the individual tiles to accommodate for the materials' expansion and contraction; however, these gaps cannot be too large, or hot gases will seep through during reentry and cause severe damage. Thus, gap fillers were created to reconcile the need for gaps, while minimizing their size and also providing some padding between the tiles. Gap fillers are made of Nomex felt and are typically 0.75" wide. Thermal barriers operate in a similar fashion to gap fillers, by filling space left between TPS components and orbiter features, such as the landing gear doors or the crew hatch. They are typically made with ceramic cloth wrapped around a tubular spring.[38]

The fourth type of softgood is a Thermal Control System (TCS) blanket, which is applied to the inner surfaces of the payload bay to help regulate the temperatures of the orbiter's systems and components.[39] There are two types of TCS blankets. The first is called a fibrous bulk blanket, and is made with a core of fibrous materials that has a density of 2 pounds per cubic foot, which is encased with a layer of Kapton.[40] The second type of TCS blanket is the multilayer blanket, which is formed from alternate layers of reflective Kapton film and Dacron net separators.[41]

Construction of the TPSF

In March 1979, the first orbiter destined to fly in space, *Columbia*, arrived at KSC, missing roughly 7,800 of its TPS tiles and nearly all of its tiles requiring the densification process.[42] While the orbiter was placed in High Bay No. 1 of the OPF for processing, High Bay No. 2 of

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[36] Nomex is the trademark name for a rigid, heat resistant felt manufactured by DuPont.
[37] Jenkins, 400-401; NASA, *Thermal Protection System*, 3-5.
[38] Jenkins, 402.
[39] Jenkins, 402; Kevin Harrington. Personal communication with Patricia Slovinac, KSC, TPSF, March 9, 2010.
[40] Kapton is an acrylic-like film developed by DuPont, that can handle a wide range of temperatures.
[41] Jenkins, 402; Dacron is the trademark name for a synthetic polyester fabric.
[42] Frank E. Jarrett. "Chronology of KSC and KSC Related Events for 1979." KHR-4, September 22, 1980, 26.

the OPF was adapted as a support area for completing work on the tiles. In summer 1980, KSC began planning for the construction of a facility dedicated to tile production, so that High Bay No. 2 could be readied for the arrival of the next orbiter, *Challenger*. Construction of the base structure of the TPS facility was set to begin in December 1980, with the installation of building systems and equipment scheduled to start February 1981.[43] For unidentified reasons, these plans were delayed.

By the mid-1980s, most TPS work was still being done at Rockwell International's plant in Downey, California (roughly 2,200 miles from KSC), or temporary quarters at KSC. By establishing a formal TPS facility at KSC, NASA could "expedite routine maintenance as well as the refurbishment work required on orbiters between missions."[44] Design work for the Thermal Protection System Facility (TPSF) was completed between March and September 1985 by the architecture/engineering firm of Jacobs Engineering Group, Inc., of Lakeland, Florida. They arranged the ground floor "based on the sequence of operations required to transform tile material into finished tiles."[45] Each phase of the fabrication process was given its own specialized work area; these areas are connected by a central corridor, to allow for the efficient movement of the materials and products from one area to another.[46]

The TPSF was constructed by the Holloway Corporation of Titusville, Florida, between July 1986 and May 1988, for a cost of approximately $4.5 million (Figure A-1). Although the facility was officially declared open at its ribbon cutting ceremony (May 2, 1988), final checkouts and installation of equipment continued until August of that year. Tile manufacturing was first completed here in 1994; blanket manufacturing did not occur until 2004.[47] For its first sixteen years, the TPSF underwent very few alterations. This work included the construction of two small rooms within the southeast corner of Room No. 122, and two rooms at the east end of Room No. 127 (see Photo Nos. 49 and 50 for room locations).

In September 2004, Hurricane Frances caused significant damage to the TPSF, as it made its way up the east coast of Florida. Roughly 35 percent of the facility's roof was lost, which caused uninhabitable conditions on the second floor level; the first floor received only minor water damage. Rehabilitation work on the building included the reconstruction of the first floor roof and the second floor walls and roof. In addition, the interior layout of the second floor changed from the original three-room configuration (see Photo No. 50) to a two-room configuration (see Figure No. A-2). All work was completed by November 2005.

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43 "Two New Facilities Planned." *Spaceport News* (19, 16), August 1, 1980: 1 and 4.
44 Pat Phillips. "Shuttle tile work closer to home." *Spaceport News* (27, 11), May 20, 1988: 7.
45 Jacobs Engineering Group Inc, Lakeland. *Design Data Manual Final Submittal, Thermal Protection Systems Facility, Launch Complex 39*. September 3, 1985, 1-1.
46 Jacobs Engineering Group, *Data Manual*; Phillips.
47 Phillips; "Inside The Tile Shop." *Spaceport News* (39, 19), September 22, 2000: 5; "KSC makes Shuttle heat-shield blankets." *Spaceport News* (44, 1), January 7, 2005: 7.

TPSF Functions

Presently, the space shuttle orbiter's TPS system is comprised of three base components: Reinforced Carbon-Carbon panels, insulation tiles, and insulation blankets. The Reinforced Carbon-Carbon panels are manufactured by Lockheed-Martin's Missile and Fire Control Facilities in Dallas, Texas.[48] The remainder of the TPS components are manufactured or repaired within the TPSF, when they are either worn out from age or damaged during a mission.

<u>Tile Production</u>

When technicians at the OPF need a new tile for the orbiter, one of two things occurs, either they create a foam version of the tile using the tile cavity as a mold, or they take a set of photographic images of the tile cavity. In either case, the model or images are sent to the Tile Machining Room (Room No. 122) in the TPSF. The foam model is considered to be in a 'ready-to-use' state, whereas the images must be uploaded to a facility computer, which takes the information and turns it into a set of electronic specifications. The foam model or electronic specifications are then used by a mill operator to form the actual tile from a production unit, using one of the room's milling machines.

There are six milling machines in the facility: two manually operated mills, three semi-automatic mills, and one fully-automatic mill. Each of the two manually-operated machines operates in a similar fashion as a key duplication machine, and is used to make specific types of cuts. The mill operator begins by placing a production unit on the cutting table of the contour milling machine, while the foam tile is placed on an adjacent surface (Figure Nos. A-3, A-4). The operator then uses a styler to trace the foam tile, providing directions to the cutting tool, which sculpts the production unit to match the model (Figure Nos. A-5, A-6). Afterwards, if there are beveled surfaces or other non-standard cuts, the tile and foam model are moved to the detail milling machine, which has a rotating table. If electronic specifications were generated, as opposed to a foam model, either the fully-automatic or one of the semi-automatic mills is used to carve the tile. In such a case, the operator loads the specifications into the mill's computer system, which mechanically guide the actions of the mill, making all of the cuts to form a complete tile (Figure Nos. A-7 through A-10).[49]

After the tile is cut, it is sent to the Heat Cleaning Ovens/Tile Firing Kilns Room (Room No. 123) to be heat cleaned, a process which takes up to eight hours from initial heat-up of the oven to final cool-down of the material (Figure Nos. A-11 through A-14). The tile is then taken into Room No. 124, the Tile Coating Room, to be weighed, and subsequently prepared for painting.

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[48] NASA. *NASA Facts: Reinforced Carbon-Carbon (RCC) Panels*. FS-2004-01-001-KSC. Revised 2006, 1.
[49] Darrell Burke. Personal communication with Patricia Slovinac, KSC, TPSF, March 10, 2010; Sean Druck. Personal communication with Patricia Slovinac, KSC, TPSF, March 10, 2010.

A tile is painted one of two colors, black (HRSI, FRCI, and TUFI) or white (LRSI), depending on its location on the orbiter. Both paint colors are comprised of glass powder, borosilicates, and alcohol. The paint is applied in a ventilated spray booth along the north wall of Room No. 124, using conventional paint spraying equipment. The painted tile is then moved to a drying chamber in the center of the room, where it is left to dry for a minimum of three hours.[50]

After the tile is sufficiently dry, it is baked in one of the kilns in Room No. 123, approximately one hour and thirty minutes for black tile, and 1 hour and 10 minutes for a white tile. The tile is put on a rack to cool, and is then returned to Room No. 124 to be reweighed, measured, and engraved with an identification number. It is subsequently transferred to Room No. 122, where its inner mold line is measured. Following this action, the tile is taken to the Waterproofing, Densification, and Chemical Kit Room (Room No. 126) where it receives its first application of waterproofing material (Figure A-15). The waterproofing of the tiles is conducted in ovens located along the west wall of the room, each of which is fitted with two chemical chambers. One of the chambers contains an acidic primer, while the second contains the waterproofing agent dimethylethoxysilane. The primer is applied first, followed by the waterproofing agent; in each case, the liquid is heated into a vapor, which is then pulled through the tile, thus waterproofing both the inside and outside of the tile.[51]

Once the first coat of waterproofing is dry, the tile is sent over to the OPF for a fit-check, and is then returned to Room No. 126 of the TPSF, where it undergoes a densification procedure. This action occurs within a special booth, where the silica powder is mixed with water to create a slurry that is applied to the tile. The tile is left to dry for roughly twenty-four hours. It is then sent to Room No. 123 to be heat cleaned, before returning to Room No. 126 for a second coat of waterproofing material, which is followed by a second fit-check at the OPF.[52]

When all of this is complete, the tile is moved to the SIP Bonding and Pressure Pad/Bond Verification Chuck Fabrication Room (Room No. 125). A SIP is applied to the underside of the tile to protect it from any structural or acoustic deflections experienced by the aluminum frame of the orbiter. It is cut from a Nomex felt material using a pattern, and then checked against the actual tile (Figure No. A-16). Afterwards, the SIP is placed face-down on a vacuum table, which holds it in place while the bonding agent, a room-temperature vulcanizing (RTV) silicon adhesive, is mixed with a catalyst and applied to the pad (Figure No. A-17). The pad is then weighed and set RTV side up on a plastic frame fitted with Velcro, which supports the SIP while it is properly positioned on the tile (Figure Nos. A-18, A-19). The entirety is then placed in a bag

[50] NASA, *Thermal Protection System*, 3; Judy Brothers. Personal communication with Patricia Slovinac, KSC, TPSF, March 8, 2010.
[51] Frank Sunderman. Personal communication with Patricia Slovinac, KSC, TPSF, March 9, 2010.
[52] Frank Sunderman.

that is pulled into a vacuum, allowing the SIP to adhere to the tile (Figure No. A-20).[53] The completed tile is then sent to the OPF for installation on the orbiter.

"Softgoods" Production

The production process for softgoods is less complicated than that of the insulation tiles. Like the tile production units, the various materials used for the softgoods components are shipped as large rolls to KSC from the manufacturer (Figure No. A-21). Upon arrival, a few rolls of each type of material are sent to Room No. 123 to be heat cleaned; the remainder are placed directly in storage at the TPSF. Typically, the softgoods technicians prefer to work with non-heat cleaned materials, but there are situations where a component is needed as soon as possible. In such an instance, the pre-heat cleaned materials will be used to shorten the component's production time.[54]

Similar to an insulation tile, the order for a new softgoods component is sent to the TPSF from technicians at the OPF. A set of engineering drawings is provided to the TPSF softgoods technicians, who either work in Room No. 127 on the ground floor, or Room No. 201 on the second floor of the east end of the facility. These technicians will use the engineering drawings as a pattern for the component. The technician will use the pattern to cut the required number of layers of each different material type needed for the specific component. The different layers are then stacked in the proper order and pinned together, in preparation for them to be sewn together; RTV is applied to the edges to keep the fabric from fraying (Figure Nos. A-22, A-23).[55]

The softgood is either sewn by hand or on one of many different types of sewing machines, dependent upon the type, size, and shape of the particular component. Room No. 127 is generally used for the production of FIBs; it contains a large, Multi-Needle Sewing Machine, as well as a Long-Arm Sewing Machine. The Multi-Needle Sewing Machine is generally used for rectangular-shaped FIBs of any thickness, that have measurements of up to 30" x 30". The blanket is set up on a wooden frame, which is then sent through the machine, sewn, and tied-off (Figure Nos. A-24 through A-26); it is then horizontally turned 90 degrees and sent through the machine a second time, creating a "quilt-like" appearance for the blanket (Figure No. A-27). The Long-Arm Sewing Machine is used for non-rectangular FIBs, such as curved blankets that are installed adjacent to a window opening or hatch. As with the rectangular blanket, the curved FIB is sewn at 1" intervals both parallel and perpendicular to the curve, creating a quilt-like appearance (Figure Nos. A-28, A-29).[56]

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[53] Kay Sunderman. Personal communication with Patricia Slovinac, KSC, TPSF, March 10, 2010.
[54] Alix Peck. Personal communication with Joan Deming and Patricia Slovinac, KSC, TPSF, July 26, 2006.
[55] Harrington; "Inside The Tile Shop."
[56] Kathy Evans. Personal communication with Patricia Slovinac, KSC, TPSF, March 9, 2010; Jean Wright. Personal communication with Patricia Slovinac, KSC, TPSF, March 9, 2010.

All other TPS softgoods components, as well as the TCS blankets, are made in Room 201, which contains standard commercial sewing machines of both the regular and long-arm variety. The machines are typically used for components that have a standard shape. Hand stitching is required for most softgoods, because like the tiles, they are custom-fit. In many instances, the technicians use a plastic or wooden clamp as an aid to hold the component while they are sewing (Figure Nos. A-30 through A-33).[57]

Aside from manufacturing a new TPS softgoods component, the technicians are able to repair existing ones that are removed from the orbiter at the OPF. This process involves similar steps, except that only materials needed for the repair are used, and they are cut to the appropriate size. Regardless of whether it is a brand new component or a repaired component, after the softgoods technicians have completed their work, it is sent to Room No. 123 to be heat cleaned (unless pre-heat cleaned materials were used) in one of three ovens along its north wall, a process that takes roughly eight hours. Afterwards, it is sent to Room No. 126 for its waterproofing application, dried, and finally sent to the OPF for installation on the orbiter.[58]

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[57] Harrington.

[58] Frank Sunderman; "KSC makes Shuttle heat-shield blankets." *Spaceport News* (44, 1), January 7, 2005: 7; NASA, *Thermal Protection System*, 3-5.

Physical Description

Exterior

The TPSF is a rectangular structure with approximate overall dimensions of 340' in length (east-west), 100' in width (north-south), and 31' in height. It is constructed of a steel skeleton faced with corrugated metal panels, sits on a poured concrete slab foundation, and has a slightly-inclined corrugated metal roof. The facility is divisible into two sections, a one-story area to the west (239' in length, 100' in width, and 20' in height), and a two-story area to the east (101' in length, 100' in width, and 31' in height).

The south elevation of the TPSF (Photo Nos. 1-4, 10) serves as the principle façade of the building. The main entrance, a one-light metal swing door, sits roughly 15' from the two-story portion of the building, and is shaded by a small canopy supported by metal posts. Seven additional door openings are located across the south elevation of the one-story section, including one pair of metal swing doors to the east of the main entrance. Heading west from the entrance, there is a pair of one-light metal swing doors with a metal canopy for equipment, a single metal swing door with a canopy, a second pair of metal swing doors, a one-light metal swing door, a solid metal swing door, and a 22' x 12' horizontal bi-fold door. The south elevation of the two-story portion of the facility contains two metal swing doors in the west half (the eastern of the two has a metal canopy), and a pair of one-light metal swing doors with a metal canopy, which are large enough for equipment.

At the ground floor level of the east elevation (Photo Nos. 4-6), there is a pair of one-light metal swing doors, sized to allow the ingress of supplies and equipment. Directly above, at the second floor level, is a is an 18'-long, 7'-wide metal landing, which provides access to two doorways. The entrance on the south consists of a pair of metal swing doors, shaded by a canopy; the one to the north is a single metal swing door. These two entrances are reached via a set of "U"-shaped metal steps. Attached to the north end of the east elevation is a large, mechanically operated dust collector. The west elevation (Photo Nos. 8-10) features one, 22' x 12' horizontal bi-fold door, at each end. Between the doors is a covered storage area, with an approximate length of 32' and width of 12'. This storage area has corrugated metal walls on the north and south, and a corrugated metal roof. Within the space, there is a single metal swing door to the north and a pair of one-light metal swing doors to the south.

The one-story portion of the north elevation (Photo Nos. 6-8) features five openings, each of which corresponds to an internal room. The easternmost door, as well as the three western doors, are one-light metal swing doors, the remaining one is a solid metal swing door. This portion of the north elevation also contains two ventilation louvers, four clusters of vent stacks, and a mechanically operated dust collector (Photo No. 11). In addition, there is a gaseous nitrogen regulation panel near the centerline of this section of the elevation (Photo No. 12). The two-story portion of the north elevation contains two, one-light metal swing doors, one towards each end, one ventilation louver, and a cluster of heated and chilled water pipes.

Interior

The internal room arrangement of the first floor of the TPSF is based on a double-loaded corridor plan, with the central hallway extending east-west (see Figure No. A-2). The majority of the rooms that directly contribute to the significance of the TPSF are at the west end and along the north side of the hallway. At the west end of the hallway is Room No. 122, the Tile Machining Room, with Room No. 123, the Heat Cleaning Ovens/Tile Firing Kilns Room (west), and Room No. 124, the Tile Coating Room (east), directly to its north. Lining the north side of the hallway are, from west to east, Room No. 125, the SIP Bonding and Pressure Pad/Bond Verification Chuck Fabrication Room; Room No. 126, the Waterproofing, Densification and Chemical Kit Room; and Room No. 127, the Equipment/Tooling Maintenance Room. The remainder of the north side of the hallway contains office and support areas, which are accessed through a small corridor. Similar support spaces and generic service rooms line the south side of the main hallway; at its east end is a large storage room. The final room that directly contributes to the significance of the TPSF is Room No. 201, the Softgoods/Ground Support Equipment Manufacturing Room, which sits on the second floor level at the east end of the building.

The Tile Machining Room, Room No. 122 (Photo Nos. 13-15), located in the southwest corner of the TPSF, has approximate overall dimensions of 92'-6" in length (east-west) and 63' in width (north-south). It features a poured concrete floor, gypsum panel walls, and an acoustic tile ceiling. The room is typically entered from the main corridor by a pair of one-light metal swing doors on its east wall. On its west wall, there is a pair of one-light metal swing doors, used for emergencies, and a bi-fold door, for equipment. Originally comprised of one large open space, by 1994, two support rooms were built in its southeast corner; it has since had two small maintenance rooms built along its north wall. The Tile Machining Room is divisible into three different areas, the first of which is the portion at the northeast corner. This section contains three manually-operated tile cutting machines and one manually operated drilling machine that actually pre-date the facility. The three milling machines are towards the west and are known as Contour Milling Machines; the eastern of the three is fitted with a rotatable table to make beveled cuts (Photo Nos. 16, 17). The drilling machine sits at the east end. Each of the machines has a metal desk to its south for the technicians.

The central area of the Tile Machining Room contains mostly large work tables and storage racks for blocks of different types of tile material, which will eventually be cut into an actual TPS tile. The southern area of Room No. 122 contains the facility's newer tile cutting machines. Within the western two-thirds of this area are three, five-axis, numerical control mills, which were installed during the building's construction (Photo No. 18). These machines were equipped with mechanical mechanisms for cutting the tiles, but the different cutting tools have to be manually changed. At the very east end of this section is the newest of the tile cutting mills, installed circa 2005 (Photo No. 19). This mill is fully automatic, receiving "instructions" from computer-drafted specifications uploaded to its system.

The Heat Cleaning Ovens/Tile Firing Kilns Room, Room No. 123 (Photo Nos. 21, 22), sits in the northwest corner of the TPSF and has rough overall dimensions of 60' in length (east-west) and 34' in width (north-south). Similar to Room No. 122, this room has gypsum board walls and an acoustic tile ceiling; however, its floor is faced with vinyl tiles. It is typically entered by a small passage between it and Room No. 124, both the east and west walls of which are fitted with a pair of one-light metal swing doors. This room also features a one-light metal swing door at the east end of its north wall and a metal swing door on its west wall, used as emergency exits for personnel. Additionally, there is a horizontal bi-fold door on its west wall for equipment.

The room is organized so that the major equipment lines the north, west, and south walls, leaving the central area open for work tables and storage racks. Along the north wall are three heat cleaning ovens (Photo No. 24), typically used for TPS blankets, and each of which features a large swing door and moveable internal racks. The oven at the west end is specifically used for production units, while the two toward the east are for fully assembled and shaped blankets. At the very west end of Room No. 123 is a large kiln (Photo No. 23) used to fire production units of the TPS tile; along the south wall are the four kilns (Photo No. 25) used for firing completed tiles. All five of these kilns are known as "elevator ovens," which means the items are set on a tray that is then raised into the actual oven area for firing. All are self-ventilated.

The Tile Coating Room, Room No. 124 (Photo No. 26), measures approximately 35'-6" in length (east-west) and 34' in width (north-south). As noted above, this room sits directly to the east of Room No. 123, to which it provides access through a small passage. The Tile Coating Room features a poured concrete floor faced with vinyl tile, gypsum board walls, and an acoustic tile ceiling. The room is typically entered from the main corridor by a pair of one-light metal swing doors on its south wall. Additionally, there is a one-light metal swing door at east end of its north wall, which serves as a personnel emergency exit to the exterior.

Along the north wall of the Tile Coating Room are four spray booths (Photo No. 27), where the tiles are painted. Each booth is fitted with a ventilation duct and exhaust fan to remove extra paint particles, as well as its own paint spray system. The paint itself is mixed on a roller table at the north end of the east wall; a crane helps maneuver the storage canisters (Photo No. 29). Once painted, the tiles are moved to a 6'-long, 5'-wide, 10'-high drying booth (Photo No. 28) in the center of the room. Access to the booth is through a pair of three-light swing doors on its north side, and, like the spray booths, it has its own ventilation system. Other features in Room No.

124 include a booth to engrave identification numbers onto tiles, located in the southwest corner, and various workstations along the south and east walls.

The SIP Bonding and Pressure Pad/Bond Verification Chuck Fabrication Room, Room No. 125 (Photo Nos. 30 through 34), sits directly to the east of Room No. 124. It has approximate overall dimensions of 49’-6” in length (east-west) and 43’-8” in width (north-south), and features a poured concrete floor, gypsum panel walls, and an acoustic tile ceiling. The room is typically entered from the main corridor by a pair of one-light metal swing doors on its south wall; a one-light metal swing door on the north wall provides an emergency exit to the exterior of the building. Room No. 125 is functionally divided into two areas, with the west half used to create chucks and the east half used for bonding SIP to tiles, blankets, etc. Near the north end of the west wall, there is a band saw used for cutting the foam that will be applied to the chuck. A foam compression test area sits to its south and features specialized tools used to check the integrity of the foam during compression. Near the band saw is a table that was designed for the sole purpose of making chucks. It contains four individual pouring stations, each of which is fitted with a specialized mechanism to place a vacuum pressure opening within the chuck. The remainder of the west half, as well as the majority of the east half, of the room contains various work tables. A unique feature of the eastern half are vacuum lines that hang from the ceiling over some of the work stations. These lines are connected to vacuum pumps within the ceiling plenum, and are attached to different vacuum bags, which are used in testing the integrity of SIP bonds.

To the east of Room No. 125 is the Waterproofing, Densification and Chemical Kit Room, Room No. 126 (Photo Nos. 35-36), which has rough overall dimensions of 47’ in length (east-west) and 43’-8” in width (north-south). This room features a poured concrete floor, gypsum board walls, and an acoustic tile ceiling. It is typically entered by a pair of one-light metal swing doors on its south wall, and contains a metal swing door on the north wall that leads to the exterior. Internally, Room No. 126 is spatially divided into two halves, the western half with chemical application equipment, and the eastern half with chemical mixing booths and work tables. In the west half, there are four waterproofing ovens (one large [Photo No. 37] and three small [Photo No. 38]) along the west wall; facing these are four drying ovens (Photo No. 39). In the eastern half of the room, there is a ventilated chemical mixing booth along the north half of the east wall; the remainder of the area contains workstations and chemical storage shelving.

The Equipment Tooling Room, Room No. 127 (Photo No. 40), has approximate measurements of 46’ in length (east-west) and 43’-8” in width (north-south). It sits directly to the east of Room No. 126, and similarly, features a poured concrete floor, gypsum board walls, and an acoustic tile ceiling. Additionally, like the neighboring rooms, it is typically entered from the main corridor through a pair of one-light metal swing doors on its south wall, and contains a one-light metal swing door on the north wall to the exterior of the TPSF. There is also a pair of metal swing doors along its east wall that provide access to an adjoining workroom. The significant element of this room is a Multi-Needle Sewing Machine (Photo No. 41), which sits in the northeast corner. This automatic machine, used for sewing TPS blankets, features thirty sewing needles, spaced at 1" on center, a built-in lubrication system for the needles, and sensors to tell the machine when to start and stop sewing operations.

The Softgoods/Ground Support Equipment Manufacturing Room, Room No. 201, has rough overall dimensions of 97' in length (north-south) and 76'-4" in width (east-west); it comprises roughly three-fourths of the second floor level at the east end of the facility (Photo Nos. 42-45). This area features gypsum board walls, an acoustic tile ceiling, and a vinyl tile faced floor. It is typically entered directly from the south-facing elevator (near the center of its west wall) or by a one-light metal swing door on its west wall at the top of a stairwell. Additionally, there is a pair of metal swing doors on the west wall that provides access to the building's mechanical room, and a door to a small storage closet in the southwest corner of the room. Historically, this room was divided into a north and south half by a partition wall, with the north room used for storage and the south room used for production activities. However, it was redesigned and rebuilt to its current configuration following significant damage from Hurricane Frances in 2004.

Although the room is divided into different areas based on function, the typical features of the room are the numerous work tables and supply racks. The tables are organized in a variety of forms, including individual tables, pairs, "L"-shaped pairs and triplets, and long rows of four or more. The supply racks are arranged throughout the room in similar fashions. Unique features of this room include an air shower just to the southeast of the elevator, and three Long-Arm Sewing Machines in the southwest portion of the room. A few standard commercial sewing machines are situated throughout the area (Photo Nos. 46, 47), as well as ceiling-mounted electrical cord reels, allowing for a large amount of flexibility of use. At the southeast corner of the room is a metal table, fitted with equipment for mixing and applying RTV.

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Figure A-1. View of TPSF while under construction at KSC, March 17, 1987.
Source: John F. Kennedy Space Center Archives, KSC-387C-565.4.

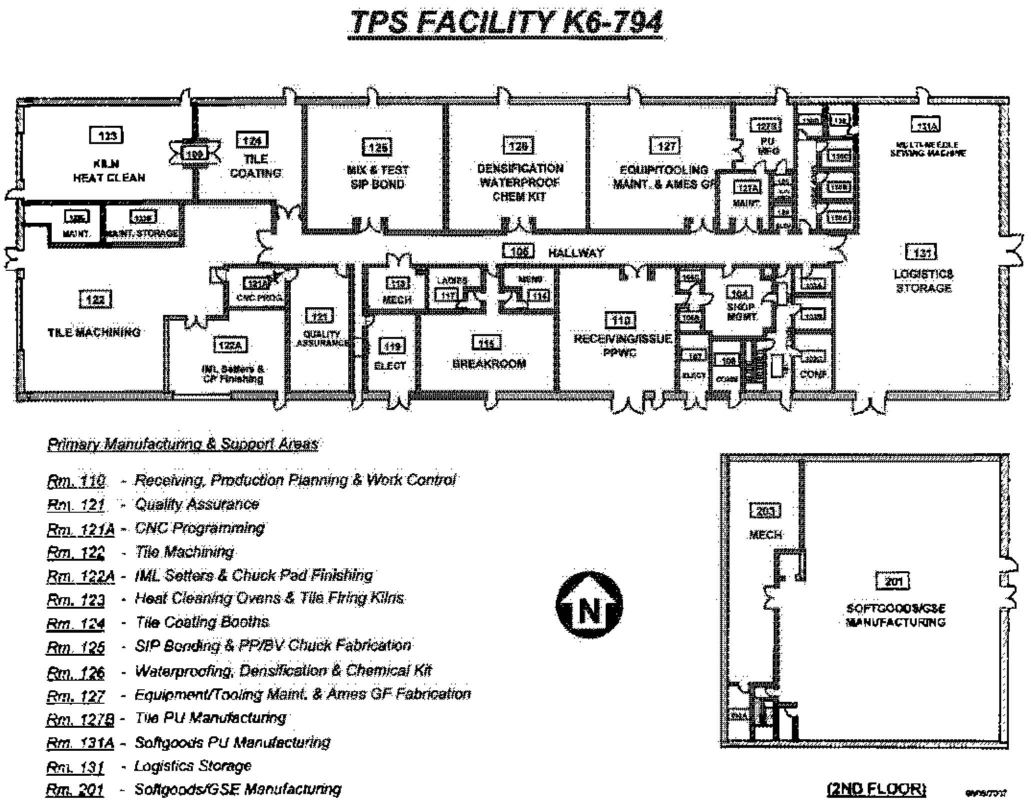

Figure A-2. Plan of TPSF, 2007.
Source: John F. Kennedy Space Center.

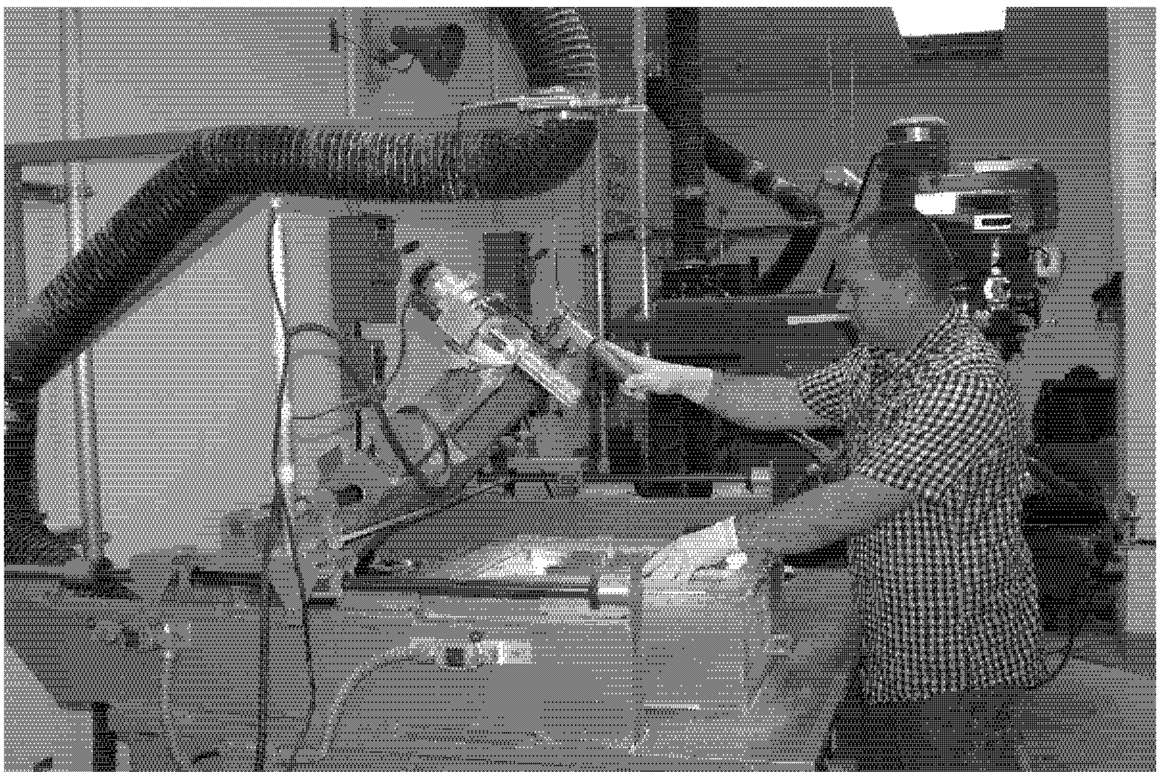

Figure A-3. Tile technician, Sean Druck, preparing Contour Milling Machine, March 10, 2010.
Source: Penny Rogo Bailes.

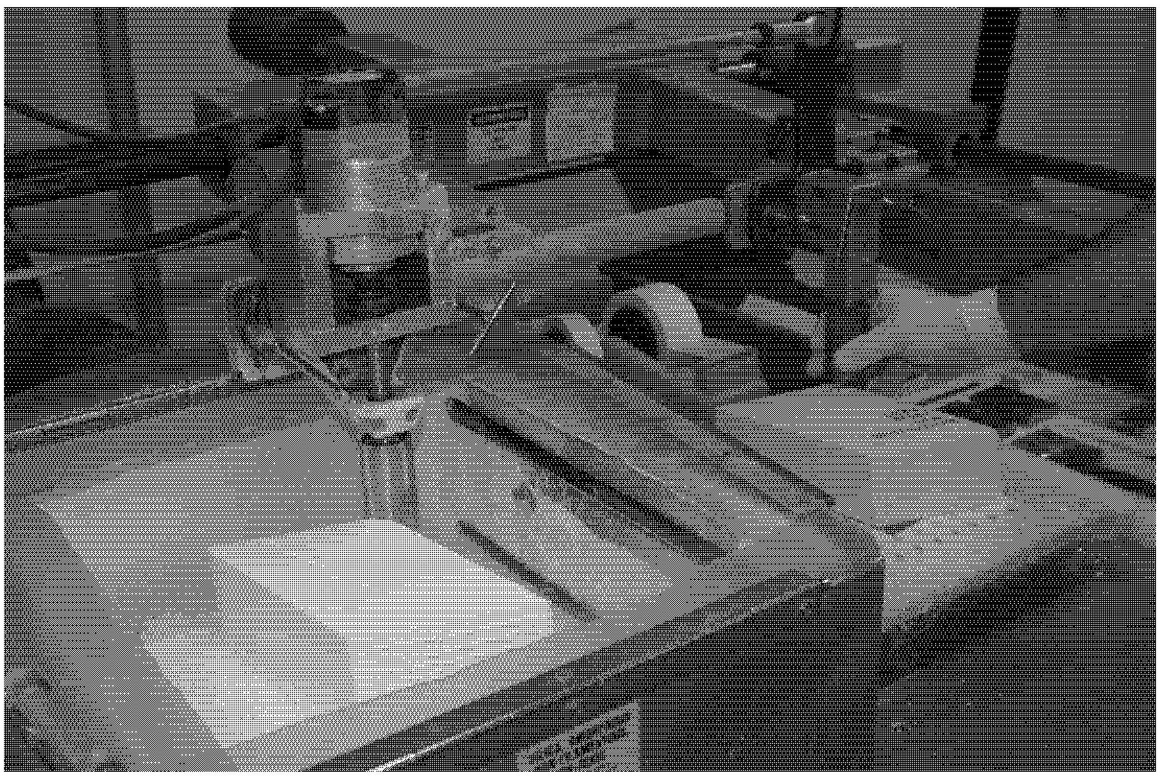

Figure A-4. Tile technician, Sean Druck, using Contour Milling Machine, March 10, 2010.
Source: Penny Rogo Bailes.

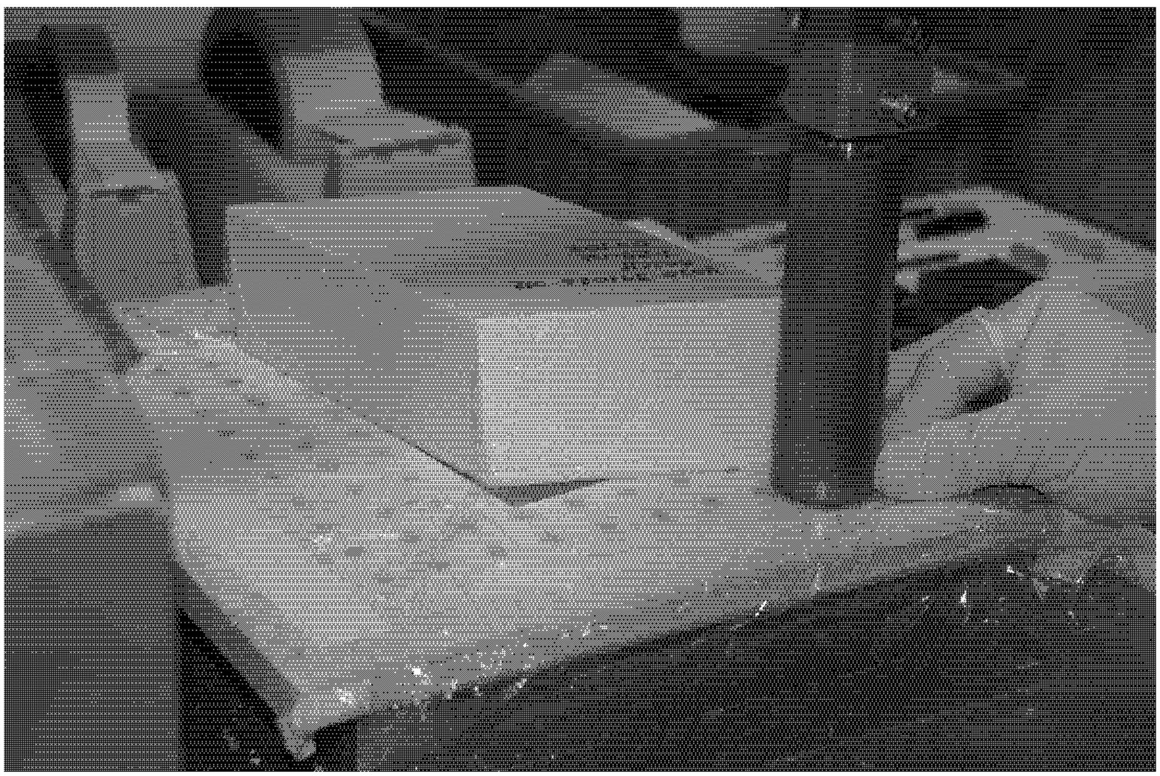

Figure A-5. Tile technician, Sean Druck, guiding styler on the Contour Mill Machine, March 10, 2010.
Source: Penny Rogo Bailes.

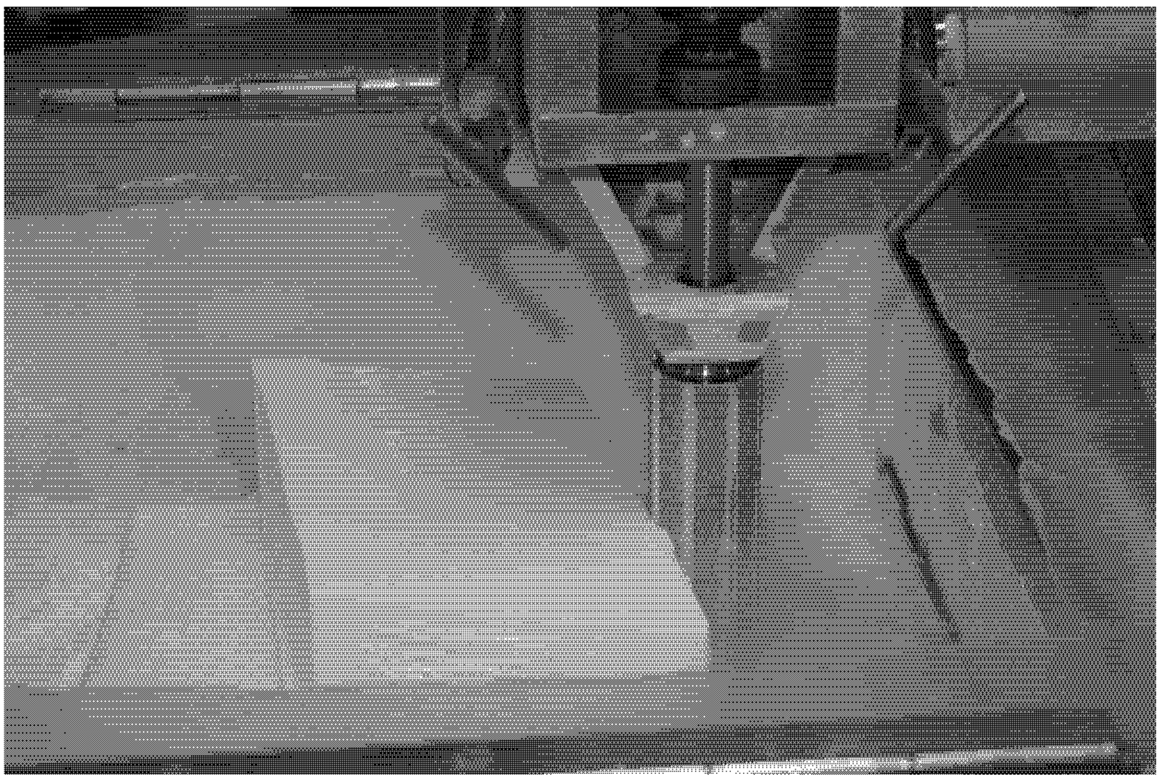

Figure A-6. Detail view of cutting tool shaping a tile on the Contour Mill Machine, March 10, 2010.
Source: Penny Rogo Bailes.

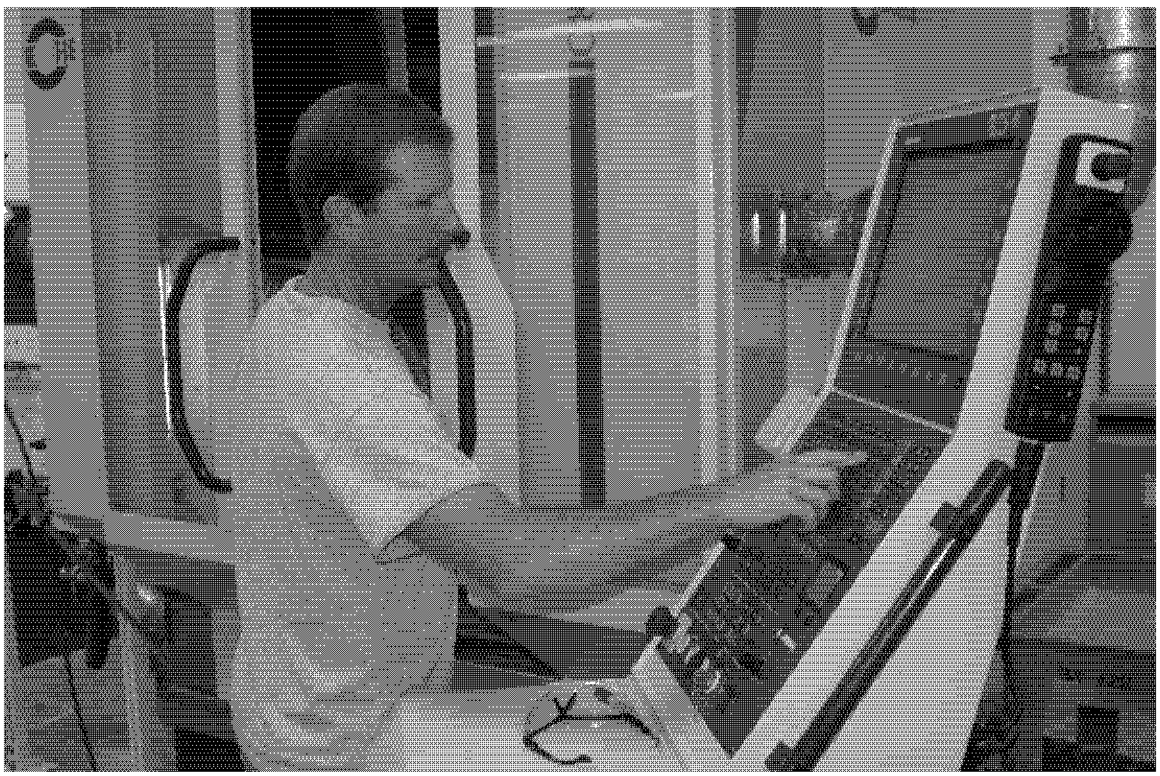

Figure A-7. A KSC tile technician loading specifications into the fully-automatic Milling Machine, March 9, 2010.
Source: Penny Rogo Bailes.

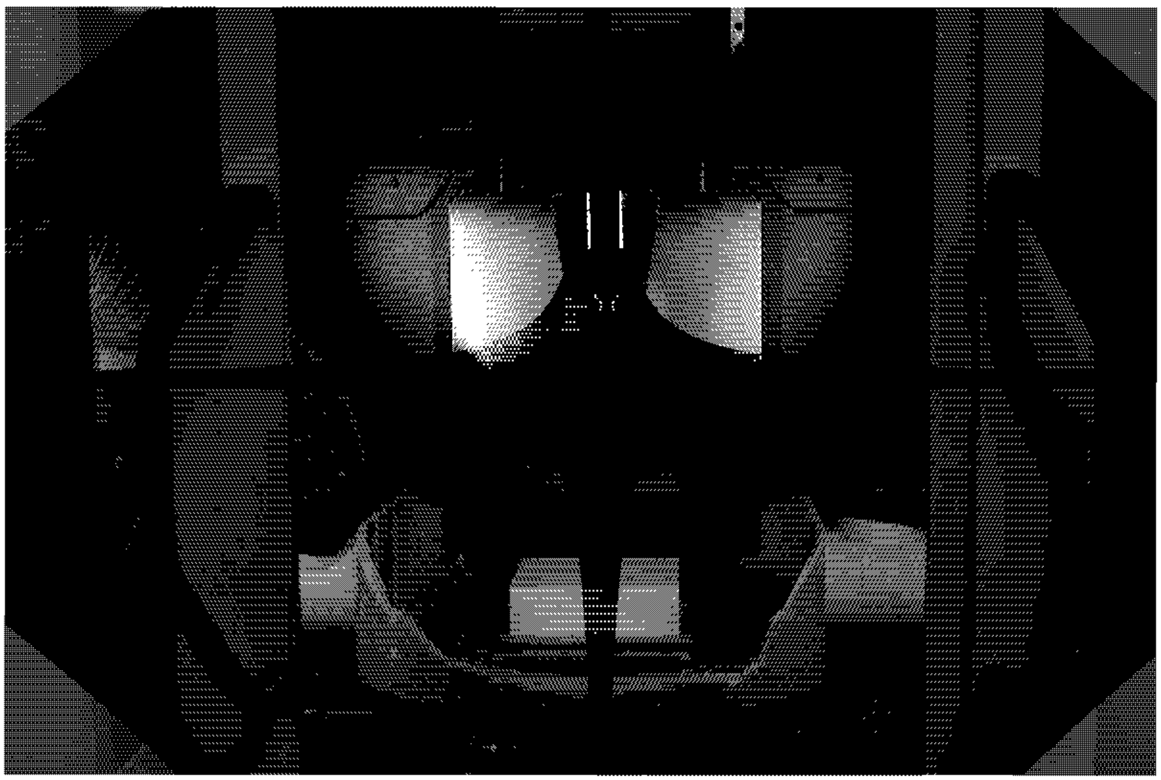

Figure A-8. Tile ready to be cut by the fully-automatic Milling Machine, March 9, 2010.
Source: Penny Rogo Bailes.

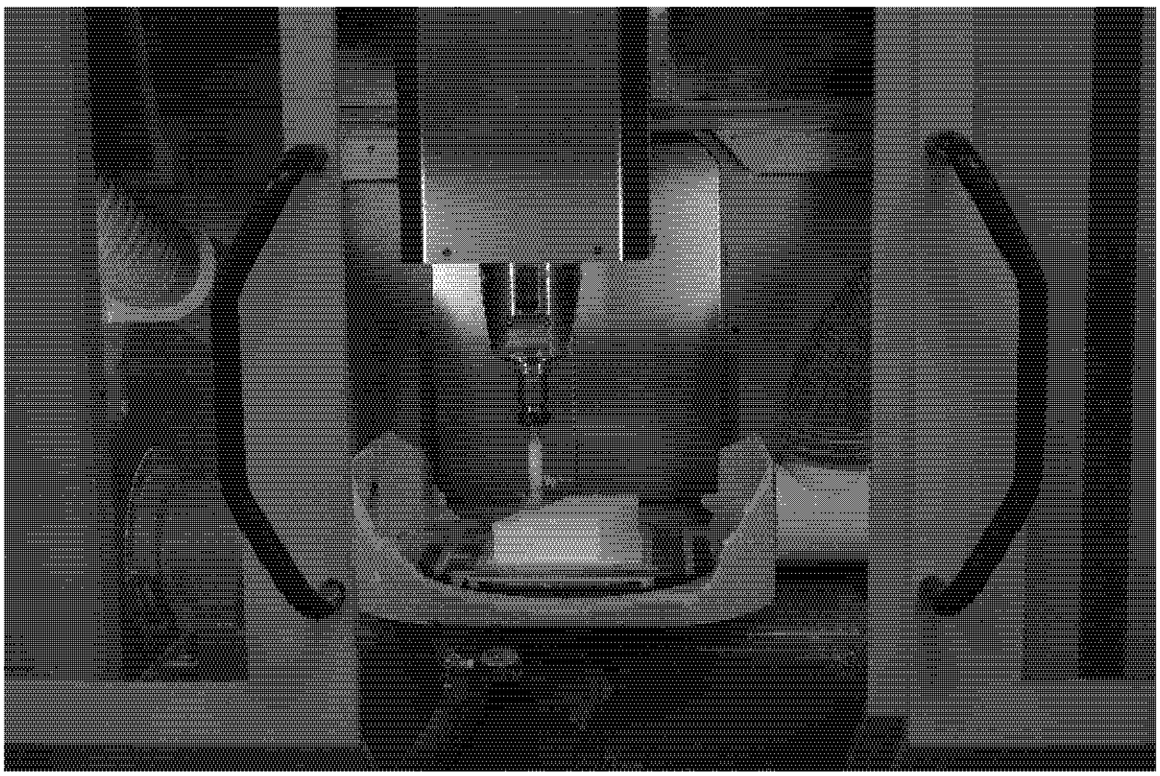

Figure A-9. Tile being cut by the fully-automatic Milling Machine, March 9, 2010.
Source: Penny Rogo Bailes.

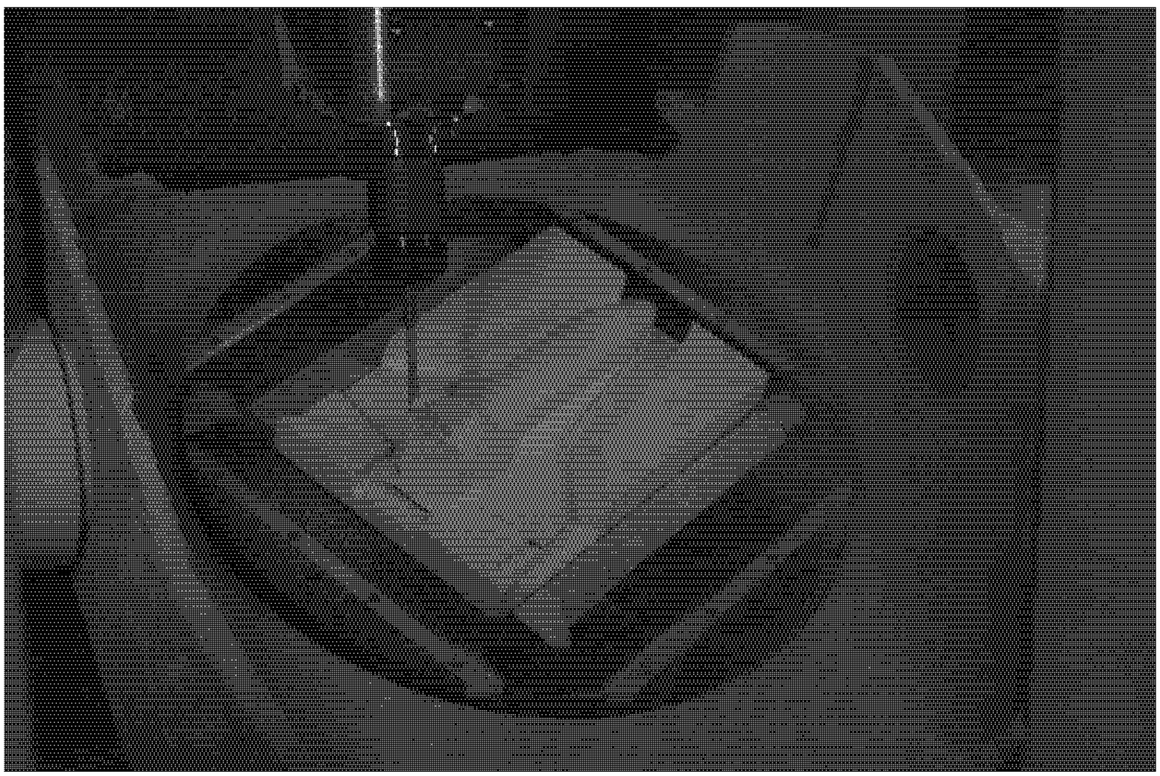

Figure A-10. Fully-automatic Milling Machine in action, March 10, 2010.
Source: Penny Rogo Bailes.

Figure A-11. Tile samples being lowered for removal from Tile Firing Kiln, March 10, 2010.
Source: Penny Rogo Bailes.

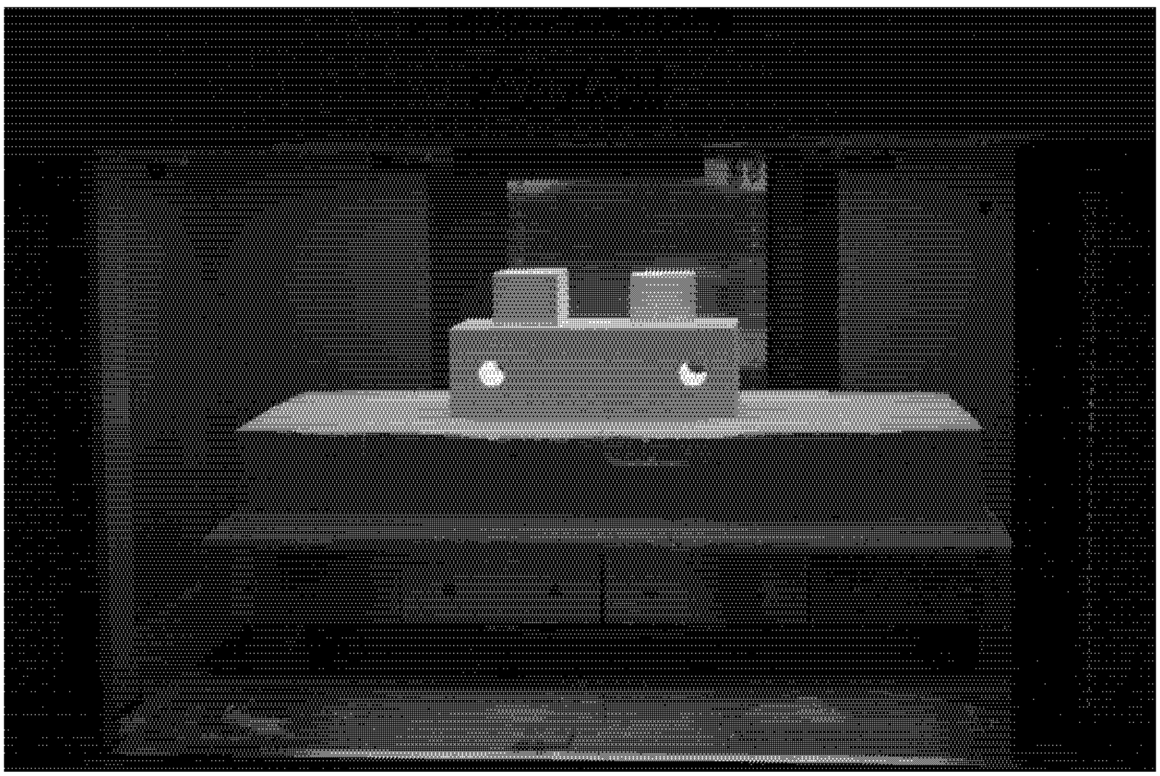

Figure A-12. Tile samples ready for removal from Tile Firing Kiln, March 10, 2010..
Source: Penny Rogo Bailes.

Figure A-13. Tile samples being removed from Tile Firing Kiln by a KSC technician, March 10, 2010.
Source: Penny Rogo Bailes.

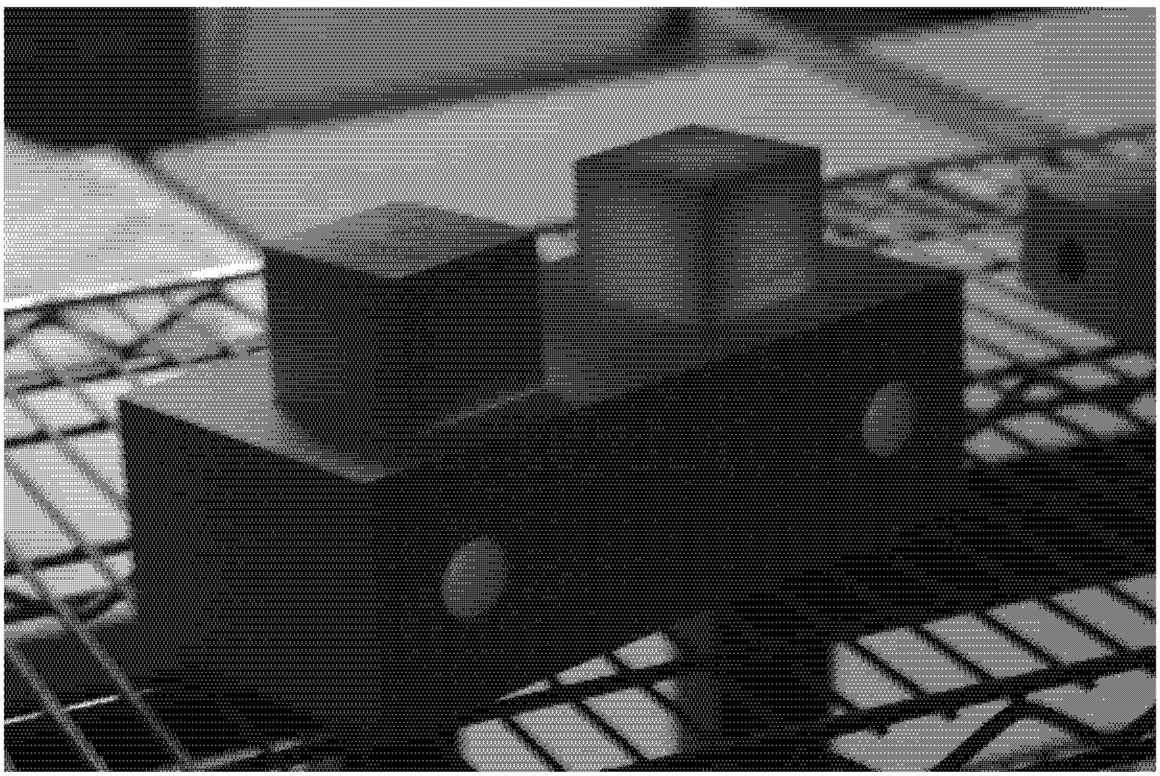

Figure A-14. Tile samples on cooling racks, March 10, 2010.
Source: Penny Rogo Bailes.

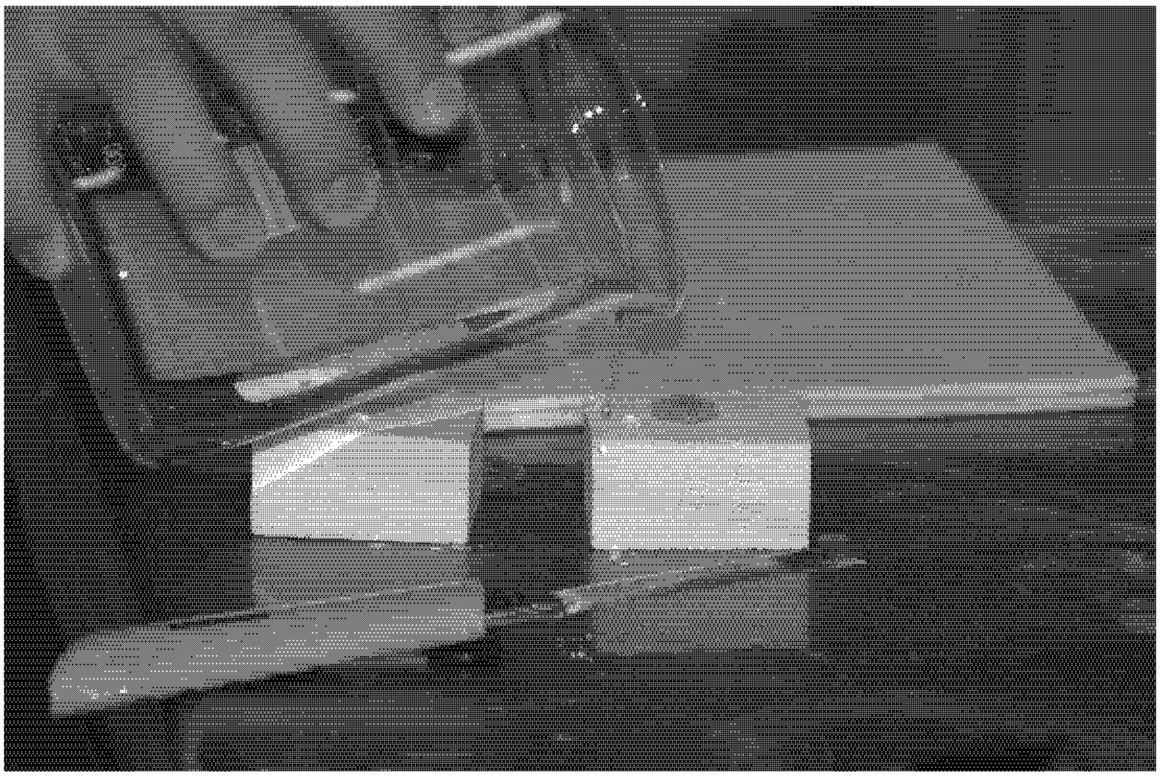

Figure A-15. Waterproofed tile sample demonstration by technician Frank Sunderman, March 10, 2010.
Source: Penny Rogo Bailes.

Figure A-16. SIP being prepared for bonding to a tile by technician Kay Sunderman, March 10, 2010.
Source: Penny Rogo Bailes.

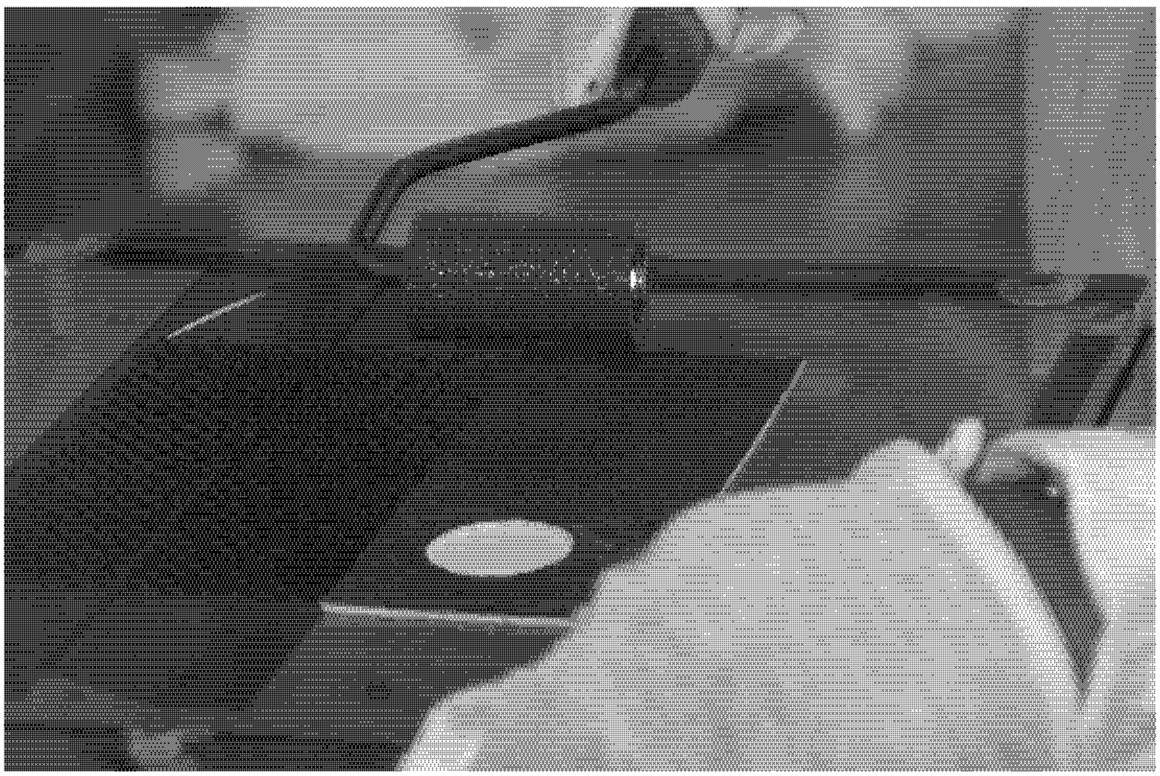

Figure A-17. RTV being applied to SIP by technician Kay Sunderman, March 10, 2010.
Source: Penny Rogo Bailes.

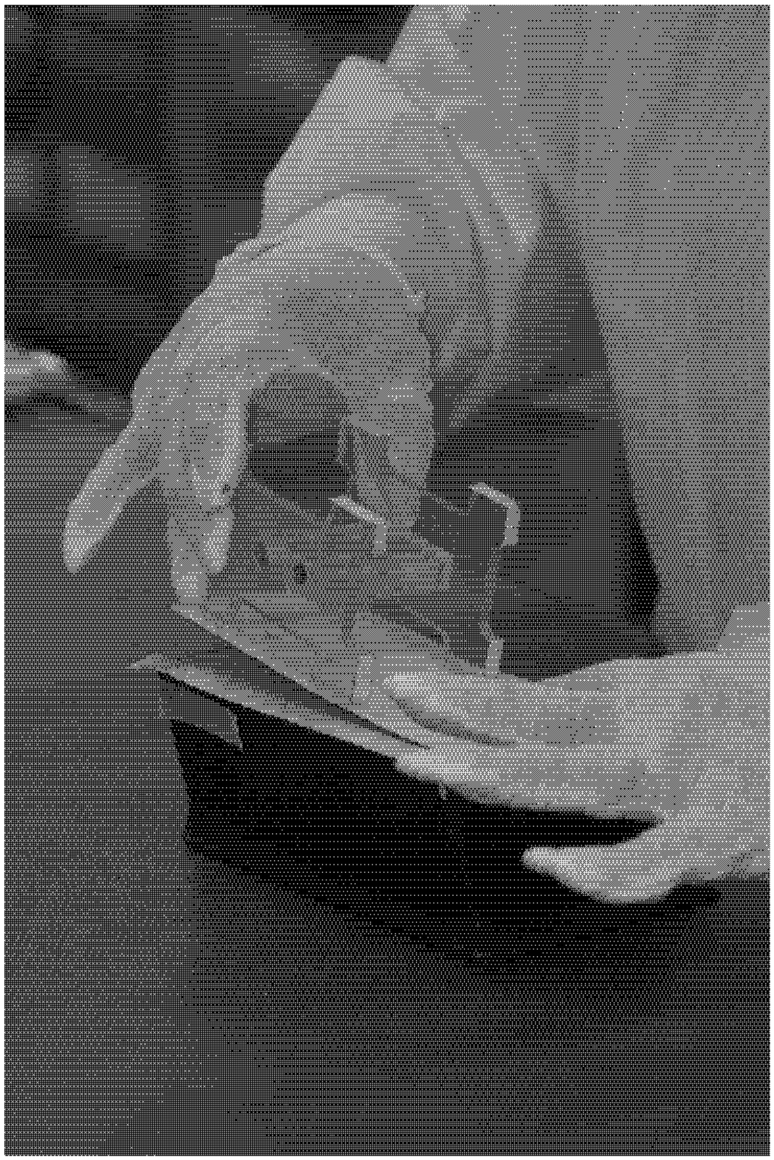

Figure A-18. SIP being positioned on a tile by technician Kay Sunderman, March 10, 2010.
Source: Penny Rogo Bailes.

Figure A-19. SIP/tile being placed into a bag by technician Kay Sunderman, March 10, 2010.
Source: Penny Rogo Bailes.

Figure A-20. Bag with SIP/tile being fitted with vacuum lines by technician Kay Sunderman and a KSC quality control manager, March 10, 2010.
Source: Penny Rogo Bailes.

Figure A-21. Rolls of material for softgoods TPS components being displayed by technician Jean Wright, March 9, 2010.
Source: Penny Rogo Bailes.

Figure A-22. RTV being applied to softgoods material by a KSC technician, March 9, 2010.
Source: Penny Rogo Bailes.

Figure A-23. Applied RTV on material for softgoods being allowed to dry, March 9, 2010.
Source: Penny Rogo Bailes.

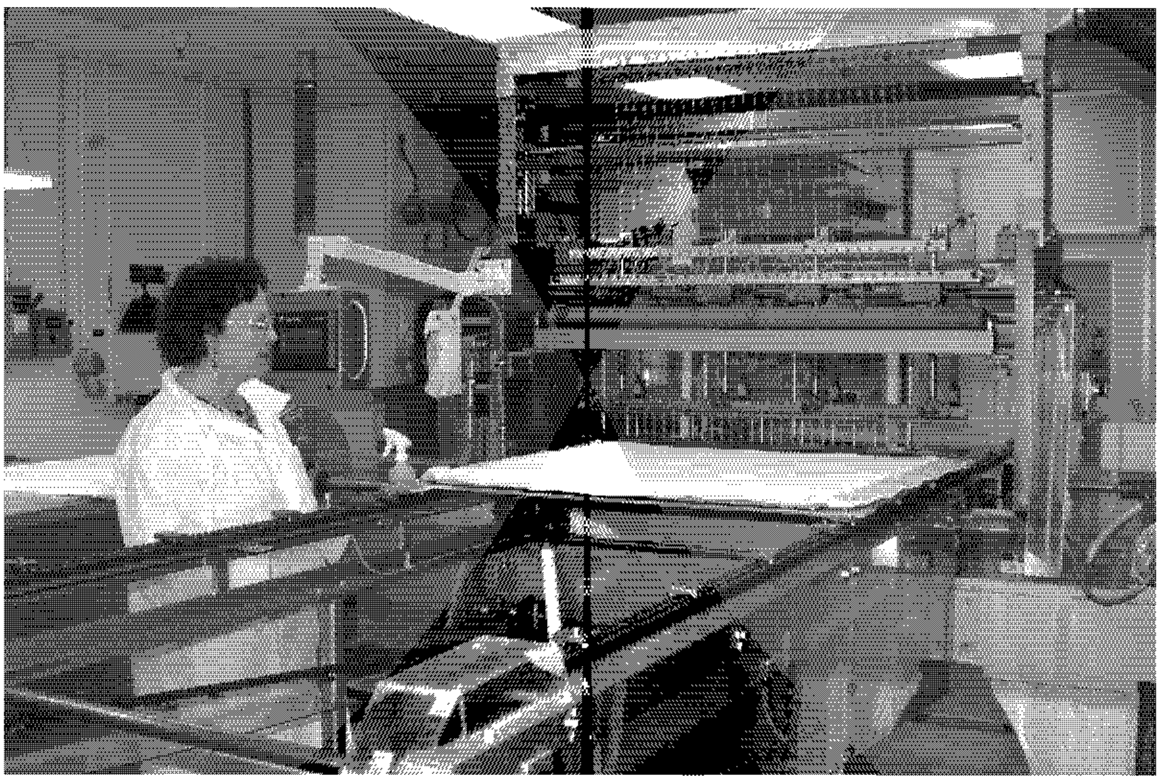

Figure A-24. FIB ready to be sent through the Multi-Needle Sewing Machine by technician Jean Wright, March 9, 2010.
Source: Penny Rogo Bailes.

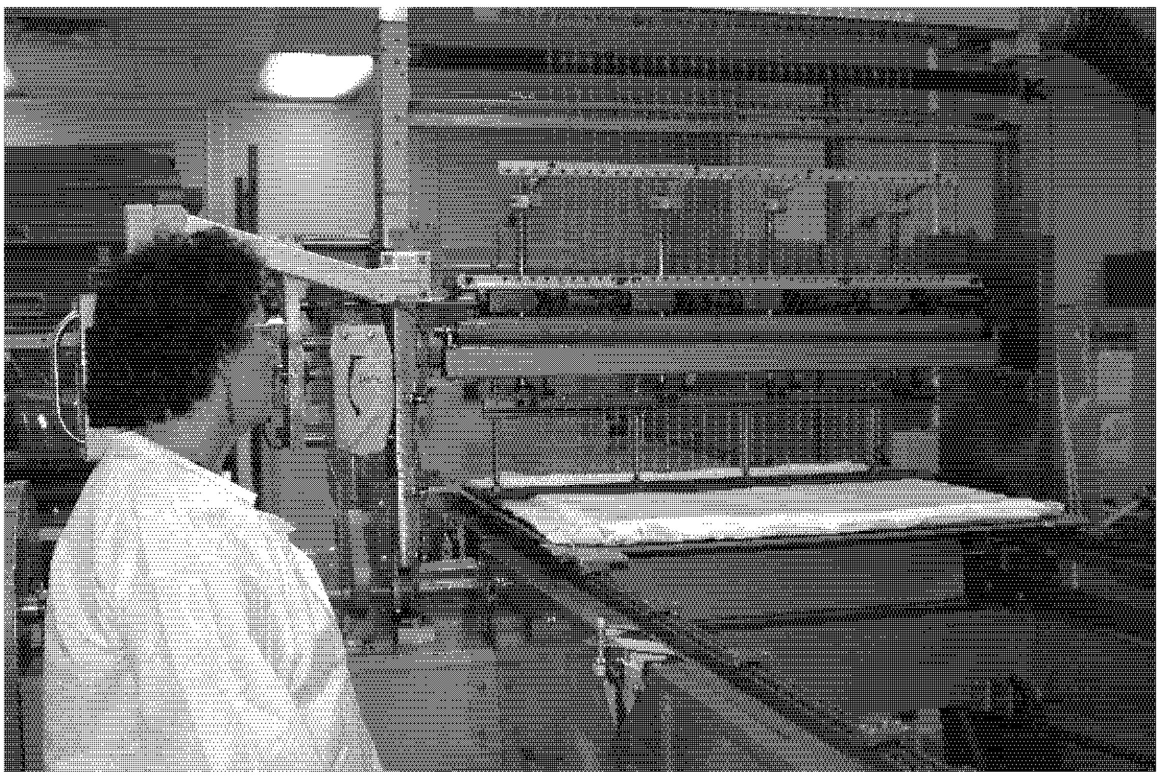

Figure A-25. FIB being sewn by Multi-Needle Sewing Machine under the watchful eye of technician Jean Wright, March 9, 2010.
Source: Penny Rogo Bailes.

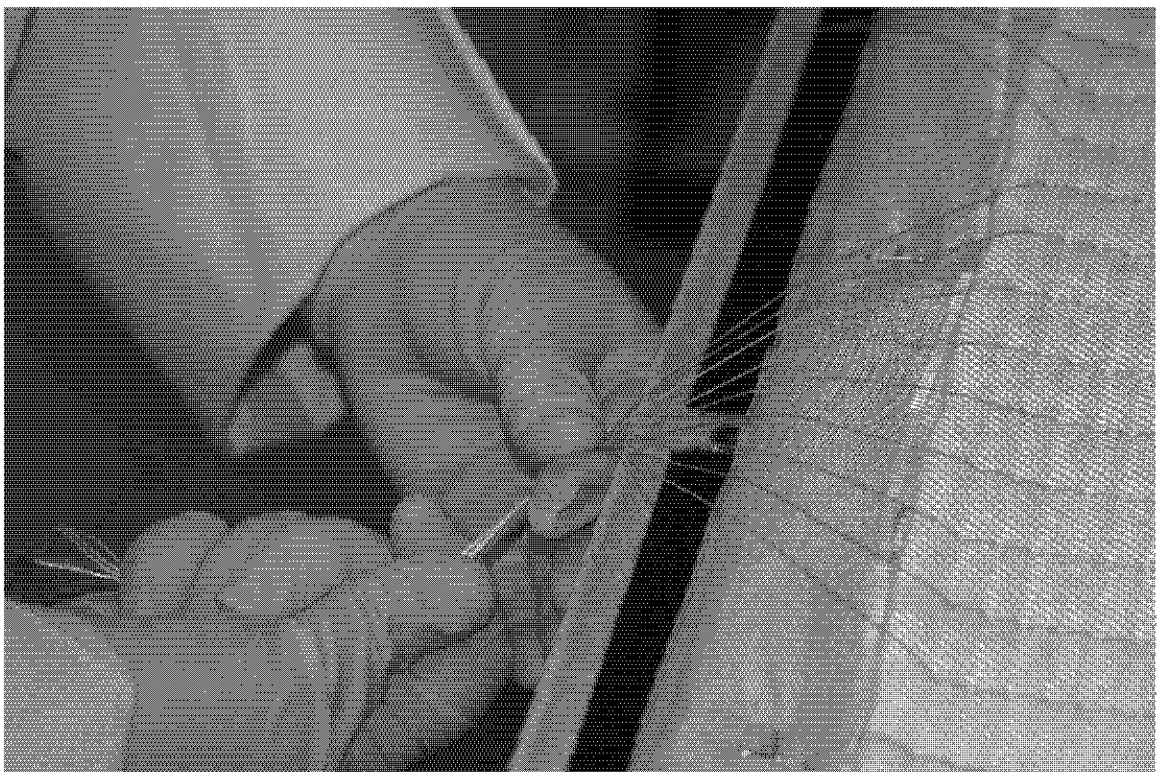

Figure A-26. FIB thread being tied-off after its first run through the Multi-Needle Sewing Machine by technician Jean Wright, March 9, 2010.
Source: Penny Rogo Bailes.

Figure A-27. FIB after sewing completed by Multi-Needle Sewing Machine, March 9, 2010.
Source: Penny Rogo Bailes.

Figure A-28. Arced FIB being sewn on Long-Arm Sewing Machine by technician Kathy Evans, March 9, 2010.
Source: Penny Rogo Bailes.

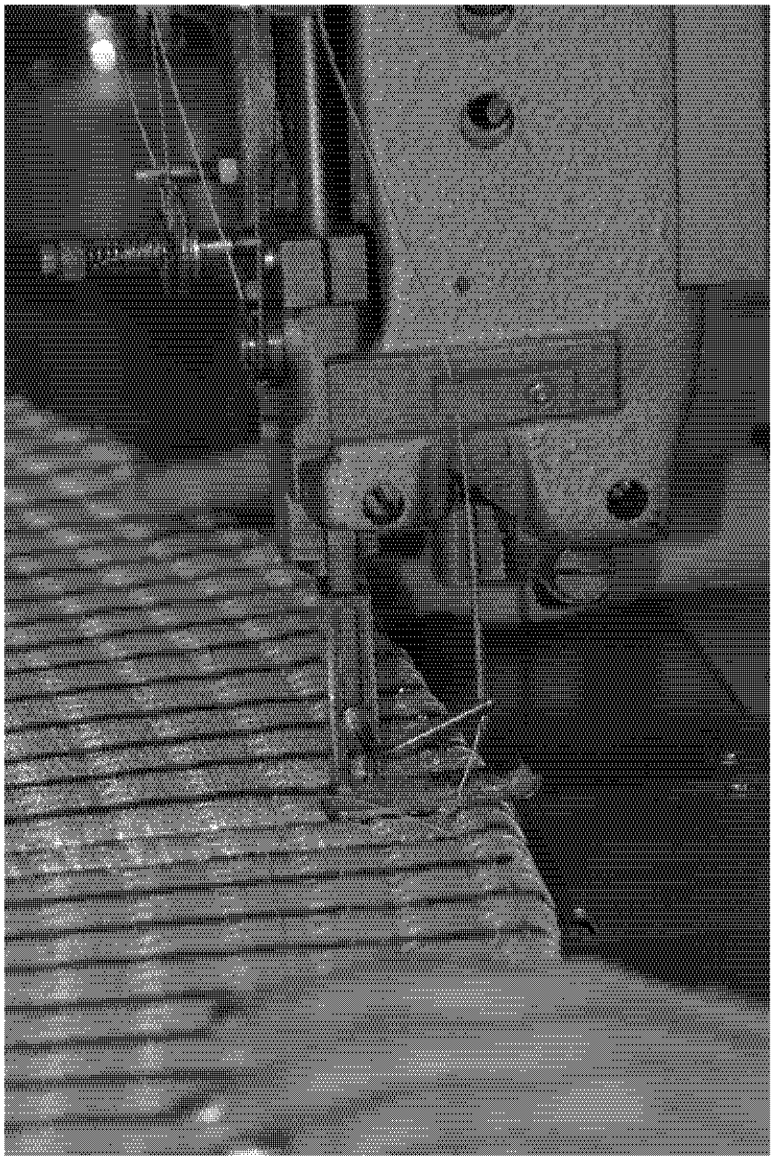

Figure A-29. Detail of arced FIB being sewn on Long-Arm Sewing Machine by technician Kathy Evans, March 9, 2010.
Source: Penny Rogo Bailes.

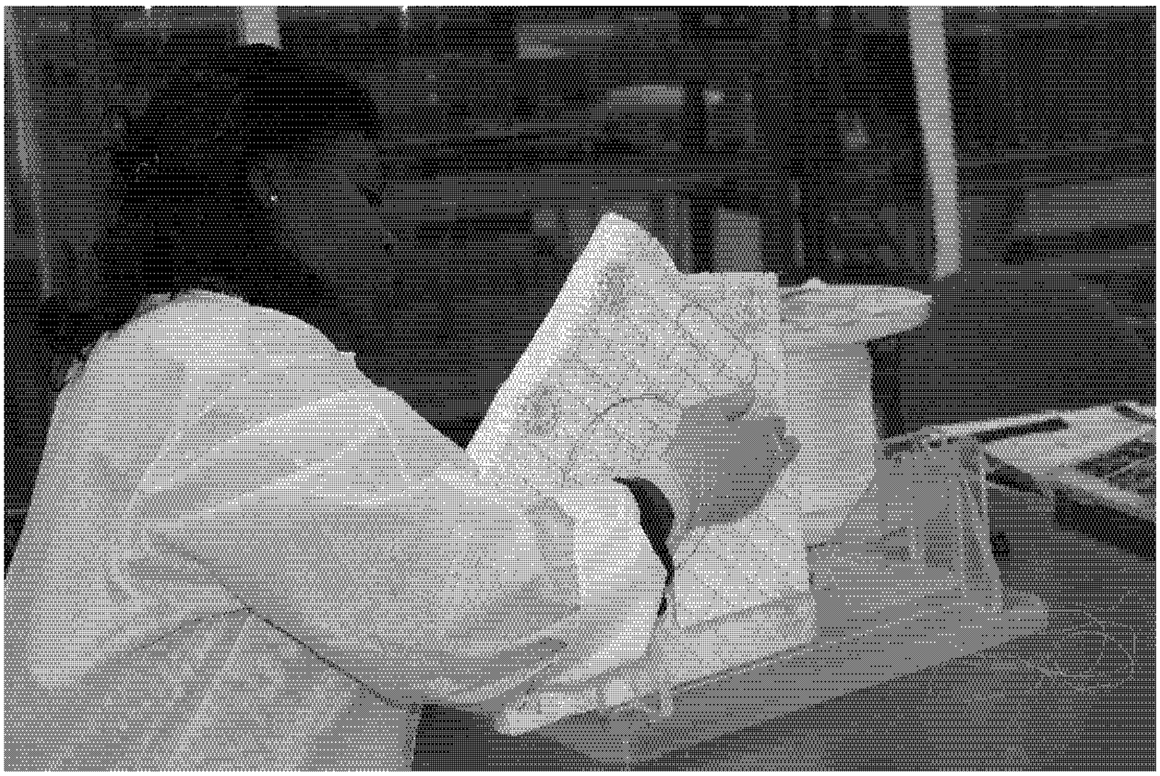

Figure A-30. Custom FRSI blanket being hand-sewn by a KSC technician, March 9, 2010.
Source: Penny Rogo Bailes.

Figure A-31. Thermal barrier being hand-sewn by a KSC technician, March 9, 2010.
Source: Penny Rogo Bailes.

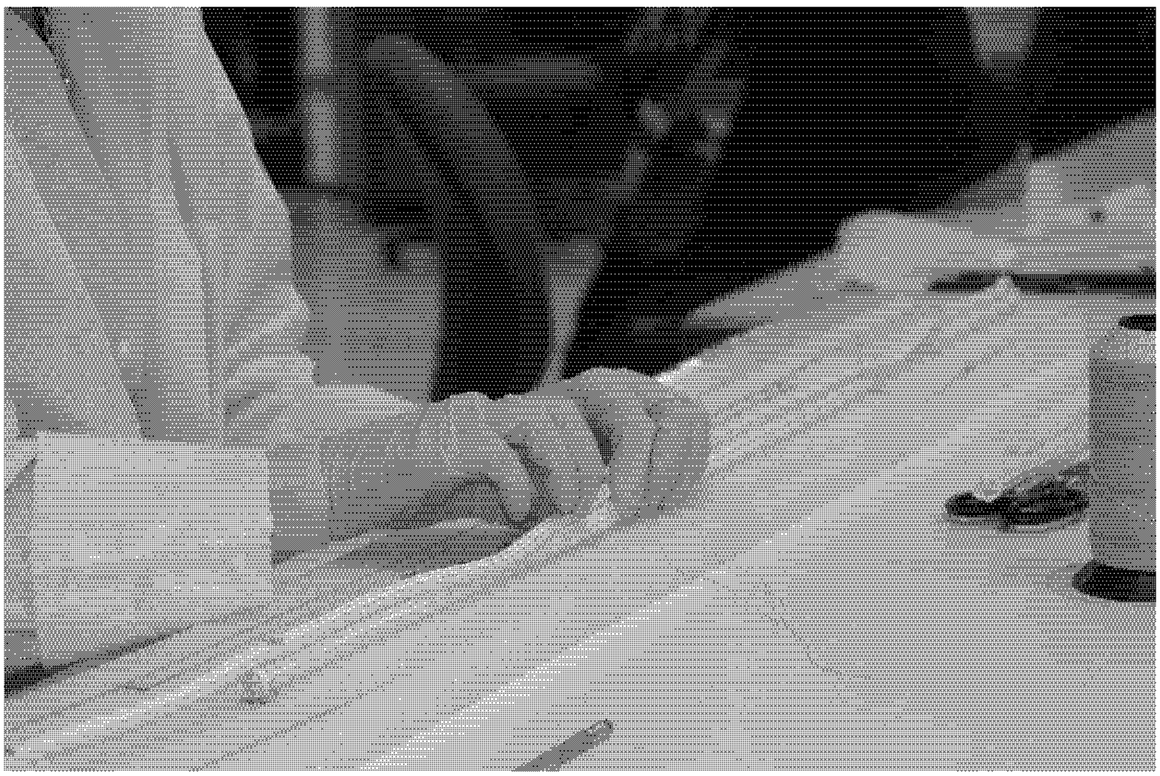

Figure A-32. Detail of thermal barrier being hand-sewn by a KSC technician, March 9, 2010.
Source: Penny Rogo Bailes.

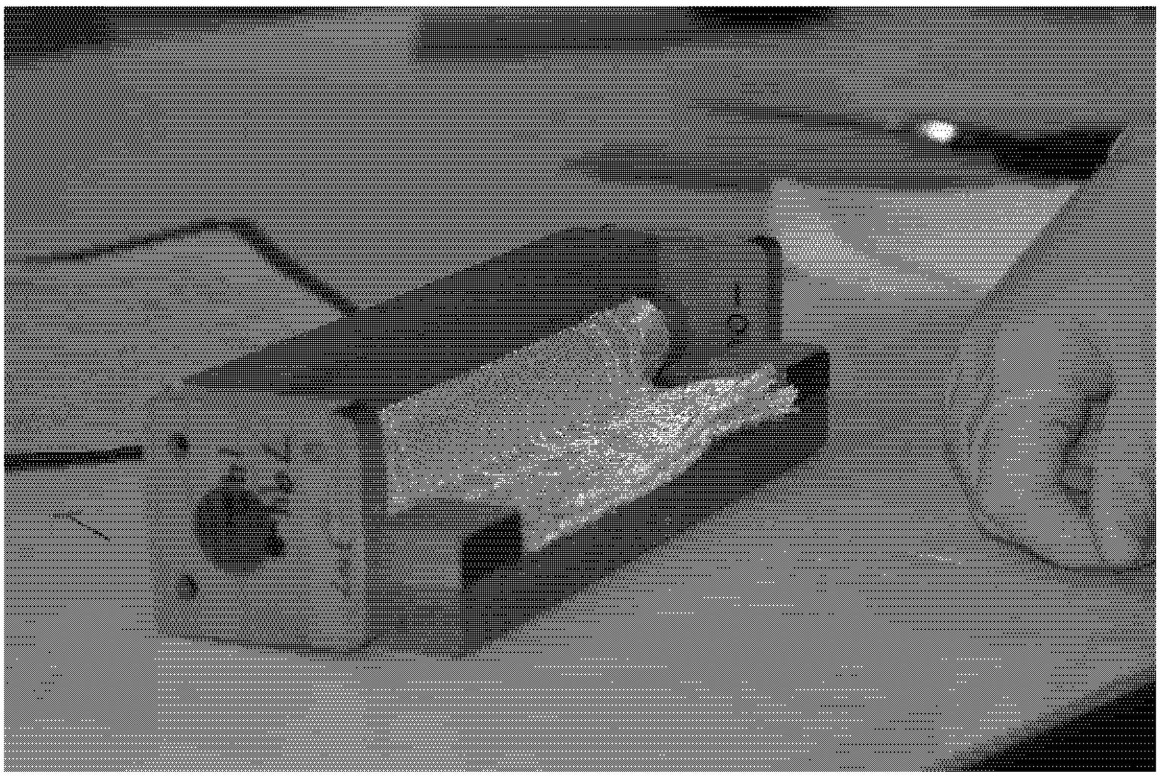

Figure A-33. Detail of a small thermal barrier being hand-sewn by a KSC technician, March 9, 2010.
Source: Penny Rogo Bailes.