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Testing Requirements for Refractory Materials

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February 2011

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ABBREVIATIONS AND ACRONYMS

ACI	American Concrete Institute
AIAA	American Institute of Aeronautics and Astronautics
AISC	American Institute of Steel Construction
Al_2O_3	aluminum oxide
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASRB	Advanced Solid Rocket Booster
ASRM	Advanced Solid Rocket Motor
ASTM	American Society for Testing and Materials
Btu	British thermal unit
CAC	calcium aluminate cement
COTS	commercial off the shelf
CP	center perforated
CxP	Constellation program
DSC	differential scanning calorimetry
DTS	Diagnostic Test Facility
EAR	Export Administration Regulation
ECO	Export Control Office
EDS	energy dispersive x-ray spectroscopy
ETDP	Exploration Technology Development Program
FF	Fondu Fyre
FOD	foreign-object-debris
g	gram
GH_2	gaseous hydrogen
GHe	gaseous helium
GN_2	gaseous nitrogen
GO	ground operations
gpm	gallon per minute
GSE	ground support equipment
HB	NASA Handbook
HCl	hydrochloric acid

IBC	International Building Code
ITAR	International Traffic in Arms Regulations
KSC	Kennedy Space Center
LC	Launch Complex
LH_2	liquid hydrogen
LO^2	liquid oxygen
LOX	liquid oxygen
MFD	main flame deflector
MIL-STD	military standard
MLP	Mobile Launcher Platform
MOR	modulus of rupture
MPa	megapascal
MSFC	George C. Marshall Space Flight Center
MSL	Materials Sciences Laboratory
NASA	National Aeronautics and Space Administration
NLS	National Launch System
OSHA	Occupational Safety and Health Administration
psi	pound per square inch
psia	pound per square inch absolute
RSRM	reusable solid rocket motor
s	second
SEM	scanning electron microscopy
SFD	side flame deflector
SLC	Space Launch Complex
SMM	Structures, Mechanisms, and Materials
SPEC	specification
SPREE	solid propellant rocket exhaust effects
SRB	solid rocket booster
SRM	solid rocket motor
SSc	Stennis Space Center
SSME	Space Shuttle Main Engine
STD	standard
STI	Scientific and Technical Information

STS	Space Transportation System
TBD	to be determined
TM	Technical Memorandum
TPP	Technology Prioritization Panel
USA	United Space Alliance

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ABSTRACT

Launch Pads 39A and 39B currently use refractory material (Fondu Fyre) in the flame trenches. This material was initially approved for the Saturn program, had a lifetime of 10 years according to the manufacturer, and has been used for over 40 years. As a consequence, the Fondu Fyre at Launch Complex 39 requires repair subsequent to almost every launch.

With the recent severe damage to the flame trenches, a new refractory material is sought to replace Fondu Fyre. In order to replace Fondu Fyre, a methodology to test and evaluate refractory products was developed. This paper outlines this methodology and discusses current testing requirements, as well as the laboratory testing that might be required. Furthermore, this report points out the necessity for subscale testing, the locations where this testing can be performed, and the parameters that will be necessary to qualify a product. The goal is to identify a more durable refractory material that has physical, chemical, and thermal properties suitable to withstand the harsh environment of the launch pads at KSC.

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TESTING REQUIREMENTS FOR REFRACTORY MATERIALS

1 INTRODUCTION

1.1 Background

Corrosion is the environmentally-induced degradation of materials. The natural marine environment at the Kennedy Space Center (KSC) has been documented by the American Society for Metals (ASM) as having the highest corrosion rate of any site in the continental United States. See Endnote 1 in Section 8. As a result, launch structures and ground support equipment (GSE) at KSC degrade faster than similar assets at other locations. With the introduction of the Space Shuttle in 1981, the already highly corrosive natural conditions at the launch pads were rendered even more severe by the acidic exhaust from the solid rocket boosters (SRBs). As a consequence, corrosion-related costs are significant for all launch structures. These costs were estimated in January 2009 to be approximately $336M over the previous 20 years of the Space Shuttle Program. The estimate included the costs associated with inspection and maintenance of the launch pads, medium-scale and large-scale blasting and repainting activities, the repair and replacement of failed refractory materials, and the replacement of badly corroded structural metal elements. Technologies for the prevention, detection, and mitigation of materials degradation in launch facilities and ground support equipment were identified by the Constellation Program Ground Operations (CxP GO) as a critical need for the safety, efficiency, affordability, and sustainability of future launch operations at KSC. Subsequently, CxP GO established an agreement with the Exploration Technology Development Program (ETDP) Structures, Mechanisms, and Materials (SMM) project to identify alternate refractory material for the protection of the launch pad flame deflectors at KSC. This report, prepared as one of the deliverables for the project, provides testing requirements for refractory materials to be used in launch pad applications as well as the available information from all previous testing of refractory materials for launch pad flame trench protection that was gathered in the process of identifying the testing requirements

Materials development, characterization, testing, and optimization would be based on identification of key refractory material performance properties that can improve the durability, performance, and safety of the launch complexes. A small-scale prototype flame deflector system would be developed (or acquired) for component-level materials testing. Material requirements; maintenance and inspection requirements; application, repair, and rehabilitation requirements; system specifications; and qualification requirements/procedures would be developed for the replacement refractory material. These refractory material technologies were to be integrated into a scaled, simulated flame deflector system and demonstrated under simulated launch conditions.

The above project plan had to be revised because of the unavailability of funding to carry out the project as it was originally planned. This report constitutes the last deliverable for the scaled-down project, and it is intended to provide the testing requirements for refractory materials to be used in launch pad applications, as well as provide the available information on all previous testing of refractory materials for launch pad flame trench protection that was gathered in the process of identifying the testing requirements.

1.2 Flame Deflector System

The launch complexes at the KSC are critical support facilities required for the safe and successful launch of vehicles into space. Most of these facilities are over 30 years old and are experiencing deterioration. See Figure 1. With constant heat/blast effects and environmental exposure, the refractory materials currently used in the NASA launch pad flame deflectors have become very susceptible to failure, resulting in large pieces of refractory materials breaking away from the steel base structure and being projected at high speeds during launch. Repair of these failures is a costly and time-consuming process. Improved materials and systems for use in launch pad flame deflectors will improve supportability in KSC launch facilities by reducing operational life-cycle costs.

The flame deflector systems at Launch Complex (LC) 39A and LC-39B are critical to protect NASA's assets, including the Space Shuttle, GSE, and personnel. As the name implies, the system diverts rocket exhaust away from critical structures through its geometric design. Further benefits are provided by a water deluge system that dampens acoustic vibrations and the high temperatures associated with launch.

Flame deflectors are typically covered with a heat-resistant material that protects the flame deflector from erosion, ablation, and extreme temperatures that are produced by the rocket propulsion systems. If this refractory layer is compromised, deterioration to the flame deflector and other load-bearing structures may result. Once compromised, the refractory material and flame deflector substructures can turn into unwanted projectiles known as foreign-object-debris (FOD) that can cause consequent damage.

LC-39A and 39B were originally designed to support the Apollo Program and the Saturn V rocket. With the advent of the Shuttle Program, the Saturn-era flame deflectors were replaced. Figure 2 shows a schematic cross section of the current flame deflector at launch complex 39A. The flame deflector system consists of a flame trench, a main flame deflector (MFD), and a pair of side flame deflectors (SFDs). The main flame deflector is designed in an in inverted, V-shaped configuration, is constructed from structural steel, and is covered with refractory concrete material. One side of the inverted "V" deflects the flames and exhaust from the Space Shuttle Main Engine (SSME), and the opposite side deflects the flames and exhaust from the SRBs. Additional protection is provided by the two movable side deflectors at the top of the trench (not shown in the figure). The SFDs direct the SRB exhaust and are needed because the SRBs are very close to the sidewalls of the flame trench. The orbiter side of the flame deflector is 38-feet high, 72-feet long and 57-feet wide. The SRB side of the flame deflector is 42-feet high, 42-feet long and 57-feet wide. The total mass of the asset is over 1 million pounds. See Endnote 2 in Section 8.

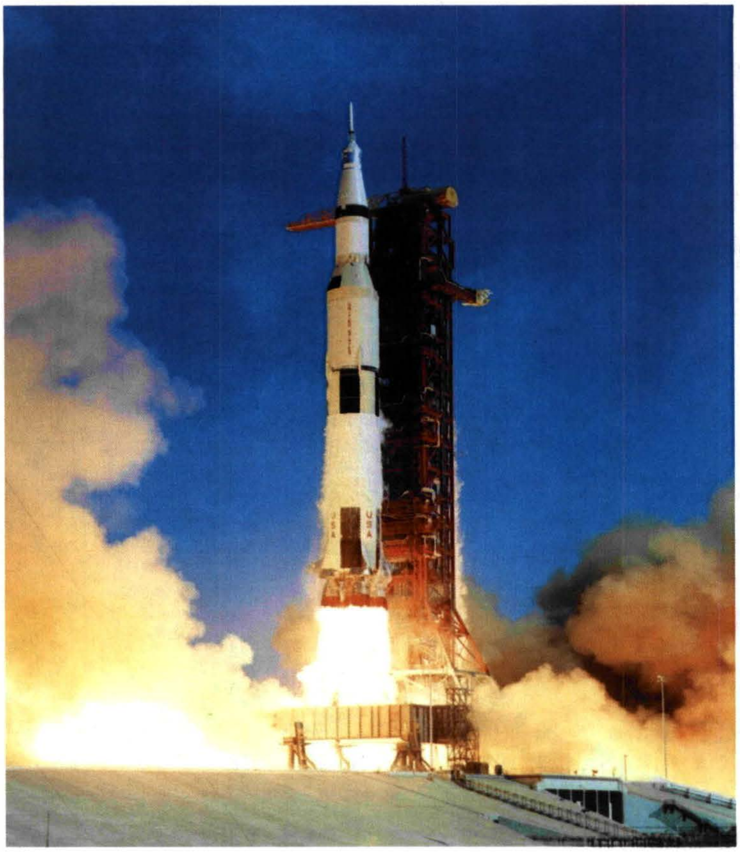


Figure 1. Launch of Apollo 11 on July 16, 1969

The flames from the SSMEs and the SRBs are channeled down opposite sides of the flame deflector. See Endnote 3 in Section 8. The deflector is constructed of steel on a structural steel I-beam framework. To protect the structure from serious degradation during launch, the faces of the flame deflector are lined with refractory concrete. This product is known as Fondu Fyre WA-1G (supplied by the Pryor Giggey Co.). The thickness of the refractory concrete is approximately 6 inches on the SRB side, 4.5 inches on the SSME side, and 4 inches on the side deflectors.

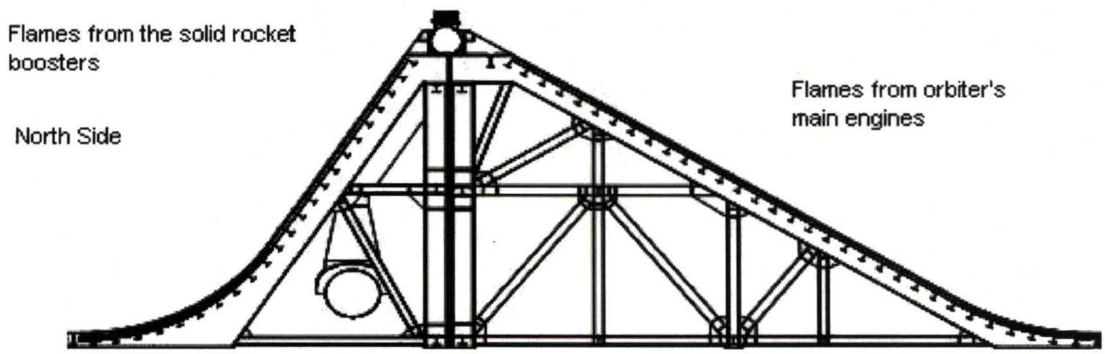


Figure 2. Cross Section of Flame Deflector at Launch Complex 39A

Figure 3 shows the configuration of the Space Shuttle viewed upward from the flame trench. The openings for the SSME exhaust and the flame deflector used to divert the rocket plume from the SRBs are labeled. The other side of the flame deflector, which is not visible in the picture, diverts the exhaust from the main engines. The SRBs burn at a much higher temperature and create a harsher loading environment than the SSME. Consequently, the SRB exhaust leads to more severe exposure conditions and results in damage that is more significant to the deflector.

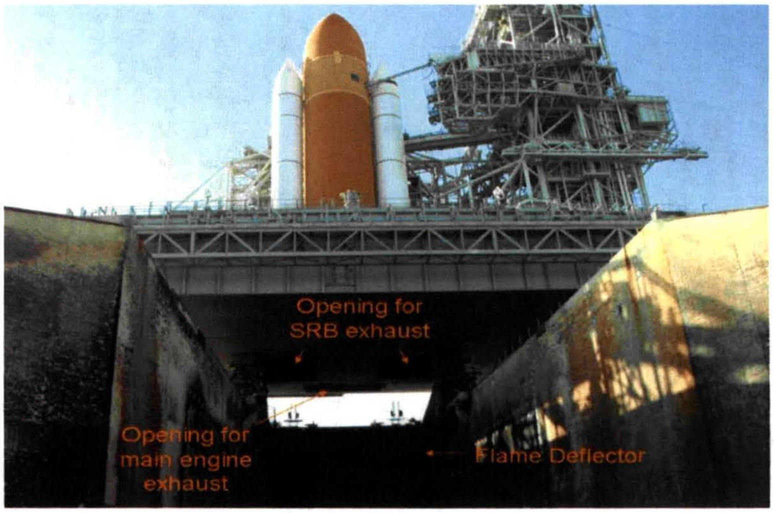


Figure 3. Openings for Flames From the Main Engine and SRBs

Figure 4 shows a view of the flame deflector underneath the SRBs. The image shows the structural steel at the bottom of the deflector, which is protected with Fondu Fyre. Figure 5 shows the SSME flame trench and deflector.

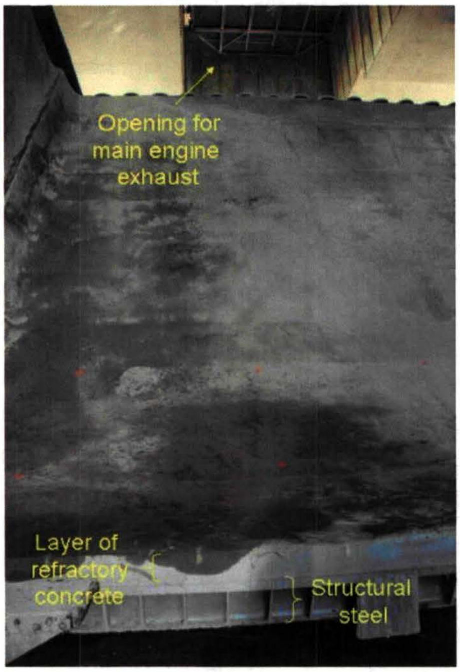


Figure 4. Magnified View of LC-39A Flame Deflector

Figure 5. SSME Flame Trench and Deflector

Safely meeting the flame deflector requirements of diverting the flame, exhaust, and small items that are dislodged during launch is dependent on the integrity and performance of the materials used to construct the flame deflectors. The use of refractory products that have superior material characteristics (under launch conditions) is necessary to protect the flame deflector, Space Shuttle, GSE, and launch personnel.

1.3 Launch Environment

The launch environment is different in the SRB and SSME flame trenches. The SRB side has historically seen more damage than the SSME side because of the harsher conditions found there. This section gives a general overview of the launch environment.

The Space Shuttle has two SRBs, which exhaust in the north flame trench, and three SSMEs, which exhaust towards the south. The SRBs have considerably more thrust, 3,300,000 pounds each, compared to the thrust of the SSMEs, 375,000 pounds each. The SRBs also burn hotter than the SSMEs and produce aluminum oxide particles that can act as abrasives or, if they are near or above melting point, may react with the refractory material. The SRBs impinge in two locations on the top of the flame deflector, underneath the MLP exhaust holes as seen in Figure 6. The light areas at the top left and right are the direct impingement areas. The areas that receive direct impingement appear lighter because of the presence of aluminum oxide particles in these locations. There are two side flame deflectors above the flame trench, shown in Figure 7. The SRBs impinge on the side deflectors before entering the main flame deflector. Examination of the impingement area shows that the material sees very different conditions than outside the impingement area. These differing conditions may cause different failure mechanisms for the refractory material. For example, the bottom lip of the deflector appears to undergo more erosion than those areas farther up the deflector towards its apex.

The launch sequence itself affects the environment. Prior to launch, water is continuously flowed onto the refractory material. This procedural requirement ensures that the sound suppression system is operational and results in the refractory material being thoroughly saturated with water during launch. This process releases approximately 300,000 gallons of water during launch, with a peak flow rate of 900,000 gallons per minute 9 seconds after launch. See Endnote 4 in Section 8. The launch timeline is as follows:

a. The sound suppression water flow starts just before SSME ignition at T – 6.6 seconds (s).

b. SSME ignition occurs at T - 6.6 s.

c. SRB ignition occurs at T – 0 s.

d. The Shuttle clears the tower approximately 6 seconds after launch. See Endnote 5 in Section 8.

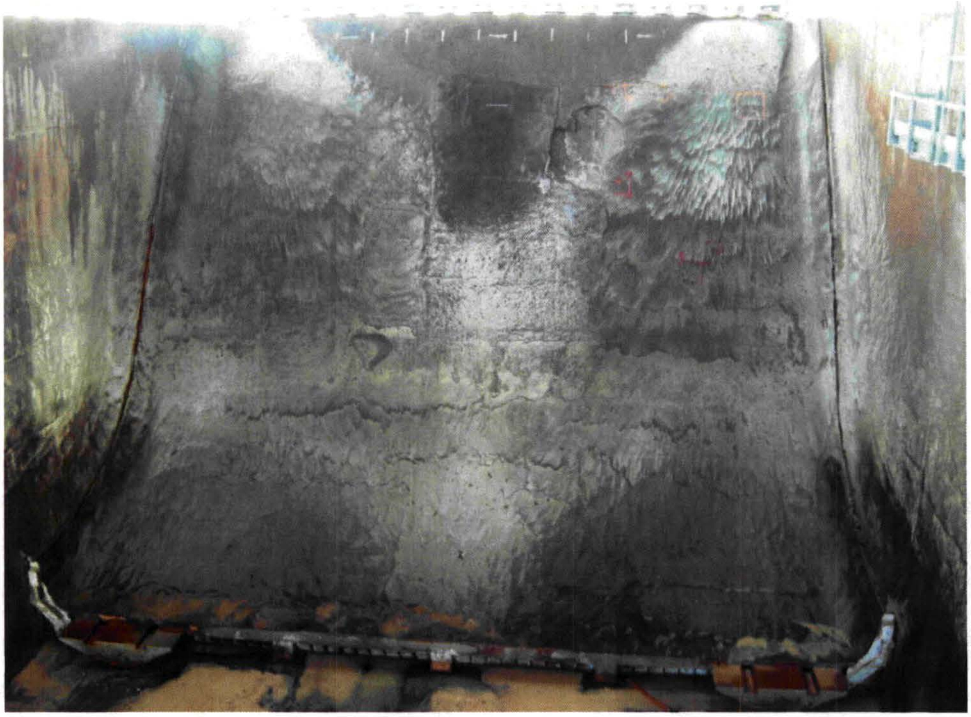


Figure 6. SRB Main Flame Deflector

Figure 7. Side Flame Deflector

1.4 History of Refractory Material Testing at KSC

Investigations on refractory materials for protection from heat and blast on launch complexes using solid rocket motors (SRMs) started in the mid 60's. A Solid-Propellant Rocket Exhaust Effects (SPREE) program (see Endnote 6 in Section 8) was established to evaluate materials for the protection of launch facilities from potentially damaging environments created by solid rocket motor exhaust gases.

The program consisted of performing scale-model test firings of both cold and hot jet streams with single nozzle configurations to derive models. Subscale test modeling was refined and correlated with full-scale launches of the Titan IIIC rocket using 120-inch SRMs. Unfortunately, this program's goal was to develop a design handbook for properly configuring a deflector system for launching with SRMs and did not concentrate on qualifying refractory materials.

Out of the 27 test firings performed, only five refractory materials from two manufacturers were used. Consequently, Fondu Fyre WA-1 was recommended for use because of its superior performance in mechanical, physical, and chemical properties over the other products. Furthermore, it was already approved and in use on Complex 34 for the Apollo Program.

Since then, investigations on thirteen different refractory materials have been performed at KSC during the launches of STS-1 through STS-9 (1981 – 1983) and again on STS-55 (1993). Over the past 30 years (Figure 8), only 10 launches out of 131 (less than 8%) were utilized for testing new refractory materials. Some of the new products showed promise, but further investigations were not performed. These investigations mostly consisted of exposing test panels from different refractory concrete manufacturers to actual launch environments (i.e., panels were placed in the flame deflector during a launch) at LC-39 with the objective of qualifying the materials for use in the flame deflectors. There is no evidence that the material used today, WA-1G (gunnable) was ever tested.

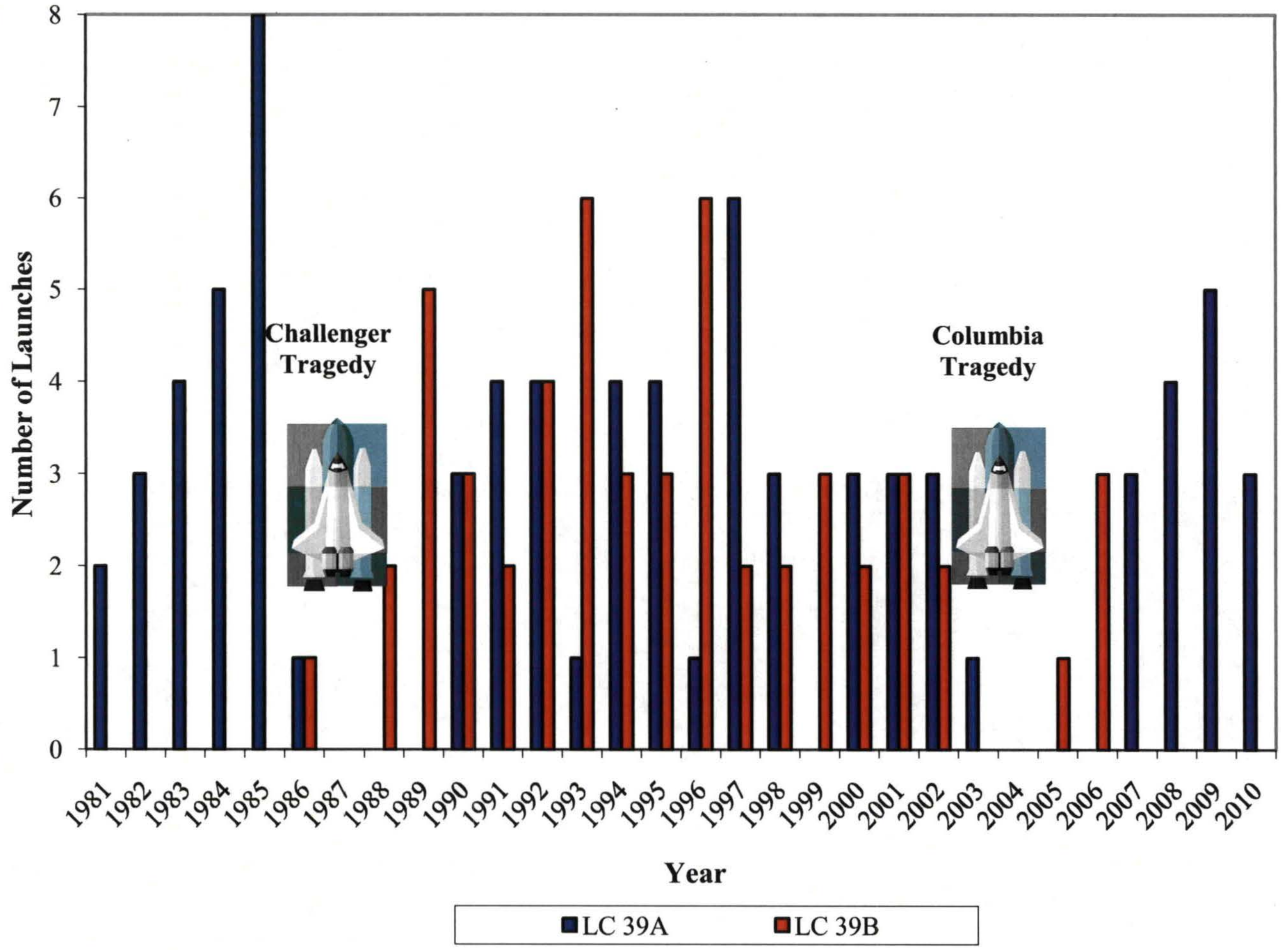


Figure 8. History of Shuttle Launches, 1981 – 2010

The main issue with qualifying a new material was the uncertainty of a product's compatibility with the existing installed system from different manufacturers. Refractory concrete panels were evaluated for average depth of erosion and pitting, where pitting is defined as the maximum depth of abrasion. Table 1 shows an overview of the test program including the number of samples tested and the products used for each test. Copies of each test report are provided in Appendix A, MMA-1918-80, STS-1; Appendix B, MTS-505-80, STS-2; Appendix C, MTS-142-82, STS-3; Appendix D, MTS-340-82, STS-1, -2, and -3; Appendix E, MTS-425-82, STS-4; Appendix F, MTB-503-83, STS-5, -6, and -7; Appendix G, MTB-250-84, STS-8 and -9; and Appendix H, 93-4436, STS-55 of this document.

Table 1. Overview of Test Program Since 1981

Report No.	Launch	Report Date	Materials Tested (# of samples)
MMA-1918-80 (Appendix A)	STS-1	July 29, 1981	Fondu Fyre WA1 (1)[1] Fondu Fyre WA1 w/wire (1)[1] WRP 1 (1)[2] WRP 3 (1)[2] Tufshot (1)[3] Tufshot w/ wire (1)[3]
MTS-505-81 (Appendix B)	STS-2	March 1, 1982	Fondu Fyre WA1 (1)[1] Fondu Fyre WA1 w/wire (1)[1] WRP 2 (1)[2] WRP 3 (1)[2] Tufshot w/ wire (1)[3]
MTS-142-82 (Appendix C)	STS-3	May 6, 1982	Fondu Fyre FSC-5 (1)[1] Fondu Fyre WA-1[1] Fondu Fyre WA-1 w/wire (1)[1] WRP 1 w/wire (1)[2] WRP 3 w/wire (1)[2] Tufshot w/wire (1)[3]
MTS-340-82 (Appendix D)	STS-1, 2, and 3	June 7, 1982	Fondu Fyre WA-1 Panel 2 Fondu Fyre WA-1 w/wire Panel 3 WRP-1 Panel 1 WRP-2, Panel 7 WRP-3 Panel 4 Tufshot Panel 6 Tufshot with fibers, Panel 5
MTS-425-82 (Appendix E)	STS-4	August 27, 1982	Fondu Fyre WA-1 (3)[1] WRP (3)[2]
MTB-503-83 (Appendix F)	STS-5, -6, and -7	September 1, 1983	Fondu Fyre WA-1 (3)[1] WRP 1 (1)[2] WRP 2 (1)[2] WRP 3 w/wire (10)[2] LI (1)[3] 17-67 (2)[3]
MTB-250-84 (Appendix G)	STS-8 and -9	May 22, 1984	Fondu Fyre HT-1 (1)[1] Fondu Fyre FSC-5 (1)[1] WRP 3 w/wire (2)[2] 17-67 (1)[3] No. 75 (2)[4]
93-4436 (Appendix H)	STS-55	July 19, 1993	Fondu Fyre WA-1 (3)[1] Mitec (3)[5]

[1]Originally Designed Concretes, now Pryor Giggey Co, [2]Wahl Refractory Products, [3]Harbison Walker Refractories, [4]Sauereisen Cement Co, [5]Mitec, Inc

2 CURRENT REQUIREMENTS

NASA KSC design requirements dictate specific standards for selecting and qualifying refractory materials for use in the launch environment. A flow chart was developed to visually display the NASA/KSC standards that must be met under KSC-DE-512-SM, Facility, System, and Equipment General Design Requirements (Figure 9). This shows the design requirement pathway that leads to understanding and predicting the launch-induced environment and eventually to the standards used to meet those environment and design requirements. A description of the launch-induced environment and corresponding requirements, as listed in the documents and standards below and specifically related to refractory materials, follows.

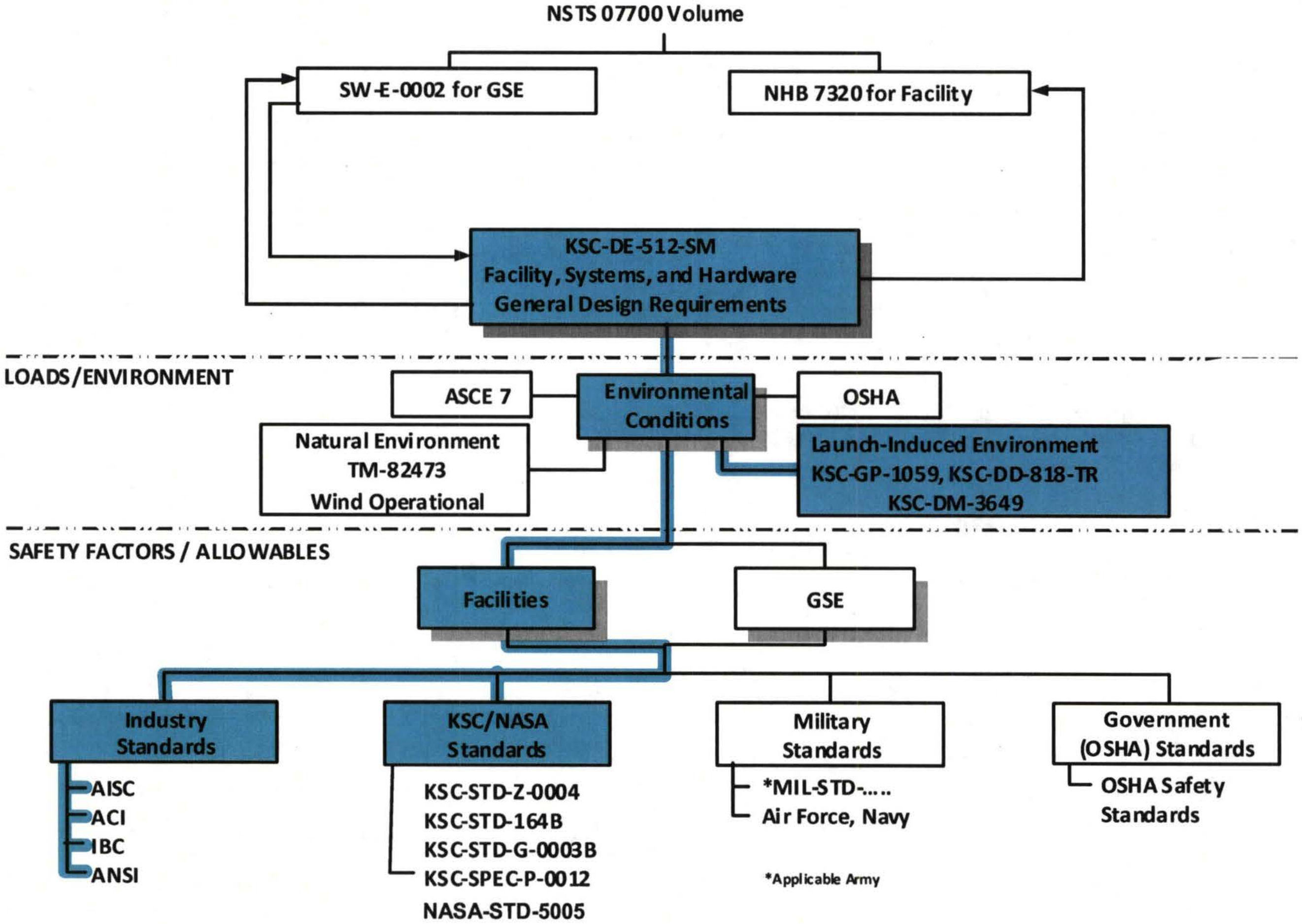


Figure 9. Flow Chart Highlighting the Developmental Path From Engineering Design Requirements to NASA/KSC Standards

2.1 KSC-GP-1059, KSC-DD-818-TR, and KSC-DM-3649

The documents KSC-GP-1059, KSC-DD-818-TR, and KSC-DM-3649 all describe the launch-induced environment. No testing and qualification requirements are listed in these documents but rather they are the supporting documents that describe launch-induced environment conditions for which the refractory concrete-related specifications are based.

KSC-GP-1059, Environment and Test Specification Levels Ground Support Equipment for Space Shuttle System Launch Complex 39 (Acoustic and Vibration, Volume I of II; Thermal and Pressure, Volume II of II, Part 1 of 2, Heating Rates, Pressure Loads, and Plume Flow Fields, and Part 2 of 2, Specific Temperatures of Selected Parts of LC-39; Acoustics, Volume III; and Thermal and Pressure, Volume IV) encompasses the thermal, pressure, acoustic, and vibration environments induced by launch of Space Shuttle vehicles from LC-39 Pads A and B. Volumes I and II predict the environments from Saturn V launches and anticipated environments for Space Shuttle launches. Volumes III and IV predict the launch-induced environments of Space Shuttle launches after the replacement of Redesigned Solid Rocket Motors (RSRM) and Solid Rocket Boosters (SRB) with Advanced Solid Rocket Boosters (ASRB). Volumes III and IV used launches from STS-1 to STS-30R to predict the new launch environments.

KSC-DD-818-TR, Summary of Measurements of KSC Launch-Induced Environmental Effects (STS-1 through STS-11), summarizes the Shuttle launch-induced environment data acquired at Kennedy Space Center during the STS launches. The measurements included using sensors to record pressure, acoustic, strain, load, temperature, heat rate, and vibration parameters.

KSC-DM-3649, Lift-off Response Spectra to Space Shuttle Launch-Induced Acoustic Pressures, summarizes computations of lift-off response spectra obtained from the acoustic pressure created and correspondingly measured during Shuttle launches. This document uses the acoustic data from STS-2 through STS-31 to derive static and dynamic loads imposed on exposed GSE during launching.

2.2 KSC-STD-Z-0004 Section 3.3.9

KSC-STD-20004, Structural Design, Standard for, defines requirements for framing of structures, ground support equipment, and temporary structures and enclosures. In section 3.3.9, the standard refers to KSC-SPEC-P-0012, Refractory Concrete, Specification for, qualification of materials used in structures that are subject to direct rocket engine exhaust impingement.

2.3 KSC-STD-164, Section 3.3.16

KSC-STD-164, Environmental Test Methods for Ground Support Equipment, Standard for, focuses on test methods for ground support equipment, with section 3.3.16 specifically related to Lift-Off Blast. Refractory materials at the launch pad must meet this standard. According to this standard, the refractory materials can only be qualified by meeting lift-off blast test conditions. No other qualification methods, such as laboratory or test chamber methods, can be substituted. The lift-off blast test can only be performed during an actual launch or on a rocket engine test stand during a test firing.

2.4 KSC-STD-G-0003

KSC-STD-G-0003, Launch Support and Facility Components, Qualification of, Standard for, establishes methods for the qualification of launch support and facility components. Section 4.0 describes five methods for qualifying a material: (1) qualification by testing, (2) qualification by similarity, (3) prior qualification, (4) qualification by usage and analysis, and (5) qualification by higher level assembly testing. Refractory materials must meet this standard (KSC-STD-G-0003).

Qualification by testing includes demonstration of operational suitability for a specific application when no qualification date is available. Three types of tests (functional, acceptance, and verification) are used in the design and development of new equipment. This testing includes using structural, dynamic, component compatibility and life cycle criteria that is similar to the launch environment but on a laboratory scale. The testing allows the use of subscale accelerated conditions of environment, functions (such as pressure, voltage, flow, etc.), tolerances, life cycles, and time. This testing includes using all natural environmental factors, including humidity, salt fog, rain, sand and dust, fungus, and solar radiation, and then inducing launch environments, including acoustics, shock, vibration, high and low temperatures, liftoff blast, electromagnetic field, and explosive gas/vapor atmosphere. The environmental testing must be in accordance to KSC-STD-164, which is testing during an actual launch or rocket engine test firing.

Qualification by similarity refers to materials that are comparable in use or rating to already-qualified materials.

Prior qualification refers to materials that were formerly qualified to the necessary environment and testing levels.

Qualification by usage and analysis refers to acceptance without a formal qualification test and based on evaluations of usage on previous programs, postlaunch data and inspection, and considering all static and dynamic operating conditions.

Qualification by higher level assembly testing refers to qualification of a component that is part of a higher assembly that has already been qualified by testing in the same application.

2.5 KSC-SPEC-P-0012

KSC-SPEC-P-0012, Refractory Concrete, Specification for, covers requirements for refractory concrete used for the heat and blast protection of the flame deflectors and other areas of a launch or test facility. The material must resist degradation of thermal protection characteristics due to the unprotected seacoast atmosphere exposure at the launch facilities. The KSC specification currently active for refractory concrete is KSC-SPEC-P-0012; however, it is currently being revised.

2.5.1 Current Specification

The current requirements for KSC-SPEC-P-0012 include a qualification process, required material characteristics, minimum fresh and hardened material requirements, as well as quality assurance provisions and packing requirements. The quality assurance section provides information on the material qualification process for use at KSC. This process includes making test specimens, as required by the specification, and exposing these specimens to an actual launch environment. Requirements listed in the specification for the acceptance of refractory concrete materials used at KSC include the following:

a. Materials: Aggregate shall be hard, dense, durable, clean, sharp, and well graded.

b. Fineness modulus: The fineness modulus shall be between 3.75 and 2.75.

c. Strength: The refractory concrete shall develop a compressive strength of 4500 psi at 7 days and 90 percent of the 7-day strength within 24 hours.

d. Rocket engine exhaust resistance: Test samples installed at designate areas of the launch facility shall not crack, spall, or erode more that 1/8 inch when subject to rocket exhaust test. Heat flux shall be up to 3300 Btu/ft^2-sec with an exposure time of approximately 10 seconds.

e. Workability: The refractory concrete shall be able to be applied pneumatically of manually to a smooth finish

f. Weathering: The refractory concrete shall resist degradation of thermal protection characteristics due to seacoast atmosphere exposure

Some of the limitations that have been identified for the existing KSC-SPEC-P-0012 specifications include the following:

a. Key performance parameters, such as the material shrinkage, are not required in the current specification.

b. No requirements on material storage are provided. Calcium aluminate cement (CAC) can hydrate with time under storage conditions that can significantly change the performance of the material.

c. No requirements are provided on placement procedures, curing, or other key construction practices. Procedures for placement of the entire refractory lining are dependent on the material being used for the refractory lining.

d. No methodology is provided for qualifying materials. Specific requirements, based on existing or newly developed standardized tests, should be included.

This specification is currently being revised to include the newly-identified requirements for refractory concrete.

2.5.2 Revised Specification

The revised specification will include many of the previous requirements, as well as new requirements based on the above noted limitations.

Table 2 lists the laboratory evaluation parameters that each material must meet in order to be considered for the second stage evaluation, a rocket engine exhaust exposure. The same laboratory evaluation requirements must then be met for the materials after exposure to the rocket engine exhaust.

Table 2. Laboratory Evaluation Requirements for Refractory Concrete, Suggested New Revision to KSC-SPEC-P-0012

Material Characteristic	Test Standard	Test Requirement
Sieve analysis	ASTM C92, using particle size distribution method	Reportable
Compressive strength	ASTM C133, using cold crushing strength method	4500 psi at 7 days, with 90 percent of 7-day strength developed within 24 hours
Thermal shock	ASTM C1171 or C24	No explosive spall in less than 6 thermal cycles when shocked to a temperature determined by the Government
Abrasion resistance	ASTM C704	Erosion not more than 3.2 mm per cycle
Shrinkage/thermal expansion	ASTM C 832-00	TBD
Modulus of rupture	ASTM C133, using modulus of rupture method	TBD
Acid resistance test	Internal Government test*	TBD
Thermal conductivity	ASTM C1113	Reportable
Specific Heat	ASTM E1269 from room temperature to maximum use temperature	Reportable
Bulk Density	ASTM C20, section 1.1.4	Reportable

*The acid resistance test was developed by the Government. Details of the test will be given in the specification and are included in this document.

Rocket Engine Exhaust Exposure:

a. The test sample must be installed at a designated test or launch site and be exposed to engine exhaust. The test will be performed by the Government.

b. The test sample must meet the same testing requirements as above after the rocket engine exposure period.

Additional Requirements:

a. The material may not contain asbestos.

b. The refractory shall be capable of meeting the requirements for a number of thermal cycles or number of year's exposure to the seacoast environment.

c. The installation, curing process, and temperatures for each phase of testing and final installation at the launch or test site shall be the same.

The reader is urged to consult with the most current version of KSC-SPEC-P-0012 for a complete list of the current and revised requirements.

2.6 NASA-STD-5005

NASA-STD-5005, Standard of the Design and Support of Ground Equipment, defines top-level requirements and provides guidance for the design and fabrication of ground support equipment. In section 5.11.3.1.5.3, the standard refers to KSC-SPEC-P-0012 for qualification of refractory materials used in structures that are subject to heat and blast protection of flame deflectors.

2.7 Product Testing

In order for a product to be considered for rocket engine exhaust testing, the product needs to meet the above referenced requirements. The product must be prepared, installed, and cured using the same methodology as intended for installation at the launch pad.

2.8 Summary

All of the standards and specifications regarded the exposure to launch environments as a critical step for the qualification of refractory materials. A summary of testing requirements referenced in different standards and specifications for refractory materials used in launch environments is shown in Table 3. This information is based on the requirements included in KSC-STD-Z-0004F, KSC-STD-164, KSC-STD-G-0003, and KSC-SPEC-P-0012.

Table 3. Summary of Testing and Qualification Requirements for Refractory Materials in Launch Environments

NASA Specification	Qualification Requirements			
	Similar Industry	Laboratory Scale	Subscale	Launch
KSC-STD-Z-0004F	Refers to KSC-SPEC-P-0012 for requirements.			
KSC-STD-164	No	No	Yes	Yes
KSC-STD-G-0003	Yes	Yes, along with KSC-STD-164 requirements	Yes	Yes
KSC-SPEC-P-0012	No	Yes	No	Yes
Revised KSC-SPEC-P-0012	No	Yes	Optional	Yes
NASA-STD-5005	Refers to KSC-SPEC-P-0012 for requirements.			

3 LABORATORY TESTING

Standardized testing of refractory materials is required to assess the characteristics of refractory products and to identify products that can be used in KSC launch environments. For refractory materials, the following standards are applicable. It should be noted that some standards are not specific to refractory products, and modifications to the testing procedures may be required. In most cases, and when possible, the standard that specifically pertains to refractory products should be used.

The following standards are applicable to the testing of refractory materials for NASA. It should be stressed that the list is not all inclusive of the standards that might be required for future needs and requirements.

a. Preparation of Refractory Samples

(1) ASTM C1140, Standard Practice for Preparing and Testing Specimens From Shotcrete Test Panels

(2) ASTM C862, Standard Practice for Preparing Refractory Concrete Specimens by Casting

b. Compressive Strength

(1) ASTM C133 (Reapproved 2003), Standard Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories

c. Abrasion/Erosion Resistance

(1) ASTM C704, Standard Test Method for Abrasion Resistance of Refractory Materials at Room Temperature

d. Shrinkage and Thermal Expansion

(1) ASTM C179, Standard Test Method for Drying and Firing Linear Change of Refractory Plastic and Ramming Mix Specimens

(2) ASTM C832 (2005), Standard Test Method of Measuring the Thermal Expansion and Creep of Refractories Under Load

(3) ASTM C1148 (2002) , Standard Test Method for Measuring the Drying Shrinkage of Masonry Mortar (Not specifically for refractory concrete - modified)

(4) ASTM E228, Standard Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

(5) ASTM C 1171, Standard Test Method for Quantitatively Measuring the Effect of Thermal Shock and Thermal Cycling on Refractories

e. Modulus of Rupture

(1) ASTM C 133 (Reapproved 2008), Standard Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories

f. Thermal Conductivity

(1) ASTM C 1113/C 1113M, Standard Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique)

g. Other Physical Properties

(1) ASTM C 20 (Reapproved 2010), Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water

(2) ASTM C 830 (Reapproved 2006), Standard Test Methods for Apparent Porosity, Liquid Absorption, Apparent Specific Gravity, and Bulk Density of Refractory Shapes by Vacuum Pressure

(3) ASTM C 1419 (Reapproved 2009), Standard Test Method for Sonic Velocity in Refractory Materials at Room Temperature and Its Use in Obtaining an Approximate Young's Modulus

(4) ASTM E 1269, Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry

3.1 Sample Preparation

Prior to use or test, refractory materials shall be stored in dry, protected, and weatherproof structures. In general, appropriate care should be exercised to protect the raw materials from weather and ensure that the manufacturer's recommendations are followed during mixing and installation. Raw material expiration dates should be checked prior to use to ensure that the final material has the properties advertised by the manufacturer and meets the requirements of NASA. Care should be exercised to ensure that the correct product is used for a particular application. Refractory products are often formulated to cast or gun the refractory product. Refractory materials for laboratory testing should be prepared with the same method that would be used to install the material at the pad.

In general, concrete samples can be prepared in three different ways: shotcreting, gunning, or casting. Casting involves mixing the components and pouring the cementitious product in place to cure. Shotcreting is an automatic delivery method that pumps a wet (already mixed) concrete to the nozzle where air is added to deliver the concrete to the target. Gunning is a process in which the cement and sand are injected into an air stream to deliver it to the nozzle. At the nozzle, the dry mix and water are combined, and the materials are pneumatically expelled to the target.

3.1.1 Sample Preparation – Shotcreting or Gunning

Forms for the production of refractory samples by the gunning process can be fabricated using ASTM C1140-03 (Appendix E). Bulk samples utilizing this specification have been prepared at KSC. See Endnote 7 in Section 8. In accordance with the requirements of ASTM C1140, samples cannot be taken from the bulk sample in the space equal to the depth plus 1 inch from the outside edges. The form should be constructed from rigid materials, so that dislodging of the refractory product through vibration or deformation is prevented. The walls and bottom of the forms fabricated at KSC used a 0.5-inch wire fabric mesh to contain the product. See Figure 10.

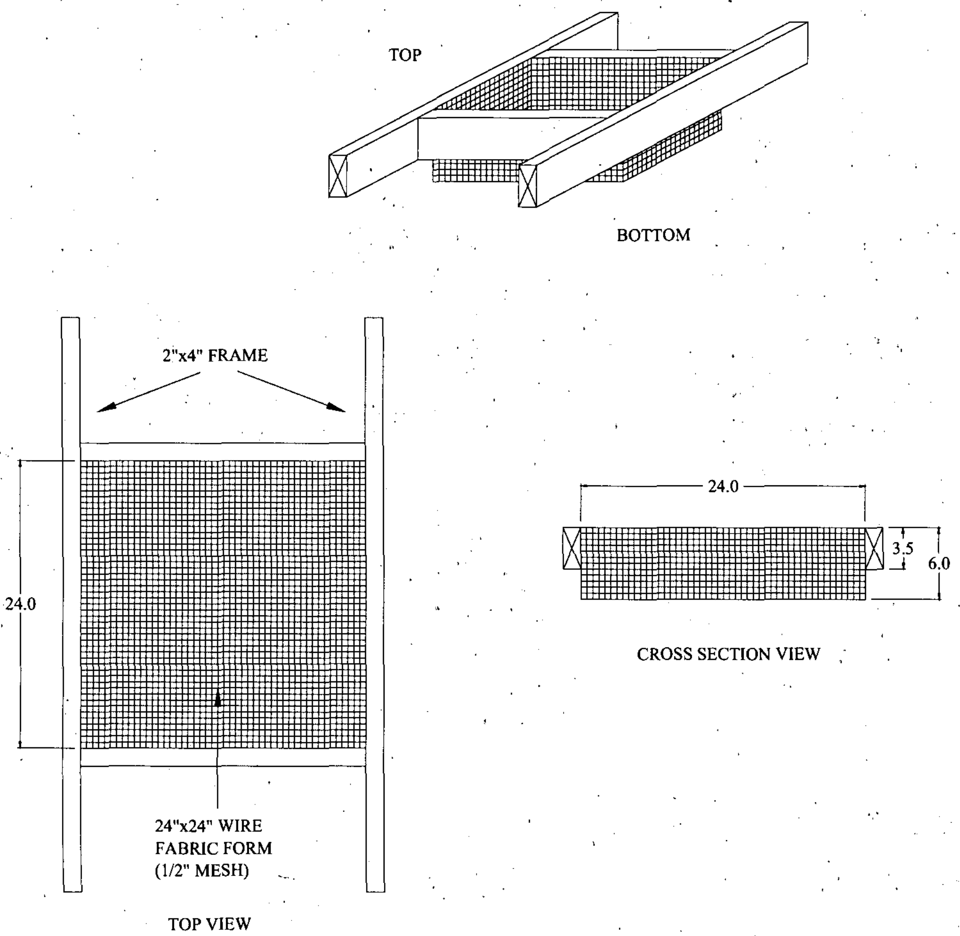


Figure 10. Forms Designed To Hold the Wet Refractory Concrete (Units in Inches)

To prepare samples, refractory materials shall be gunned or shotcreted into forms at an angle as shown in Figure 11. In the prior referenced testing, two forms were used for each sample in the study. Sample size or quantity should be sufficient to produce the amount of replicate samples needed for laboratory testing. After material placement, the samples shall cure under ambient conditions in accordance with manufacturers' recommendations. ASTM C1140 recommends the samples be tightly wrapped to prevent water from evaporating during the curing process.

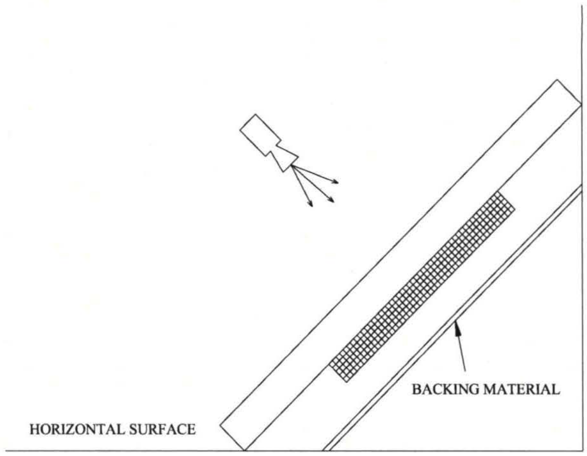


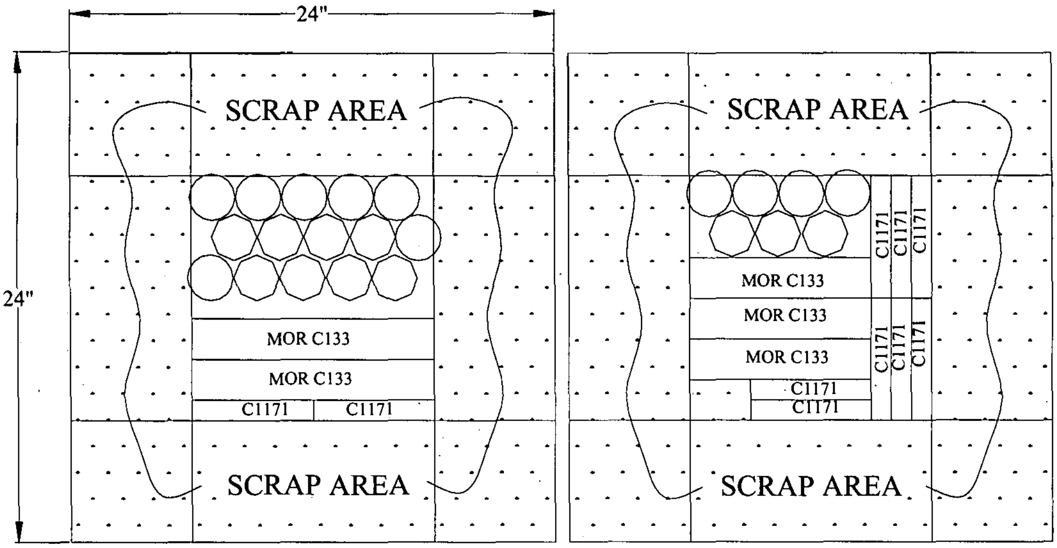
Figure 11. Position of the Forms During Spray Application

The gunning process and the formation of the bulk cementitious material have been reported (see Endnote 8 in Section 8) and photos of the sample preparation are shown in Figure 12. The photo on the left shows spraying of the refractory mix and the photo on the right shows gunned but still wet refractory material in the form.

Figure 12. Sample Preparation (Zampell Refractories in Tampa, Florida)

In accordance with ASTM C1140, the edges of the forms should be discarded, and the remainder of the sample should be cut to meet ASTM standards for sample testing. Each sample (cores and cubes) should be cut from the center interior section, discarding the top and bottom from each piece.

To prepare individual samples for testing, the ambient-cured bulk refractory material is removed from the form and cut using both a diamond saw and a core drill. Figure 13 shows an example cut pattern that has been used to produce cylindrical, cube, and bar shaped samples that were required for laboratory testing as a part of a prior project. See Endnote 9 in Section 8. The dark areas on the side are discarded.



MOR C133- 5 SAMPLES (2"x2"x9", from center)
C1171- 10 SAMPLES (1"x1"x6", from center)
Compression Cores- 20 SAMPLES (2" round x 2" tall, from center)

Figure 13. Example of Cut Pattern for Each Sprayed Sample (Units in Inches)

3.1.2 Sample Preparation - Casting

Cast specimens should be produced following the guidance of ASTM C862. According to this procedure, a paddle mixer (Figure 14) is used to prepare the wet cementitious mixture. ASTM C862 gives details on water addition and mixing procedures.

As quickly as possible following the mixing phase, the wet cementitious material should be packed into appropriate molds for the tests to be conducted. The product is then consolidated using a vibration table until the top surfaces appear smooth. The filled molds are then placed in a humidity chamber (greater than 95% humidity) at ambient temperature for a curing period of 24 hours. The specimens are then removed from the molds and are allowed to continue curing under ambient conditions for at least 7 days.

Figure 14. Paddle Mixer Used at KSC To Prepare Refractory Samples

3.2 Laboratory Testing and Standards

This section describes the tests that can be used to evaluate the performance of a refractory material in a controlled laboratory environment. These tests are suggested to be part of the new qualifying process of a refractory material, though they cannot be used to qualify a refractory product without physical launch pad (or simulated launch pad) testing. The official qualification procedure is found in Section 2.

3.2.1 Sieve Analysis

Particle size distribution of a refractory concrete can be explained using ASTM C92 (Note 13). This test method utilizes a set of calibrated sieves for the analysis prewetted and wetted cementitious material. According to this standard, the concrete is weighed prior to analysis and placed through a series of sieves, starting with the one with the coarsest opening. Results from this standard are based (and reported) upon the material retained in each sieve, as well as the dust loss of the material passing through the final sieve.

3.2.2 Specific Heat Analysis

Specific heat capacity, or simply specific heat, can be defined as the quantity of heat required to raise the temperature of 1 gram of substance by 1 degree Celsius at constant pressure. ASTM E1269 is used to determine specific heat using differential scanning calorimetry (DSC). DSC measures the specific heat of materials by measuring differences in the heat flow into the test material and a reference material or blank.

The specific heat of the sample (as a function of temperature) is a reportable quantity that may be used by engineers to help select refractory products to satisfy launch pad requirements.

3.2.3 Cold Compressive Strength

The compressive strength of a refractory material can be determined in accordance with ASTM C133. In brief, the cold crushing strength or compression strength (*CS* in lb_f/in^2 or psia) is defined by:

$$CS = \frac{Fmax}{A}$$

where,

F_{max} = maximum force or load applied at the yield point of the material (lb_f)
A = average (between top and bottom) cross-sectional area to which the load is applied (in^2)

A complete description of the process used to measure cold crushing strength is in ASTM C133. Samples are usually 2-inch cubes or 2-inch-diameter cylinders. Prior to testing, the samples should be dried in a 110°C oven for 18 hours. The compressive strength can then be measured using standard mechanical or hydraulic compression testing machines conforming to the requirements of ASTM E4, Practices for Force Verification of Testing Machines. A photo of the Instron Universal Test Machine (Model 5889) that meet these requirements is shown in Figure 15. Figure 16 shows samples before and after crushing.

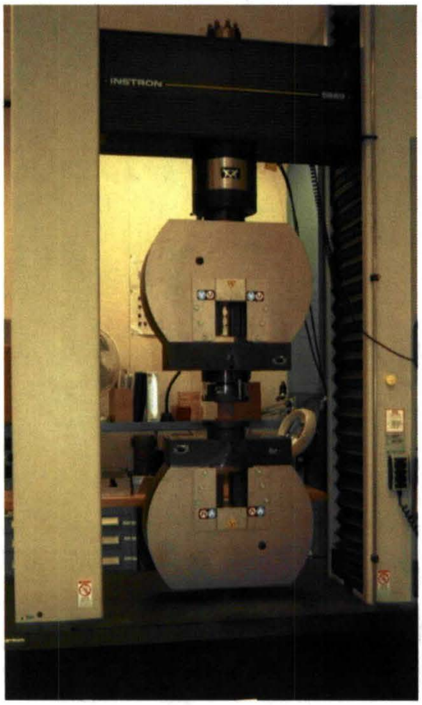


Figure 15. Instron in the Material Testing Laboratories, O&C Building, KSC

When tested according to ASTM C133 and according to the requirements of KSC-SPEC-P-0012, the refractory material shall develop a minimum compressive strength of 31.0 megapascal (MPa) (4500 psi) at 7 days, with 90 percent of the 7-day strength developed within 24 hours.

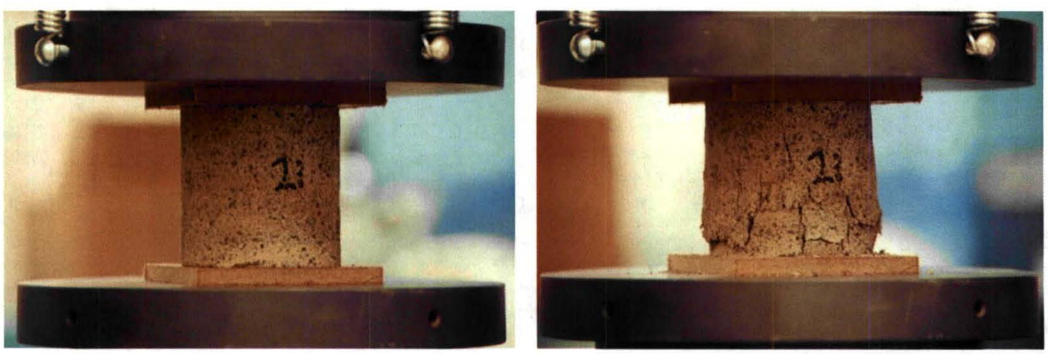


Figure 16. Cylindrical Sample Prior To and After Crushing

3.2.4 Abrasion Resistance

Solid rocket motors (SRMs) produce aluminum oxide (Al_2O_3) and hydrochloric acid as a by-product. When the SRMs are operational, the particulates are expelled from the motors at considerable velocities. As a consequence, it is desirable to investigate the refractory materials resistance to abrasion. ASTM C704 is used to investigate this phenomenon under ambient laboratory conditions.

Samples used for ASTM C704 are cut from bulk refractory materials and should measure between (4" by 4" by 1") to (4½" by 4½" by 2½" or 3"). Prior to testing, the samples are dried in an oven at 110°C until a constant weight is achieved. The sample's resistance to abrasion is then investigated by propelling 1000g silicon carbide media in air at a pressure of 65 psi. The abrasive media is impinged upon the sample at a 90-degree incident angle.

An important point to note is that ASTM C704 investigates the abrasion resistance of refractory materials under ambient conditions. The abrasion resistance under elevated temperature launch pad conditions may differ greatly.

3.2.5 Cold Modulus of Rupture

The modulus of rupture can be explained in accordance with ASTM C133. The cold strength of a refractory material gives an indication of its suitability for the materials use in refractory construction, but it should not be construed as providing an equivalent level of performance at elevated temperature. The modulus of rupture (*MOR* in lb_f/in^2 or psia) is defined by

$$MOR = \frac{3FmaxL}{2bd\text{^}2}$$

where,

F_{max}	= maximum force applied at rupture (lb_f)
L	= span between supports (inches)
b	= breadth or width of the specimen (inches)
d	= depth of the specimen (inches)

Typically, the modulus of rupture is determined from cast or gunned refractory material with nominal dimensions of 9" by 2" by 2". Prior to testing, all specimens should be placed into a 110 °C oven until constant mass is achieved. Testing must be completed within 2 hours after the specimen is removed from the oven.

The measurements are performed (with rectangular bars and three stress points) using a standard mechanical or hydraulic compression testing machine conforming to the requirements of ASTM E4. Examples of refractory specimens and load-bearing cylinders for MOR testing are shown in Figure 17 and Figure 18. Figure 17 shows the condition of a refractory sample prior to MOR testing. Figure 18 shows the same sample after the MOR process is complete.

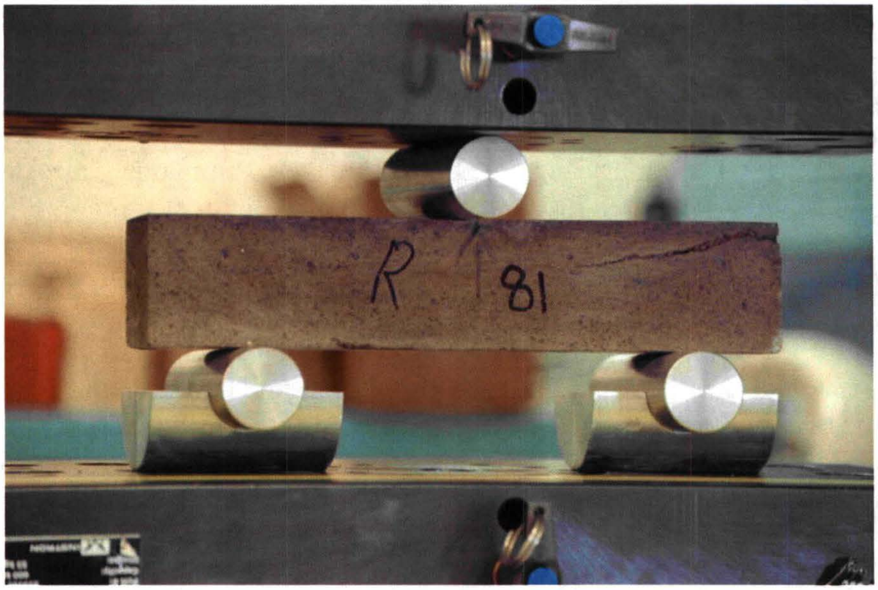


Figure 17. Modulus of Rupture Testing – Fondu Fyre (Pad Sprayed), Sample 81, Control, MOR = 837 psia (Before Compression)

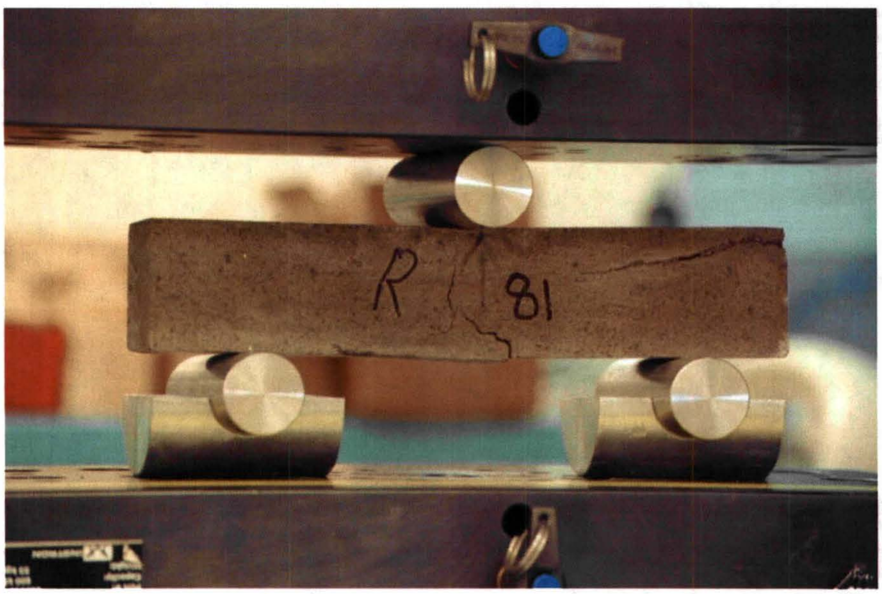


Figure 18. Modulus of Rupture Testing – Fondu Fyre (Pad Sprayed), Sample 81, Control, MOR = 837 psia (After Compression)

3.2.6 Thermal Expansion and Creep of Refractories

The shrinkage\thermal expansion shall be tested in accordance with ASTM C832. In summary, this test method subjects refractory materials to elevated temperatures under a 25-psi compressive stress for 50 hours. During the process, sensors continuously measure the linear change of the specimens parallel to the direction of the compressive stress.

A review of prior sensor data indicates that the maximum temperature achieved on the launch pads is 2165 °F at the time of this writing. It is suggested that the thermal expansion and creep of the refractory product be measured to a temperature equivalent to the maximum temperature that the refractory concrete is subject to at the launch pad. Sensor data for the final Shuttle flights may necessitate that the refractory product is evaluated at higher temperatures. The thermal expansion under load shall be reported. The reader is encouraged to refer to the latest revision of KSC-SPEC-P-0012 for thermal expansion requirements.

3.2.7 Thermal Shock

The thermal shock properties of a refractory material can be explained in accordance with ASTM C1171, ASTM C1419, and ASTM C133. These test methods are used to indicate the extent to which a refractory material can withstand stresses generated by sudden changes in temperature.

ASTM C1171 relies on sudden changes in temperature to generate stress within the refractory materials. Crack and flaw-free samples with the nominal dimensions of 1" x 1" x 6" are cut from the bulk material and are subsequently dried to a constant weight in a 110 °C oven. The sonic velocity is determined according to ASTM C1419, and the samples are then divided into two separate groups. Modulus of rupture testing (ASTM C133) on the first group (prior to heating) is used to make comparison to the post cyclic sonic velocity and modulus of rupture evaluations after the heating cycles.

One heating cycle results from the exposure of the sample to an elevated temperature of 1200 ± 15°C (2190 ± 25°F) for a 10-to-15 minute duration. The samples are then removed from the furnace for 10 to 15 minutes. This procedure is considered a single cycle. According to ASTM C1171, this procedure (or cycle) is repeated five times, the sonic velocity is again determined, and MOR testing is performed to evaluate the post cyclic strength of the sample.

A direct comparison of velocity and strength loss measurements is then used to help delineate the performance of different refractory materials. Furthermore, any spalling of the specimens during the cyclic heating and cooling process should be noted and can be used as a metric to disqualify the use of the product.

3.2.8 Thermal Conductivity

The thermal conductivity of the refractory samples may be determined in accordance with ASTM C1113. In summary, ASTM C1113 uses a constant electric current that is applied to a pure platinum wire between two bricks of the refractory material. The heat that is generated from the electric current is conducted away from the wire at a rate that is dependent upon the thermal conductivity of the refractory material. Using a minimum of four test temperatures, the k-Value (thermal conductivity) can be ascertained from this standard.

3.2.9 Acid Resistance Tests

Because of the presence of some amount of acid in the launch environment, or the potential thereof, the acid resistance should be determined/compared for different candidate flame trench refractory materials.

The acid soak test is used to determine a refractory material's resistance to degradation when placed in a bath of 0.1M hydrochloric acid (HCl). This procedure has been performed in the NASA Corrosion Technology Laboratory at the Kennedy Space Center.

The test compares the cold compression strength before and after acid exposure to evaluate acid resistance. The test is performed as follows. Specimens consisting of 2-inch cubes or 2-inch tall, 2-inch-diameter cylinders are dried overnight in a 110 °C oven. Each sample is individually submerged in a 200-ml volume of the 0.1M HCl acid in a plastic cup for 14 days. Midway through the exposure, the HCl is drained and a new solution is added. After 14 days, the specimens are rinsed and dried in an oven, and the compression strength is measured according to ASTM C133. The percent loss of strength after acid exposure is used to compare the relative acid resistance of different materials.

3.2.10 Density, Porosity, Water Absorption, and Apparent Specific Gravity

Porosity is the ratio of the volume of the open pores to the bulk volume of a material. Bulk density is defined as the mass of a material divided by the total volume it occupies. The total volume includes particle volume, interparticle void volume and internal pore volume. As with crushing strength, both water content and heat treatments factor significantly into apparent porosity and bulk density of the refractory material. See Endnote 10 in Section 8.

Apparent porosity, water absorption, apparent specific gravity, and bulk density are primary properties of refractory materials that can be measured using ASTM C20 or ASTM C830. These properties are widely used in the evaluation and comparison of product quality and as part of the criteria for selection and use of refractory products in a variety of industrial applications.

According to ASTM C20, refractory samples are dried prior to testing in a 110 °C oven until a constant mass is achieved. This mass is recorded. Specimens are then submerged in boiling water for a 2-hour duration and are allowed to cool. The weight of each sample is then measured while the samples are suspended in the water (to calculate the specific gravity). Finally, the samples are blotted dry with a moistened linen to remove all water from the surface, and then they are subsequently weighed.

The bulk density of the samples is calculated as follows

$$B = \frac{D}{V}$$

Where,

B= bulk density
D = dry weight
V= volume

The porosity of the samples is calculated as follows

$$P, \% = \frac{W - D}{V} X\ 100$$

Where,

P = porosity
W = saturated weight
D = dry weight
V= volume

The water absorption of the samples is calculated as follows

$$A, \% = \frac{W - D}{D} X\ 100$$

Where,

A = water absorption
W = saturated weight
D = dry weight

The apparent specific gravity is calculated as follows

$$T = \frac{D}{D - S}$$

Where,

T = apparent specific gravity
D = dry weight
S = suspended weight

3.2.11 Petrographic Analysis of Refractory Materials

Concrete petrography is the study of hardened concrete microstructure using microscopic techniques. The study of concrete microstructure can be used to investigate properties and issues related to mix design, water/cement ratios, composition, degradation, chemical attack, corrosion of steel reinforcement, microcracking, porosity, and grain size. To investigate these issues, cross-sectioned samples of (cured) refractory materials can be analyzed prior to and immediately after being exposed to rocket blast.

In addition to optical microscopy, scanning electron microscopy (SEM) with energy dispersive x-ray spectroscopy (EDS) can provide information that is beneficial to the analysis of the cementitious materials. SEM/EDS is particularly useful in determining mineralogical composition and in visually documenting significant pores, pore throats, clays, framework grains, and cements. The NASA Corrosion Technology Laboratory and the NASA Materials Sciences Laboratory at the Kennedy Space Center have the equipment necessary to perform a suitable analysis.

X-ray diffraction is an established technique that provides semi-quantitative determination of sample mineralogy and can be used to estimate and elucidate hydrated and nonhydrated phases of refractory materials. The NASA Corrosion Technology Laboratory and the NASA Materials Sciences Laboratory at the Kennedy Space Center have the equipment necessary to perform a suitable analysis.

4 ROCKET ENGINE EXHAUST TESTING

4.1 LC-39 Full-Scale Testing

To meet the requirements of the standards in Section 2, a new refractory concrete product must be exposed to an actual launch environment. To assist in this requirement, two test stands were constructed and installed at the bottom east and west sides of the main flame deflector, SRB side (Figure 19). The east and west test stands are capable of holding three samples each (Figure 20).

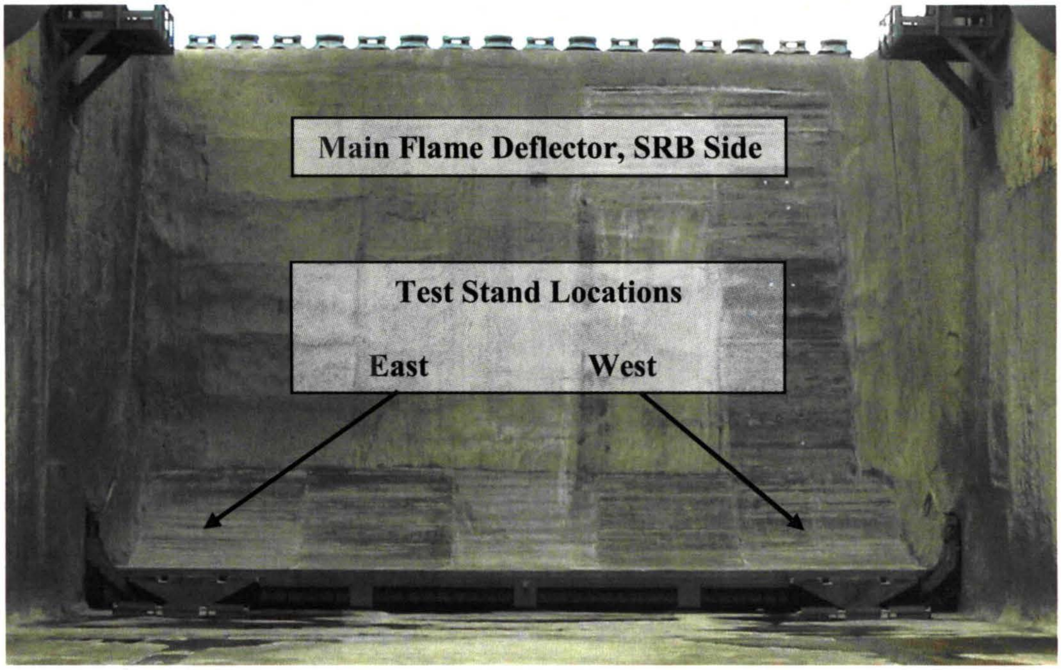


Figure 19. Typical Three Sample Test Stand

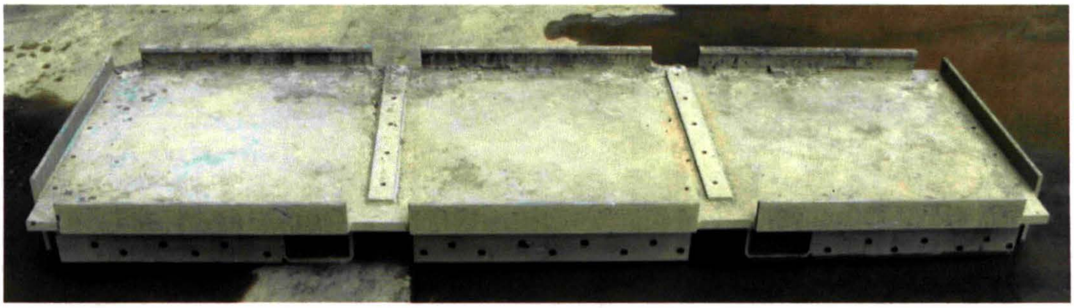


Figure 20. Test Stand Locations

Samples for this testing must be prepared in the same manner as they are intended to be used. The finished dimension of the test samples must be in accordance with sketch in Figure 21, taken from KSC-SPEC-P-0012.

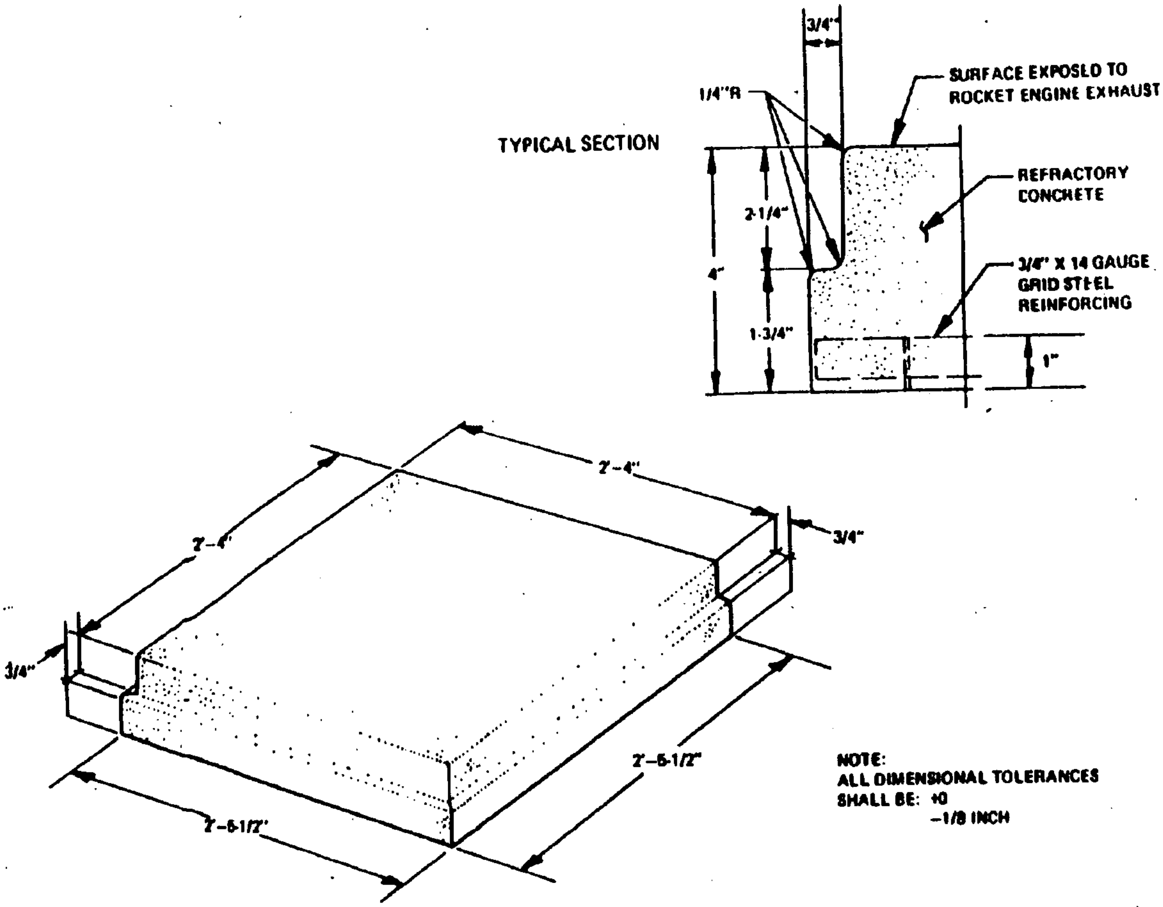


Figure 21. Typical Sample Size From KSC-SPEC-P-0012

4.1.1 Installation and Prelaunch Analysis

Based on the current effort to qualify additional refractory materials for the use on the LC-39 main flame deflector, test samples shall be installed at designated areas of the facility and then subjected to rocket engine exhaust. The intended procedure is outlined below and is based on the historical testing completed at KSC. Specific instances of work will be coordinated by NE-M9 and data transferred to NE-L for documentation by a KSC Materials Sciences Laboratory (MSL) report.

The specimen shall conform to the dimensions outlined in the latest revision of KSC-SPEC-P-0012, and installed in a manner similar to the test frames required in Ground Support Equipment Engineering Order EO3-79K09546, Refractory Test Frames.

Panels shall be installed with GE SCM 3404 on the bottom of the refractory concrete test panels to ensure levelness and adequate structural support of the integrated test panel.

Tap test stall be performed by NE-M9 and United Space Alliance (USA) engineering to determine the soundness of the samples.

Ablative coating, such as Dow Corning 3-6077 Silicone Ablative RTV (white colored) NSN 10753-0012-801 or other approved equal per KSC-SPEC-F-0006, shall be applied to the areas surrounding the panels to protect the fixtures used to secure the samples.

The installation shall be documented with photographs by NE-M9/NE-L or a designee.

The dimensions of the test specimens shall be measured after installation to a tolerance of 1.5 mm (1/16 in) using an optical scanner with a higher resolution performed by USA Optics.

4.1.2 Postlaunch Analysis

The postlaunch condition shall be documented with photographs by NE-M9/NE-L or a designee.

A postlaunch survey of any liberated debris may be performed by base operations contractor based on a consensus within NE.

The dimensions of the test specimens shall be measured after installation on the deflector to a tolerance of 1.5 mm (1/16 in) using an optical scanner with a higher resolution performed by USA Optics.

The test samples will not be removed unless the sample loses pieces of a 2 in x 2 in x 2 in or greater, or other structural detect is denoted by NE-M9/NE-L and USA engineering when determining the soundness of the samples.

For multiple launches, the test stands will be swapped, with intact samples remaining installed between launches.

The dimensions of the test specimens shall be measured after installation on the deflector to a tolerance of 1.5 mm (1/16 in) using an optical scanner with a higher resolution performed by USA Optics.

An additional sample coupon may be installed at the direction of NE-M9 to avoid the possibility of generating FOD during launch. Sample installation will proceed in accordance with previous installation section.

Installation shall be documented with photographs by NE-M9/NE-L or a designee.

The sample may remain in test indefinitely at the direction of NE-M9.

4.2 Subscale Rocket Engine Exhaust Test Stands and Material Dimensions

Subscale refractory testing has been performed at various locations. This section presents preliminary designs for refractory material sample size and test stand configurations using a standard 5-inch center perforated (CP) solid rocket motor. The basic designs are a modification of 80K60515 drawings used for full-scale live launches at LC-39A. The subscale samples are designed (smaller) for easier handling; 26.5-inch square at the base instead of 29.5-inch square, resulting in a 20 percent reduction in volume. Figures 22 through Figure 26 depict the new test stand designs and material dimensions for subscale testing.

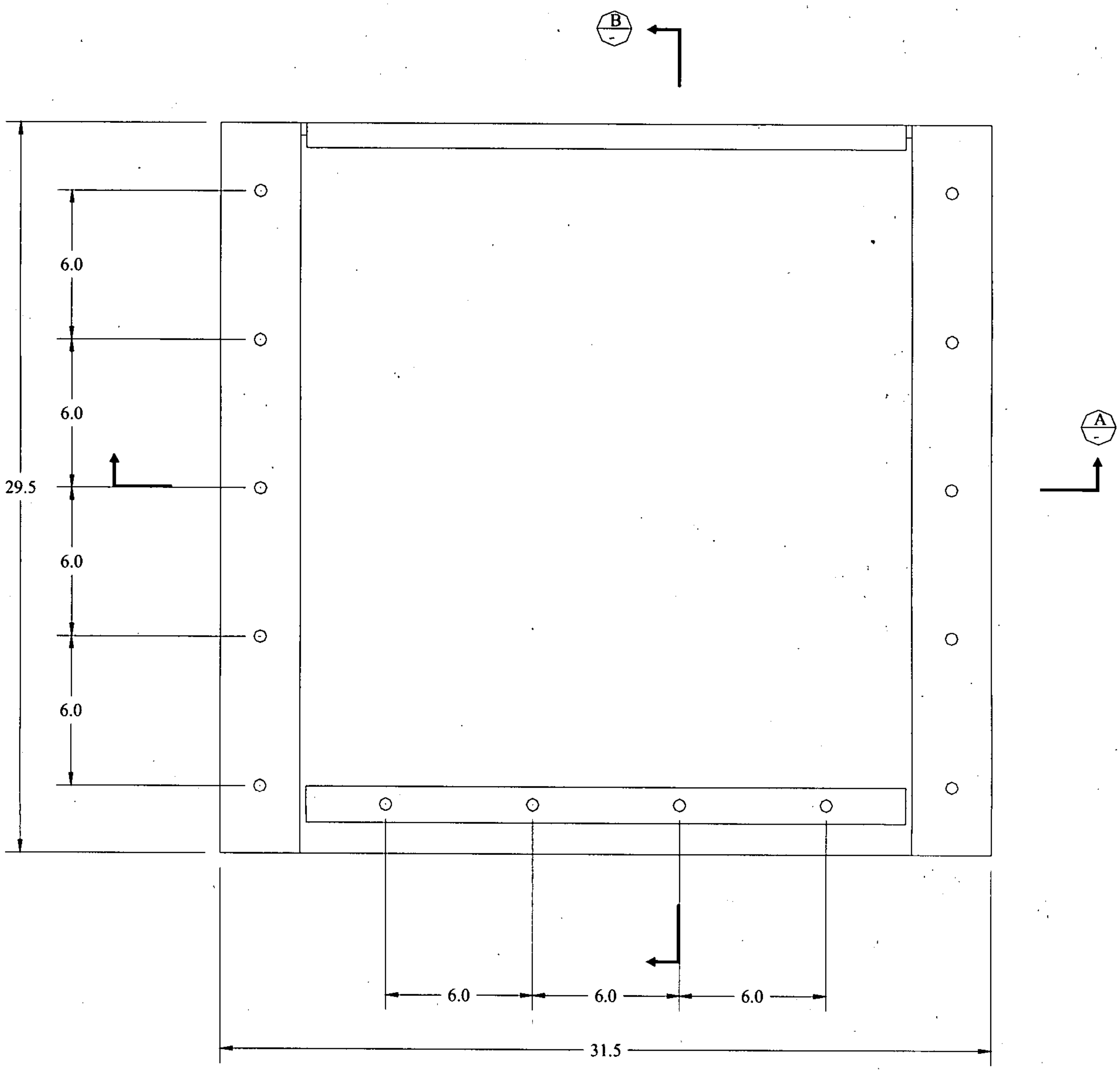


Figure 22. Preliminary Test Stand Design, Top View

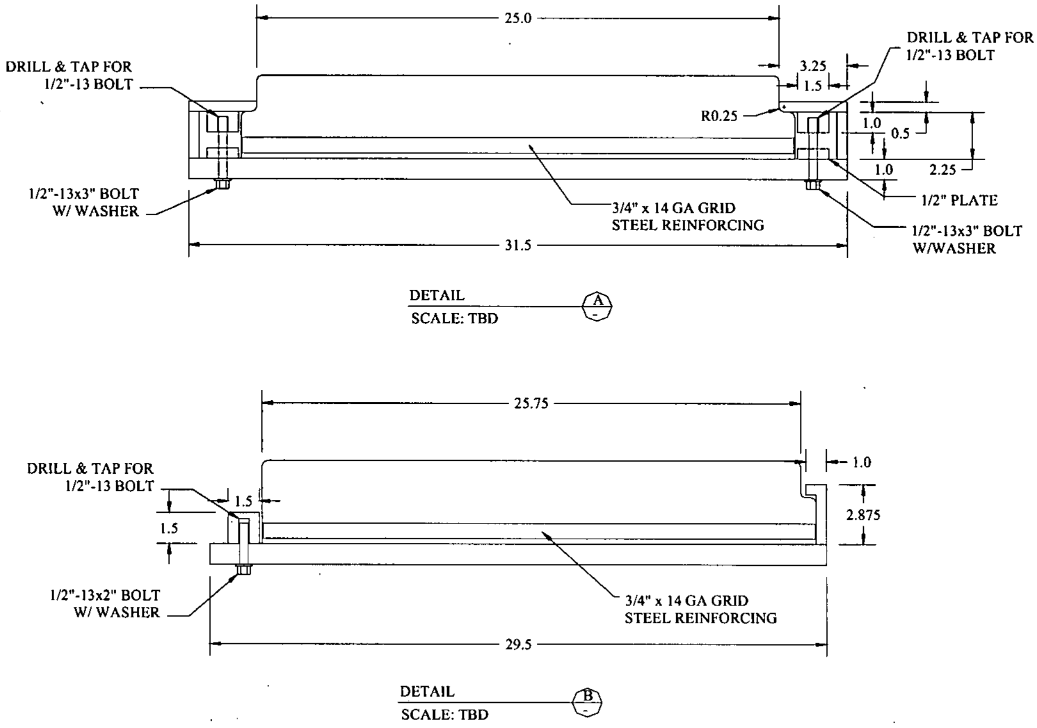


Figure 23. Cross-Section Details From Top View

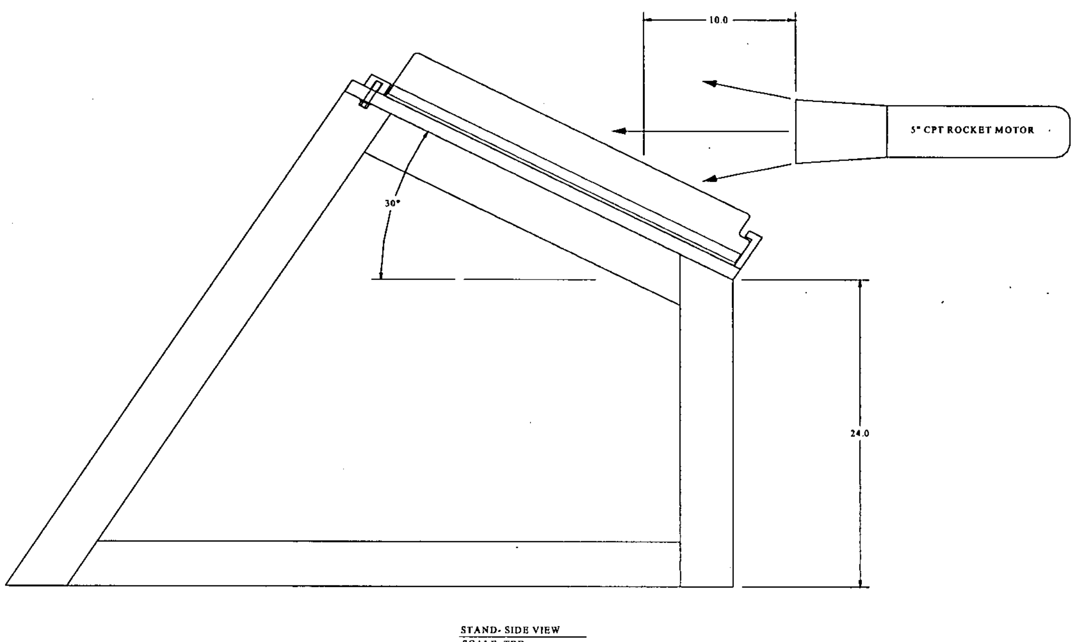


Figure 24. Test Stand Side View

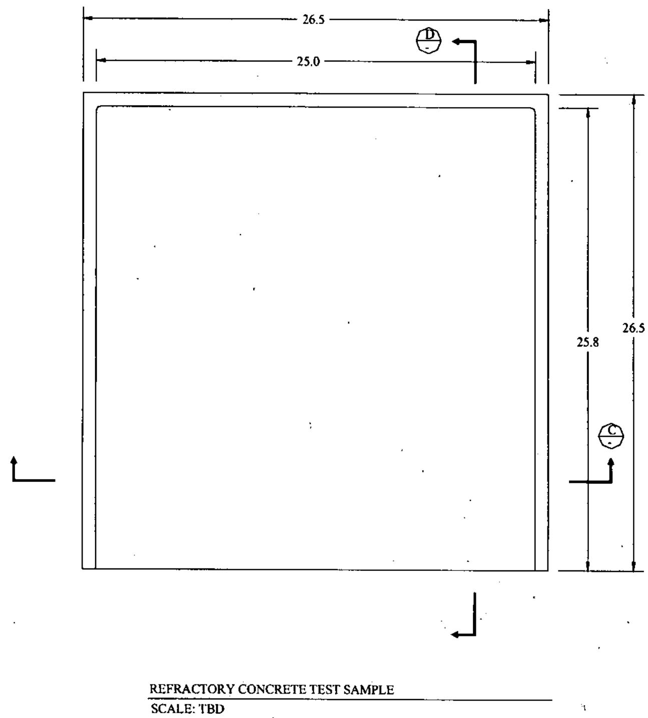


Figure 25. Refractory

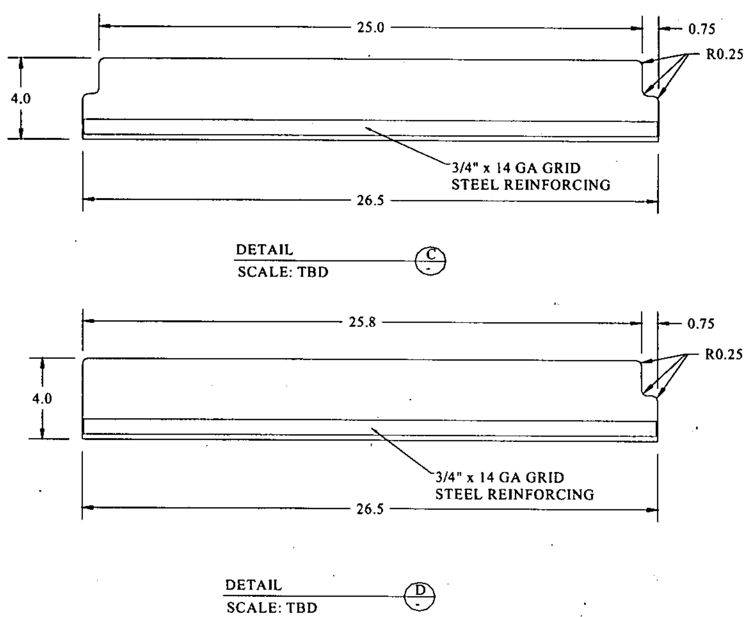


Figure 26. Refractory Material Sample Cross-Sections

5 SUBSCALE PARAMETERS

Qualification testing for new refractory materials must take place in either an actual rocket launch or a rocket engine test (KSC-STD-164). This section provides environmental data taken during the launches of STS-126, STS-119, STS-125, and STS-127, which can be used to provide guidance on the test parameters of a particular subscale test. Temperature, pressure, acoustic pressure, acceleration, strain, total heat flux (calorimeter), and radiative heat flux (radiometer) were measured during those launches. In addition, environmental data found in KSC-GP-1059, KSC-DD-818-TR, and KSC-DM-3649 should be consulted when finalizing subscale test parameters. Temperature, pressure, and heat flux values are thought to be directly comparable between the Shuttle launch and subscale testing. Maximum values of these parameters, as well as graphs that show the parameters over time, are reported. Strain and acceleration are impacted by the overall structural design and cannot be simulated in subscale testing. There are limitations to subscale testing, which will be discussed as well.

5.1 Launch Environment Assessment

The launch environment was measured in the flame trench during the launches of STS-126 (Endeavour, November 14, 2008), STS-119 (Discovery, March 15, 2009), STS-125 (Atlantis, May 11, 2009), and STS-127 (Endeavour, July 15, 2009). Complete results are reported in NASA-TM-2010-216294, KSC Launch Pad Flame Trench Environment Assessment.

Temperature, pressure, acoustic pressure, acceleration, total heat flux (calorimeter), and radiative heat flux (radiometer) were measured. The sensors used for each measurement and their locations are given in Table 4. The locations of the sensors are shown in Figure 27 thru Figure 30. Sensors were located on both the east and west flame trench walls for locations 1 – 7. The specific location was labeled with an "E" or "W" after the number to denote the east or west wall as shown in the figures. Sensors at locations 1 – 4 were exposed to the exhaust environment. Locations 4E and 4W were at the bottom of the deflector near the walls and adjacent to the test stands and will be used to test materials during the last Shuttle launches, as shown in Figure 31. The sensors for accelerometer measurements at locations 5 – 7 were placed in the catacombs on the cold face of the flame trench wall. These sensors were not directly exposed to the heat of the launch but were used to analyze the acoustical response of the reinforced concrete structure. Locations 8W and 9W were located on the west side flame deflector, underneath the MLP (Figure 29). These locations did not have equivalent measurements on the east side. Accelerometer and strain gauge measurements were made on the SRB and SSME flame deflectors, with locations as shown in Figure 30. These locations are the only ones where measurements were taken on the deflector structure at the time of this writing.

There are plans to have sensors mounted directly on the hot face of the SRB side of the main flame deflector during the launch of STS-133 and STS-134. The current plan is to install a combination of similar sensors, witness rods, and specially designed slug-type calorimeters. These measurements should be consulted when designing a subscale test.

Table 4. Sensors Used During Launch Environment Assessment

Measurement	Sensor Model Name/No.	Locations
Temperature	NANMAC 9300 Erodible Thermocouple	1, 2, 3, 4
Pressure	Stellar Technology ST 150	1, 2, 3, 4, 8W, 9W
Acoustic Pressure	Kistler 6013C	4
Accelerometer	Wilcoxon 797L	5, 6, 7, SRB, SSME
Calorimeter	Medtherm 64-2000-600-19-20054AT	1, 2, 3, 4
Radiometer	Medtherm 4TP-2000-600-23-200264AT	1, 4
Strain	CEA-06-125UR-350	SRB, SSME

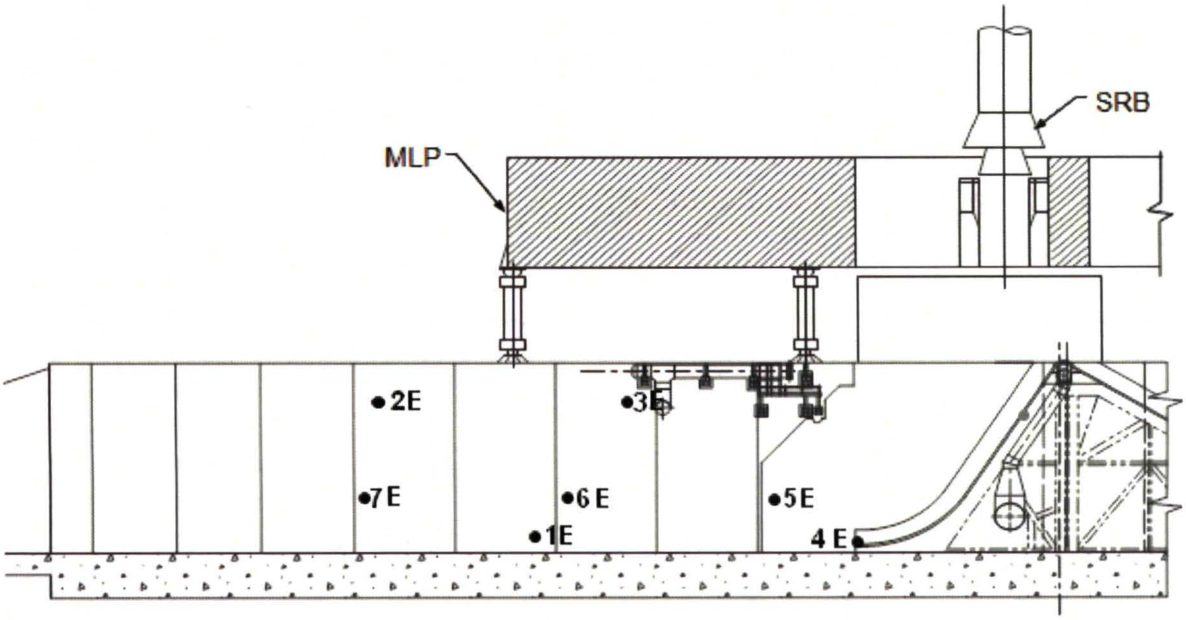


Figure 27. Sensor Locations on the East Wall of the SRB Flame Trench

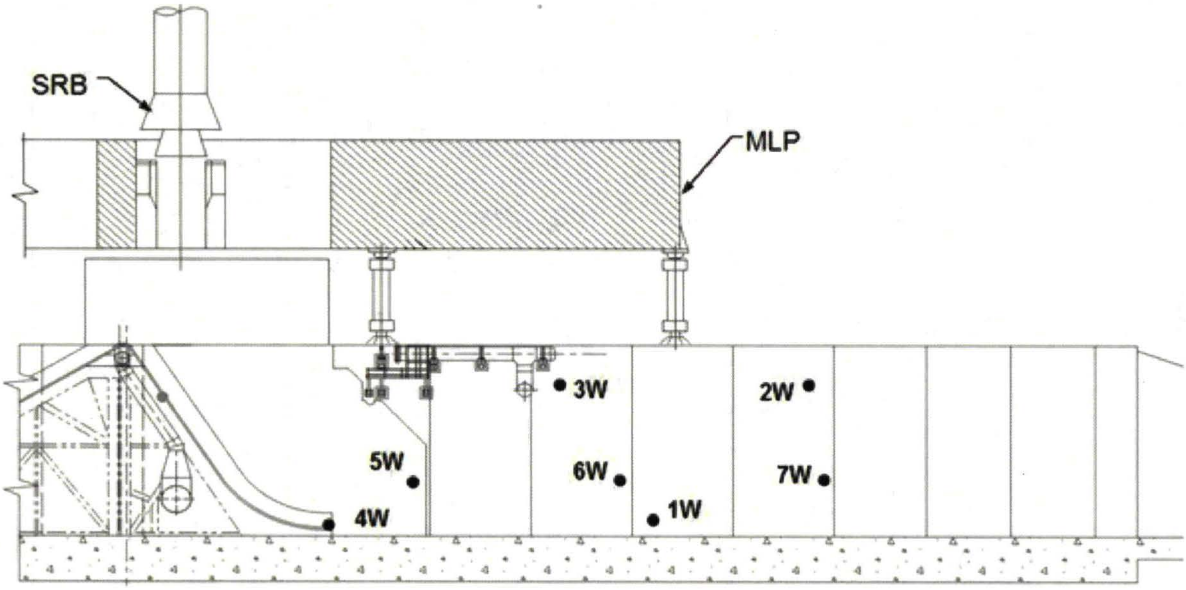


Figure 28. Sensor Locations on the West Wall of the SRB Flame Trench

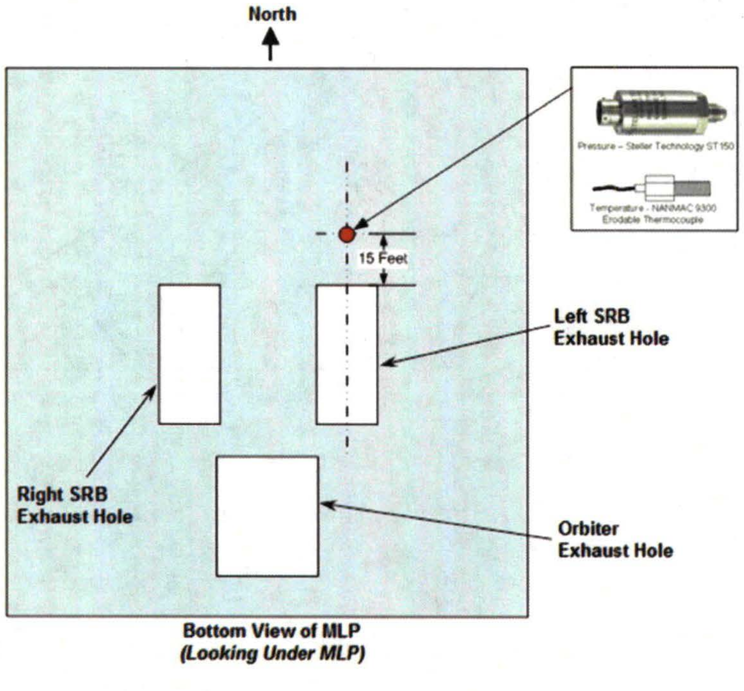


Figure 29. Location of Pressure Sensor 9W Underneath the MLP

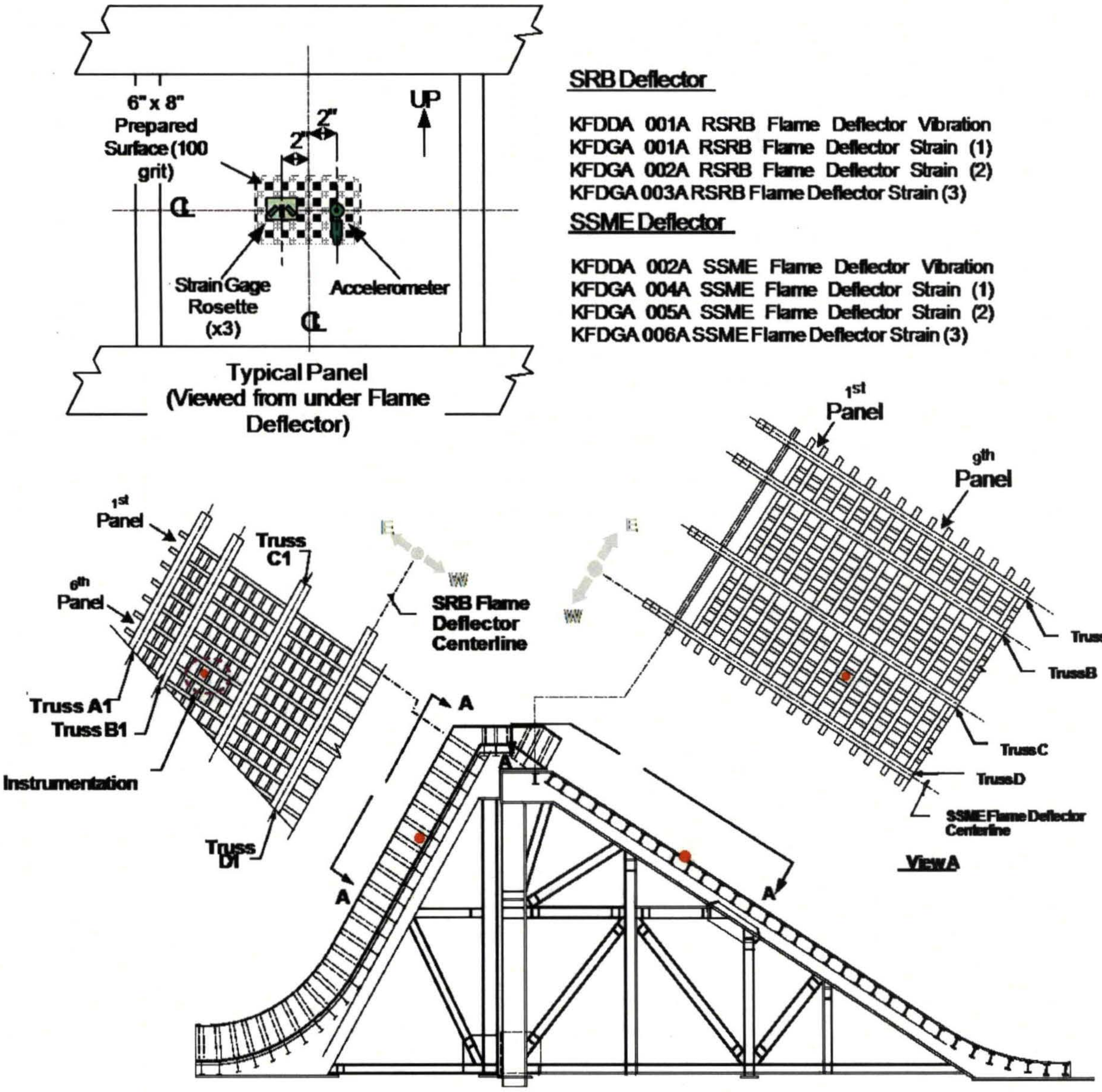


Figure 30. Sensor Locations on the SRB and SSME Flame Deflectors

Figure 31. Location 4E Is Highlighted in the Circle

5.2 Parameters for Subscale Testing

This section lists the environmental parameters measured during four Shuttle launches and may be used as guidance for designing subscale rocket exhaust tests. Temperature, heat flux, and pressure are thought to be parameters that can be closely mimicked in subscale rocket exhaust testing. Acceleration and strain are dependent on the configuration of the overall deflector system and would be difficult to duplicate in subscale testing. At the time this report was written, the harshest environment for temperature and heat flux was found at locations 4E and 4W. Location 8W had the highest measured pressure. Results from future measurements on the hot face of the flame deflector should exceed these values (for testing) and should be used when designing a subscale test. The maximum measured temperature, pressure, and heat flux (as of this date) are given in Table 5.

Table 5. Maximum Temperature, Pressure, and Heat Flux Measured During the Launch of STS-126, STS-119, STS-125, and STS-127

Parameter	Maximum value	Location
Temperature	2165 °F	4E
Pressure	99.4 psig	8W
Total heat flux (calorimeter)	2493 btu/ft^2·sec	4W
Radiant heat flux (radiometer)	72.1 btu/ft^2·sec	4W

The maximum values for temperature and radiant heat flux were relatively consistent for the launches, while the maximum pressure and total heat flux were highly variable. Currently, KSC-SPEC-P-0012 necessitates that the refractory material withstand a heat flux of 3300 btu/ft^2·sec for approximately 10 seconds. This is the only environmental condition specifically called out in the specification. The value is consistent with this measured value, but it will likely be low when compared to the heat flux measured on the deflector face. The time of exposure, 10 seconds, is about twice as long as seen during a launch of the Shuttle. Further details are given in the following sections, while complete results are reported in the NASA/TM-2010-216294.

5.2.1 Temperature

The maximum temperatures measured at locations 4E and 4W are presented in Table 6. The temperatures were higher on the east wall than on the west wall. Location 4 is the hottest measured point on both walls, reaching maximum temperatures of 2165 and 1922 °F on the east and west sides, respectively.

Table 6. Maximum Temperatures (°F) Measured During Three Launches

Sensor Location	STS-119	STS-125	STS-127	All Launches Max
4E	1936 °F	2165 °F		2165 °F
4W	1654 °F	1806 °F	1922 °F	1922 °F

Figure 32 shows the temperatures at locations 4E and 4W during the launch of STS-125. At both locations, the temperature exhibits a double maximum. The two maxima occur about 2 and 5 seconds after the initial heating. This behavior is consistent with the measurements at 4E and 4W during all launches. At the other locations, a single temperature maximum is reached at about the same time as the second maximum at location 4. This behavior was consistent during the different launches.

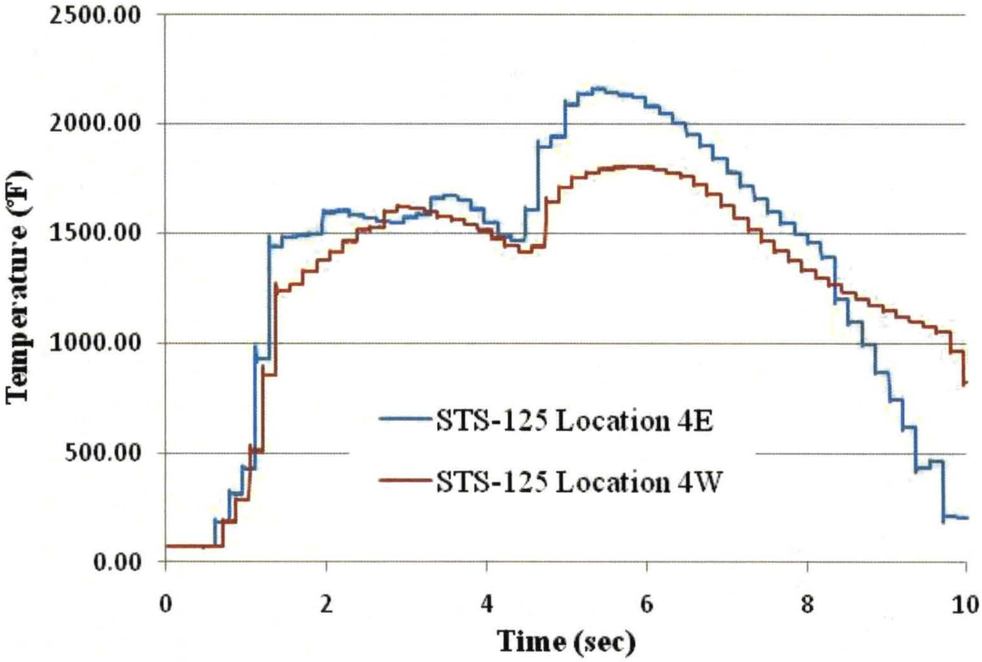


Figure 32. Selected Temperature Measurements During the Launch of STS-125

5.2.2 Pressure

Table 7 gives the maximum and minimum pressures at locations 8W, 4E, and 4W for each launch. The maxima and minima over all launches for each location are also given. As would be expected, the highest pressures were found on the side flame deflector, location 8W. At locations 4 and 8, the pressure initially spikes for 0.2 to 0.4 second. After this, the reading is elevated, and it is consistent with the profile from other launches. At locations 1, 2, and 3, there is an initial increase in pressure, followed by a period of negative pressure, before returning to ambient atmospheric pressure. Figure 33 shows pressure data taken during STS-126 for location 8W, 4W, and 4E.

Table 7. Maximum and Minimum Pressures (psig) Measured During Three Launches

	STS-126		STS-119		STS-125		All Launches	
Sensor location	Max	Min	Max	Min	Max	Min	Max	Min
8W	91.5	-2.3	99.4	-2.1	56.4	-2.1	99.4	-2.3
4E	45.6	-2.9	36.8	-22.9	61.1	-0.6	61.1	-22.9
4W	45.1	-2.4	45.6	-3.1	42.1	-0.1	45.6	-3.1

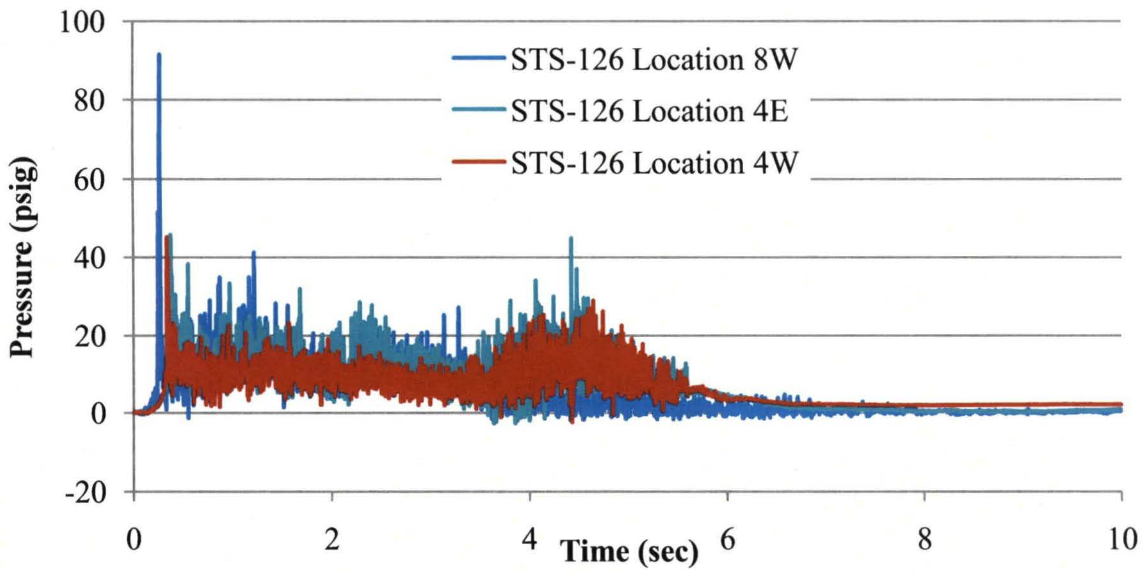


Figure 33. Selected Pressure Measurements During STS-126

5.2.3 Calorimeter and Radiometer

Total heat flux and radiative heat flux were measured with a calorimeter and radiometer during two launches. Total heat flux was taken at locations 1 through 4 on both walls, while radiative flux was taken only at locations 1 and 4. The convective heat flux can be inferred by taking the difference between the two values.

Table 8 and Table 9 lists the maximum total heat flux measurements for locations 1 and 4 on both walls. The total heat flux was highest at location 4W. At this location, the flux has two broad maxima near 2 and 5 seconds after initial heating begins. This is the only location to exhibit this behavior. At all locations, the heat flux spikes to large values for short periods, ranging from 10 to 100 milliseconds, during the launch. Radiative heat flux is also highest at location 4W, and it has the double maxima similar to total heat flux. Radiative heat flux does not exhibit the spiking behavior that total heat flux does. Figure 34 shows selected calorimeter measurements. Figure 35 shows selected radiometer measurements.

Table 8. Maximum Calorimeter Measurements (btu/ft^2 sec) Obtained During Two Launches

Sensor Location	STS-126	STS-119	All Launches Max
1E	95.0	109.7	109.7
4E	306.8	155.0	306.8
1W	104.1	107.1	107.1
4W	652.2	2492.5	2492.5

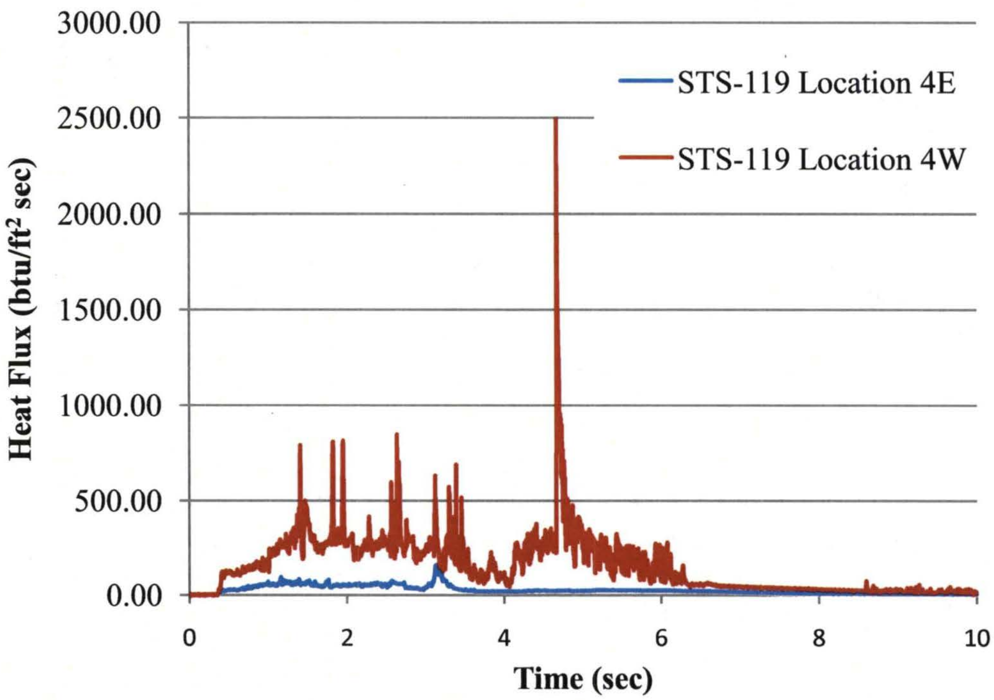


Figure 34. Selected Calorimeter Measurements During STS-119

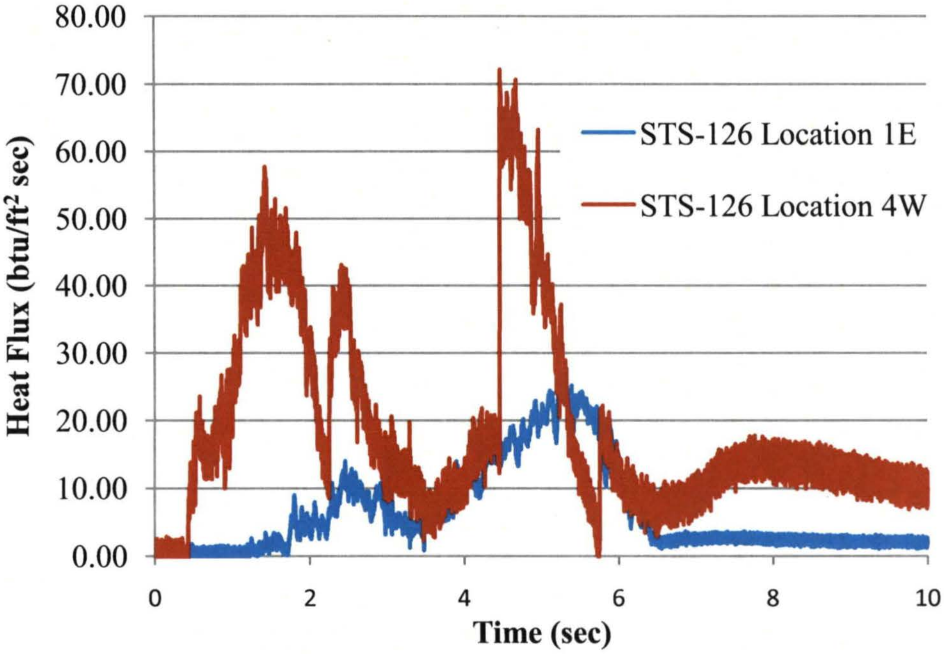


Figure 35. Selected Radiometer Measurements During STS-126

5.3 Limitations of Subscale Testing

The measured values of temperature, pressure, and heat flux reported here are not the highest values the refractory material will see, since the sensors were not in the most severe locations. Future launches will attempt to measure these parameters directly in the SRB impingement zone. Before conducting a subscale test, these updated values and sensor locations should be taken into account.

Subscale testing is likely to cause more erosion than would occur during full-scale launch because of the concentrated rifling effect of the smaller rocket motor. Earlier subscale testing, reported in an AIAA 92-3978, ASRM Plume Deflector Analysis Program, found a smaller BATES aluminum oxide particle heat flux about three times larger than for the full-scale ASRM motor plume, because of the much smaller scaled radius.

It is not possible to duplicate the launch environment seen at LC-39A and 39B. Strain and acceleration are dependent not only on the characteristics of the rocket motor exhaust but on the design of the launch structure as well. In addition, all parameters of a subscale test may not directly correlate to full-scale launches.

Even if a material withstands a subscale launch test, it may not be successful in full-scale launches. The structural design of the flame deflector and trench, the reinforcement of the structural material, and other environmental conditions (e.g., weather) all affect refractory material performance.

6 ENGINE TEST STAND FACILITIES

There are a few rocket engine test stands with the potential to perform subscale testing. Facilities at John C. Stennis Space Center (SCC), Marshall Space Flight Center, and ATK Aerospace Systems are described here. Many factors go into the selection of a subscale test facility. These factors include the size of the rocket, the use of liquid or solid fuels, the ability to scale the test, and the cost of using the facility.

6.1 John C. Stennis Space Center

Stennis Space Center (SSC) is located in Hancock County, Mississippi, at the Mississippi/ Louisiana border. It is NASA's largest rocket engine test facility. It is the primary center for testing and flight certifying rocket propulsion systems for the Space Shuttle and future generations of space vehicles.

Construction of the 13,500-acre complex began in October 1961. The test area is surrounded by a 125,000-acre acoustical buffer zone. The facility's large concrete and metal test stands were originally used to test-fire the first and second stages of the Saturn V rockets and are now used to flight certify the Space Shuttle Main Engines.

The site was originally selected by the U.S. Government because it was located in a thinly populated area that had barge access. Furthermore, the site is advantageously located between the Michoud Assembly Facility and the launch facility in Cape Canaveral Air Force Station in Florida. SCC maintains a number of rocket motor test facilities with various capabilities of testing.

6.1.1 A-1 and A-2 Test Stands

Both test stands are a single-position, vertical firing fixture that can accommodate test articles up to 33 feet in diameter. An exterior view of the A-2 test complex is shown in Figure 36.

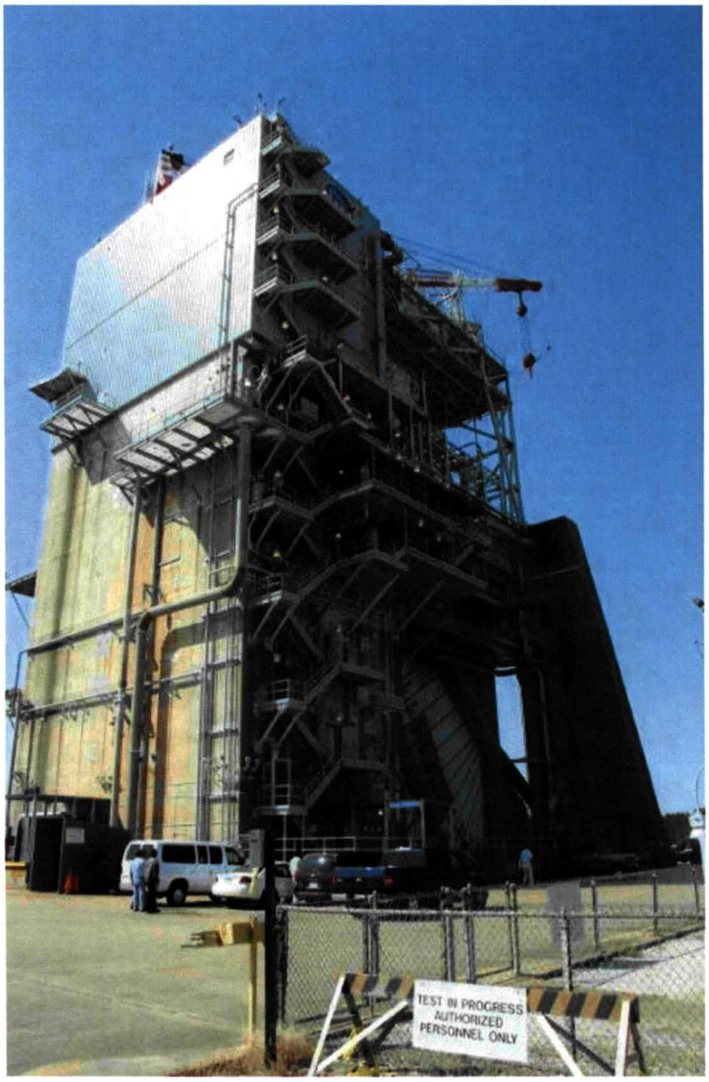


Figure 36. Exterior View of the A-2 Test Stand

Both test facilities are designed to use liquid hydrogen (LH_2) and liquid oxygen (LOX) propellants and can accommodate support fluids that include gaseous helium (GHe), gaseous hydrogen (GH_2), and gaseous nitrogen (GN_2). The A-2 Test Stand is equipped with an altitude diffuser used to simulate altitude conditions during engine testing. The maximum dynamic load that each structure is capable of testing is 1.1 million foot-pounds. See Endnote 11 in Section 8.

Figure 37 shows the relative size of the flame deflector in relation to members of the refractory site review team.

Figure 37. View of the A-2 Flame Duct and Diffuser

6.1.2 B-1 and B-2 Test Stands

Each B-1 and B-2 Test Complex consists of a dual-position, vertical, static-firing test stand. The B Complex is 295 feet tall and is equipped with a 200-ton main derrick-lifting crane. The test stand was designed to use LH_2 and LOX propellants and can accommodate various support fluids that include gaseous helium, gaseous hydrogen and gaseous nitrogen. The maximum dynamic load that each structure is capable of testing is 11 million foot-pounds. See Endnote 12 in Section 8.

The refractory material team from KSC intended to inspect one of the test stands. Unfortunately, a direct inspection at that time was impossible since the area was cleared for a test. The rocket test is shown in Figure 38.

Figure 38. Rocket Motor Test at Stennis B-1 Complex

As a part of a prior project, NASA Corrosion Test Laboratory personnel photo-documented the B-2 Test Stand flame deflector (Figure 39).

Similar to the A-2 Test Stand discussed in 6.1.1, the B-2 test stand is a steel structure that is much larger in scale. Figure 39 is used to give a comparative size of the B-2 flame duct in relation to others that are discussed in this report.

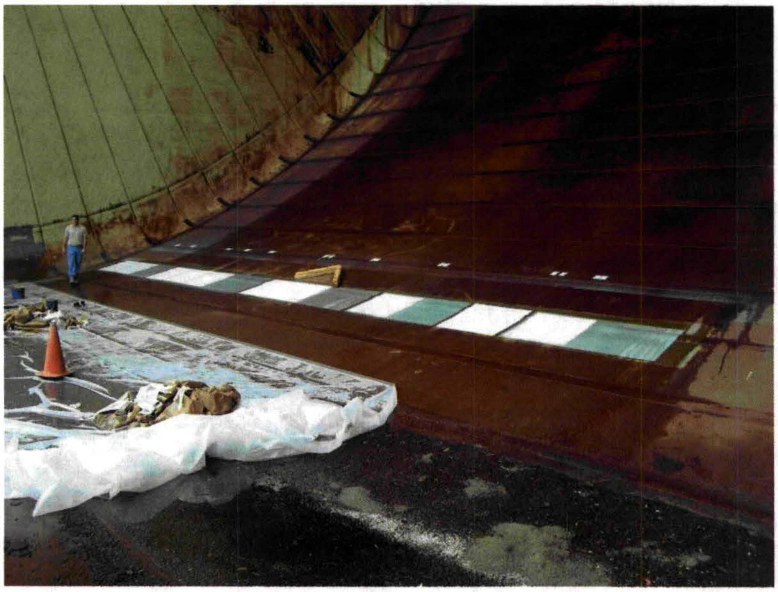


Figure 39. Stennis B-2 Flame Deflector

6.1.3 E-1 Test Facility

The E-1 Test Facility, originally designed as a developmental rocket engine component test facility for the National Launch System (NLS) Program, is available for developmental testing projects requiring high pressure and high flow rate cryogenic fluids, hydrogen, oxygen, inert gases, and industrial water. The E-1 facility is a multicell (3) with horizontal testing capabilities for large-scale propulsion programs (Figure 40).

Figure 40. Stennis E-1 Flame Deflector

The E-1, Cell 1 is primarily designed for pressure-fed LO_2/LH_2, LO_2/HC, and hybrid-based motors with thrust loads up to 750K pound-force. The E1, Cell 2 is designed for LH_2 and LO_2 turbopump assembly testing with thrust loads up to 60K pound-force. The E1, Cell 3 is designed for LO_2-rich turbopump assembly testing with thrust loads up to 60K pound-force.

6.1.4 E-2 Test Facility

The E-2 Test Facility was constructed to support materials development by subjecting test articles (including refractory concrete) to extreme temperature conditions and fluctuations. This facility has support capabilities, which include hot gas, cryogenic fluids, gas impingement, inert gases, industrial gases, specialized gases, hydraulics, and water.

The E-2 facility is a multicell complex that is capable of testing intermediate-size engines in both the vertical and horizontal configurations (Figure 41).

Figure 41. E-2 Cell 1 Test Stand at Stennis Space Center

E-2 Cell 1 is a horizontal test cell, and utilizes propellants such as LOX, LH_2 and RP-1. The horizontal test cell is capable of testing motors with thrust loads up to 120 thousand foot-pounds. See Endnote 13 in Section 8. Cell 2 is the vertical test cell and utilizes LOX and RP-1 propellants. This test cell is capable of testing motors with up to 100 thousand foot-pounds of thrust. See Endnote 14 in Section 8.

Figure 42 shows an overview of the Cell 2 flame duct. As shown in the photo, the flame deflector was built from steel over an I-beam steel structure. The facility has a 4,000 gallon per minute (gpm) water deluge system that is used to protect the flame duct from plume radiant heating during testing. See Endnote 15 in Section 8.

Figure 42. Stennis Space Center E-2 2 Vertical Test Flame Duct

6.1.5 E-3 Test Facility

The E-3 horizontal test cell can test motors up to 60 thousand foot-pounds of thrust and has support capabilities that include LOX, GO_2, and GH_2. Cell 2 is a vertical test cell that is capable of testing engines that use LOX, hydrogen peroxide, and HC propellants. Cell 2 can accommodate engines with thrust loads up to 25 thousand foot-pounds of thrust. See Endnote 16 in Section 8. It can also be configured horizontally for using a Diagnostic Test Facility (DTF) rocket engine. This engine is used to generate a subscale (approximately 5% of full scale) rocket-deflector test bed that has a similar plume impingement environment (heat flux, pressure, turning angle, etc.). Instrumentation measures the time-dependent erosion rates of various refractory materials and visualizes the plume/deflector interactions.

Figure 43 shows the flame duct for the vertical E-3 test fixture. Numerous tests have been conducted at the vertical E-3 test stand. Tests have included small-scale combustion devices, such as catalyst beds, to larger devices such as ablative thrust chambers and a flight-type engine. See Endnote 17 in Section 8.

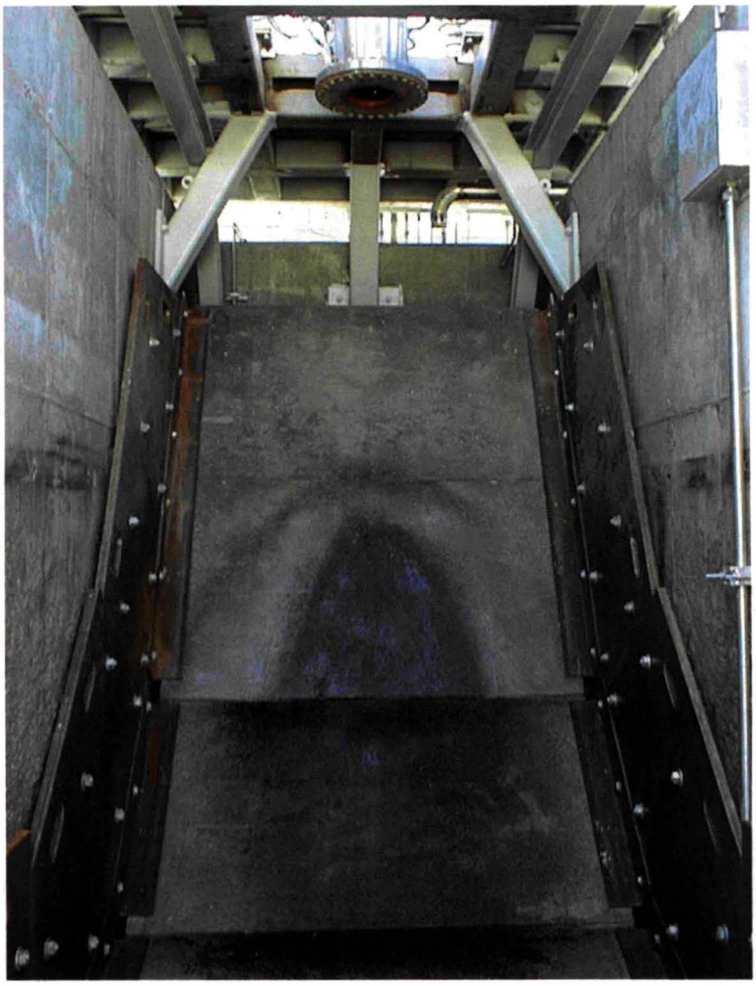


Figure 43. E-3 Vertical Configuration Test Cell Flame Duct

Figure 44 shows the horizontal E-3 test fixture. This configuration was set up specifically for testing erosion rates of candidate refractory materials.

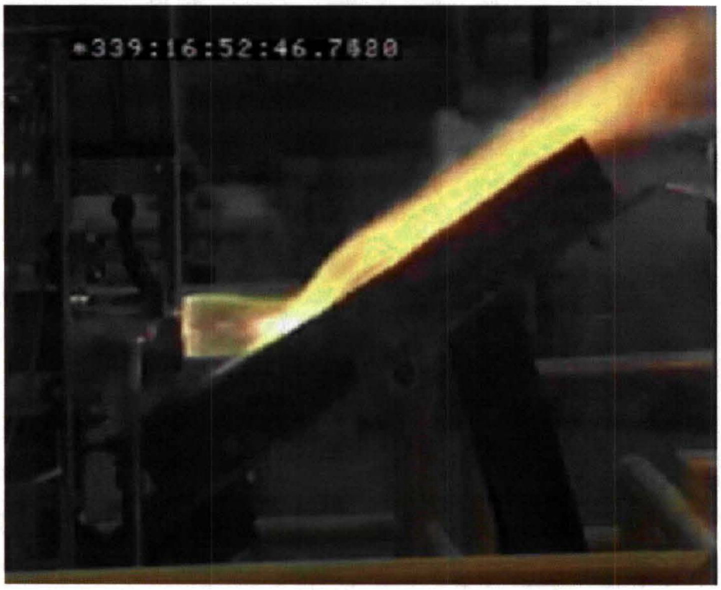


Figure 44. E-3 horizontal Test Configuration

6.1.6 Building 3300 at Stennis Space Center

Building 3300 at Stennis Space Center contained remnants of components used for scale model testing of candidate refractory materials. Examples of these components are shown in Figure 45 and Figure 46.

Figure 45. Test Duct at Stennis Space Center

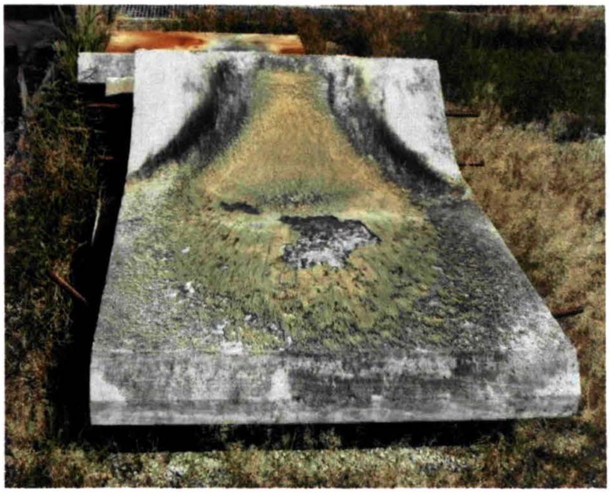


Figure 46. Refractory Concrete Apron at Stennis Space Center

These components were used as a part of a program designed to support the acquisition of data for baseline deflector design and refractory economical requirements. The program had four objectives:

- Establish ROM bounds on the extent of material loss and damage.
- Develop comparative data on the ability of various refractory materials to withstand the rocket plume environment.
- Develop engineering and scientific data characterizing surface and plume interaction phenomena.
- Evaluate (model scale) the operational capability of the deflector.

Scaling of the test articles was driven by the availability of the Bates motor and propellant cartridges. The Bates motor (approximately 6000 lb thrust) was fired down the apron in a manner geometrically similar to that for a full-scale deflector. The plume deflector was designed in the configuration shown in Figure 47. See Endnote 18 in Section 8.

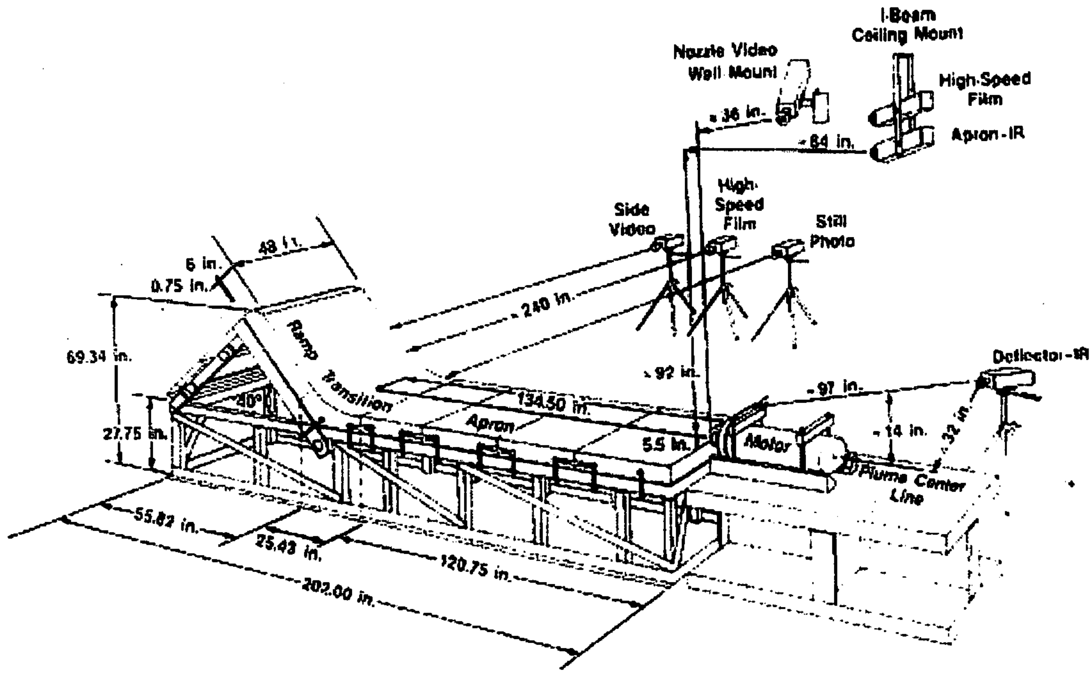


Figure 47. Stennis Plume Deflector Test Rig

6.2 George C. Marshall Space Flight Center (MSFC)

The MSFC is the U.S. Government civilian rocketry and spacecraft propulsion research center. The original home of NASA, Marshall is today the agency's lead center for Space Shuttle propulsion and its external tank. Located on the Redstone Arsenal near Huntsville, Alabama, MSFC is named in honor of General of the Army George Marshall. Marshall's East Test Area contains various explosionproof test cells, separated from each other and equipped with basic propellants for testing full- and subscale rocket engines. The Advanced Engine Test Facility in Marshall's West Test Area is another area in the test laboratory used to test rocket engines. It is used to assess and validate new propulsion technologies and prototype hardware for large rocket engines. See Endnotes 18, 19, 20, 21, 22, and 23 in Section 8.

6.2.1 Dynamic Test Stand

The dynamic test stand is located in the East Test Area and is officially a Historic National Landmark. This test stand was built in 1964 for mechanical and vibration tests on fully assembled Saturn V rockets and was modified in 1977 for vibration tests on the mated Space Shuttle and for evaluation of the craft's dynamic characteristics. See Figure 48.

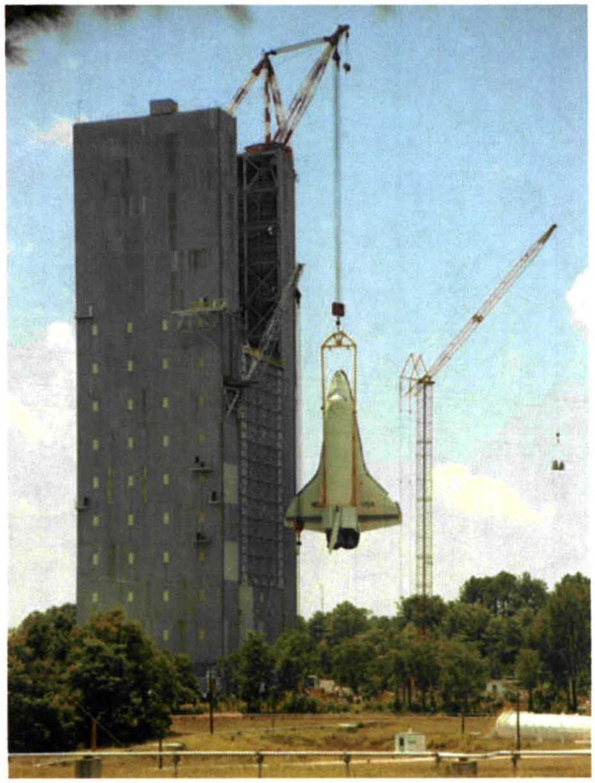


Figure 48. MSFC Dynamic Test Stand

6.2.2 Load Test Annex Facility

Located in the East Test Area, this structural test stand features a multimillion pound, movable crosshead weight, mounted on four towers. The facility is capable of sustaining the force loads experienced by large launch vehicles and can accommodate stages of up to 100 feet high and 54 feet in diameter. See Figures 49 and 50.

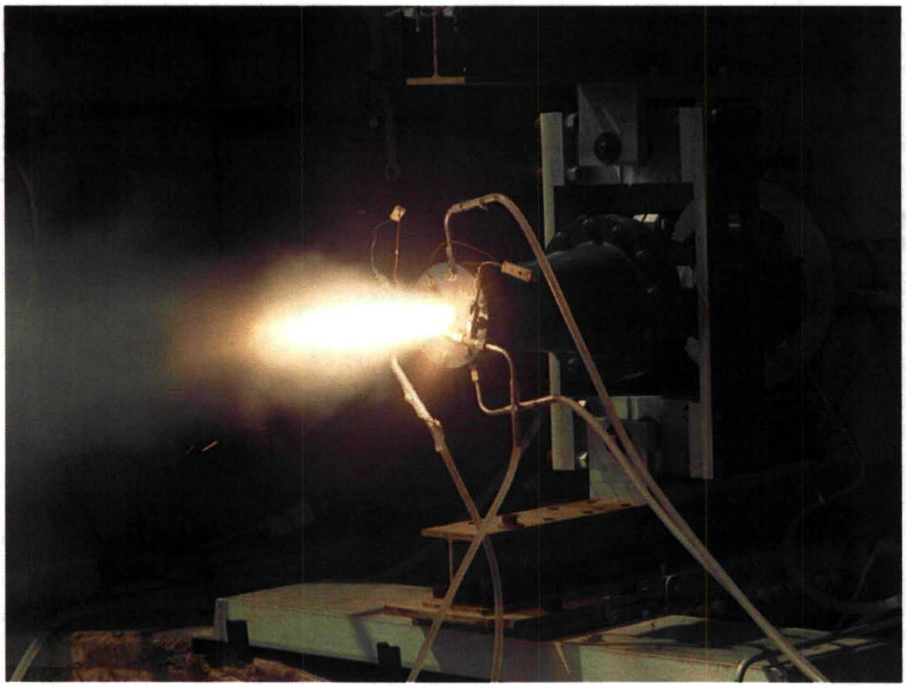


Figure 49. MSFC Test Stand 116, Solid Fuel Torch Test

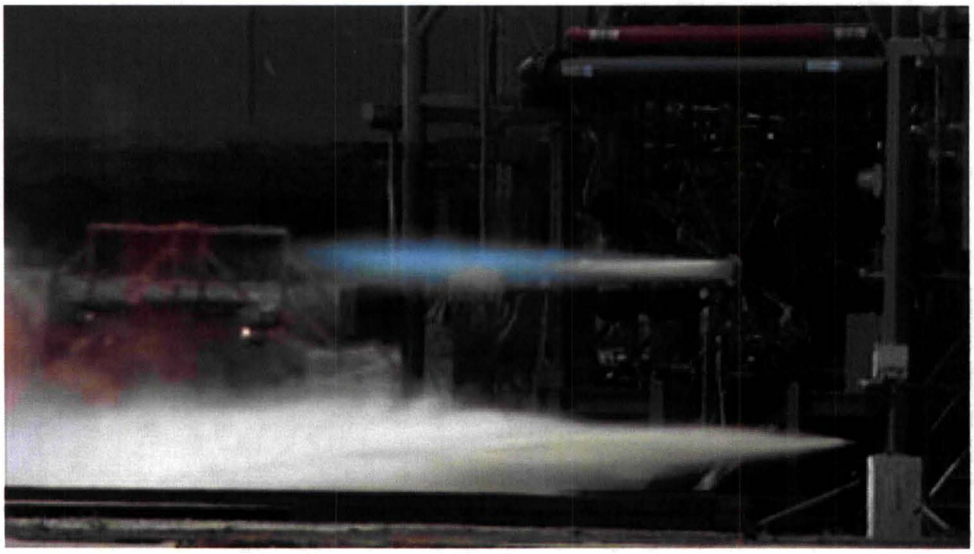


Figure 50. MSFC Test Stand 115, Solid Fuel Torch Test

6.2.3 Advanced Engine Test Facility

The Advanced Engine Test Facility is located in the West Test Area and was originally designed for testing the first stage of the Saturn V moon rockets. The rockets boasted five F-1 engines, which produced a combined thrust of 7.5 million pounds. See Figure 51.

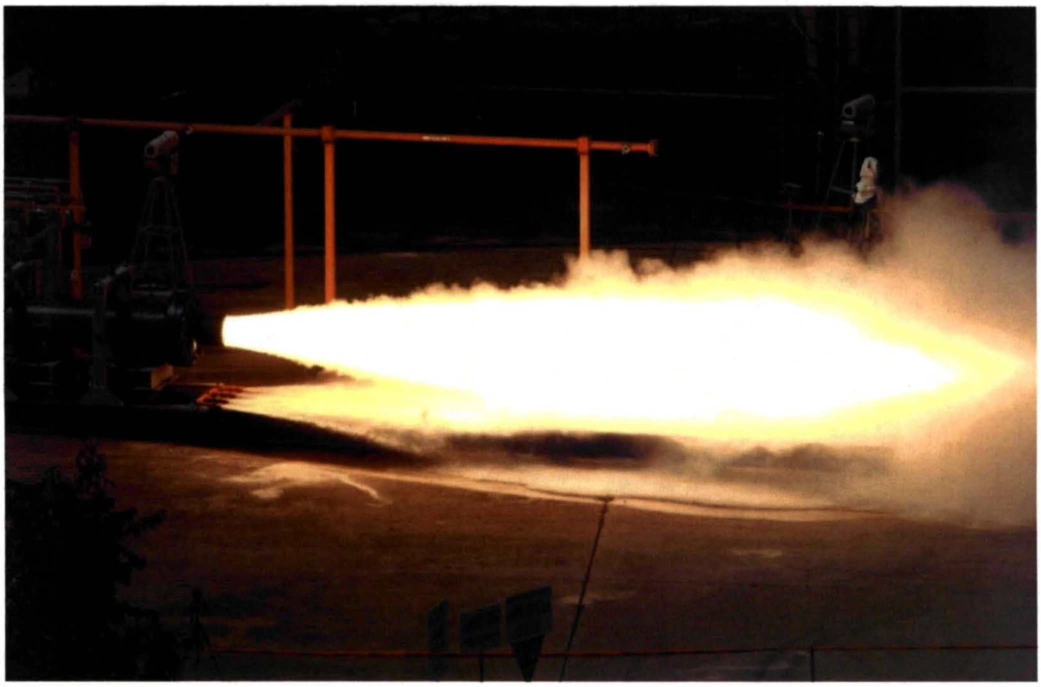


Figure 51. A Scaled-Down 24-Inch Version of the Space Shuttle's Reusable Solid Rocket Motor Fired at a MSFC Test Stand

6.3 ATK Aerospace Systems

ATK is a pioneer in solid rocket propulsion systems, strategic missiles, missile defense, lightweight space deployables, solar arrays, and satellite thermal management systems. ATK's space propulsion and ordnance products reflect more than 45 years of experience, providing high-performance and reliable propulsion for the aerospace industry. Their capabilities are focused mainly on solid rocket motors. SRMs range in size from full-scale Space Shuttle reusable solid rocket motor (RSRM), 126 feet long and 12 feet in diameter, to smaller sizes such as 3-inch STAR series. Rocket motor test stand configurations are either in the horizontal or vertical position, depending on motor size, and can be modified according to test requirements. Small-scale testing can be performed on thermal protection materials as short as approximately 1 second in duration. A typical 5-inch CP test would run approximately 2 to 3 seconds. Larger FPCs (40-pound charge) and SPCs (70- pound charge) motors configured horizontally will burn for up to approximately 35 seconds for the FPC and approximately 70 seconds for the SPC. Burn times and temperature depend on chosen propellant and throat diameter. See Figures 52, 53, and 54.

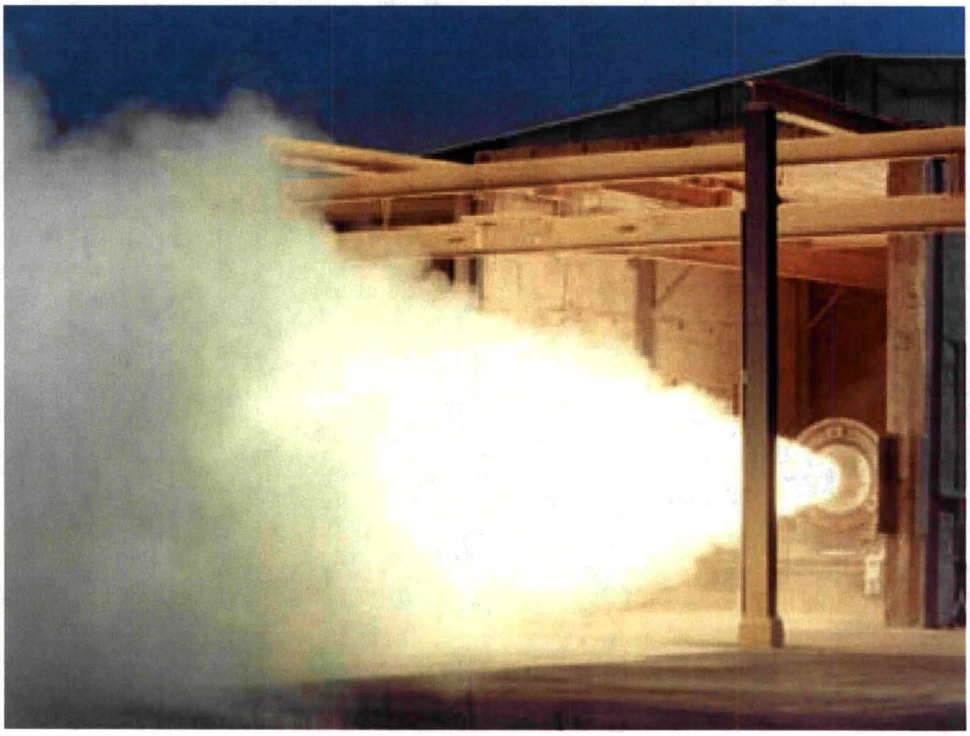


Figure 52. Horizontal Testing of an ASAS 21-120 Motor

Figure 53. Space Shuttle RSRM

Figure 54. Space Shuttle RSRM Test Firing at the ATK, Promontory, Utah Facility

7 LIST OF REFERENCES

AIAA 92-3978, ASRM Plume Deflector Analysis Program, Petersen, T.V.; Makel, D. B.; Thurman, C.

ASCE 7 Guide, Guide to the Use of the Wind Load Provisions of ASCE 7-02??

ASTM C20, Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water

ASTM C24, Standard Test Method for Pyrometric Cone Equivalent (PCE) of Fireclay and High Alumina Refractory Materials

ASTM C92, Standard Test Methods for Sieve analysis and Water Content of Refractory Materials

ASTM C133, Standard Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories

ASTM C179, Standard Test Method for Drying and Firing Linear Change of Refractory Plastic and Ramming Mix Specimens

ASTM C704, Standard Test Method for Abrasion Resistance of Refractory Materials at Room Temperature

ASTM C830, Standard Test Methods for Apparent Porosity, Liquid Absorption, Apparent Specific Gravity, and Bulk Density of Refractory Shapes by Vacuum Pressure

ASTM C832, Standard Test Method of Measuring the Thermal Expansion and Creep of Refractories Under Load

ASTM C862, Standard Practice for Preparing Refractory Concrete Specimens by Casting

ASTM C1113, Standard Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique)

ASTM C1140, Standard Practice for Preparing and Testing Specimens From Shotcrete Test Panels

ASTM C1148, Standard Test Method for Measuring the Drying Shrinkage of Masonry Mortar

ASTM C1171, Standard Test Method for Quantitatively Measuring the Effect of Thermal Shock and Thermal Cycling on Refractories

ASTM C1419, Standard Test Method for Sonic Velocity in Refractory Materials at Room Temperature and its Use in Obtaining an Approximate Young's Modulus

ASTM E4, Standard Practices for Force Verification of Testing Machines

ASTM E228, Standard Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

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KSC-DD-818-TR, Summary of Measurement of KSC Launch-Induced Environmental Effects (STS-1 Through STS-11)

KSC-DE-512-SM, Facility, System, and Equipment General Design Requirements

KSC-DM-3649, Lift-Off Response Spectra to Space Shuttle Launch-Induced Acoustic Pressures

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KSC-SPEC-P-0012, Refractory Concrete, Specification for

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NHB 7320.1, Facilities Engineering Handbook

NSTS -7700, Volume XIV, Space Shuttle System Payload Accommodations

SW-E-0002, Ground Support Equipment General Design Requirements

8 ENDNOTES

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APPENDIX A. MMA-1918-80, STS-1

CLAUTICE 3243 RM 3150

TASK REQUEST

1. DATE SUBMITTED	2. DESIRED COMPLETION DATE	3. AUTHORIZING DOCUMENT
Sept. 29, 1980	One Month after Launch of STS-1	-

4. SAMPLE DESCRIPTION:

Refractory Concrete Test Samples:
1. Design Concrete Company
   (a) Fondu Fyre WA-1 (Approved for Saturn) - 2 Test Samples
   (b) Fondu Fyre WA-1 (Experimental) - 2 Test Samples
2. Wahl Refractory Products Company
   (a) H. T. Bond Mortar (Experimental) - 3 Test Samples
3. Harbison-Walker Refractories
   (a) Refractory Concrete -------------- 2 Test Samples
   (b) Refractory Concrete (Stainless Steel Fibers) - 2 Test Samples

5. SYSTEM REMOVED FROM/OR USED IN:

Samples for test - Refractory Concrete.

Location to be SRB Flame Deflector, 79K09546.

6. ANALYSIS REQUESTED:

SEE "REFRACTORY MATERIALS TEST PLAN" - attached.
The three materials are on hand and testing is to be initiated by taking thickness measurements and color photographs of the initial condition of the surfaces.

After exposure to SRB exhaust during STS-1 the samples are to be removed and returned to the laboratory for further thickness measurements and a determination of surface erosion. The final surface condition such as spalling will be recorded and color photographs taken for comparison with initial surface conditions.

An evaluation of performance and acceptance or rejection recommendations will be made by formal report.

7. REMARKS:

-

8. REQUESTER:	9. PHONE:	10. COMPANY:	11. MAIL CODE:
W. Clautice, PRC-1217	867-3243	PRC	PRC-1217
12. NASA APPROVAL: M. G. Olsen (signature)	13. PHONE: 867-3748	14. MAIL CODE: DD-MED-1	15. DATE: 9/29/80

FOR LAB USE ONLY

INVESTIGATOR	TASK NUMBER	SAMPLE NUMBER
C.V. Moyers	MMA-1918-80	

KSC FORM 23-41 (REV. 1/70)

REFRACTORY CONCRETE MATERIALS TEST PLAN

I. MATERIALS FOR TESTING (KSC-SPEC-P-0012)

1. Design Concretes Company

   a. Fondu Fyre WA-1* - 2 Test Samples
   b. Fondu Fyre WA-1 (Experimental) - 2 Test Samples
   Delivery date July 21, 1980

   * Approved for Saturn

2. Wahl Refractory Products Company

   a. H.T. Bond Mortar (Experimental) - 3 Test Samples

      The 3 test samples are at KSC.
      The vendor delivered them on Feb. 12, 1980
      They are stored by TG-FLD-22.

3. Harbison - Walker Refractories

   a. Refractory Concrete - 2 Test Samples
   b. Refractory Concrete - 2 Test Samples (Stainless Steel Fibers)
   Delivery Date June 20, 1980

ETED 4. North American Refractories Company

   a. Narco Cast 60 - 2 Test Samples
   b. Narco Tab - 2 Test Samples
   Delivery date Aug. 1, 1980

II. TEST SAMPLE DELIVERY, HANDLING AND STORAGE

The refractory concrete test samples as specified in KSC-SPEC-P-0012, Figure 1 are massive and require special handling. They weigh approximately 200 lbs. each and are 2 Ft-4 in. square and 4 inches thick. Vendors have been instructed to deliver their samples in crates on pallets, marked as specified in paragraph 5.4 of specification KSC-SPEC-P-0012.

In addition, each vendor has been instructed to send copies of shipping notices to M. G. Olsen, DD-MED-1, C. L. Springfield, TG-FLD-22, and W. Clautice, PRC-1217 to alert them of the date shipped. Freight Traffic, Sam Clymer (867-3240) has been requested to notify Carlos Springfield, TG-FLD-22 (867-4614) when test samples are received so that he can direct them to a special storage area maintained by the laboratory.

Each vendor has been give the following address for shipment of samples:

Chief, Freight Traffic, NASA
Bldg. M7-6744
3rd St. and Avenue C
Kennedy Space Center, FL 32899
ATTN: Carlos Springfield, TG-FLD-22

III. INSTALLATION AND REMOVAL OF TEST SAMPLES

TG-SMD-1 (Wayne Parris/Bob Laakso) will initiate and manage the Support Request to BSI for the handling, installation, and removal of the refractory concrete test samples in the existing SRB flame deflector test fixtures. A PCN will be issued to accommodate charges. BSI is to provide all services necessary. Bolt heads and seams are to be covered with ablative coating (Dow Corning Q3-6077) as specified in Dwg. 79K09546 Sheets 1 and 2, attached.

After the launch the samples are to be removed and transported to an area designated by the laboratory, TG-SMD-1, Carlos Springfield, 867-4614. Prior to removal of samples contact Carlos Springfield. Photographs are to be taken of the samples prior to their removal.

IV. SPECIMEN ORIENTATION

The test fixture on the SRB flame deflector, DWG 79K09546 will accommodate six specimen samples. The number of samples to be submitted are ~~15~~ 11. Therefore, 3 launches will be required before the testing of all samples is accomplished.

A pattern of testing orientation in the test fixtures is as follows:

Wahl HT Bond Mortar	Fondu Fire WA-1 *	~~WAHT~~ Wahl ~~(EXP)~~	Fondu Fyre ~~Narco 60~~ WA-1 (EXP)	H/W	H/W + S.S.

* Approved for Saturn

LAUNCH NO. 1

H/W	Fondu Fyre WA-1 (EXP)	~~Narco 60~~	~~Narco TAB~~	Fondu Fyre WA-1 *	~~Wahl HT Bond Mortar~~

*Approved for Saturn

LAUNCH NO. 2

Wahl HT Bond Mortar	~~Narco TAB~~	H/W + S.S.			

LAUNCH NO. 3

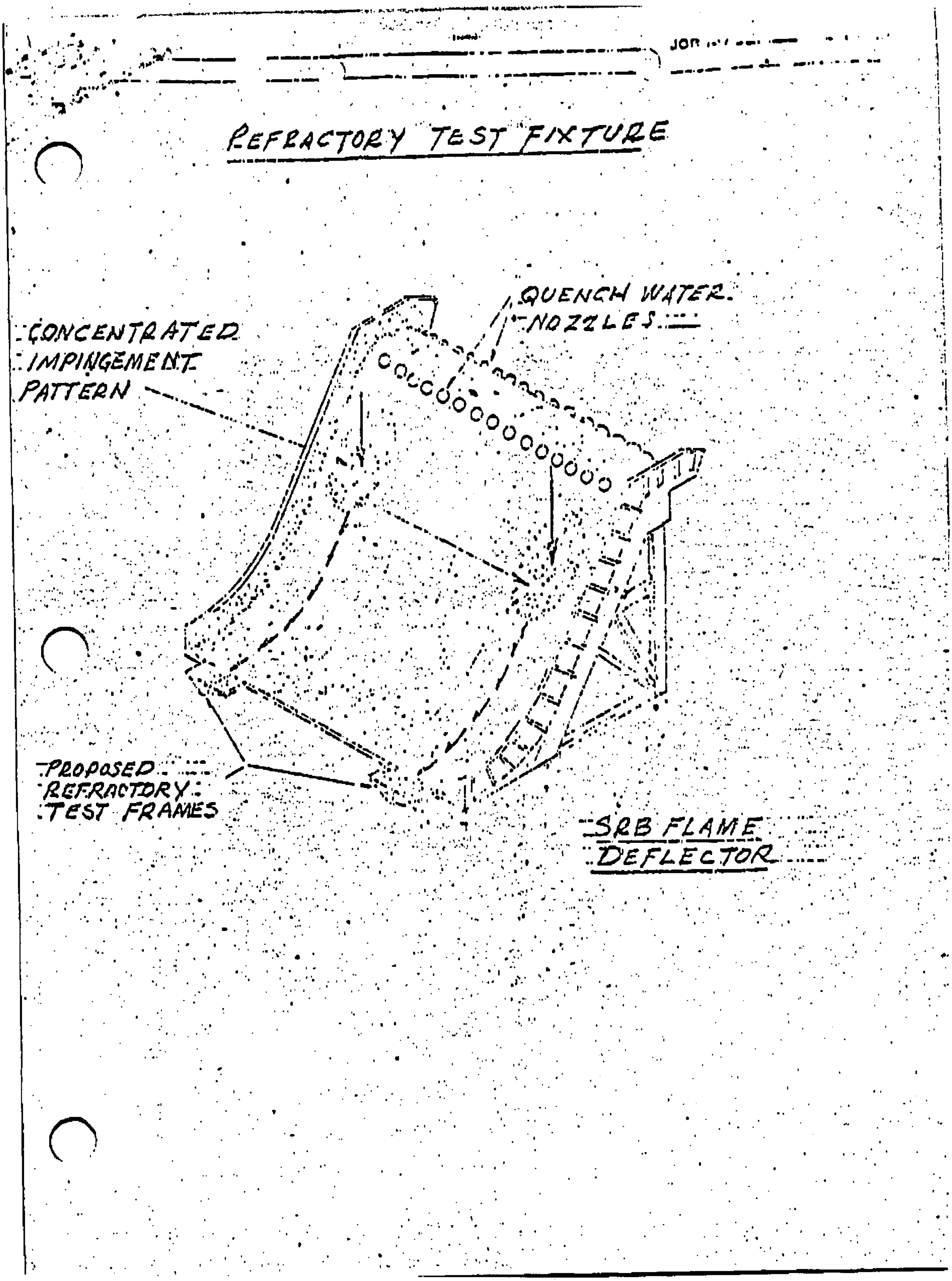
V. LABORATORY MEASUREMENTS OF TEST SAMPLES

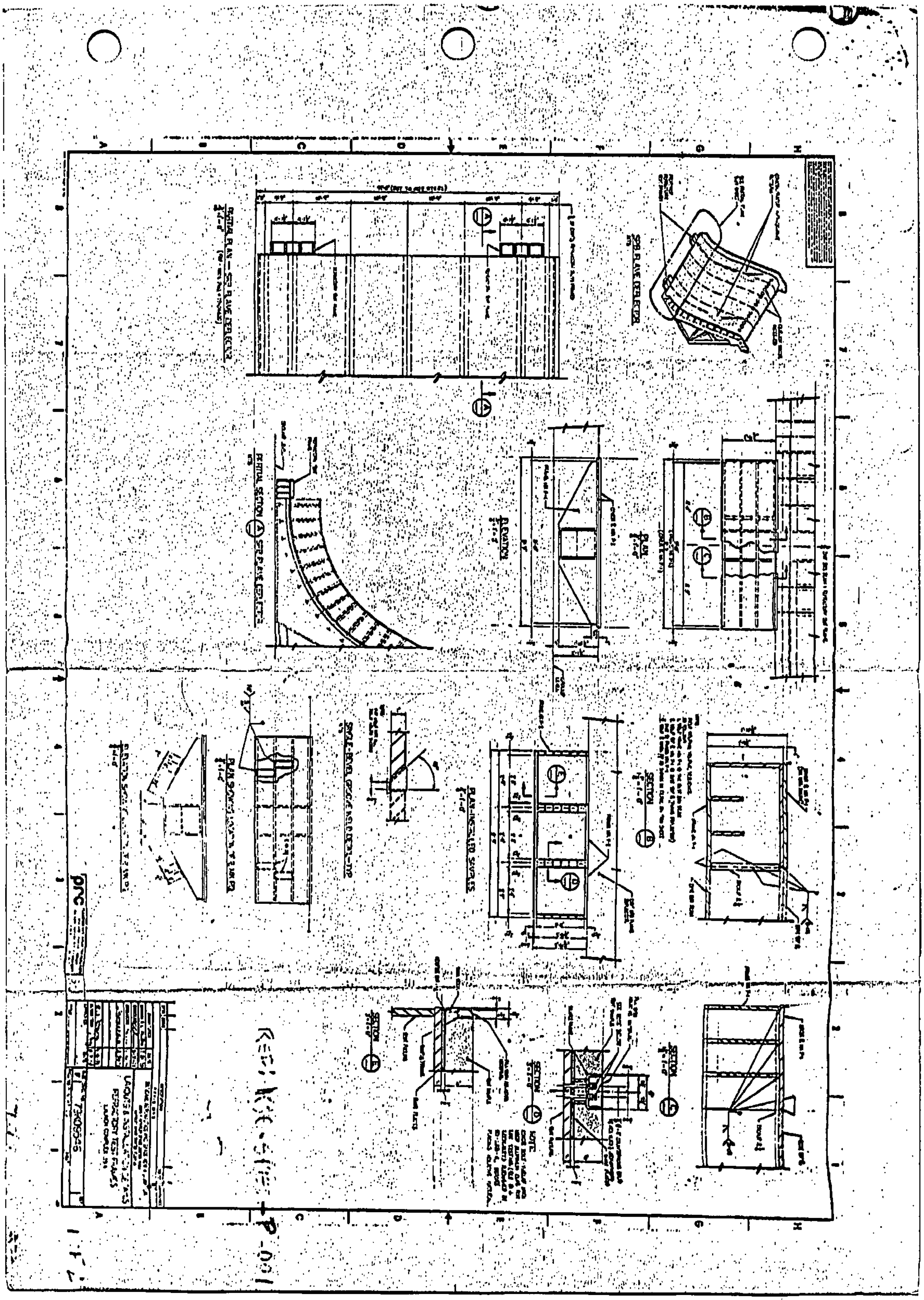
All samples are to be tested and evaluated in accordance with KSC-SPEC-P-0012.

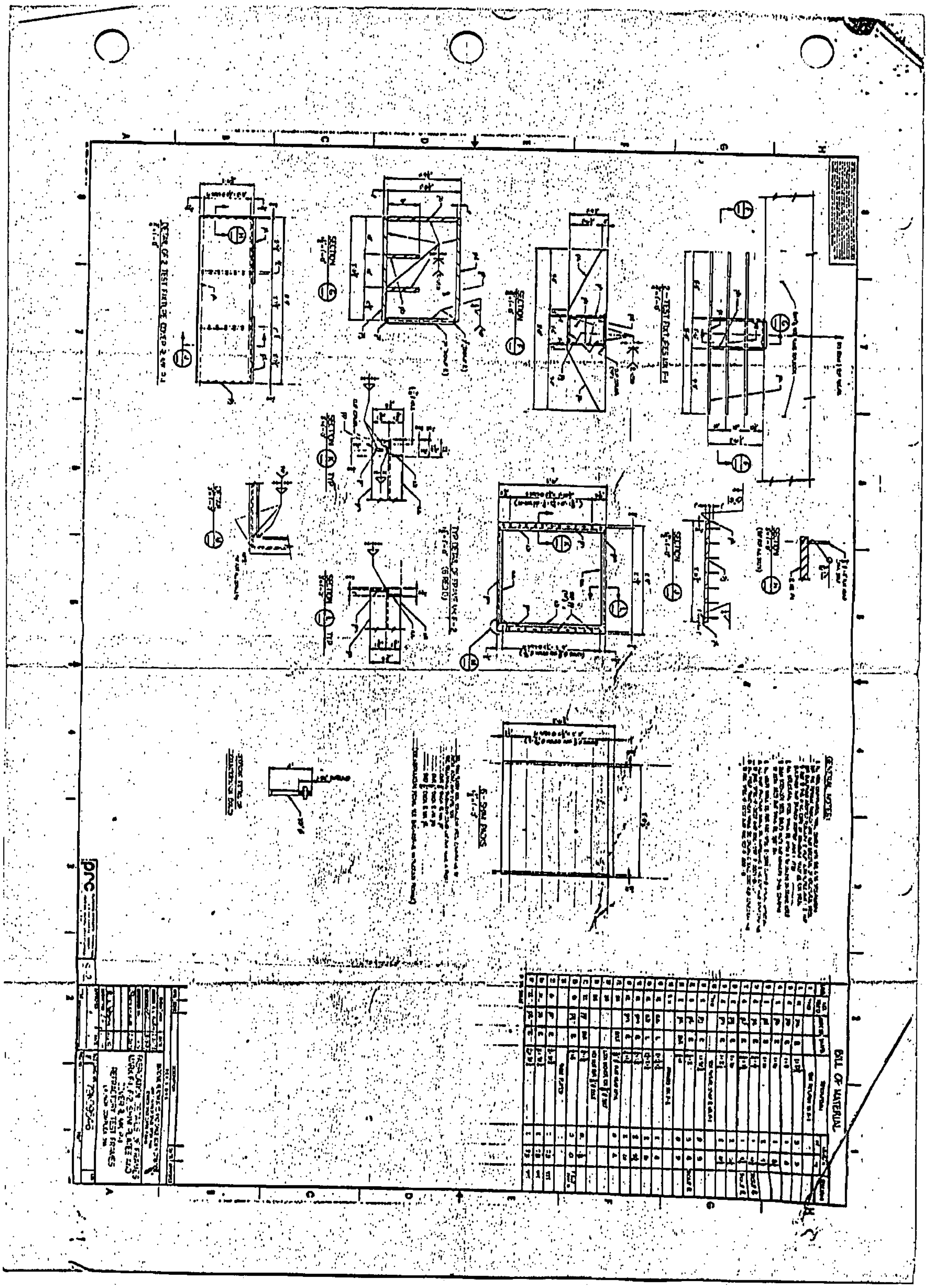
Prior to installation, each test sample will be measured for an a-curate determination of thickness using a template and a dial gage indicator mounted on a flat level table or surface. TG-FLD-22 to determine and perform the measurements. Each test sample will be photographed to record their surface condition and texture prior to testing and other conditions determined as deemed necessary.

After the launch test, the specimens will be returned to the same area where initial measurements were made. The thickness will be remeasured using the same techniques to determine the loss of thickness due to general surface erosion. Any damage or local spalling or cracking will be noted and recorded. Each specimen will be photographed with close-up shots of special conditions.

The laboratory, TG-FLD-22, will evaluate the relative performance of the test samples based upon their findings in accordance with KSC-SPEC-P-0012.


REFRACTORY TEST FIXTURE
QUENCH WATER NOZZLES
CONCENTRATED IMPINGEMENT PATTERN
PROPOSED REFRACTORY TEST FRAMES
SRB FLAME DEFLECTOR





KSC-SPEC-P-0012
April 25, 1979

REFRACTORY CONCRETE, SPECIFICATION FOR

DESIGN ENGINEERING DIRECTORATE

KSC-SPEC-P-0012
April 25, 1979

REFRACTORY CONCRETE, SPECIFICATION FOR

Approved:

Raymond L. Clark
Director of Design Engineering

JOHN F. KENNEDY SPACE CENTER, NASA

KSC-SPEC-P-0012
April 25, 1979

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KSC-SPEC-P-0012
April 25, 1979

JOHN F. KENNEDY SPACE CENTER, NASA

REFRACTORY CONCRETE,

SPECIFICATION FOR

This specification has been approved by the Design Engineering Directorate of the John F. Kennedy Space Center (KSC) and is mandatory for use by KSC and associated contractors.

1.0 SCOPE

This specification covers requirements for refractory concrete used for the heat and blast protection of flame deflectors, and other areas of a launch facility.

2.0 APPLICABLE DOCUMENTS

The publications of the issue in effect on the date of issuance of invitation for bids form a part of this specification and, where referred to thereafter by basic designation only, are applicable to the extent indicated by the references thereto. In the event of difference between this specification or its accompanying drawings and the referenced specification, this specification and its accompanying drawings shall govern to the extent of such difference.

2.1 Governmental.

2.1.1 Standards.

Military

MIL-STD-129	Marking for Shipment and Storage

(Copies of standards required by the contractor in connection with specific procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer.)

2.2 Non-Governmental.

American Society for Testing and Materials (ASTM)

C 33	Concrete Aggregates
C 39	Compressive Strength of Cylindrical Concrete Specimens

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pennsylvania, 19103.)

3.0 REQUIREMENTS

3.1 Qualification. The refractory concrete furnished under this specification shall be a product that has been tested and has passed the qualification tests specified in 4.3, and has been listed or approved for listing on the approved products list.

3.2 Materials. The fine aggregate shall be hard, dense, durable, clean, sharp, and well graded.

3.3 Properties.

3.3.1 Fineness Modulus. When tested in accordance with 4.3.2, the fineness modulus shall be between 3.75 and 2.75.

3.3.2 Strength. When tested in accordance with 4.3.3, refractory concrete shall develop a compressive strength of 4500 psi (minimum) at 7 days and 90 percent of the 7-day strength within 24 hours. If desired to develop improved properties, use of randomly dispersed steel wire fibers shall be permitted provided steel fibers do not segregate and clog nozzles.

3.4 Stability. When maintained in the original unopened bag for a period of 1 year, the material shall meet the requirements of this specification.

3.5 Rocket Engine Exhaust Resistance. Test samples installed at designated areas of the launch facility and then subject to rocket engine exhaust, shall not crack, spall, or erode more than 1/8 inch when tested in accordance with 4.3.1.4. Heat flux will be up to 3300 Btu/ft^2-sec; time of exposure will be approximately 10 seconds.

3.6 Workability. The refractory concrete shall be capable of being applied pneumatically or manually (trowel) to a uniform, smooth finish.

3.7 Weathering. The material shall resist degradation of thermal protection characteristics due to seacoast atmosphere exposure.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility. Unless otherwise specified, the manufacturer is responsible for the performance of all inspection requirements specified herein. Except as otherwise specified, the manufacturer may utilize his own or any other inspection facilities and services acceptable to NASA. Inspection records of the examinations and tests shall be kept complete and available to the Government for a period of five years, unless otherwise specified in the contract or order. The Government reserves the right to perform any of the inspections set forth in the specification, where such inspections are deemed necessary, to ensure supplies and services conform to the prescribed requirements.

4.2 Product Qualification Requirements. To become a qualified product, material shall meet the requirements of Section 3 and pass the qualification tests of 4.3.1 through 4.3.3.

4.3 Qualification Tests.

4.3.1 Test Sample. A test sample shall be required in accordance with figure 1 and the following requirements.

4.3.1.1 Reinforcement. Reinforcing steel shall be Bufnel Gripsteel as manufactured by Keene Corporation, Santa Fe Springs, California or equal. Reinforcing steel shall be free from rust, scale, grease, or other coating which may reduce the bond.

4.3.1.2 Cover for Reinforcement. Minimum concrete coverage for reinforcing steel from the surface exposed to the rocket engine exhaust shall not be less than 1-1/2 inches.

4.3.1.3 Surface Finish. Surface finish shall be uniform and smooth.

4.3.1.4 Rocket Engine Exhaust Exposure. The test sample shall be installed at the designated launch site location and exposed to a rocket engine exhaust. The test sample shall be examined for conformance to 3.5. Installation and examination of the test samples shall be performed by the Government.

4.3.2 Fineness Modulus. The fineness modulus of the aggregate shall be determined in accordance with ASTM C 33.

4.3.3 Strength. The compressive strength shall be determined in accordance with ASTM C 39.

4.4 Certificate of Conformance. The manufacturer shall submit a certificate of conformance stating that the material furnished is essentially identical to the material furnished for qualification testing and complies with the requirements specified herein.

4.5 Test Reports. The manufacturer shall submit a certified laboratory report describing the tests performed in accordance with 4.3.2 and 4.3.3.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging. Unless otherwise specified, material shall be furnished in bags containing 100 pounds of a premixed combination of refractory aggregate in hydraulic setting binder.

5.2 Packing. Packing shall be in a manner which will ensure arrival at the designation in satisfactory condition and be acceptable to the carrier at the lowest rate.

5.3 Palletization. When specified (see 6.2), shipping containers shall be palletized using standard wooden pallets.

5.4 Marking. In addition to any special marking required by the contract, or order, bags shall be marked in accordance with MIL-STD-129. Each bag shall display the following information.

a. Title, number, and date of this specification

b. Name of the product

c. Batch number

d. Manufacturer's name and address

e. Weight of contents

f. Date of manufacture

g. Toxic precautions

h. Necessary supplementary information to ensure safe and proper use of the material

5.5 Mixing and Application Instructions. Mixing and application instructions shall be included with each shipment.

6.0 NOTES

6.1 Intended Use. The refractory concrete is intended for use on the flame deflector and other areas of a launch complex to protect the facility from radiant heat and flame impingement effects of the rocket engine exhaust plume of a launch vehicle.

6.2 Ordering Data. Procurement documents should specify the following:

a. Title, number, and date of this specification

b. Number of 100-pound bags

c. Certification of Conformance (see 4.4)

d. Test Reports (see 4.5)

e. Palletization, if required (see 5.3)

NOTICE: When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

CUSTODIAN:

NASA-John F. Kennedy Space Center

PREPARING ACTIVITY:

John F. Kennedy Space Center
Mechanical Design Division
Design Engineering Directorate

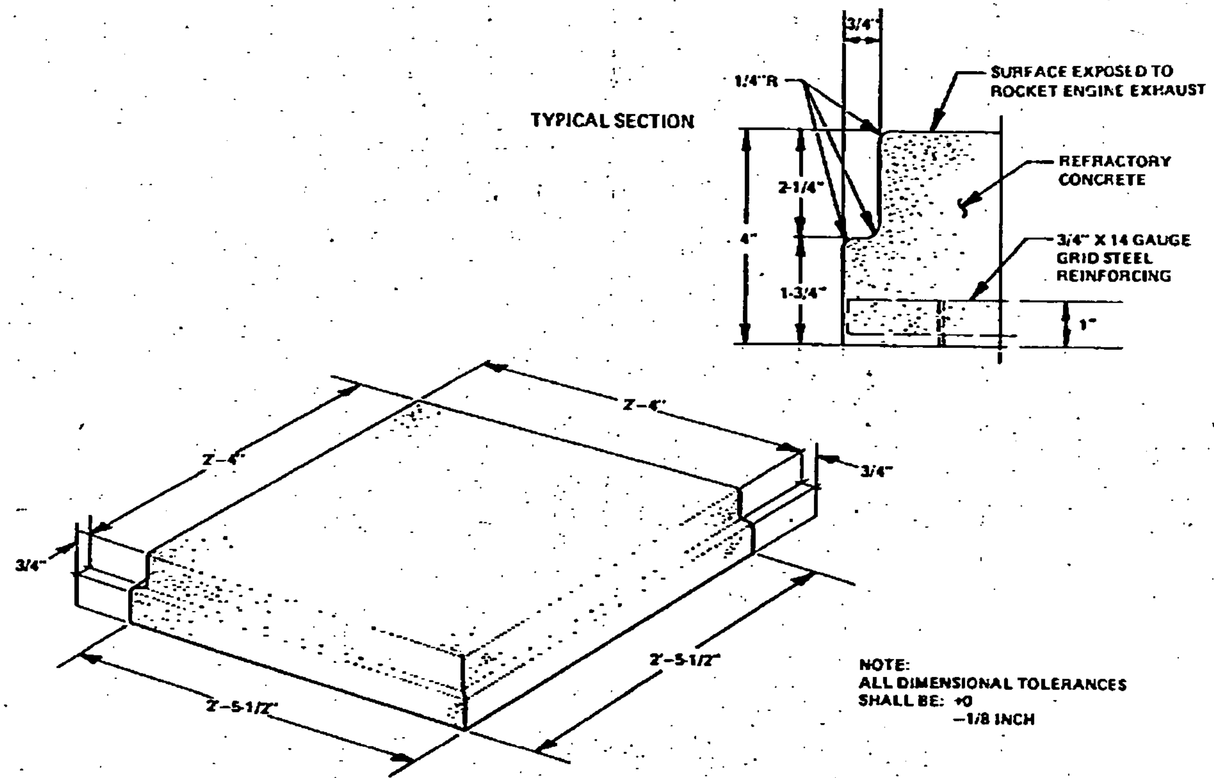

Figure 1. Test Sample Configuration

TASK REQUEST

1. DATE SUBMITTED	2. DESIRED COMPLETION DATE	3. AUTHORIZING DOCUMENT
4-9-76	4-77	N/A

4. SAMPLE DESCRIPTION:

Refractory concrete used on flame deflectors.

5. SYSTEM REMOVED FROM/OR USED IN:

N/A

6. ANALYSIS REQUESTED:

Assist in the installation and evaluation of refractory concrete samples on LC-17. Samples to be installed on carrier plates with Gripsteel. Samples shall be installed on the North side of the umbilical tower base at a location where severe spalling is evident.

Also assist in the identification of appropriate laboratory tests for evaluation of refractory concrete which would be suitable for specification purposes.

7. REMARKS:

Arrangements have been made with Mr. Bob Wilson, the LC-17 Facility Manager, for installation of the test samples.

8. REQUESTER:	9. PHONE:	10. COMPANY:	11. MAIL CODE:
12. NASA APPROVAL:	**13. PHONE:**	**14. MAIL CODE:**	**15. DATE:**
M. G. Olsen *M. G. Olsen*	7-2102	DD-SED-3	4-9-76

FOR LAB USE ONLY

INVESTIGATOR	TASK NUMBER	SAMPLE NUMBER
JOE MORRISON	MTB 075-76	

KSC FORM 22-81 (REV. 1/70) NASA/KSC NOV/73

NASA
MALFUNCTION/MATERIALS ANALYSIS SECTION
MATERIALS ANALYSIS BRANCH
FLUIDS AND ANALYSIS DIVISION
TG-FLD-22, ROOM 1218, O&C BUILDING
KENNEDY SPACE CENTER, FLORIDA 32899
JULY 29, 1981

MMA-1918-80

1.0 FOREWORD

1.1 On 29 September, 1980, W. E. Clautice, PRC-1217, requested testing of refractory concrete test panels, the testing to comprise thickness measurements, color photographs, and visual observations both before and after exposure to SRB exhaust during STS-1 Launch.

1.2 Preparations for this test had been underway for some time. Test frames designed by PRC had been installed at LC39. Test panels prepared to KSC specification had been solicited from four vendors. One vendor, North American Refractories Company, had declined to furnish samples, for reasons outlined in their letter, which is reproduced in the appendix. Three vendors had furnished samples as follows:

1.2.1 Designed Concretes Co.
2 panels Fondu Fyre WA-1 (Approved for Saturn)
1 panel Fondu Fyre WA-1 with wire
1 panel Fondu Fyre FSC-5

1.2.2 Wahl Refractory Products Co.

1 panel WRP1	Color-White	PSM Cast, H_2O, Fiber
1 panel WRP2	Color-Gray	Cement Fondu; Parry Sand, H_2O, Fiber
1 panel WRP3	Color-Gray	Cement Fondu 50m Ball Mill Calcined Flint Clay H_2O Fiber

1.2.3 Harbison-Walker Refractories

2 panels Tufshot
2 panels Tufshot with 3.25% type 310 SS melt extracted fibers

1.3 Shipping documents for these panels are reproduced in the appendix.

1.4 In the interests of expediency the support requests for the handling, installation, and removal of the test panels were initiated and managed by TG-FLD-22.

2.0 TEST PROCEDURE

2.1 TEST PANEL SELECTION

The 11 test panels supplied by the three vendors were examined by the requester, W. E. Clautice, PRC-1217, R. J. Davis, DD-MED-33, and C. V. Moyers, TG-FLD-22. Mr. Clautice selected 6 panels for exposure during STS-1 launch.

2.2 TEST PANEL IDENTIFICATION

The panels supplied by Designed Concretes bore 1 inch black stencilled identifying marks on the upper surface. No identifying marks were found on the other panels. The six selected panels were assigned numbers as follows:

PANEL NO	DESCRIPTION
1.	Wahl, (WRP-1), Contained silver-colored chopped wire.
2.	Designed Concretes, "WA-1"
3.	Designed Concretes, "WA-1-W/WIRE"
4.	Wahl, (WRP-3), Contained gold-colored chopped wire. (WRP-3)
5.	Harbison-Walker, (Chopped wire).
6.	Harbison-Walker.

2.3 PRE-EXPOSURE THICKNESS DETERMINATIONS

A template to locate 13 points on each panel (Figure 1), and a caliper to determine thickness at each point were designed and fabricated. The 6 panels were placed on inspection racks which afforded access to both top and bottom surfaces (Figure 2), and thickness at each of the predetermined points was measured. Photographs were made of each panel, and they appear later in this report.

2.4 SRB EXHAUST EXPOSURE

The panels were then installed in the two refractory test frames (DWG 79K09546) at the bottom of the SRB flame deflector in the north end of the flame trench at LC39A (Figure 3). Each frame holds three panels. The holddown clamps and the areas between panels were coated with Dynatherm E-320 ablative coating. The panels were installed in numerical sequence from east to west. Figure 4 shows a test frame with panels installed. The panels remained on the test frames until after STS-1 launch.

2.5 POST-EXPOSURE THICKNESS DETERMINATIONS

After launch, the panels were photographed. They were then removed from the test frames and transported to the inspection racks, where the same template and caliper were used to make thickness determinations. The depths of representative spalled areas were determined, using a depth gage provided with a dial indicator and a tip with a radius of about 1/8 inch.

3.0 RESULTS

Figures 5 through 28 show the individual panels as received, as installed in the test frames before launch, and as they appeared after launch. Figures 29 through 34 show individual thickness measurements before and after launch, and the thickness loss at each location.

Table 1 shows the average thickness losses and observations of surface conditions after launch.

Based on examination of the ablative coating around the panels after launch, it appears that the east rack (panels 1, 2, and 3) received more severe exposure, and that the panels nearest the sides (panels 1 and 6) received slightly less exposure than the other panels on the same rack. Some variation in exposure is to be expected as the vehicle is steered during liftoff in response to the effects of wind at the time of launch.

4.0 CONCLUSION

All of the panels lost more than the maximum 1/8" permitted by KSC-SPEC-P-0012.

5.0 RECOMMENDATIONS

A second exposure of these panels to the SRB exhaust is recommended, with the east to west positions of the panels changed from 1, 2, 3 - 4, 5, 6 to 4, 5, 6 - 1, 2, 3. It is also recommended that reference plates with a known thickness of ablative coating be embedded flush with the surface of the ablative coating applied to the racks. This will permit assessment of the relative severity of exposure for each panel.

INVESTIGATOR: C V Moyers
C. V. MOYERS

APPROVED: C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MMAS/NASA

TABLE 1

CONDITION OF PANELS AFTER STS-1

Panel No.	Average Thickness Loss, Inches	Average Thickness Loss, % of 4"	OBSERVATIONS
1.	0.163	4.1	Few spalls, mostly large, to 0.222" deep. "Fibers" exposed.
2.	0.256	6.4	Very few spalls, to 0.258" deep. Portions of pre-existing crack covered by fused layer. Surface generally rought but uniform. Panel remained intact when removed.
3.	0.325	8.1	One spall 0.214 deep. Cracked into six segments with some fused material over portions of cracks. Cracks measured to 0.373" deep, with deeper narrow fissures. Surface generally rough but uniform. Panel remained intact when removed.
4.	0.235	5.9	Small, numerous spalls, to 0.174" deep. Gouge at edge 0.370 deep. Orange rust stain. Exposed carbon steel wires deeply oxidized, easily broken.

TABLE 1
(Continued)

Panel No.	Average Thickness Loss, Inches	Average Thickness Loss, % of 4"	OBSERVATIONS
5.	0.238	5.9	Moderate number of spalls, medium to small, to 0.346" deep. "Fibers" exposed.
6.	0.192	4.8	Moderate number of spalls, mostly large, to 0.258" deep. Corner inadvertently cracked during removal.

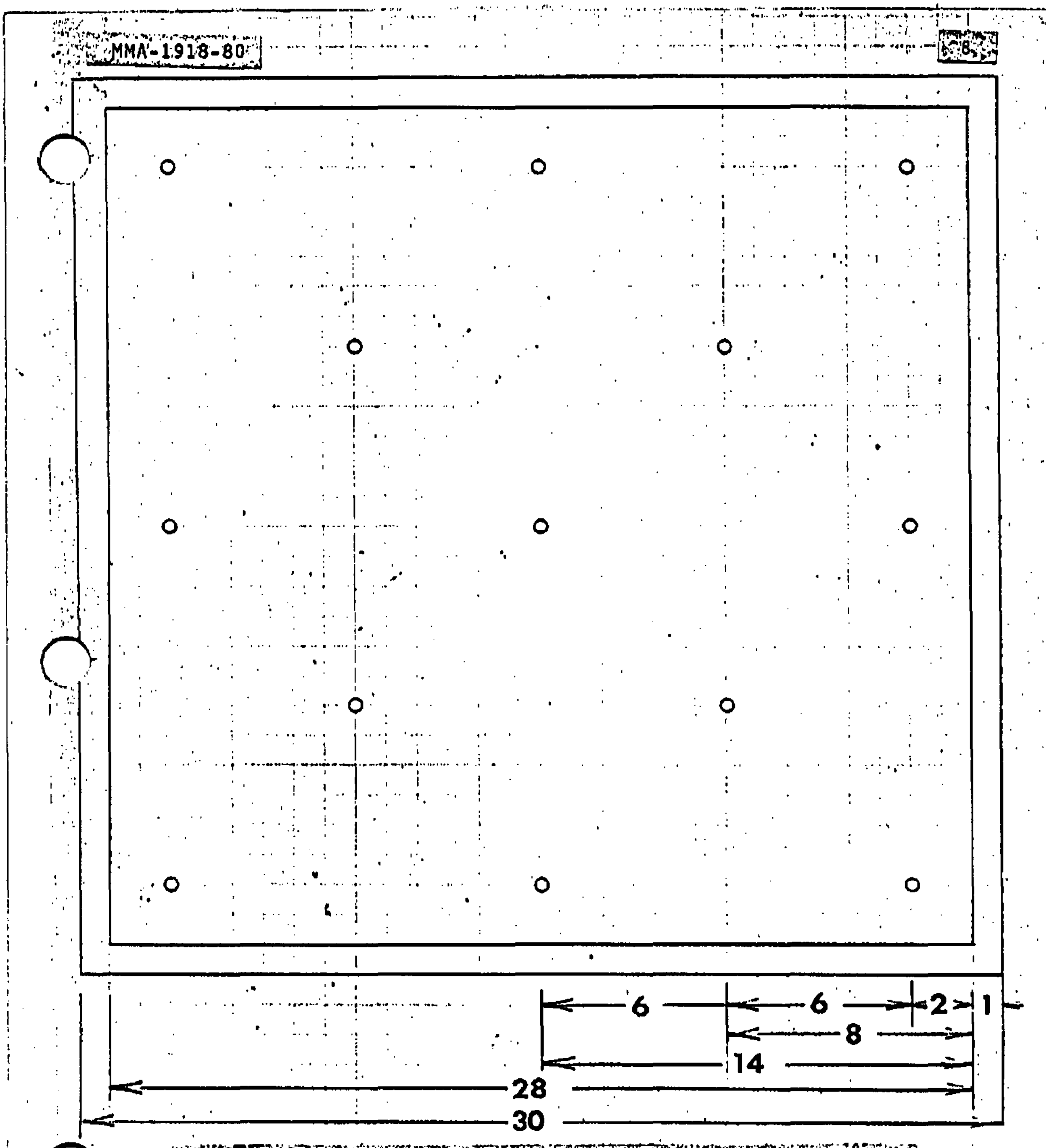

FIGURE 1.
LOCATIONS OF THICKNESS MEASUREMENTS.
DIMENSIONS ON THE OTHER AXIS ARE THE SAME AS THESE SHOWN.

MMA-1918-80

9

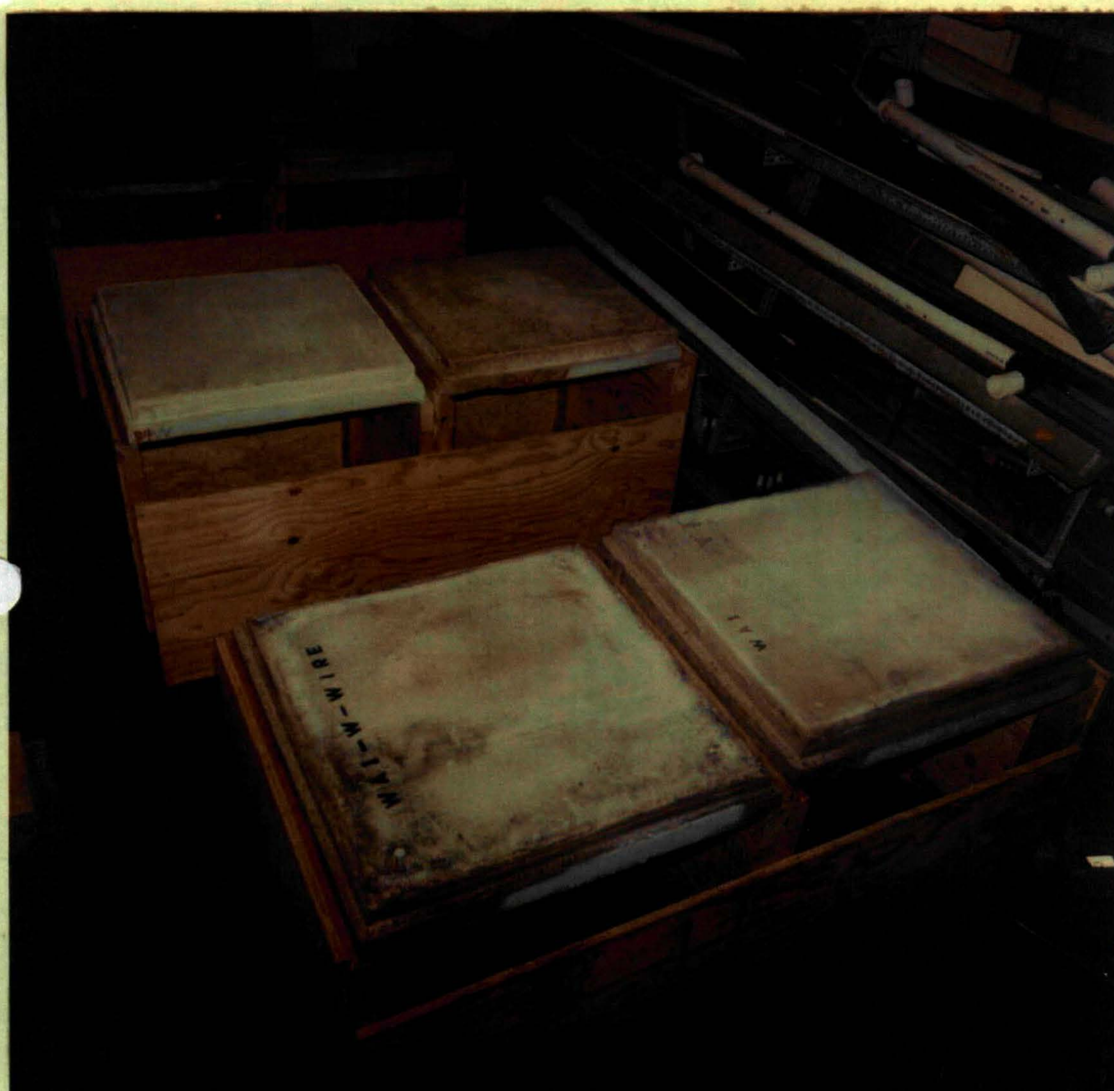

FIGURE 2.
TEST PANELS ON INSPECTION RACKS.

MMA-1918-80

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FIGURE 3.
SRB FLAME DEFLECTOR AND TEST FRAMES.

MMA-1918-80

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FIGURE 4.
EAST TEST FRAME WITH TEST PANELS INSTALLED.

MMA-1918-80

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FIGURE 5.
PANEL 1, AS RECEIVED.

MMA-1918-80

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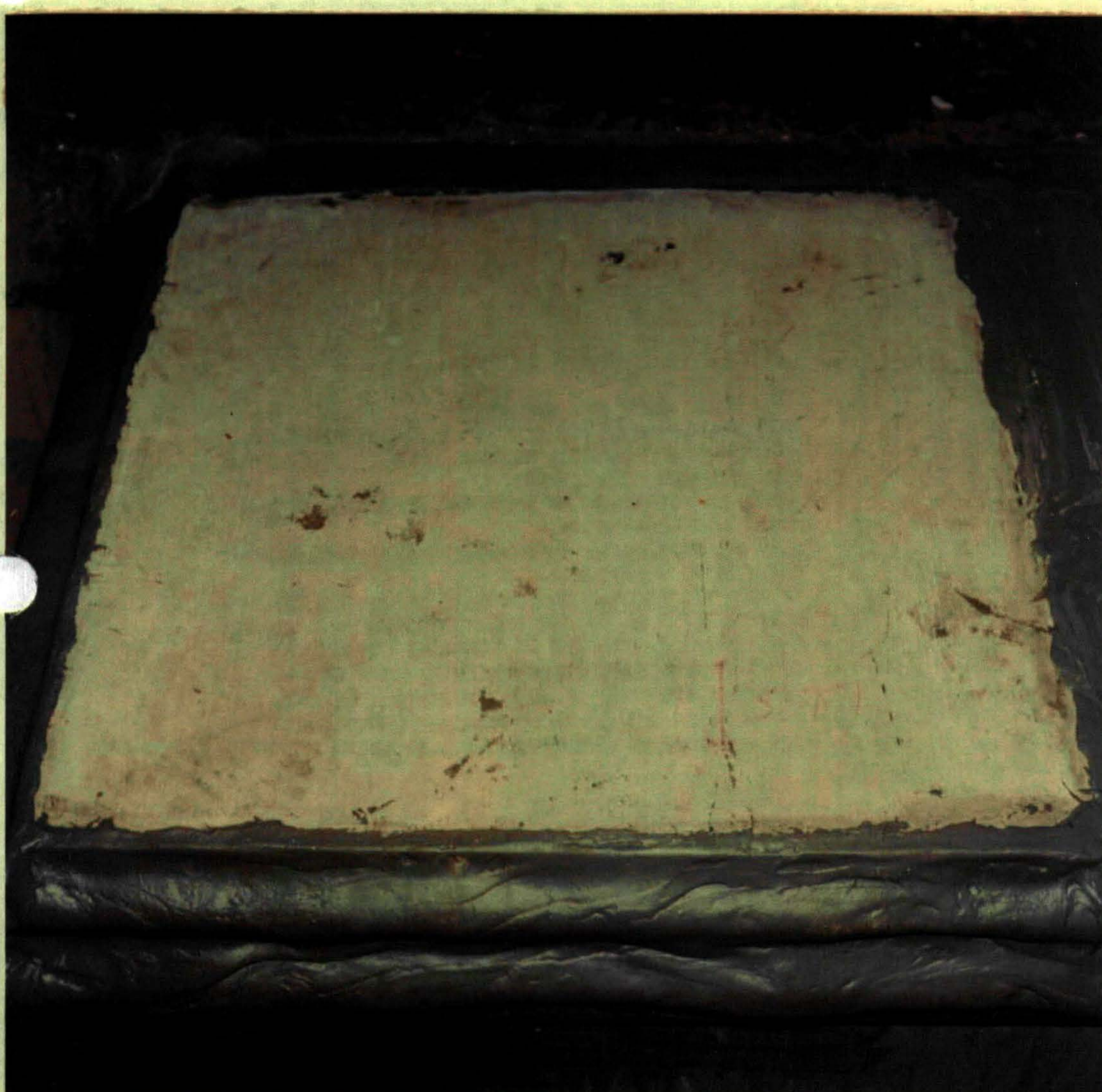

FIGURE 6.
PANEL 1, INSTALLED IN TEST FRAME, BEFORE LAUNCH.

MMA-1918-80

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FIGURE 7.
PANEL 1, IN TEST FRAME, AFTER LAUNCH.

MMA-1918-80

15

FIGURE 8.
PANEL 1, ON INSPECTION RACK, AFTER LAUNCH.

MMA-1918-80

16

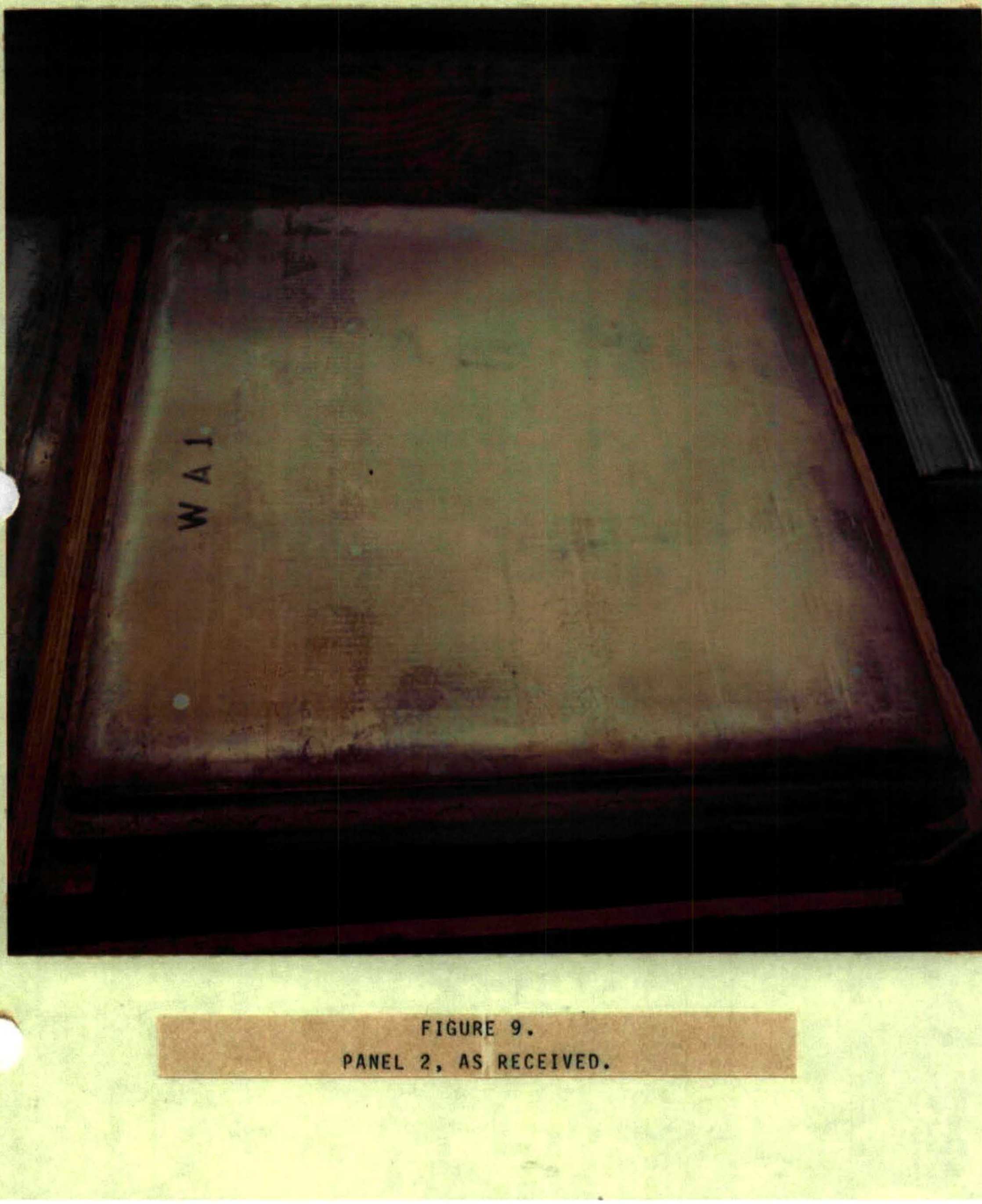

FIGURE 9.
PANEL 2, AS RECEIVED.

FIGURE 10.
PANEL 2, INSTALLED IN TEST FRAME, BEFORE LAUNCH.

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FIGURE 11.
PANEL 2, IN TEST FRAME, AFTER LAUNCH.

MMA-1918-80

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FIGURE 12.
PANEL 2 ON INSPECTION RACK, AFTER LAUNCH.

MMA-1918-80

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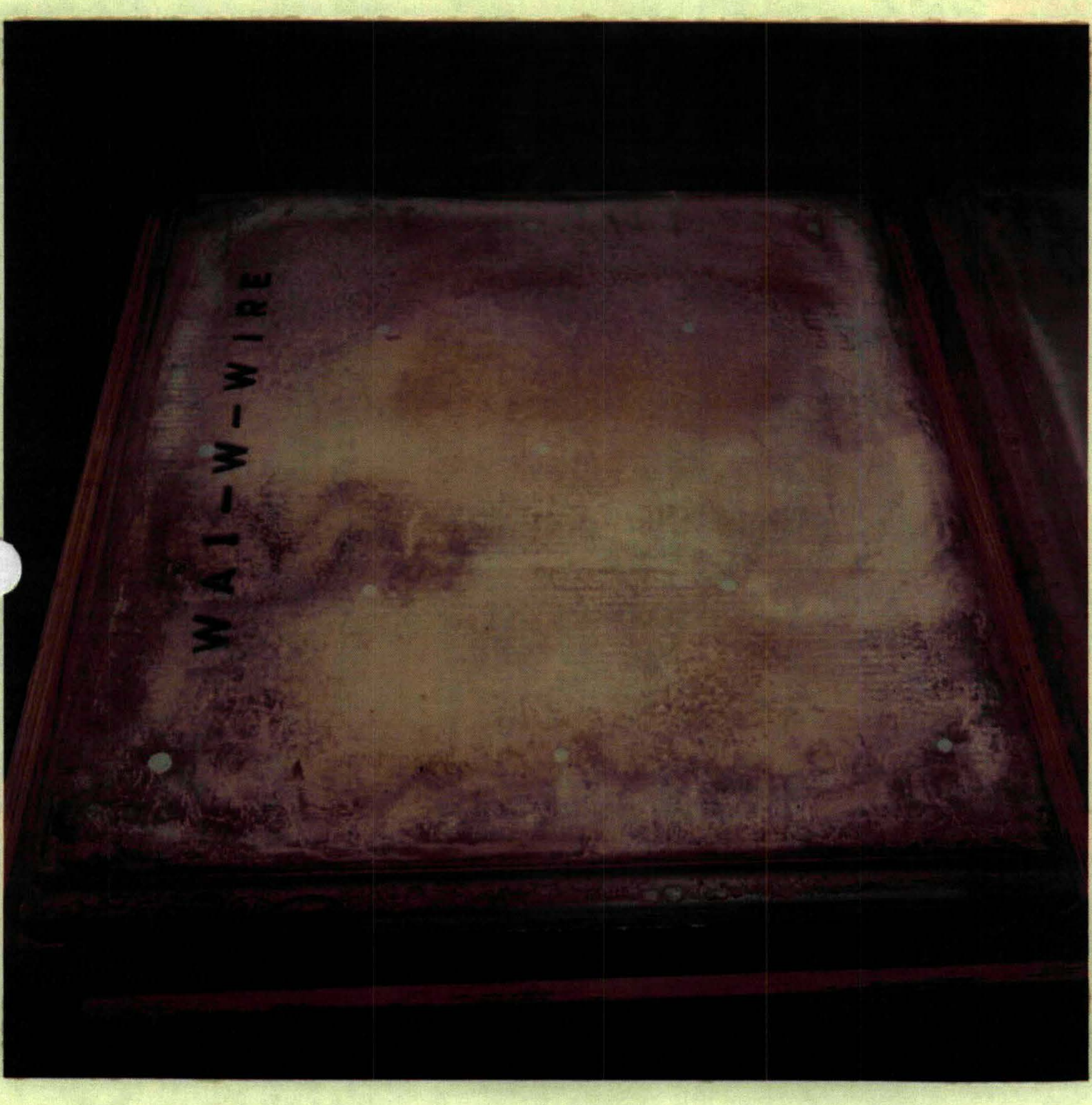

FIGURE 13.
PANEL 3, AS RECEIVED.

FIGURE 14.
PANEL 3, INSTALLED IN TEST FRAME, BEFORE LAUNCH.

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FIGURE 15.
PANEL 3, IN TEST FRAME, AFTER LAUNCH

MMA-1918-80

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FIGURE 16.
PANEL 3, IN INSPECTION RACK, AFTER LAUNCH.

FIGURE 17.
PANEL 4, AS RECEIVED.

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FIGURE 18.
PANEL 4, INSTALLED IN TEST FRAME, BEFORE LAUNCH.

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FIGURE 19.
PANEL 4, IN TEST FRAME, AFTER LAUNCH.

MMA-1918-80

27

FIGURE 20.
PANEL 4, ON INSPECTION RACK, AFTER LAUNCH.

MMA-1918-80

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FIGURE 21.
PANEL 5, AS RECEIVED.

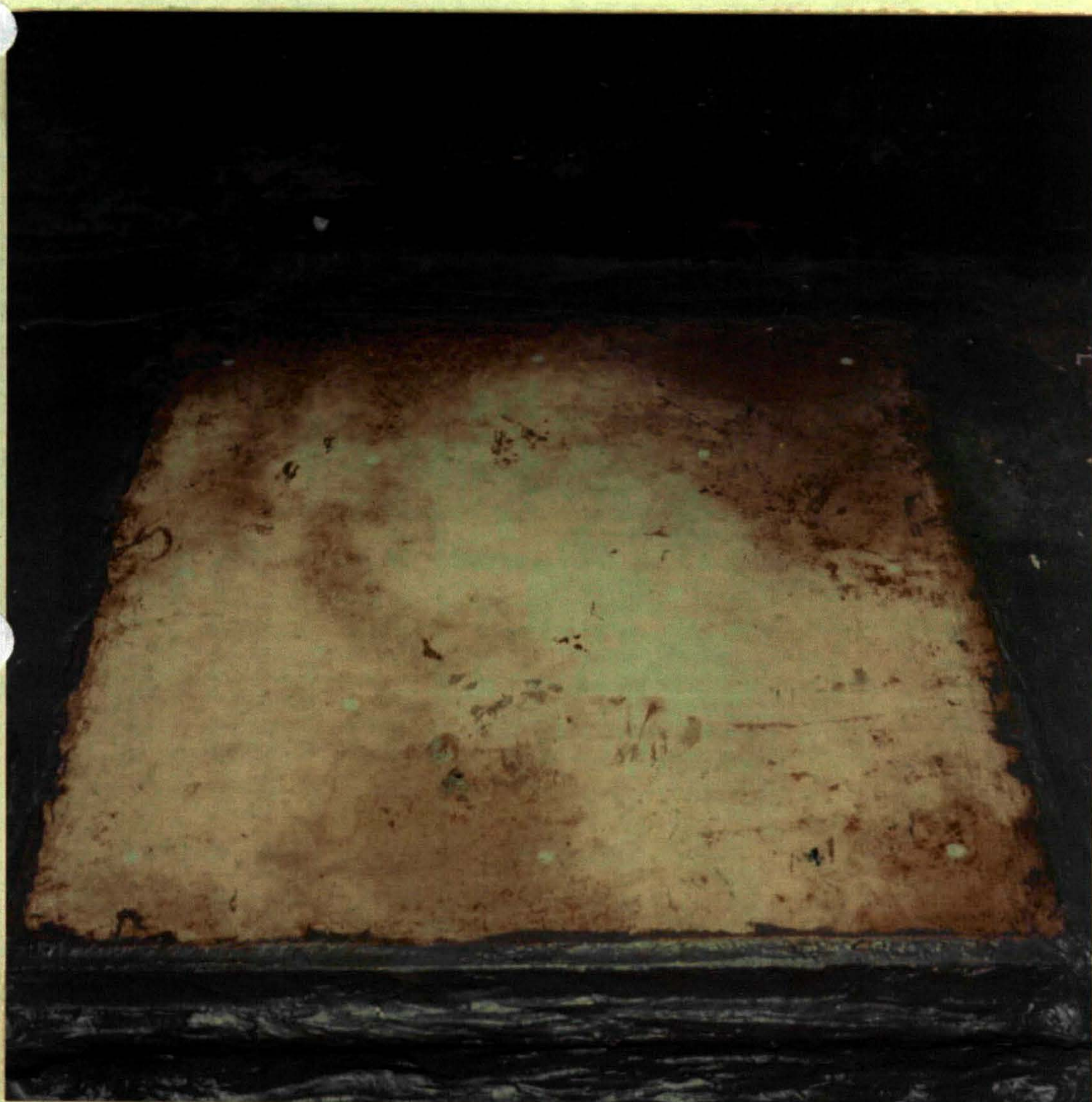

FIGURE 22.
PANEL 5, INSTALLED IN TEST FRAME, BEFORE LAUNCH.

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FIGURE 23.
PANEL 5, IN TEST FRAME, AFTER LAUNCH.

FIGURE 24.
PANEL 5, ON INSPECTION RACK, AFTER LAUNCH.

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FIGURE 25.
PANEL 6, AS RECEIVED.

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FIGURE 26.
PANEL 6, INSTALLED IN TEST FRAME, BEFORE LAUNCH.

MMA-1918-80

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FIGURE 27.
PANEL 6, IN TEST FRAME, AFTER LAUNCH.

MMA-1918-80

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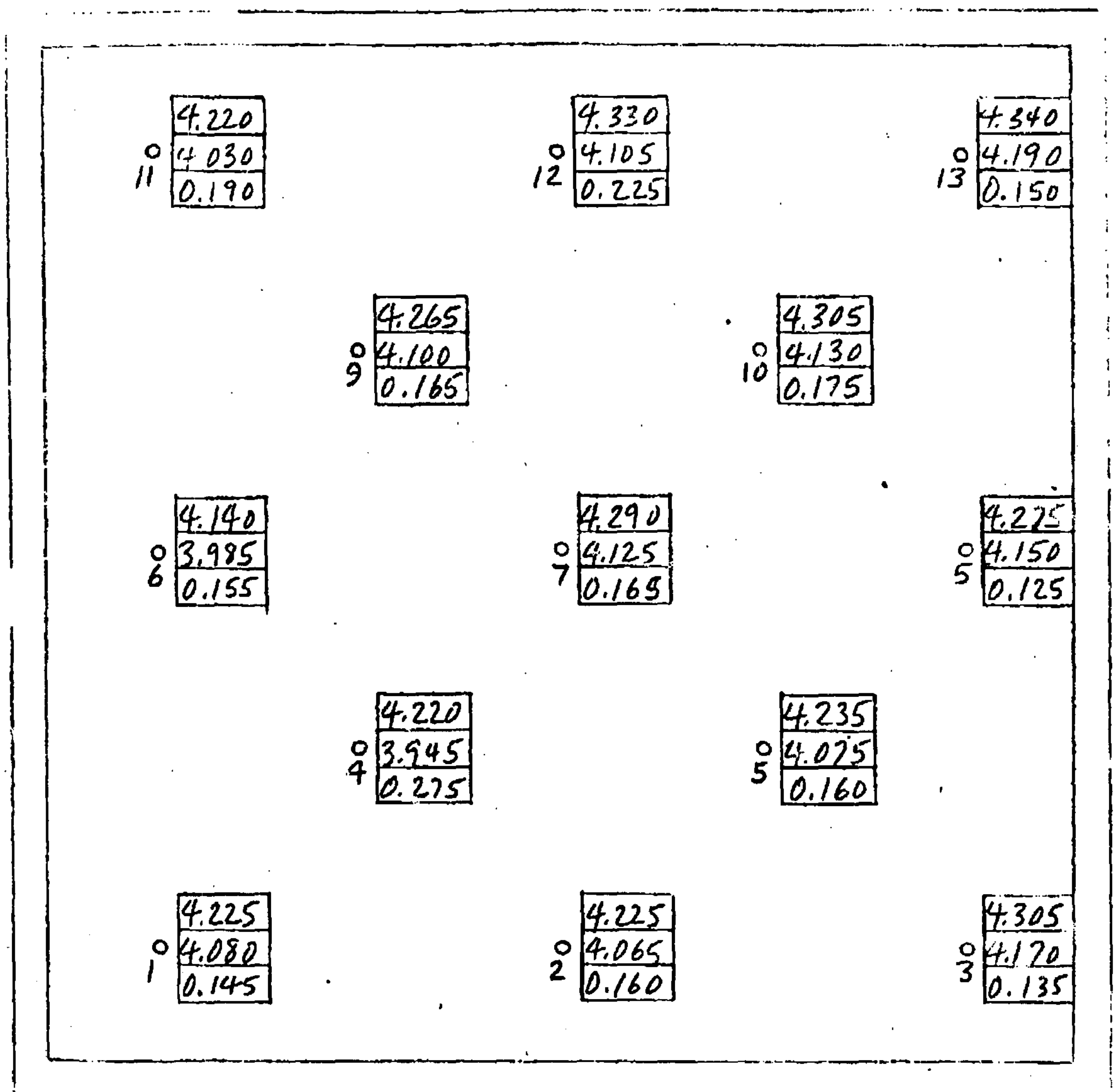
FIGURE 28.
PANEL 6, ON INSPECTION RACK, AFTER LAUNCH.



AVG- LOSS 0.163

FIGURE 29.
THICKNESS MEASUREMENTS, PANEL 1.

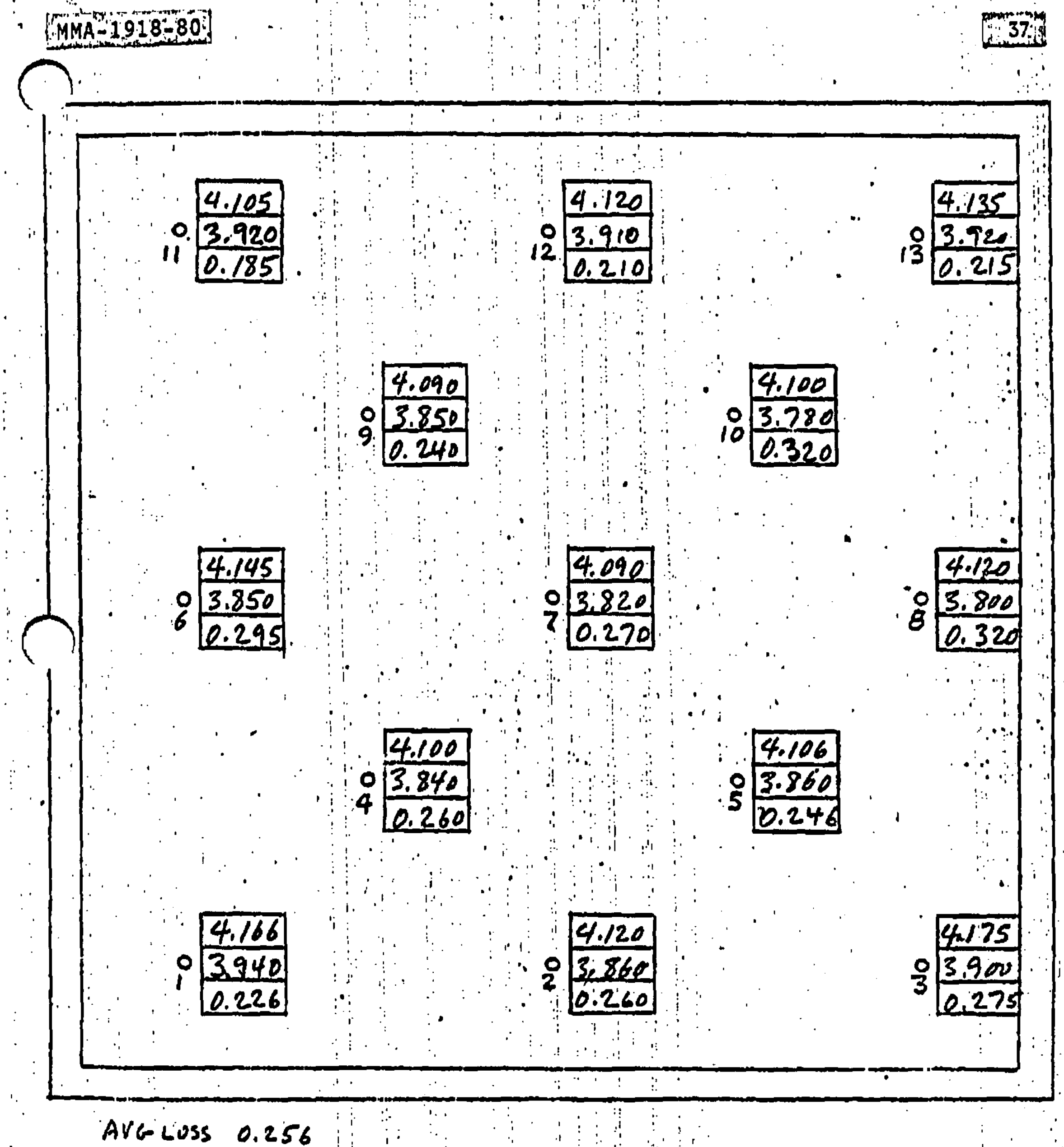


FIGURE 30.
THICKNESS MEASUREMENTS, PANEL 2.

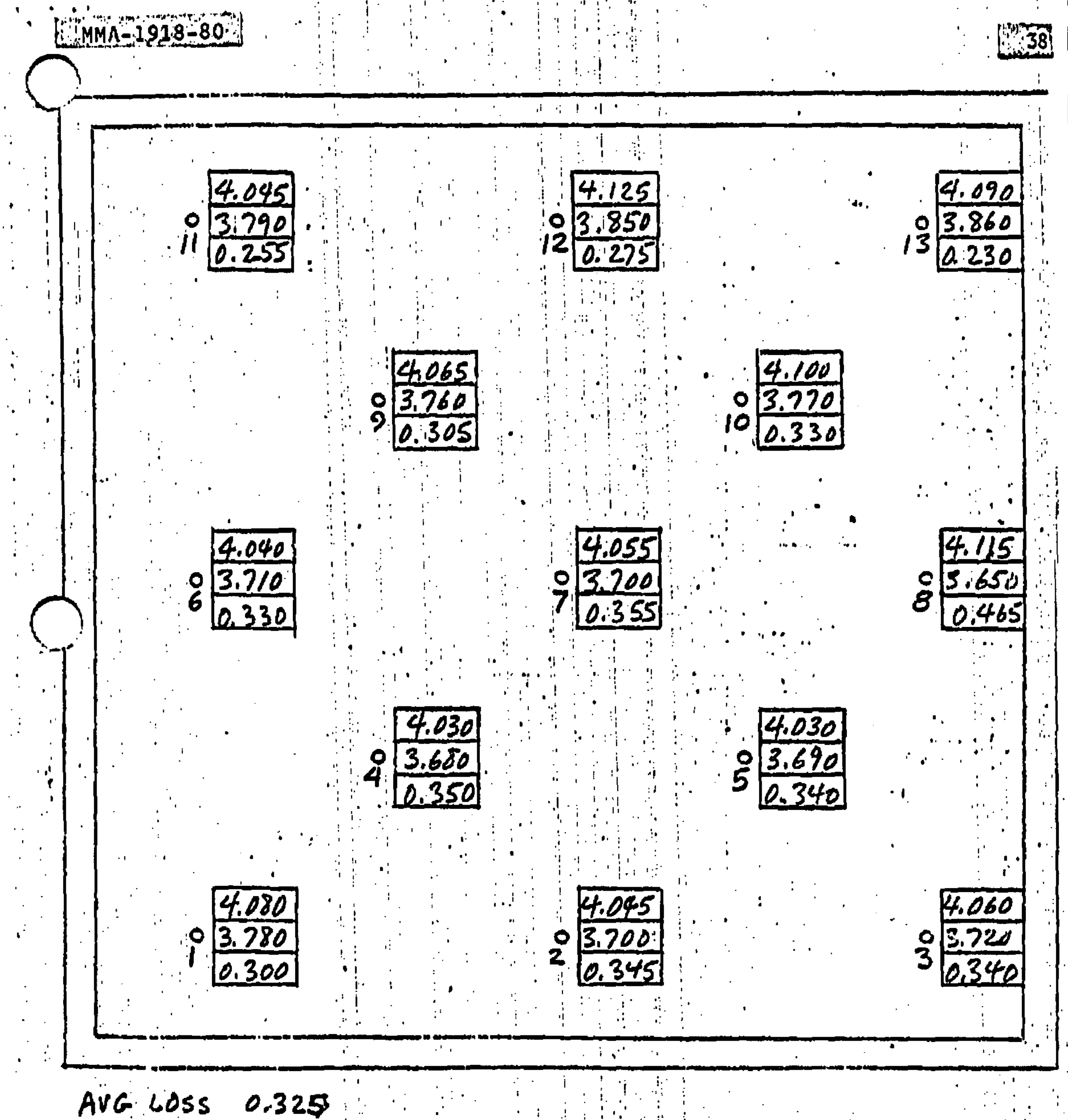


FIGURE 31.
THICKNESS MEASUREMENTS, PANEL 3.

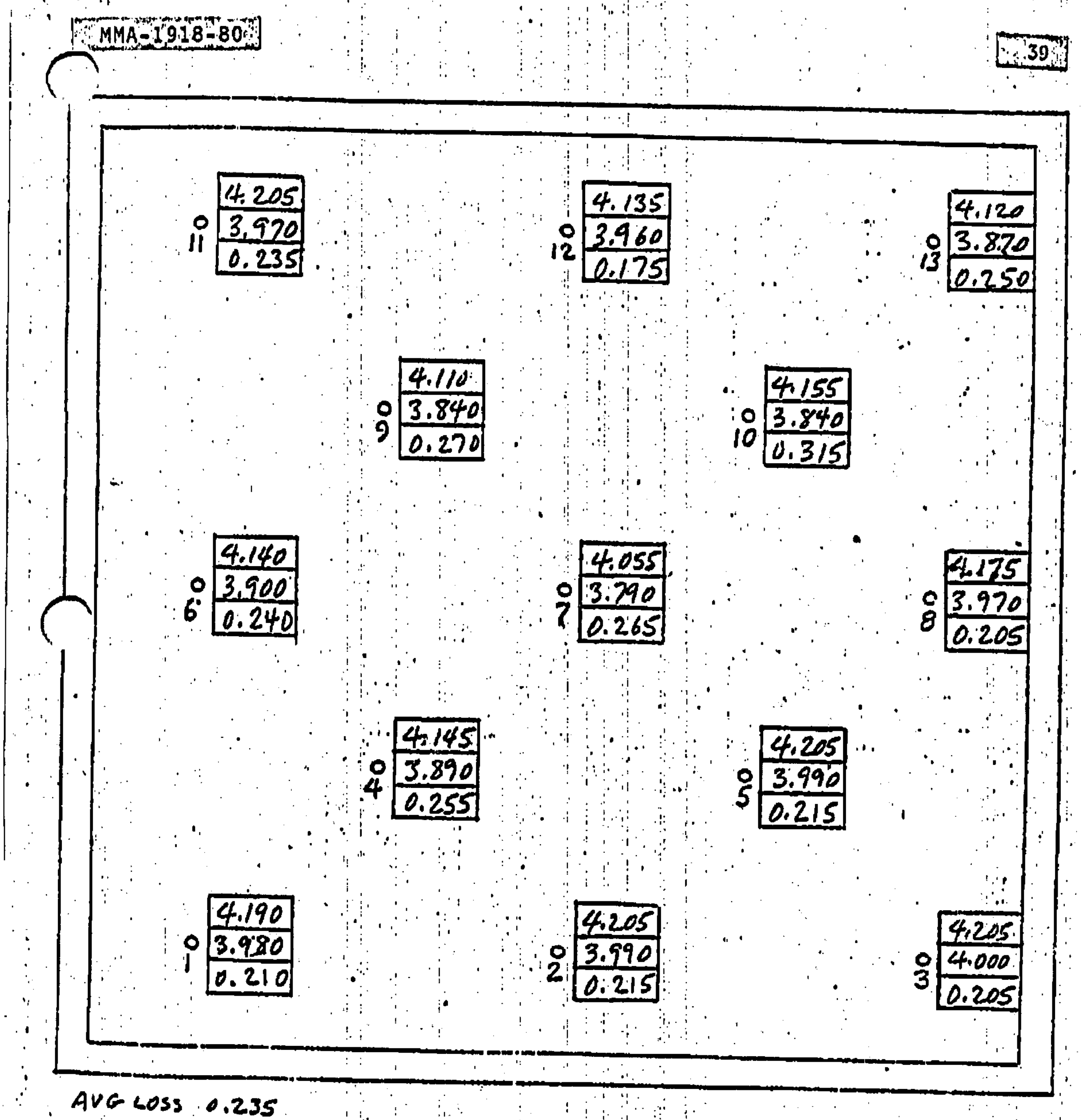


FIGURE 32.
THICKNESS MEASUREMENTS, PANEL 4.

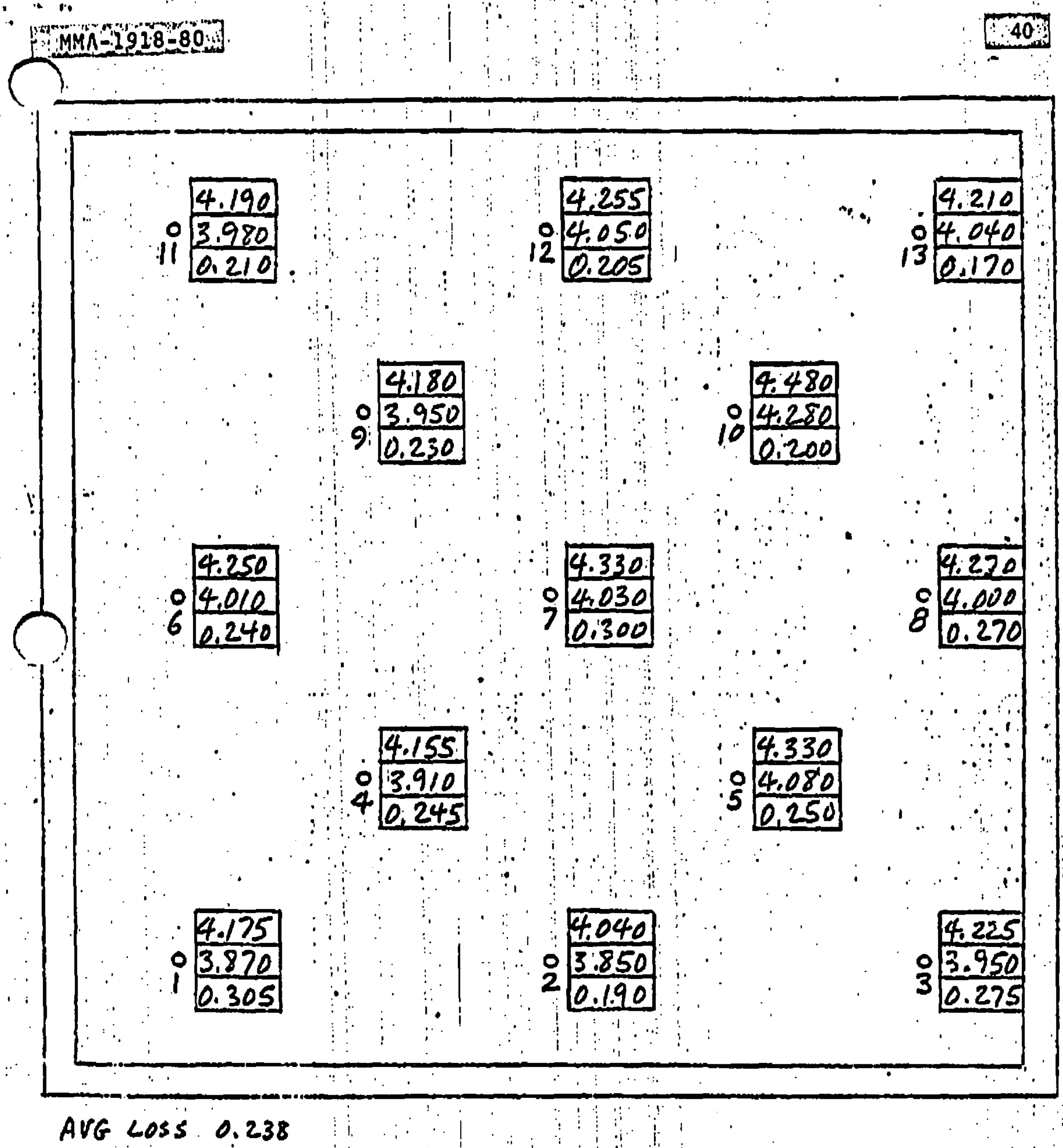


FIGURE 33.
THICKNESS MEASUREMENTS, PANEL 5.

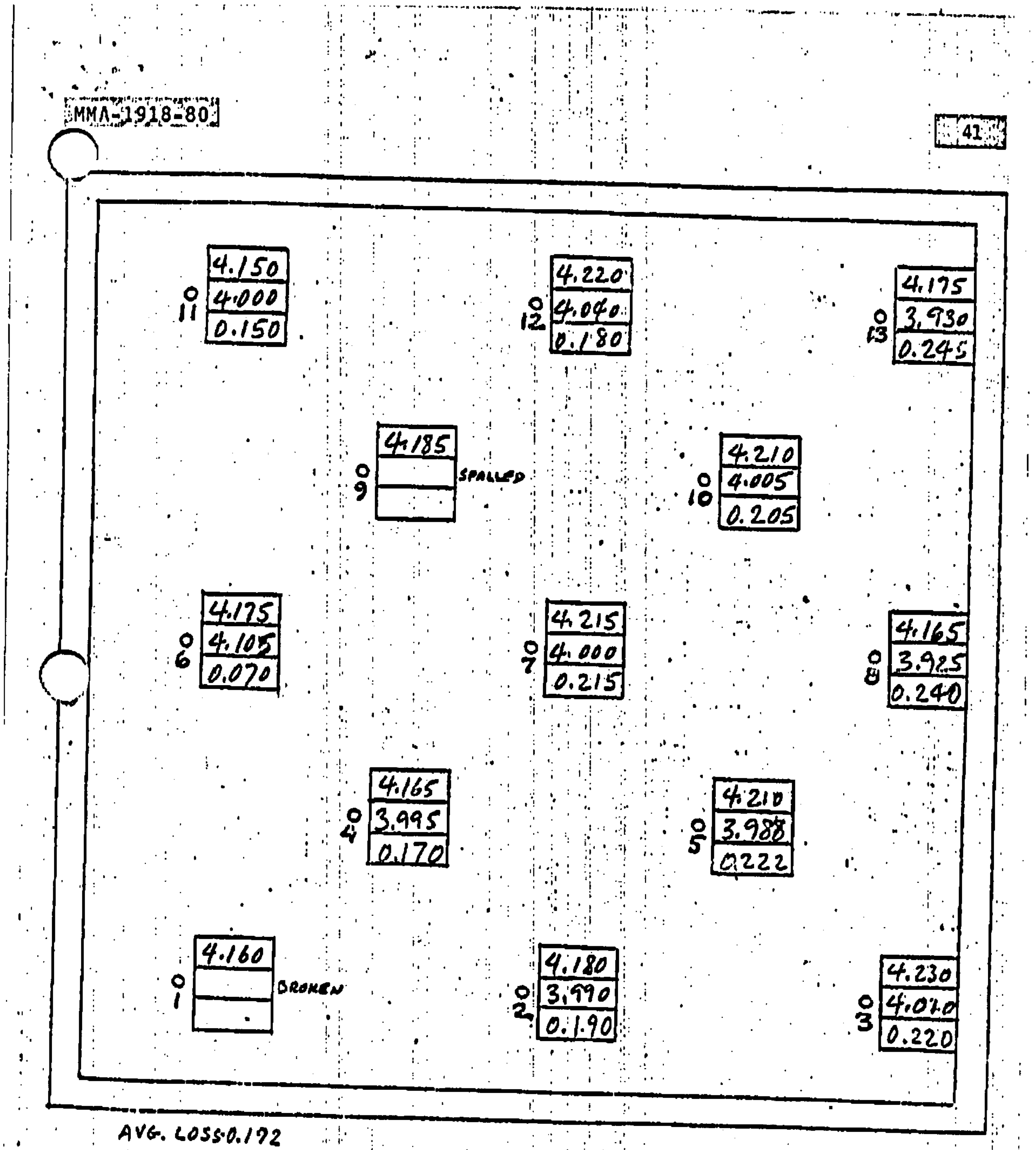


FIGURE 34.
THICKNESS MEASUREMENTS, PANEL 6.

APPENDIX

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NORTH AMERICAN REFRACTORIES CO.

HANNA BUILDING • EAST 14TH AND EUCLID • CLEVELAND, OHIO 44115 • (216) 621-5200

July 21, 1980

Mr. Bill Clautice
Planning Research Corp.
Systems Service Co.
P. O. Box 21266
Kennedy Space Center, Fla. 32815
Mail Code PRC 1217

Dear Mr. Clautice,

Confirming Our phone conversation this date, this letter will confirm our company decision not to furnish test samples of refractory concrete for possible use at launch sites.

As we discussed, many of the specifications outlined in KSC-SPEC-P-0012 were tests not normally performed on regular refractory products, but rather were tests used on regular portland cement. Some of the fineness requirements would have limited us in the type of product to be recommended and some of the other requirements raised questions not previously encountered.

We regret that we will be unable to furnish the test samples you require and hope you will be able to obtain enough samples to run the test you have indicated.

Perhaps in the future if you have other needs we will be able to work with you at that time. If we can be of service in any way, be sure to call on us.

Sincerely,

G. T. Lanford

G. Truett Lanford
84 Hatchineha Road
Haines City, Fla. 33844
813-439-4519

CC: R. A. Lund
J. M. Scanlon
E. S. Chrzan
Research Dept.
File

gtl/c

an Eltra company

84 HATCHINEHA RD.
HAINES CITY, FLORIDA 33844

TELEPHONE
OFFICE: 813-439-4519
HOME: 813-439-3568

G. TRUETT LANFORD
Sales Representative

NORTH AMERICAN REFRACTORIES CO.
an Eltra company

AIGHT BILL OF LADING—SHORT FORM—Original—Not Negotiable.

PACKING SLIP
DELIVERY MEMO

..D, subject to the classifications and tariffs in effect on the date of the issue of this Bill of Lading,
Santa Fe Springs, California 7/28 19 80 from THE PRYOR-GIGGEY CO. 44

CHIEF FRT. TRAFFIC, NASA
BLDG M7-6744
3RD STREET AND AVE C
KENNEDY SPC CNT FL 32899
Attn: Carlos Springfield

** SPECIAL INSTRUCTIONS *
BILL TO PLANNING RESEARCH
CORP. W. CLAUTICE CODE
PRC-1217. PO BOX 21256
KENNEDY SPACE CENTER FL.

SOLD TO: CASH SALE - CH

...NO.	ORDER DATE	DATE ENTERED	DUE DATE	SHIP DATE	F.O.B.	SHIP VIA	
36	07/22/80	07/22/80	07-31-80	07-23-80	DELIVERED	TRUCK/PREPAID	SANTA F

QUANTITY ORDERED	UNIT	W.H.	PRODUCT NO.	DESCRIPTION	QUANTITY SHIPPED	BACK ORDERED
2		10	95999999	MISC FONDU FYRE WA-1 SAMPLE	2	-0-
1		10	95999999	MISC FONDU FYRE WA-1 W/WIRE	1	-0-
1		10	95999999	MISC FONDU FYRE FSC-5 SAMPLE ATTN CARLOS SPRINGFIELD CODE - TG-FLD-22 SAMPLES PER NASA SPEC P-0012 FIG 1 CONFIGURATION.	1	-0-

CARRIER CONSOL
CARRIER'S NUMBER
ROUTE
DELIVERING
C.O.D. SHIPMENT

TERMS	PALLETS	FREIGHT CHARGES	MISCELLANEOUS CHARGE
NET CASH 30 DAYS	SINGLE FACED ___ DOUBLE FACED 1		

...NOT SHIPPED ARE BACK ORDERED AND WILL BE SHIPPED AS SOON AS POSSIBLE. ...CK ORDERS—THIS COLUMN SHOWS ONLY QUANTITIES ON ORDER BEFORE SHIPMENT IS

WE HEREBY CERTIFY THAT THESE GOODS WERE PRODUCED IN COMPLIANCE WITH ALL APPLICABLE REQUIREMENTS OF SECTION 6, 7 AND 12 OF THE FAIR LABOR STANDARDS ACT, AS AMENDED, AND OF REGULATIONS AND ORDERS OF THE UNITED STATES DEPARTMENT OF LABOR ISSUED UNDER SECTION 14 THEREOF.

...ges	HM	Kind of Package, Description of Articles, Special Marks, and Exceptions	Weight (Sub. to Cor.)	Class or Rate	Check Column
		FIRE BRICK or FIRE BRICK SHAPES Pallet	1105#		
		PLASTIC FIRE BRICK			
		HI TEMP BONDING MORTAR			
		Red Corp 7 - Hdqtrs Rm 3361 Mitchell Cardwell			

If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE—Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.

†Shipper's imprint in lieu of stamp; not a part of bill of lading approved by the Interstate Commerce Commission.

...reed or declared value of the property is hereby specifically stated by the shipper to be not exceeding

†This is to certify that the above named materials are properly classified, described, packaged, marked and are in proper condition for transportation according to applicable regulations of the Department of Transportation.

THE PRYOR-GIGGEY CO. Shipper, Per [signature] Agent, Per [signature] 7/28/80

...post-office address of shipper. P.O. Box 739, Whittier, California 90608

Forward to Consignee

HARBISON-WALKER REFRACTORIES
2 Gateway Center, Pittsburgh, Pennsylvania 15222

NOTICE OF SHIPMENT

Industrial Marketing
Pittsburgh Product Support

cc: Mr. Carlos Springfield
Mr. Bill Claudio
Mr. Melvin Olson 4.5
F. E. Schlott
L. A. Beyer
Lab. No. PD-1511

Purchase Order Number	Requisition Number	Shop Order Number	Date	Report Number
			July 22, 1980	213

SOLD TO: Chief, Freight Traffic N.A.S.A.
Building M-7-6744
3rd Street & Avenue C
Kennedy Space Center, Florida 32899

SHIPPED
From: Garber Research Center
To: Same
Via: Ryder Truck Lines
XX Prepaid / Collect
Car Number and Initials:

QUANTITY	DESCRIPTION	UNIT PRICE	AMOUNT
4	Tufshot Gun Mix, gunned test launch pad samples		
	(2 Pcs. gunned into hexmesh)		
	(2 Pcs. gunned over 2A-3½ 310 SS anchors using 3.25% type 310 SS melt extracted fibers)		
	Shipped on four low-pallet boxes.		
	Net Weight: 12800		
	Gross weight: 13600		
	Shipped per instructions from Mr. F. E. Schlott		
	PERKINS (Receiving KSC) 7332.		

Phone (419) 334-2658

46

THE WAHL REFRACTORY PRODUCTS COMPANY
P. O. Box 430, Green Springs Road, Fremont, Ohio 43420

January 7, 1981

Mr. Mel Olsen
J.F.
Kennedy Space Center, Fla. 32899
DD-MED-1

Dear Mr. Olsen:

The following information concerns our telephone conversation of January 7, 1981.

Panel #	Constituent
WRP 1 Color-White	PSM Cast H_2O Fiber
WRP 2 Color-Gray	Cement Fondu Parry Sand H_2O Fiber
WRP 3 Color-Gray	Cement Fondu 50m Ball Mill Calcined Flint Clay 3/F Flint Clay H_2O Fiber

If you have any questions concerning this information, please don't hesitate to let me know.

Sincerely,

WAHL REFRACTORY PRODUCTS COMPANY

Daniel H. Lease

SENT COPY TO [illegible]
1-14-81

CASTABLES PLASTICS MORTARS REFRACTORY ENGINEERING

ORIGINAL INVOICE

TELEPHONE
(419) 334-2658

WRP COMPANY

the WAHL refractory products company

HIGH TEMPERATURE CEMENTS — PLASTIC FIRE BRICK

767 S. R. 19 South — P. O. Box 430 — Fremont, Ohio 43420

47

SOLD TO:
NASA
Chief, Freight Traffic
Bldg. M7-G744
3rd. St. & Ave. C.
Kennedy Space Center, Florida 32899

SHIP TO:
Same
Bldg. M7-G744
Att: Carlos Springfield
3Rd. St. & Ave. C.
Kennedy Space Center, Florida

ROUTE: Carolina - Prepaid

INVOICE NO. 863 - A

ORDER NO.	REQUISITION NO.	DATE SHIPPED		FROM	DATE
de TG-FLD-22		2-12-80	F.O.B.-Fremont, O	Fremont, O	2-12-80

DESCRIPTION		QUANTITY	UNIT PRICE	AMOUNT
	TERMS:			
3	Test Panels (approx. 190# ea.)	570#	TEST	NO CHARGE
		1 Pallet		

RECEIPT OF SHIPMENT RECORD

MODE	CARRIER	CARRIER PRO NO.	GBL	PCS	WEIGHT	MISC	DATE
T	KCF	P047-0350116		1	570		2-21-80

DATE REC'D	CONTRACT NUMBER	PR NUMBER	NAME OF SHIPPER	STATE	LOCATION
0052			WAHL REFRACTOR.	OH	DIRECT

TIME UNLOADING STARTED: 1110
TIME UNLOADING COMPLETED: 1130
DATE/TIME INTO QA:
DATE/TIME OUT OF QA:

DIRECT DELIVERY: O&C
M/F: RM/1318
CARLOS SPRINGFIELD

WEATHER:
COMMODITY:
VEHICLE:
INSPECTED BY: J. T. Williams (Fold Here)

REMARKS/TALLY RECORD

HAND RECEIPT
REC'D BY: J. D. Morman
DATE: 2-21-80 TIME: 1:30

KSC FORM 7-204A NS (REV. 8/77) DOCUMENT CENTER/FREIGHT TRAFFIC

APPENDIX B. MTS-505-81, STS-2

NASA
MATERIALS TESTING SECTION
MATERIALS ANALYSIS BRANCH
FLUIDS AND ANALYSIS DIVISION
TG-FLD-22, ROOM 1218, O&C BUILDING
KENNEDY SPACE CENTER, FLORIDA 32899
MARCH 1, 1982

MTS 505-81

SUBJECT: Exposure Test of Refractory Concrete Test Panels to Solid Rocket Booster (SRB) Exhaust During STS-2 Launch

RELATED DOCUMENTATION: MMA-1918-80, July 29, 1981

1.0 FOREWORD

1.1 On 3 September, 1981, Gary Kurtz, PRC-1217, requested testing of refractory concrete test panels, the testing to comprise thickness measurements, color photographs, and visual observations both before and after exposure to SRB exhaust during the launch of STS-2.

1.2 This test is a continuation of the testing reported in MMA 1918-80, dated July 29, 1981. The test panels provided by vendors and the test fixtures are described in that report, which covers the exposure of 6 panels to SRB exhaust during STS-1.

2.0 TEST PROCEDURES

2.1 TEST PANEL SELECTION AND IDENTIFICATION

In Test Report MMA 1918-80 a second exposure of the initial panels to the SRB exhaust was recommended, with the east-to-west positions of the panels changed from 1, 2, 3 - 4, 5, 6 to 4, 5, 6 - 1, 2, 3. It was also recommended that reference plates with a known thickness of ablative coating be embedded flush with the surface of the ablative coating applied to the racks. This was intended to permit assessment of the relative severity of exposure for each panel. At the request of the vendor, Wahl Refractory Products Company, test panel 1 was removed from the test. It contained chopped stainless steel wire which increased its cost with no apparent improvement in performance. This panel was replaced by a previous unexposed panel. The panels selected with their east-to-west exposure positions are as follows:

Exposure Position East-to-West	Panel NO.	
1	4	Wahl (WRP-3), Contained carbon steel wire
2	5	Harbison-Walker Tufshot, Contained "fibers" (310 ss)
3	6	Harbison-Walker Tufshot.
4	7	Wahl (WRP-2) (Previously unexposed)
5	2	Designed Concretes, Fondu Fyre WA-1
6	3	Designed Concretes, Fondu Fyre WA-1 w/Wire

2.2 PRE-EXPOSURE THICKNESS DETERMINATIONS

The 6 panels were placed on inspection racks which afforded access to both top and bottom surfaces, and thickness at each of the predetermined points was measured, using the template and caliper employed in previous measurements. Photographs of each previously exposed panel, made at that time, appear in MMA-1918-80. Figure 10 shows panel 7 before exposure.

2.3 SRB EXHAUST EXPOSURE

The panels were then installed in the two refractory test frames (DWG 79K09546) at the bottom of the SRB flame deflector in the north end of the flame trench at LC39A. Each frame holds three panels. The holddown clamps and the areas between panels were coated with Dynatherm E-320 ablative coating. The panels were installed in the positions indicated in paragraph 2.1. Reference panels were embedded flush with the surface of the ablative coating in areas between test panels. The panels were then exposed to SRB exhaust during STS-2 launch.

2.4 POST-EXPOSURE THICKNESS DETERMINATIONS

After launch, the panels were examined and photographed. It was observed that the steel reinforcing grid of test panel 6 in position 3 was completely exposed. Later, when photographs were being made, it was found that position 3 was empty (see photograph, Figure 9). It is conjectured that the remaining portions of panel 6 may have been considered loose debris by the cleanup crew and removed inadvertently during cleanup of the flame trench. It was also observed that none of the reference plates remained in place after the launch.

The panels were then removed from the test frames and transported to the inspection racks, where the same template and caliper were used to make thickness determinations. The depths of representative spalled areas were determined, using a depth gage provided with a dial indicator and a tip with a radius of about 1/8 inch.

3.0 RESULTS

Figures 1 through 12 show the individual panels in the test frames after launch, and on inspection racks after launch, as well as panel 7 as received. Figures 13 through 17 show individual thickness measurements before and after STS-1 and STS-2 launches, and the thickness losses at each location.

Table 1 shows the average thickness losses and observations of surface conditions after launch.

3.1 All surviving previously-exposed panels showed surprisingly lower losses during their second exposure than during their first. Indeed, in a number of locations, there was an actual increase in thickness during STS-2 launch. This is attributed to exhaust residue buildup. Tests performed after STS-1 launch indicated that material on the surfaces of panels after exposure was probably SRB exhaust product. This work was not completed before the publication of MMA 1918-80. A report of the analysis is therefore included in this report as Appendix 1.

3.2 Panel 7, which was exposed for the first time during STS-2 launch, was in the worst condition of the panels surviving this launch. One corner was badly damaged, and large, deep pits covered a large part of its surface. Nevertheless, thickness measurements in some predetermined locations showed losses comparable to those of the other panels during their first exposure.

4.0 CONCLUSIONS

4.1 The effect of previous launch exposure and differences in launch conditions could be factors in causing the difference in material losses during the first and second launch. For example, about four times as much water was consumed during the second launch as during the first launch because of changes in the sound suppression system.

4.2 Reference panels for exposure severity assessment must be securely fastened. Panels embedded in ablative coating as the only securing means will not survive a launch.

4.3 Panel 7 is badly deteriorated, and further exposure is not warranted.

4.4 The following panels are now on hand:

Panel No.	Number of Launch Exposures	Description
1	1 (STS-1)	Wahl WRP-1. Contained "fibers" (stainless steel wire)
2	2	Designed Concretes, Fondu Fyre WA-1
3	2	Designed Concretes, Fondu Fyre WA-1 w/Wire
4	2	Wahl WRP-3. Contained carbon steel wire
5	2	Harbison-Walker Tufshot. Contained "fibers" (310 ss)
7	1 (STS-2)	Wahl WRP-2
Undesignated	0	Designed Concretes, Fondu Fyre WA-1 (same as Panel 2)
"	0	Designed Concretes, Fondu Fyre FSC-5
"	0	Harbison-Walker Tufshot (same as Panel 6)
"	0	Harbison-Walker Tufshot with "fibers" (310 ss) (same as Panel 5)

5.0 RECOMMENDATIONS

5.1 Six panels from the above list should be selected for exposure to STS-3 launch exhaust. Panel 7 should not be considered.

5.2 If time permits, a method of securing reference panels for assessing severity of exposure should be devised.

INVESTIGATOR: CV Moyers
C. V. MOYERS

APPROVED: C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MTS, NASA

TABLE 1

CONDITION OF PANELS AFTER STS-2 LAUNCH

Panel No.	Average Thickness Loss, Inches	Observations
2	0.087	Coated with residue, cracks healed, pits to 0.311" deep, generally uniform appearance.
3	0.073	Coated with residue, cracks healed, pits to 0.201" deep, generally uniform appearance.
4	0.003	Coated with residue, few pits to 0.278" deep, generally uniform appearance.
5	0.063	Heavy coating of residue, but many uncoated irregular pits to 0.656" deep. Cracks healed in places, mostly open.
6	---	Steel grid completely exposed after launch. Remains of panel not recovered.
7	0.259	Severely eroded, pits to > 1.00" deep.

MTS-505-81

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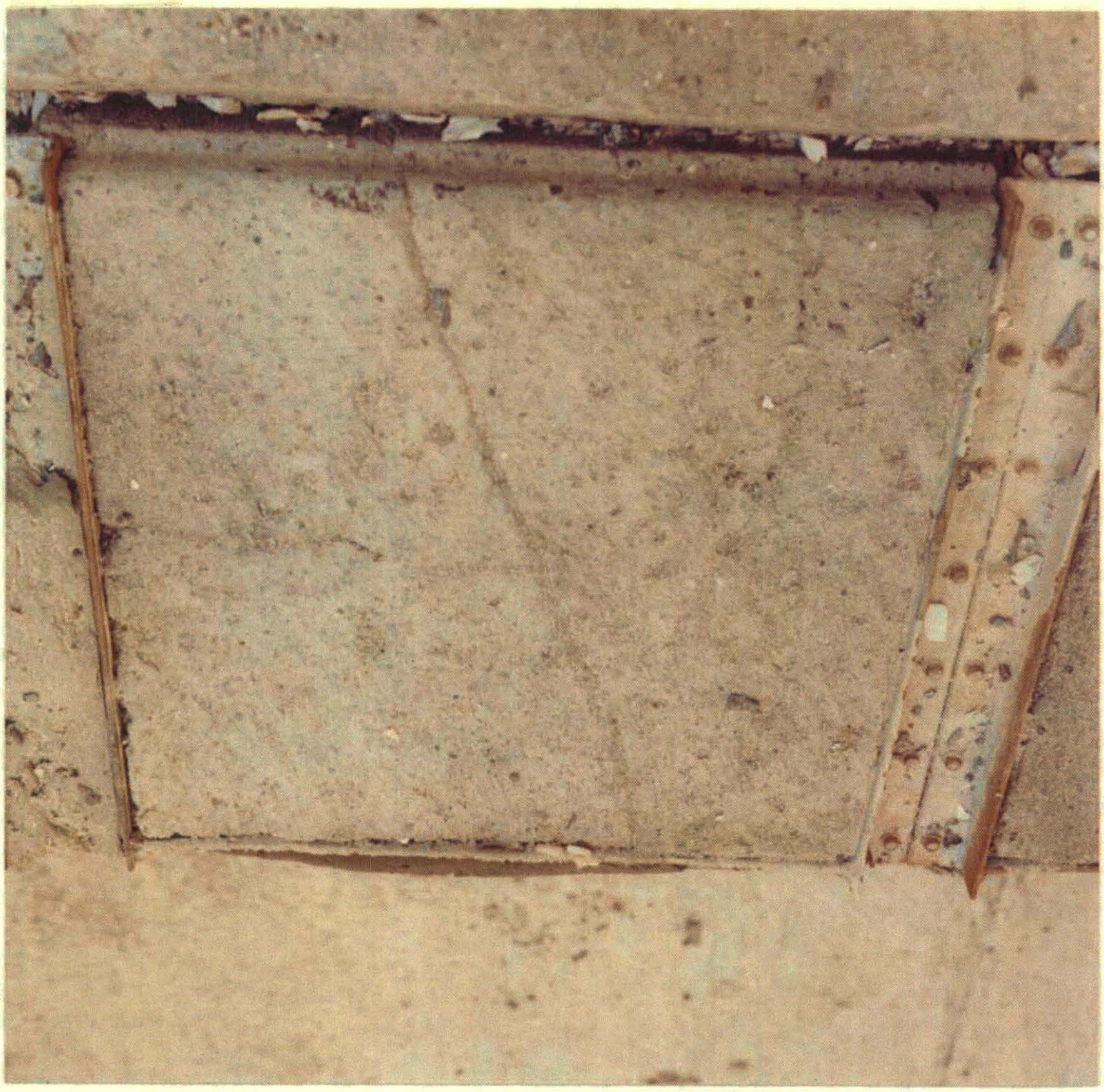

FIGURE 1

PANEL 2 IN TEST FRAME, POSITION 5, AFTER STS-2 LAUNCH. DESIGNED CONCRETES FONDU FYRE WA-1.

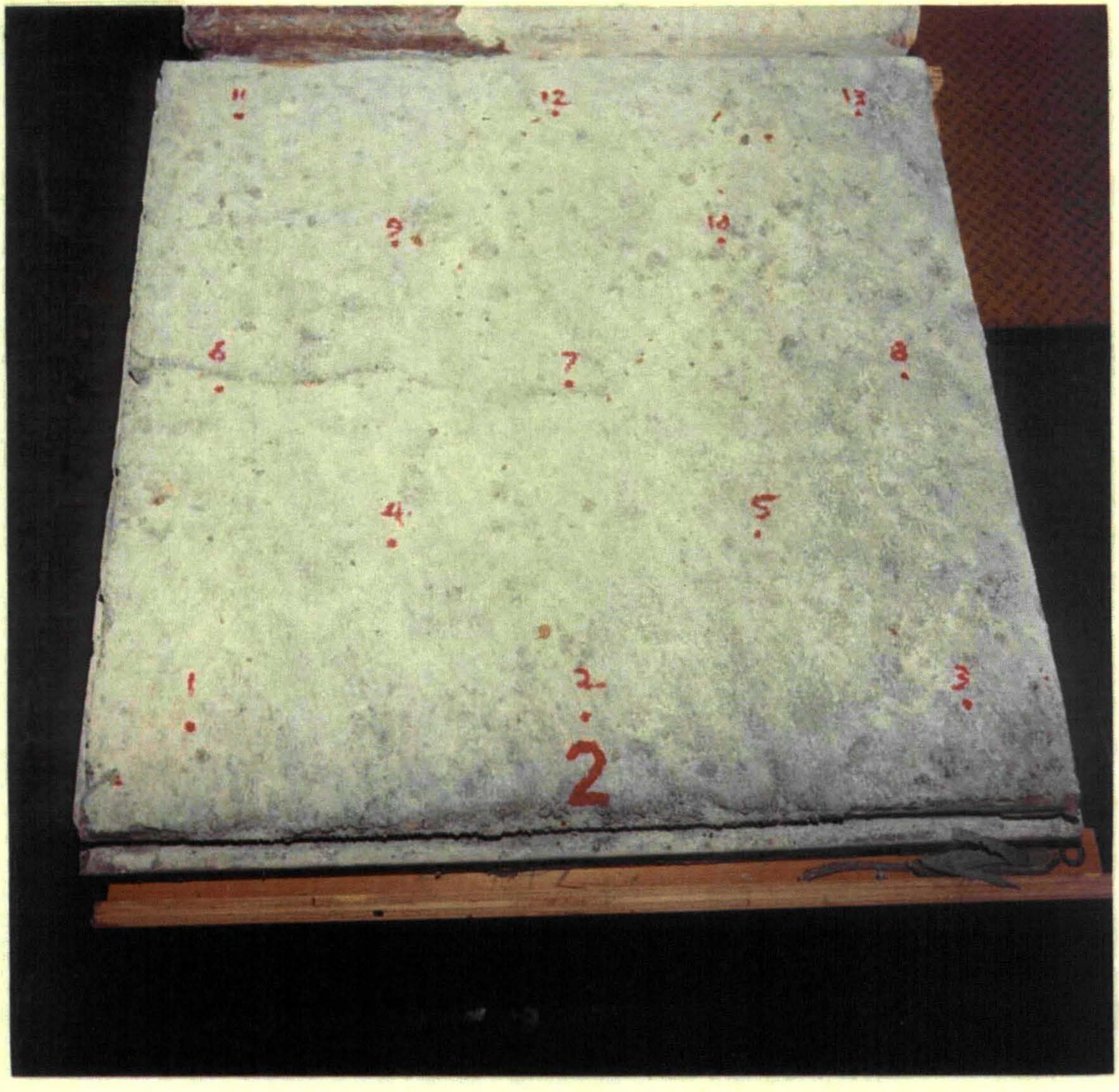

FIGURE 2
PANEL 2 IN INSPECTION RACK AFTER STS-2 LAUNCH

FIGURE 3

PANEL 3 IN TEST FRAME, POSITION 6, AFTER STS-2 LAUNCH

DESIGNED CONCRETES FONDU FYRE WA-1, W/WIRE

MTS-505-81 11

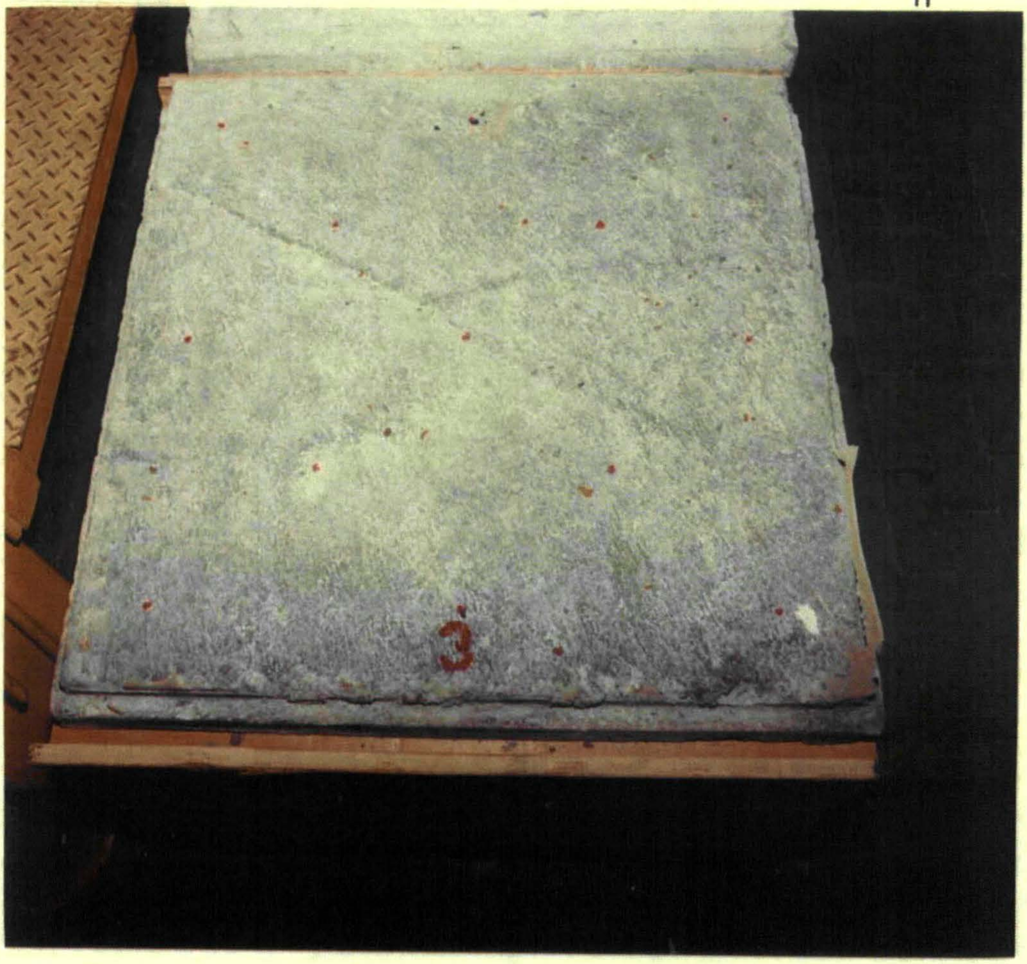

FIGURE 4
PANEL 3 IN INSPECTION RACK AFTER STS-2 LAUNCH

MTS-505-81

12

FIGURE 5

PANEL 4 IN TEST FRAME, POSITION 1, AFTER STS-2 LAUNCH

WAHL WRP-3 WITH CARBON STEEL WIRE.

MTS-505-81

13

FIGURE 6

PANEL 4 IN INSPECTION RACK AFTER STS-2 LAUNCH.

MTS-505-81

14

FIGURE 7

PANEL 5 IN TEST FRAME, POSITION 2, AFTER STS-2 LAUNCH.
HARBISON-WALKER TUFSHOT WITH "FIBERS" (310SS)

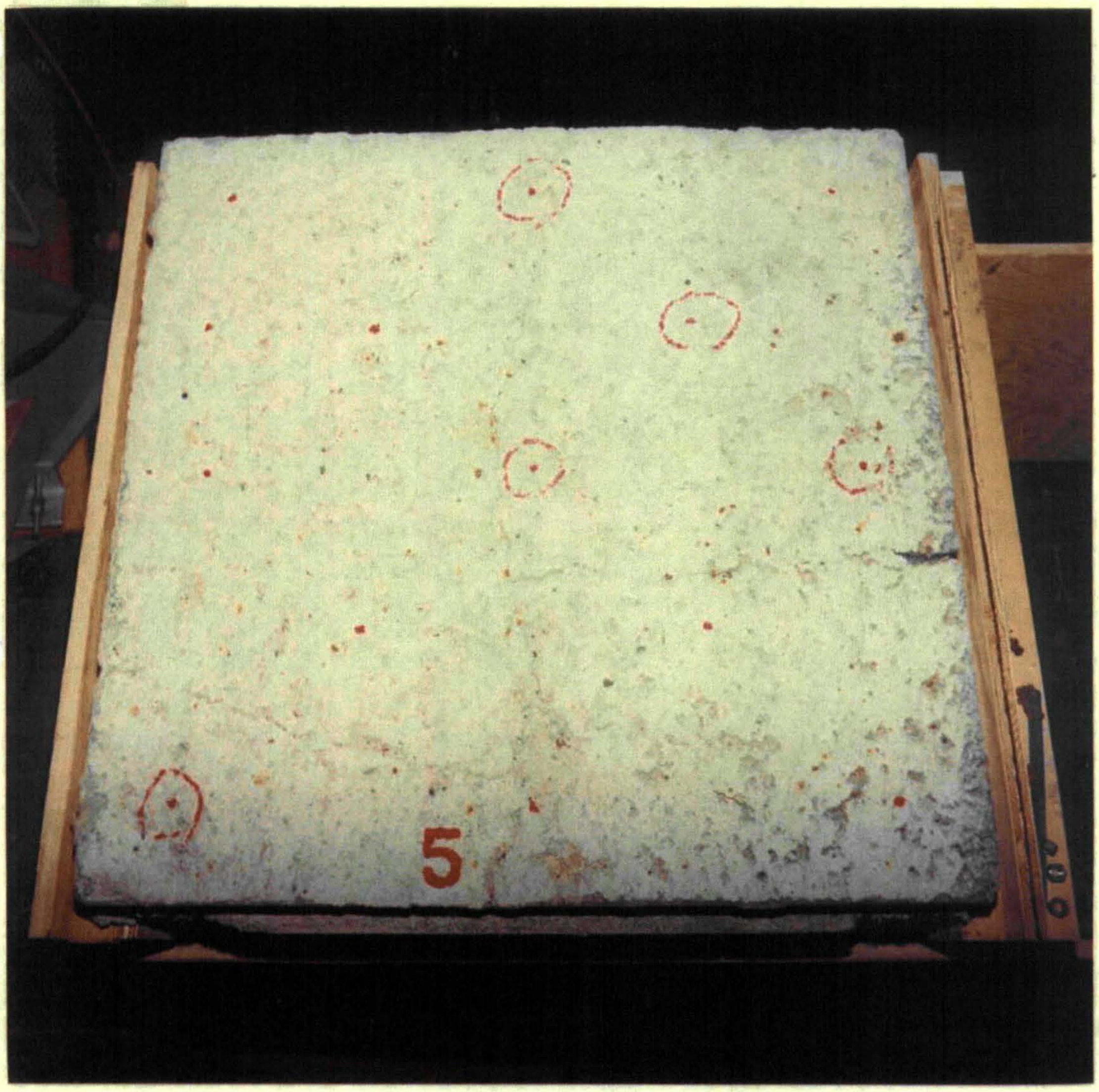

FIGURE 8

PANEL 5 IN INSPECTION RACK AFTER STS-2 LAUNCH

MTS-505-81

16

FIGURE 9

TEST FRAME, POSITION 3, AFTER STS-2 LAUNCH. THE REMAINS OF PANEL 6, HARBISON-WALKER TUFSHOT, HAD BEEN REMOVED BEFORE PANEL RETRIEVAL.

MTS-505-81

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FIGURE 10

PANEL 7, WAHL WRP-2, BEFORE EXPOSURE TO STS-2 LAUNCH

MTS-505-81

18

FIGURE 11

PANEL 7 IN TEST FRAME, POSITION 4, AFTER STS-2 LAUNCH

MTS-505-81

19

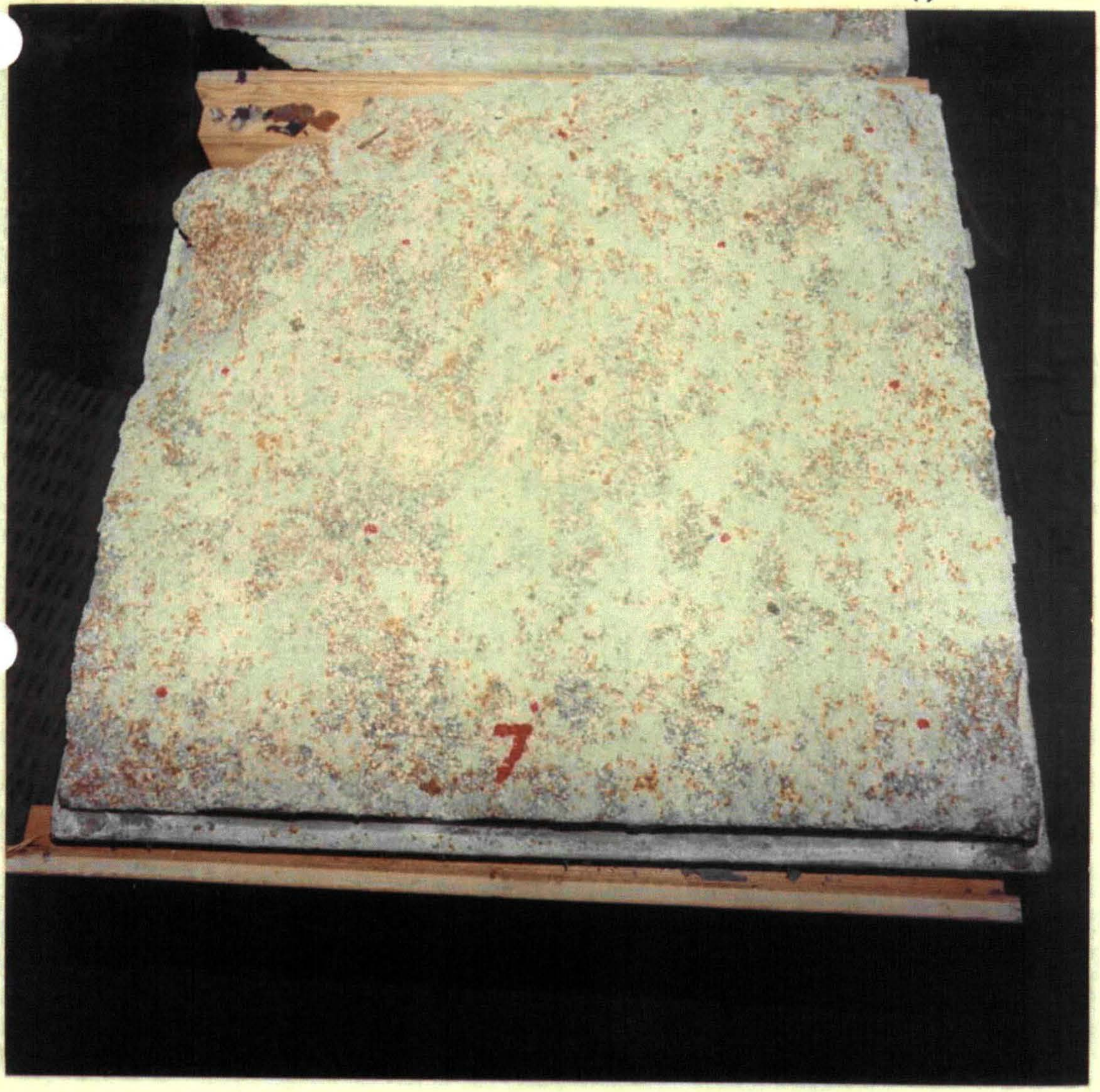


FIGURE 12
PANEL 7 IN INSPECTION RACK AFTER STS-2 LAUNCH

MTS-505-81

Point	STS-1	STS-2
11	4.105	3.920
	3.920	3.828
	0.185	0.092
12	4.120	3.910
	3.910	3.808
	0.210	0.102
13	4.135	3.920
	3.920	3.833
	0.215	0.087
9	4.090	3.850
	3.850	3.748
	0.240	0.102
10	4.100	3.780
	3.780	3.728
	0.320	0.052
6	4.145	3.850
	3.850	3.728
	0.295	0.122
7	4.090	3.820
	3.820	3.693
	0.270	0.127
8	4.120	3.800
	3.800	3.788
	0.320	0.012
4	4.100	3.840
	3.840	3.778
	0.260	0.062
5	4.106	3.860
	3.860	3.748
	0.246	0.112
1	4.166	3.940
	3.940	3.868
	0.226	0.072
2	4.120	3.860
	3.860	3.798
	0.260	0.062
3	4.175	3.900
	3.900	3.768
	0.275	0.132

AVERAGE THICKNESS LOSS

STS-1	0.256
STS-2	0.087
TOTAL	0.343

FIGURE 13

THICKNESS MEASUREMENTS, PANEL 2, DESIGN CONCRETES FONDU FYRE WA-1

Location	STS-1	STS-2
11	4.045	3.790
	3.790	3.748
	0.255	0.042
12	4.125	3.850
	3.850	3.848
	0.275	0.002
13	4.090	3.860
	3.860	3.778
	0.230	0.082
9	4.065	3.760
	3.760	3.728
	0.305	0.032
10	4.100	3.770
	3.770	3.688
	0.330	0.082
6	4.040	3.710
	3.710	3.668
	0.330	0.042
7	4.055	3.700
	3.700	3.598
	0.355	0.102
8	4.115	3.650
	3.650	3.558
	0.465	0.092
4	4.030	3.680
	3.680	3.458
	0.350	0.222
5	4.030	3.690
	3.690	3.578
	0.340	0.112
1	4.080	3.780
	3.780	3.728
	0.300	0.052
2	4.045	3.700
	3.700	3.708
	0.345	-0.002
3	4.060	3.720
	3.720	3.628
	0.340	0.092

AVERAGE THICKNESS LOSS

STS-1	0.325
STS-2	0.073
TOTAL	0.398

FIGURE 14

THICKNESS MEASUREMENTS, PANEL 3, DESIGN CONCRETES FONDU FYRE WA-1 W/WIRE

Location 11

STS-1	STS-2
4.502	3.970
3.970	3.948
0.235	0.022

Location 12

STS-1	STS-2
4.135	3.960
3.960	3.938
0.175	0.022

Location 13

STS-1	STS-2
4.120	3,870
3.870	3.908
0.250	-0.038

Location 9

STS-1	STS-2
4.110	3.840
3.840	3.798
0.270	0.042

Location 10

STS-1	STS-2
4.155	3.840
3.840	3.858
0.315	-0.018

Location 6

STS-1	STS-2
4.140	3.900
3.900	3.798
0.240	0.102

Location 7

STS-1	STS-2
4.055	3.790
3.790	3.778
0.265	0.012

Location 8

STS-1	STS-2
4.175	3.970
3.970	4.010
0.205	-0.040

Location 4

STS-1	STS-2
4.145	3.890
3.890	3.898
0.255	-0.008

Location 5

STS-1	STS-2
4.205	3.990
3.990	4.018
0.215	-0.028

Location 1

STS-1	STS-2
4.190	3.980
3.980	3.978
0.210	0.002

Location 2

STS-1	STS-2
4.205	3.990
3.990	4.000
0.215	-0.010

Location 3

STS-1	STS-2
4.205	4.000
4.000	4.020
0.205	-0.020

AVERAGE THICKNESS LOSS

STS-1	0.235
STS-2	0.003
TOTAL	0.238

FIGURE 15

THICKNESS MEASUREMENTS, PANEL 4, WAHL WRP-3

Location 11

STS-1	STS-2
4.190	3.980
3.980	3.938
0.210	0.042

Location 12

STS-1	STS-2
4.255	4.050
4.050	3.990
0.205	0.060

Location 13

STS-1	STS-2
4.210	4.040
4.040	3.938
0.170	0.102

Location 9

STS-1	STS-2
4.180	3.950
3.950	3.898
0.230	0.050

Location 10

STS-1	STS-2
4.480	4.280
4.280	0.200
0.200	0.080

Location 6

STS-1	STS-2
4.250	4.010
4.010	3.918
0.240	0.092

Location 7

STS-1	STS-2
4.330	4.030
4.030	4.040
0.300	-0.010

Location 8

STS-1	STS-2
4.270	4.000
4.000	3.988
0.270	0.012

Location 4

STS-1	STS-2
4.155	3.910
3.910	3.868
0.245	0042

Location 5

STS-1	STS-2
4.330	4.080
4.080	3.928
0.250	0.152

Location 1

STS-1	STS-2
4.175	3.870
3.870	3.968
0.305	-0.098

Location 2

STS-1	STS-2
4.040	3.850
3.850	3.598
0.190	0.252

Location 3

STS-1	STS-2
4.225	3.950
3.950	3.908
0.275	0.042

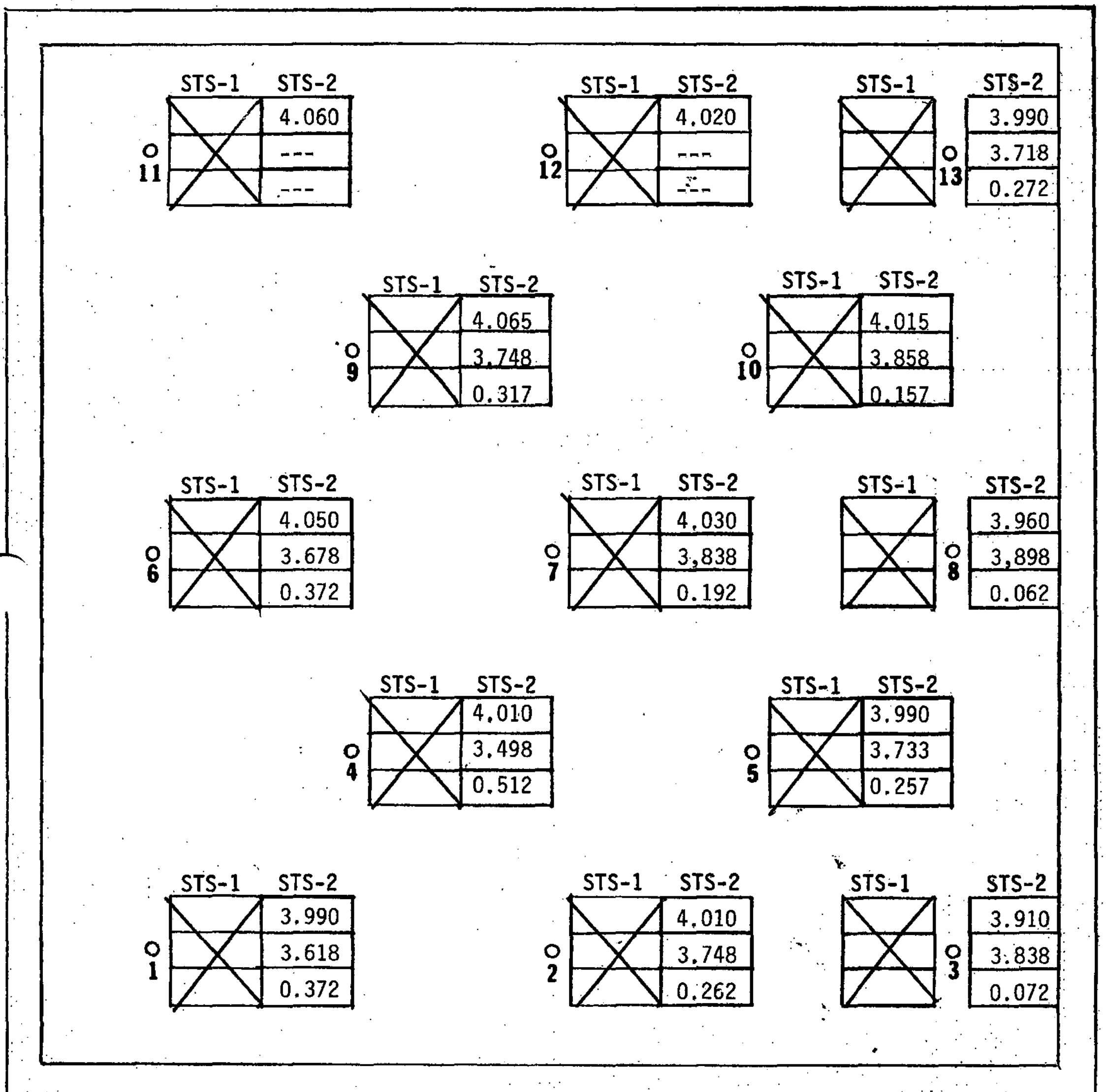
AVERAGE THICKNESS LOSS

STS-1	0.238
STS-2	0.063
TOTAL	0.301

FIGURE 16

THICKNESS MEASUREMENTS, PANEL 5, HARBISON-WALKER TUFSHOT WITH "FIBERS"

MTS-505-81



AVERAGE THICKNESS LOSS

STS-1 ---

S-2 0.259

TOTAL 0.259

FIGURE 17

THICKNESS MEASUREMENTS, PANEL 7, WAHL WRP-2

APPENDIX I

25

MICROCHEMICAL ANALYSIS SECTION
TG-FLD-21, Room 1274, O&C Building
NASA/KSC
Sept. 16, 1981

SUBJECT: Analysis of Refractory Concrete Test Panels

LABORATORY REQUEST NO: MAS-310-81

1.0 Foreword

1.1 Requester: C. V. Moyers/NASA/TG-FLD-22 (867-4614)

1.2 Requester's Sample Description: Material removed from refractory concrete test panels after exposure to SRB Exhaust During STS-1 Launch. Panel 1 - Surface layer and base material. Panel 2 - Fused material and base material.

1.3 Requested: Are blackened surface and fused material refractory concrete or SRB exhaust products?

2.0 Chemical Analysis and Results

2.1 The samples were analyzed by X-ray fluorescence spectrometry for qualitative elemental composition and by X-ray powder diffractometry for phase identification.

2.2 The results of both types of analysis are presented in Table I.

3.0 Conclusions

Alpha aluminum oxide (corundum), the phase known to be formed in solid rocket booster exhaust product, was found in both the blackened surface and the fused material, but not in either Panel 1 or 2 base material. It therefore appears likely that the blackened surface and fused material are SRB exhaust products and not refractory concrete.

Chemist: H. D. Bennett

Approved: J. F. Jones

TABLE I

Sample	X-Ray Fluorescence	X-Ray Diffraction
Panel 1 - Blackened Surface	Major Al, Ca Minor Fe, Ti Trace Zr, Zn, K, Cl, S, Si, Ni	alpha Aluminum Oxide, α- Al_2O_3 (Corundum)
Panel 1 - Base Material	Major Al, Ca, Ti Minor Fe, K, Si, Zn Trace Ni, S, Zr	Silicon Oxide, SiO_2 (Cristobalite) Aluminum Silicate, $3Al_2O_3 \cdot 2SiO_2$ (Mullite) Silicon Oxide, SiO_2 (Quartz) Calcium Carbonate, $CaCO_3$ (Aragonite) Aluminum Oxide Hydrate, $Al_2O_3 \cdot 3H_2O$ (Gibbsite)
Panel 2 - Fused Material, Downstream Edge	Major Al, Ca, Ti, Fe Minor Zn, K, Si Trace Ni, Cl, S	alpha Aluminum Oxide, α - Al_2O_3 (Corundum)
Panel 2 - Base Material	Major Ca, Ti, Fe Minor K, Si Trace Zn, S, Cl, Ni, Zr	Titanium oxide, TiO_2 (Rutile) Iron (II, III) Oxide, Fe_3O_4 (Magnetite) Calcium Magnesium meta Silicate, $CaMg(SiO_3)_2$, (Diopside) Additional unidentified phases, probably silicates

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TG-FLD-2	1
TG-FLD-22	ALL THAT ARE LEFT

TASK REQUEST

1. DATE SUBMITTED	2. DESIRED COMPLETION DATE	3. AUTHORIZING DOCUMENT
3 Sept 81	One Month after Launch of STS-2	

SAMPLE DESCRIPTION:

Refractory Concrete Test Samples:

1. Design Concrete Company
   (a) Fondu Fyre WA-1 (Approved for Saturn) - 2 Test Samples
   (b) Fondu Fyre WA-1 (Experimental) - 2 Test Samples
2. Wahl Refractory Products Company
   (a) H. T. Bond Mortar (Experimental) - 3 Test Samples
3. Harbison-Walker Refractories
   (a) Refractory Concrete -------------- 2 Test Samples
   (b) Refractory Concrete (Stainless Steel Fibers) - 2 Test Samples

5. SYSTEM REMOVED FROM/OR USED IN:

Samples for test - Refractory Concrete

Location to be SRB Flame Deflector, 79K09546.

6. ANALYSIS REQUESTED:

SEE "REFRACTORY MATERIALS TEST PLAN" - attached
The materials are on hand. Six panels are to be exposed to SRB Exhaust during STS-2. Testing is to be initiated by taking thickness measurements and color photographs of the initial condition of the surfaces.

After exposure to SRB exhaust during STS-2, the samples are to be removed and returned to the laboratory for further thickness measurements and a determination of surface erosion. The final surface condition such as spalling will be recorded and color photographs taken for comparison with initial surface conditions.

An evaluation of performance and acceptance or rejection recommendations will be made by formal report.

7. REMARKS:

8. REQUESTER:	9. PHONE:	10. COMPANY:	11. MAIL CODE:
G. KURTZ, PRC 1217 Gary Kurtz	867-3407	PRC	PRC-1217
12. NASA APPROVAL: R. J. Davis for M. Olsen R. J. DAVIS	13. PHONE: 867-7584	14. MAIL CODE: DD-MED-33	15. DATE: 9-3-81

FOR LAB USE ONLY

INVESTIGATOR	TASK NUMBER	SAMPLE NUMBER
Moyers	MTS 505-81	

KSC FORM 22-81 (REV. 1/70)

REFRACTORY CONCRETE MATERIALS TEST PLAN

I. MATERIALS FOR TESTING (KSC-SPEC-P-0012)

1. Design Concretes Company

a. Fondu Fyre WA-1* - 2 Test Samples
b. Fondu Fyre WA-1 (Experimental) - 2 Test Samples
Delivery date July 21, 1980

* Approved for Saturn

2. Wahl Refractory Products Company

a. H.T. Bond Mortar (Experimental) - 3 Test Samples

The 3 test samples are at KSC.
The vendor delivered them on Feb. 12, 1980
They are stored by TG-FLD-22.

3. Harbison - Walker Refractories

a. Refractory Concrete - 2 Test Samples
b. Refractory Concrete - 2 Test Samples (Stainless Steel Fibers)
Delivery Date June 20, 1980

LETED 4. North American Refractories Company

a. Narco Cast 60 - 2 Test Samples
b. Narco Tab - 2 Test Samples
Delivery date Aug. 1, 1980

II. TEST SAMPLE DELIVERY, HANDLING AND STORAGE

The refractory concrete test samples as specified in KSC-SPEC-P-0012, Figure 1 are massive and require special handling. They weigh approximately 200 lbs. each and are 2 Ft-4 in. square and 4 inches thick. Vendors have been instructed to deliver their samples in crates on pallets, marked as specified in paragraph 5.4 of specification KSC-SPEC-P-0012.

In addition, each vendor has been instructed to send copies of shipping notices to M. G. Olsen, DD-MED-1, C. L. Springfield, TG-FLD-22, and W. Clautice, PRC-1217 to alert them of the date shipped. Freight Traffic, Sam Clymer (867-32[illegible]) has been requested to notify Carlos Springfield, TG-FLD-22 (867-4614) when test samples are received so that he can direct them to a special storage area maintained by the laboratory.

Each vendor has been give the following address for shipment of samples:

Chief, Freight Traffic, NASA
Bldg. M7-6744
3rd St. and Avenue C
Kennedy Space Center, FL 32899
ATTN: Carlos Springfield, TG-FLD-22

III. INSTALLATION AND REMOVAL OF TEST SAMPLES

TG-SMD-1 (Wayne Parris/Bob Laakso) will initiate and manage the Support Request to BSI for the handling, installation, and removal of the refractory concrete test samples in the existing SRB flame deflector test fixtures. A PCN will be issued to accommodate charges. BSI is to provide all services necessary. Bolt heads and seams are to be covered with ablative coating (Dow Corning Q3-6077) as specified in Dwg. 79K09546 Sheets 1 and 2, attached.

After the launch the samples are to be removed and transported to an area designated by the laboratory, TG-SMD-1, Carlos Springfield, 867-4614. Prior to removal of samples contact Carlos Springfield. Photographs are to be taken of the samples prior to their removal.

IV. SPECIMEN ORIENTATION

The test fixture on the SRB flame deflector, DWG 79K09546 will accommodate six specimen samples. The number of samples to be submitted are ~~15~~.11 Therefore, 3 launches will be required before the testing of all samples is accomplished.

A pattern of testing orientation in the test fixtures is as follows:

Wahl HT Bond Mortar	Fondu Fire WA-1 *	~~WAHT (EXP)~~ Wahl	Fondu Fyre ~~Narco 60~~ WA-1 (EXP)	H/W	H/W + S.S.

* Approved for Saturn

LAUNCH NO. 1

H/W	Fondu Fyre WA-1 (EXP)	~~Narco 60~~	~~Narco TAB~~	Fondu Fyre WA-1 *	~~Wahl HT Bond Mortar~~

*Approved for Saturn

LAUNCH NO. 2

Wahl HT Bond Mortar	Narco TAB	H/W + S.S.			

LAUNCH NO. 3

V. LABORATORY MEASUREMENTS OF TEST SAMPLES

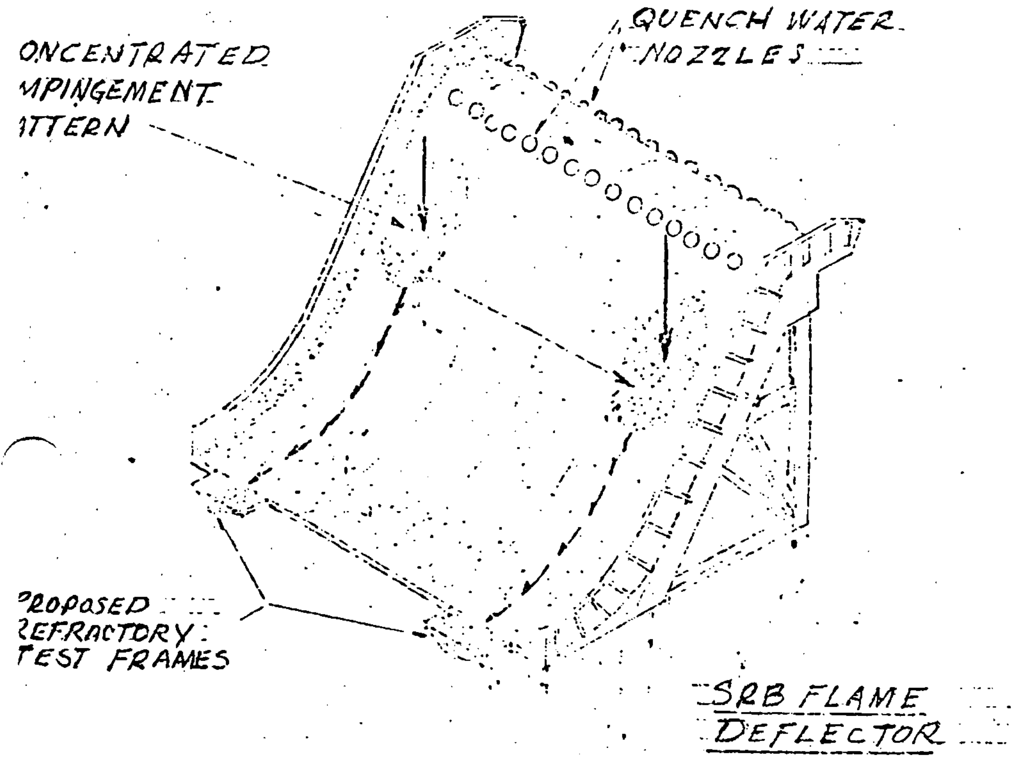
All samples are to be tested and evaluated in accordance with KSC-SPEC-P-0012.

Prior to installation, each test sample will be measured for an a-curate determination of thickness using a template and a dial gage indicator mounted on a flat level table or surface. TG-FLD-22 to determine and perform the measurements. Each test sample will be photographed to record their surface condition and texture prior to testing and other conditions determined as deemed necessary.

After the launch test, the specimens will be returned to the same area where initial measurements were made. The thickness will be remeasured using the same techniques to determine the loss of thickness due to general surface erosion. Any damage or local spalling or cracking will be noted and recorded. Each specimen will be photographed with close-up shots of special conditions.

The laboratory, TG-FLD-22, will evaluate the relative performance of the test samples based upon their findings in accordance with KSC-SPEC-P-0012.

REFRACTORY TEST FIXTURE



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SF-ENG/ROBERT MILLER	1
SF-ENG-3/R. GILLETT	1
TG-FLD-2	1
TG-FLD-22	ALL THAT ARE LEFT

APPENDIX C. MTS-142-82, STS-3

NASA
MATERIALS TESTING SECTION
MATERIALS ANALYSIS BRANCH
FLUIDS AND ANALYSIS DIVISION
TG-FLD-22, ROOM 1218, O&C BUILDING
KENNEDY SPACE CENTER, FLORIDA 32899
MAY 6, 1982

MTS-142-82

SUBJECT: Exposure Test of Refractory Concrete Test Panels to Solid Rocket Booster (SRB) Exhaust During STS-3 Launch

RELATED DOCUMENTATION: MMA-1918-80, July 29, 1981
MTS-505-81, March 1, 1982

1.0 FOREWORD

1.1 On 1 March, 1982, M. G. Olsen, DD-MED-1, requested testing of refractory concrete test panels, the testing to comprise thickness measurements, color photographs, and visual observations both before and after exposure to SRB exhaust during the launch of STS-3.

1.2 This test is a continuation of the testing reported in MMA 1918-80, dated July 29, 1981, and MTS-505-81, dated March 1, 1982. The test panels provided by vendors and the test fixtures are described in MMA 1918-80, which covers the exposure of 6 panels to SRB exhaust during STS-1. Exposure of test panels during STS-2 launch is described in MTS-505-81.

2.0 TEST PROCEDURES

2.1 TEST PANEL SELECTION AND IDENTIFICATION

Starting with this test, the positions of the panels in the flame trench are designated as A, B, C, D, E, and F, from east to west in alphabetical order. Of the panels exposed during STS-2 launch, panel 6 did not survive the launch, and panel 7 was considered too badly deteriorated for further testing. The other four panels were selected for reexposure during STS-3 launch. For the other two spaces, panel 1, which had been exposed to STS-1 launch, and a previously unexposed panel, designated panel 8, were selected. The six panels with their exposure positions are as follows:

Exposure Position East-to-West	Panel NO.	
A	8	Designed Concretes, Fondu Fyre FSC-5
B	3	Designed Concretes, Fondu Fyre WA-1 w/Wire
C	2	Designed Concretes, Fondu Fyre WA-1
D	1	Wahl (WRP-1), contained "fibers" (stainless steel wire)
E	4	Wahl (WRP-3), contained carbon steel wire
F	5	Harbison-Walker Tufshot, contained "fibers" (310 ss)

2.2 PREEXPOSURE THICKNESS DETERMINATIONS

Panel 8 was placed on an inspection rack which afforded access to both top and bottom surfaces, and thickness at each of the predetermined points was measured, using the template and caliper employed in previous measurements. Photographs of each previously exposed panel, made after the last exposure, appear in MTS-505-81 and MMA-1918-80. Figure 1 shows panel 8 before exposure.

2.3 SRB EXHAUST EXPOSURE

The panels were then installed in the two refractory test frames (DWG 79K09546) at the bottom of the SRB flame deflector in the north end of the flame trench at LC39A. Each frame holds three panels. The holddown clamps and the areas between panels were coated with Dynatherm E-320 ablative coating. The panels were installed in the positions indicated in paragraph 2.1, and were then exposed to SRB exhaust during STS-3 launch.

2.4 POST-EXPOSURE INSPECTION

2.4.1 After STS-3 launch, it was found that five of the six panels were gone, along with the frames and many of the bolts. Two reinforcing grids, with fragments of concrete adhering, were found hanging on the perimeter fence to the north of the pad. Frames, ablative coating, reinforcing grids, and some refractory concrete fragments were found scattered both inside and outside the perimeter road.

2.4.2 The surviving panel, Number 1 in position D, was removed from the test frame and transported to the inspection rack, where the same template and caliper were used to make thickness determinations. The depths of representative spalled areas were determined, using a depth gage provided with a dial indicator and a tip with a radius of about 1/8 inch.

3.0 RESULTS

3.1 Figure 2 shows panel 1 after launch, and Figures 3 through 8 show the condition of the test frames and sample frames after launch.

3.2 Panel 1 was dark in color, with scattered light colored patches, apparently the result of shallow spalling which removed the darker surface layer. The deepest pit was 0.270" deep. The average thickness loss during this launch was 0.155 inches. Figure 9 shows individual thickness measurements before and after both STS-1 and STS-3 launches.

4.0 CONCLUSIONS

4.1 Only panel 1, Wahl WRP-1, survived the launch. The thickness loss and depth of pits were comparable to those experienced by this panel during the first launch.

4.2 Two factors which may have contributed to the bolt failures which resulted in the loss of sample frames and samples are inadequate cure of the ablative coating (Figure 8), and deterioration of the fasteners during the first two launches and intervening exposure to weather and pad operations.

4.3 Both contractor and government quality inspection will be requested for future sample installations. This should assure complete mixing and adequate application of the ablative coating.

4.4 The sample frames have been redesigned, using larger studs which can be replaced when necessary. The grip length has been shortened, reducing the bending moments. This should provide a longer life and prevent sample loss.

4.5 Eleven panels were received for this investigation. Their present status is as follows:

Panel No.	Number of Launch Exposures	Description
1	2 (STS-1 & STS-3)	Wahl WRP-1. Contained "fibers" (stainless steel wire)
2*	3	Designed Concretes, Fondu Fyre WA-1
3*	3	Designed Concretes, Fondu Fyre WA-1 w/Wire
4*	3	Wahl WRP-3. Contained carbon steel wire
5*	3	Harbison-Walker Tufshot. Contained "fibers" (310 ss)

* Destroyed during STS-3 launch.
** Destroyed during STS-2 launch.

Panel No.	Number of Launch Exposures	Description
6**	2	Harbison-Walker Tufshot
7	1 (STS-2)	Wahl WRP-2 (no longer usable)
Undesig-nated	0	Designed Concretes, Fondu Fyre WA-1 (same as Panel 2)
8*	1 (STS-3)	Designed Concretes, Fondu Fyre FSC-5
Undesig-nated	0	Harbison-Walker Tufshot (same as Panel 6)
Undesig-nated	0	Harbison-Walker Tufshot with "fibers" (310 ss) (same as Panel 5)

* Destroyed during STS-3 launch.
** Destroyed during STS-2 launch.

INVESTIGATOR: Clyde V Moyers
CLYDE V. MOYERS

APPROVED: C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MTS NASA

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APPENDIX D. MTS-340-82, STS-1, -2, AND 3

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MATERIALS TESTING SECTION
MATERIALS ANALYSIS BRANCH
FLUIDS AND ANALYSIS DIVISION
TG-FLD-22, ROOM 1218, O&C BUILDING
KENNEDY SPACE CENTER, FLORIDA 32899
JUNE 7, 1982

MTS-340-82

SUBJECT: Exposure Tests of Refractory Concrete Test Panels to Solid Rocket Booster (SRB) Exhaust During the First Three STS Launches: Summary Report

RELATED DOCUMENTATION: MMA-1918-80, JULY 29, 1981
MTS-505-82, MARCH 1, 1982
MTS-142-82, MAY 6, 1982

1.0 FOREWORD

1.1 At the request of DD-MED-1, 6 refractory concrete test panels have been exposed to SRB exhaust during each of the first three STS-launches.

1.2 Panels were supplied by three vendors.

1.3 The purpose of the tests was to qualify additional suppliers of refractory concrete for use in flame trench refurbishment.

1.4 The three reports listed above in "Related Documentation" relate procedures and results of tests conducted during each of the three launches.

1.5 This report summarizes those tests and their results.

2.0 TEST PROCEDURE

2.1 The thickness of each panel was measured before and after each launch exposure at 13 locations determined by a template. The maximum depths of pits were also determined.

2.2 The panels were secured in test frames at the bottom of the flame deflector in the north end of the flame trench of Launch Complex 39A. Figure 1 shows the flame trench and test frames. Ablative coating was applied to the areas surrounding the panels. Figure 2 shows a test frame with panels installed.

3.0 TEST RESULTS

3.1 Table 1 summarizes test results for the three launches.

3.2 Figures 3 through 9 show test panels in the condition in which measurements were last made. The graphics in the corners of the photographs showing average thickness loss and pit depth are the same as those included in Table 1.

4.0 DISCUSSION OF RESULTS

4.1 For the panels exposed, differences in average thickness loss and maximum pit depth were small, with two exceptions. Wahl WRP-2, Panel 7, showed much greater overall loss than the others. Of the others, Harbison-Walker Tufshot with fibers, Panel 5, showed much greater pit depth.

4.2 Harbison-Walker Tufshot, Panel 6, did well in STS-1 exposure, but was destroyed during STS-2 exposure.

4.3 Four products have each been subjected to two launch exposures with comparably good performances for thickness loss and pit depth:

Designed Concretes Company WA-1
Designed Concretes Company WA-1 with wire
Wahl Refractory Products Company WRP-1
Wahl Refractory Products Company WRP-3

5.0 CONCLUSIONS

5.1 The four products listed in the paragraph above should be considered for further testing.

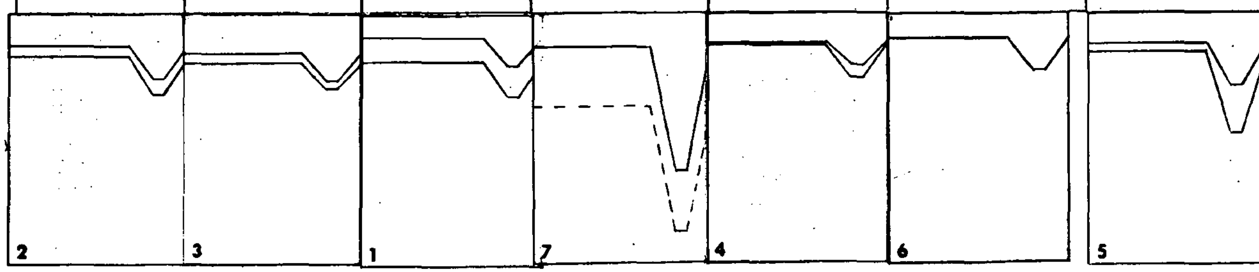
5.2 The two Harbison-Walker panels on hand (Tufshot and Tufshot with fibers) might be considered for testing.

INVESTIGATOR: C V Moyers
C. V. MOYERS

APPROVED: C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MTS, NASA

TABLE 1

	DESIGNED CONCRETES CO.		WAHL REFRACTORY PRODUCTS COMPANY			HARBISON-WALKER REFRACTORIES	
	FONDU-FYRE WA-1 PANEL 2	FONDU-FYRE WA-1 WITH WIRE PANEL 3	WRP-1 PANEL 1	WRP-2 - PANEL 7	WRP-3 - PANEL 4	TUFSHOT - PANEL 6	TUFSHOT WITH FIBERS PANEL 5
STS-1	AVG. LOSS 0.256 MAX PIT 0.258 CRACKED DURING INSTALLATION. NO ADVERSE EFFECTS.	AVG. LOSS 0.325 MAX PIT 0.214 CRACKED DURING LAUNCH. NO ADVERSE EFFECTS	AVG. LOSS 0.171 MAX PIT 0.222	NOT EXPOSED	AVG. LOSS 0.235 MAX PIT 0.174	AVG. LOSS 0.192 MAX PIT 0.258	AVG. LOSS 0.238 MAX PIT 0.346
STS-2	AVG. LOSS 0.087 CUMULATIVE 0.343 MAX PIT 0.311	AVG. LOSS 0.073 CUMULATIVE 0.398 MAX PIT 0.201	NOT EXPOSED	AVG. LOSS 0.257 MAX PIT >1.000 BADLY ERODED-WITHDRAWN FROM TEST.	AVG. LOSS 0.003 CUMULATIVE 0.238 MAX PIT 0.278	PANEL NOT RECOVERED	AVG LOSS 0.063 CUMULATIVE 0.301 MAX PIT 0.656 SOME DEEP PITS MAY BE ASSOCIATED WITH CRACKS.
STS-3	PANEL NOT RECOVERED.	PANEL NOT RECOVERED.	AVG. LOSS 0.208 CUMULATIVE 0.379 MAX PIT 0.270	NOT EXPOSED	PANEL NOT RECOVERED.	---	PANEL NOT RECOVERED.

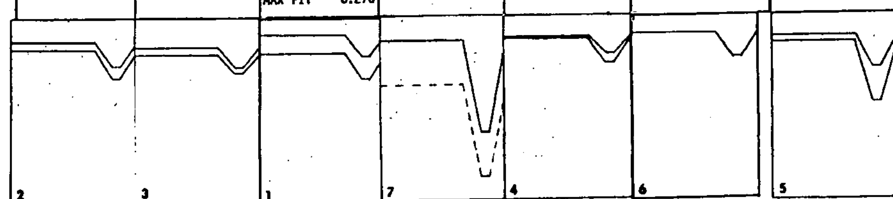


THE HORIZONTAL LINES ON THE GRAPHS REPRESENT AVERAGE PANEL THICKNESS AND THE RIGHT PORTION OF EACH GRAPH REPRESENTS MAX PITS DEPTH. THE TOP OF THE GRAPH REPRESENTS THE ORIGINAL PANEL SURFACE. VERTICAL DISTANCES ARE FULL SCALE.

FOR PANEL 7, THE SOLID LINE REPRESENTS THE VERAGE OF THE POINTS MEASURED. MANY POINTS WERE OUTSIDE THE RANGE OF THE MEASURING EQUIPMENT. THE BROKEN LINE IS ESTIMATED, BUT IS NEARER THE ACTUAL CONDITION.

TABLE 1

	DESIGNED CONCRETES CO.		WAHL REFRACTORY PRODUCTS COMPANY			HARBISON-WALKER REFRACTORIES	
	FONDU-FYRE WA-1 PANEL 2	FONDU-FYRE WA-1 WITH WIRE PANEL 3	WRP-1 PANEL 1	WRP-2 - PANEL 7	WRP-3 - PANEL 4	TUFSHOT - PANEL 6	TUFSHOT WITH FIBERS PANEL 5
STS-1	AVG. LOSS 0.256 MAX PIT 0.258 CRACKED DURING INSTALLATION. NO ADVERSE EFFECTS.	AVG. LOSS 0.325 MAX PIT 0.214 CRACKED DURING LAUNCH. NO ADVERSE EFFECTS.	AVG. LOSS 0.171 MAX PIT 0.222	NOT EXPOSED	AVG. LOSS 0.235 MAX PIT 0.174	AVG. LOSS 0.192 MAX PIT 0.258	AVG. LOSS 0.238 MAX PIT 0.346
STS-2	AVG. LOSS 0.087 CUMULATIVE 0.343 MAX PIT 0.311	AVG. LOSS 0.073 CUMULATIVE 0.398 MAX PIT 0.201	NOT EXPOSED	AVG. LOSS 0.257 MAX PIT >1.000 BADLY ERODED-WITHDRAWN FROM TEST.	AVG. LOSS 0.003 CUMULATIVE 0.238 MAX PIT 0.278	PANEL NOT RECOVERED	AVG LOSS 0.063 CUMULATIVE 0.301 MAX PIT 0.656 SOME DEEP PITS MAY BE ASSOCIATED WITH CRACKS.
STS-3	PANEL NOT RECOVERED.	PANEL NOT RECOVERED.	AVG. LOSS 0.208 CUMULATIVE 0.379 MAX PIT 0.270	NOT EXPOSED	PANEL NOT RECOVERED.	---	PANEL NOT RECOVERED.



THE HORIZONTAL LINES ON THE GRAPHS REPRESENT AVERAGE PANEL THICKNESS AND THE RIGHT PORTION OF EACH GRAPH REPRESENTS MAX PITS DEPTH. THE TOP OF THE GRAPH REPRESENTS THE ORIGINAL PANEL SURFACE. VERTICAL DISTANCES ARE FULL SCALE.

FOR PANEL 7, THE SOLID LINE REPRESENTS THE VERAGE OF THE POINTS MEASURED. MANY POINTS WERE OUTSIDE THE RANGE OF THE MEASURING EQUIPMENT. THE BROKEN LINE IS ESTIMATED, BUT IS NEARER THE ACTUAL CONDITION.

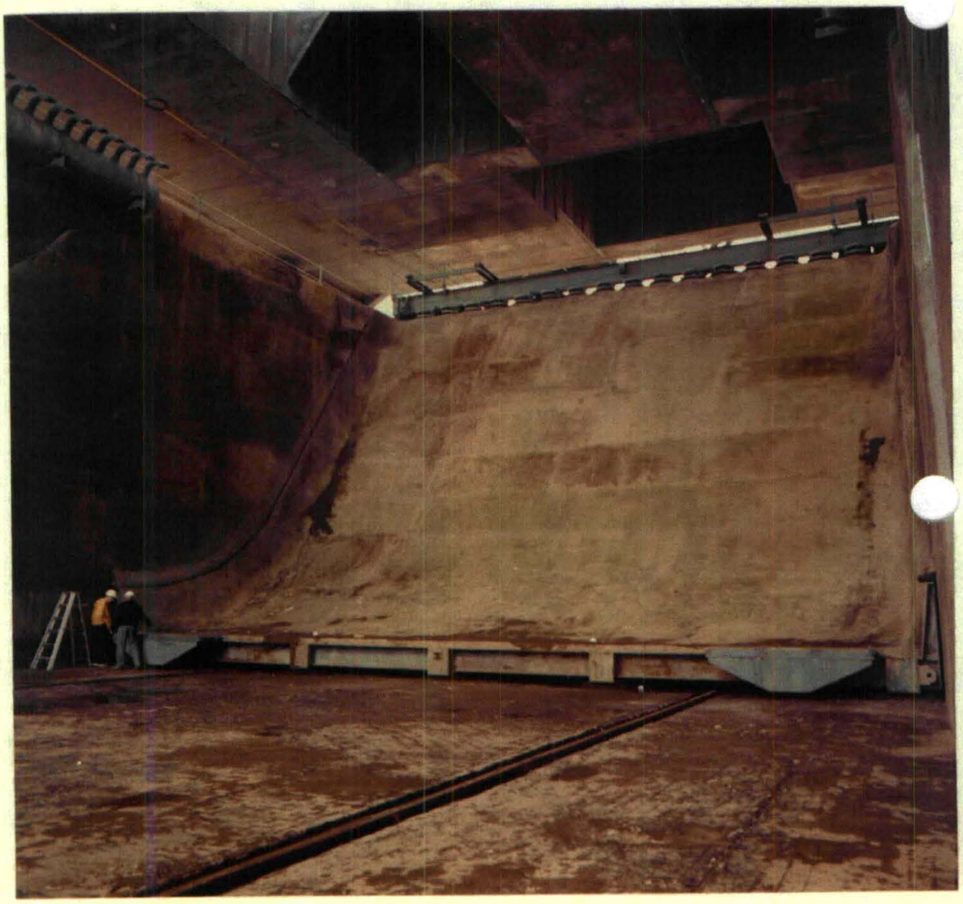


FIGURE 1
FLAME TRENCH, SHOWING TEST FRAMES AT BOTTOM OF FLAME DEFLECTOR

6

FIGURE 2
TEST FRAME WITH TEST PANELS INSTALLED

7

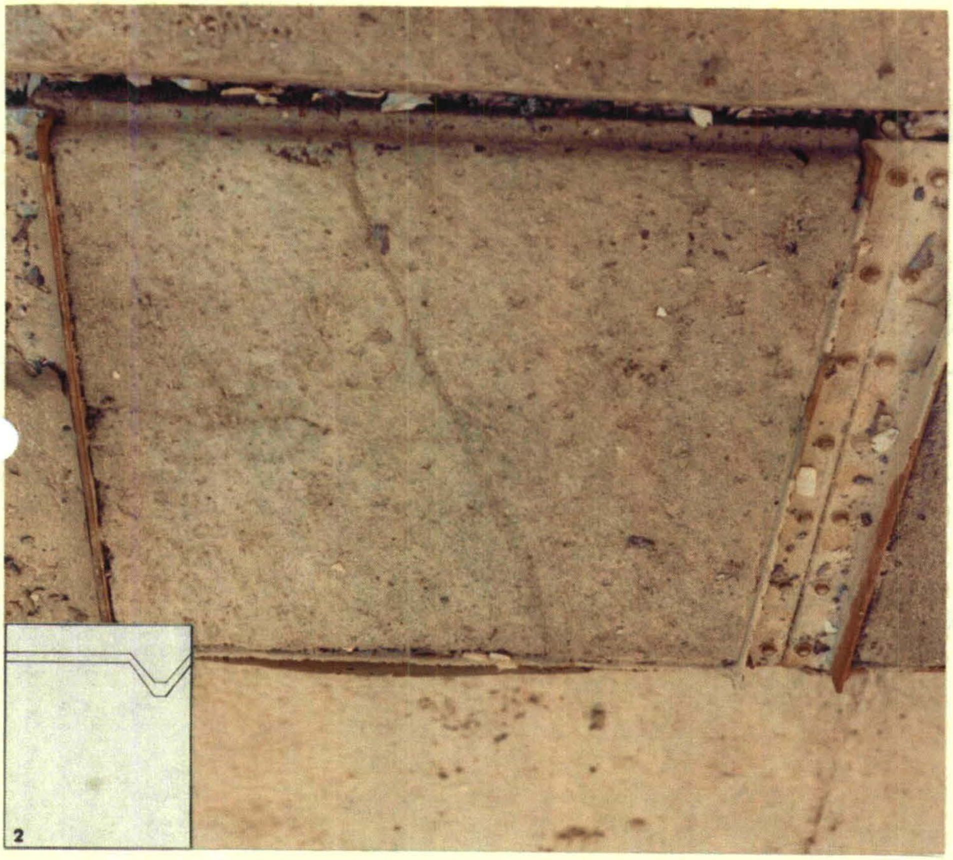


FIGURE 3
DESIGNED CONCRETES WA-1 AFTER STS-2

8

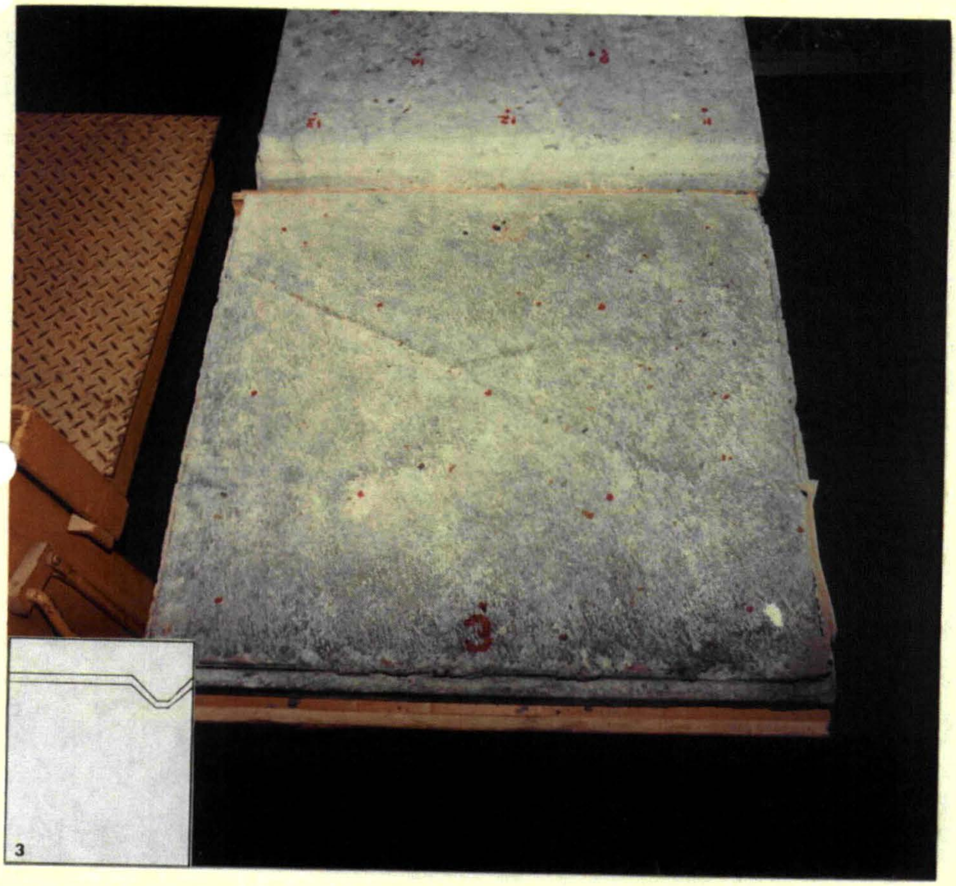


FIGURE 4
DESIGNED CONCRETES WA-1 W/W AFTER STS-2

FIGURE 5
WAHL WRP-1 AFTER STS-3

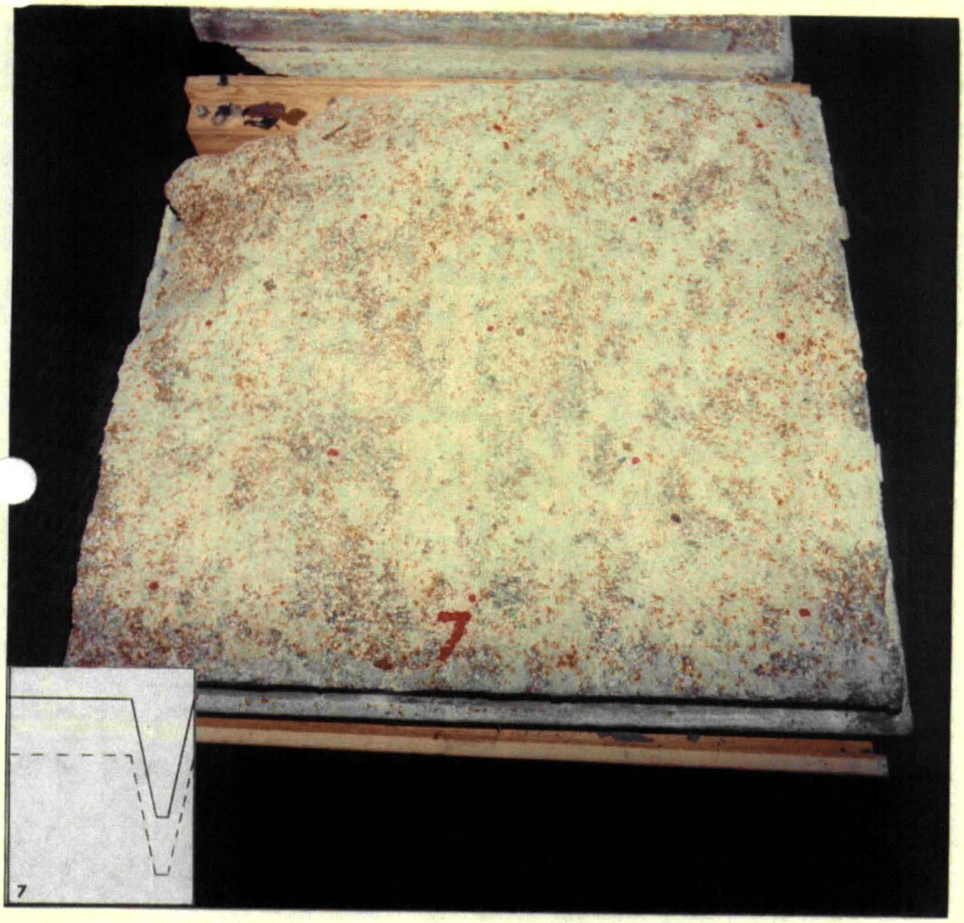


FIGURE 6
WAHL WRP-2 AFTER STS-2

11

FIGURE 7
WAHL WRP-3 AFTER STS-2

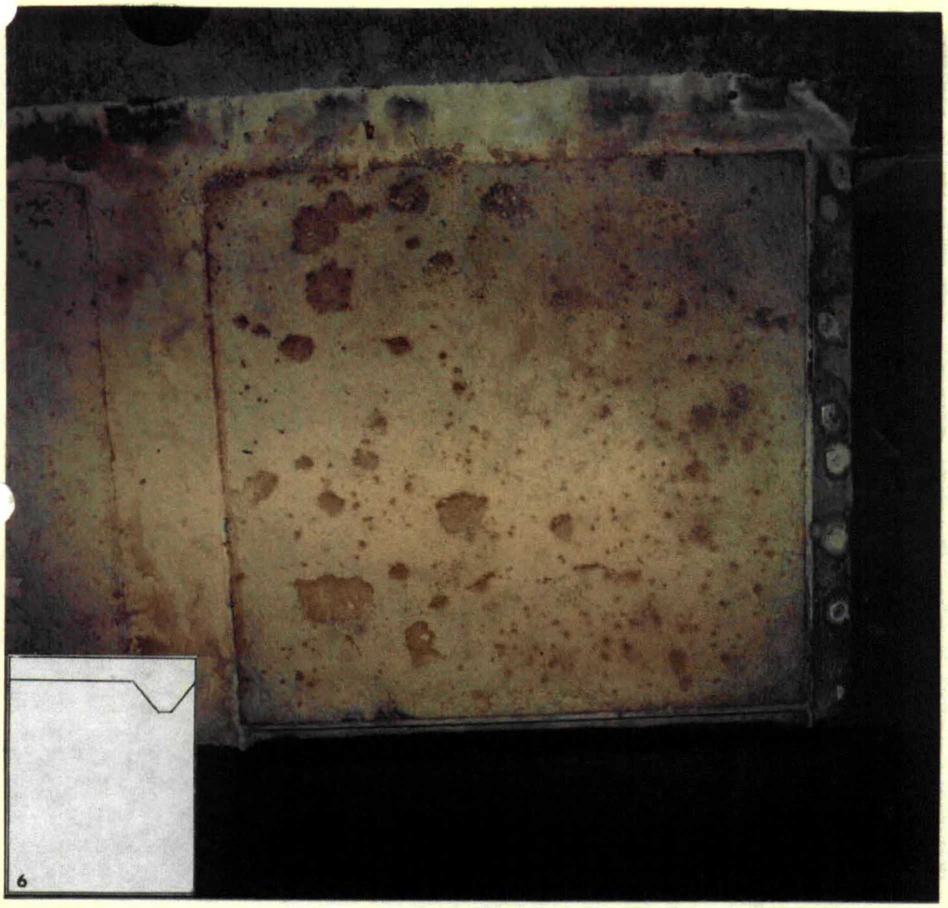


FIGURE 8
HARBISON-WALKER TUFSHOT AFTER STS-1

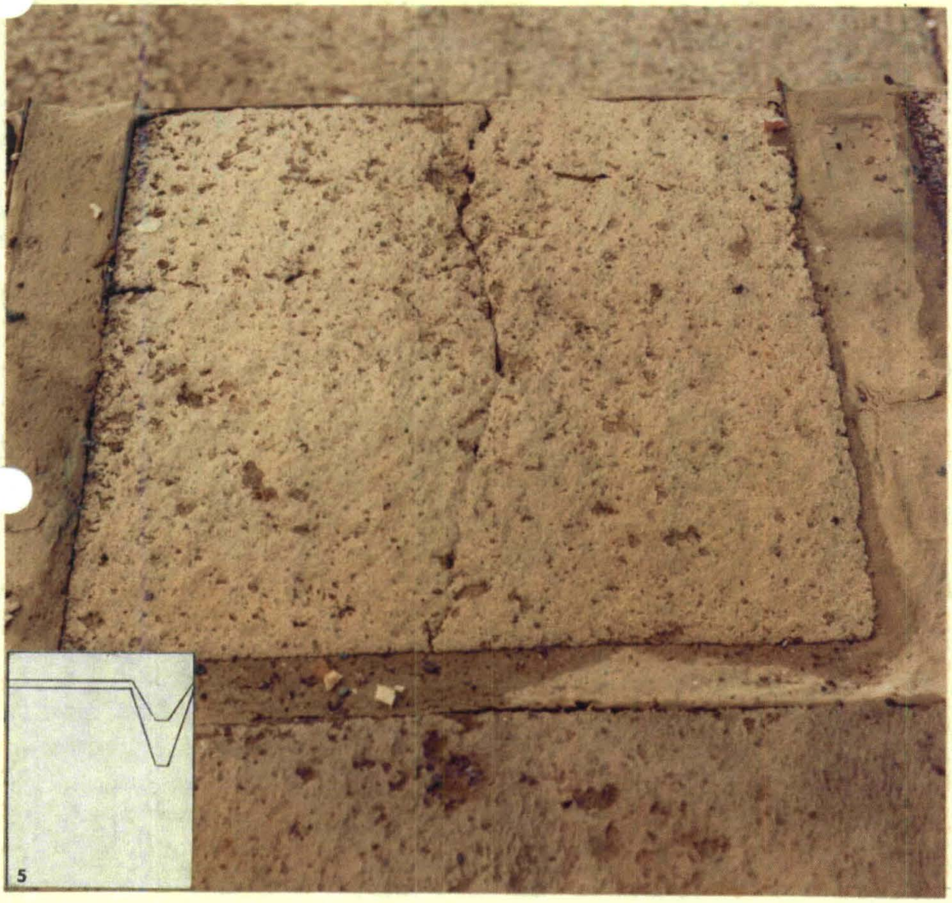


FIGURE 9
HARBISON-WALKER TUFSHOT W/W/ AFTER STS-2

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DD-MED-1/OLSEN	5
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SF-ENG/ROBERT MILLER	1
SF-ENG-3/R. GILLETT	1
TG-FLD-2	1
TG-FLD-22	ALL THAT ARE LEFT

APPENDIX E. MTS-425-82, STS-4

NASA
MATERIALS TESTING SECTION
MATERIALS ANALYSIS BRANCH
FLUIDS AND ANALYSIS DIVISION
TG-FLD-22, ROOM 1218, O&C BUILDING
KENNEDY SPACE CENTER, FLORIDA 32899
AUGUST 27, 1982

MTS-425-82

SUBJECT: Exposure Test of Refractory Concrete Test Panels During STS-4 Launch

RELATED DOCUMENTATION: MTS-340-82 Exposure tests of Refractory Concrete Test Panels to Solid Rocket Booster (SRB) Exhaust During the First Three STS Launches

1.0 FOREWORD

This test was a continuation of the test program described in MTS-340-82. Six test panels were prepared by the Development Testing Branch, using material from two manufacturers.

2.0 TEST PROCEDURE AND RESULTS

The test procedure was similar to that followed in previously reported tests of this kind. Results are as follows:

BRAND/ MFGR	PANEL NUMBER	EXPOSURE POSITION	MAXIMUM PIT DEPTH (INS)	% OF LOCATIONS WITH APPARENT THICKNESS INCREASE*	AVERAGE THICKNESS LOSS (INS)
FONDU FYRE	11	B	0.325	0	0.048
	13	D	0.700 (1.00 AT CRACK)	0	0.178
	15	F	0.227	15	0.047
WAHL	10	A	0.142	62	-0.011 (INCREASE IN THICKNESS)
	12	C	0.361	15	0.077
	14	E	0.180	15	0.022

* Thickness was measured at 13 locations on each panel.

Cracks were noted in several panels, but did not appear to be significant except in panel 13, in which the cracks had been widened and deepened by erosion.

3.0 DISCUSSION

3.1 The condition of panel 13 compared with that of the other two of the same composition exemplifies the uneven exhaust exposure at different locations across the flame trench which has been observed in previous launches.

3.2 Apparent increases in thickness were measured in a number of locations, especially on the Wahl panels. As in some previous occurrences, they are attributed to the accretion of exhaust products.

INVESTIGATOR: Clyde V Moyers
CLYDE V. MOYERS

APPROVED: C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MTS, NASA

TASK REQUEST

1. DATE SUBMITTED	2. DESIRED COMPLETION DATE	3. AUTHORIZING DOCUMENT

SAMPLE DESCRIPTION:

5. SYSTEM REMOVED FROM/OR USED IN:

6. ANALYSIS REQUESTED:

7. REMARKS:
Cys to: Frank McSweeny
Gary Kuehly (2 cys)
+ Reg Dist

8. REQUESTER:	9. PHONE:	10. COMPANY:	11. MAIL CODE:
NASA APPROVAL:	13. PHONE:	14. MAIL CODE:	15. DATE:

FOR LAB USE ONLY

INVESTIGATOR	TASK NUMBER	SAMPLE NUMBER
	MTS-425-82	

KSC FORM 22-81 (REV. 1/70)

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APPENDIX F. MTB-503-83, STS-5, -6, AND -7

NASA
ENGINEERING DEVELOPMENT
GROUND SUPPORT OFFICE
MATERIALS ANALYSIS OFFICE
MATERIALS TESTING BRANCH
DE-MAO-2, ROOM 1218, O&C BUILDING, PHONE 867-4614
KENNEDY SPACE CENTER, FLORIDA 32899
SEPTEMBER 1, 1983

MTB-503-83

SUBJECT: Exposure Tests of Refractory Concrete Test panels to Solid Rocket Booster(SRB) Exhaust During the First Seven STS Lanches: Summary Report

RELATED DOCUMENTATION: MMA-1918-80, JULY 29, 1981
MTS-505-82, MARCH 1, 1982
MTS-142-82, MAY 6, 1982
MTS-340-82, JUNE 7, 1982
MTS-425-82, AUGUST 27, 1982

1.0 FOREWORD

1.1 At the request of DD-MED-1, refractory concrete test panels have been exposed to SRB exhaust during each of the first seven STS-launches.

1.2 Panels were supplied by three vendors, except for six panels which were fabricated at KSC from vendor-supplied materials.

1.3 The purpose of the test was to qualify additional suppliers of refractory concrete for use in flame trench refurbishment.

1.4 The five reports listed above in "Related Documentation" relate procedures and results of tests conducted during the first four launches.

1.5 This report summarizes the results of those tests, as well as the hitherto unreported tests during STS-5, STS-6 and STS-7 launches.

2.0 TEST PROCEDURE

2.1 The panel thickness was measured before and after each launch exposure at 13 locations on each panel. A template was used to identify the locations to be measured. The maximum depths of pits were also determined.

2.2 For launch exposure the panels were secured in test frames at the bottom of the flame deflector in the north end of the flame trench of Launch Complex 39A. Panel positions were designated A through F in alphabetical order from east to west. Ablative coating was applied to the areas surrounding the panels to protect the fixtures used to secure the samples in place.

3.0 RESULTS

3.1 Table 1 summarizes test results for the seven launches. Table 2 is a more detailed tabulation of results.

3.2 Figures 1 through 3 show graphically the effects of launch exposure on individual panels.

4.0 DISCUSSION OF RESULTS

The material now in use in the flame trench is Designed Concretes' Fondu Fyre WA-1. The results for this material shown in Figure 1 represent five panels with a total of seven launch exposures. Three of these panels were fabricated at KSC. Three other materials show lower average thickness losses per launch than WA-1:

4.1 Harbison Walker Refractories 17-67
The average loss is low, but represents only two exposures of one panel prepared by the vendor.

4.2 Wahl Refractory Products WRP-3 (With Wire)
The average loss is low, and represents eleven exposures of six panels, three of which were prepared at KSC.

4.3 Wahl Refractory Products WRP-3 without wire
The average loss is low, but represents only two exposures of one panel prepared by the vendor.

4.4 In a memorandom to M.G. Olsen, DD-MED-1, dated August 22, 1983 Gary Kurtz, PRC 1211, has reviewed the test program so far, and has discussed the problems in test exposure and interpretation of results. In the evaluation of results he suggests the following criteria:

"a. eliminate specific materials from contention that crack or form deep fissures. Exceptions to this rule would be panels that have knowingly been mishandled or otherwise, improperly installed. This would be consistent with the requirements as stated in KSC-SPEC-P-0012, section 3.5.

b. eliminate maximum spalling depth from the list of SPEC requirements. It appears to be basic property of the refractories that they all spall.

c. use a minimum of two panels of a specific material for a minimum of three launch exposures. One of the panels should be prepared by NASA, KSC personnel or its contractor.

d. use Fondu Fyre WA-1 average loss as a minimum standard of acceptability. This may seem somewhat arbitrary, but then so was the 1/8" loss quoted in the SPEC. Attempts to arrive at an acceptable figure for loss (other than zero) all seem subjective and without any real meaning. The only practical viewpoint with the information available at this time is that Fondu Fyre WA-1 did well but it would be beneficial to find better materials. Cost effectiveness has not been considered so far, however, material cost, labor, scheduling, and availability will have to be factored into the acceptability equation at some point."

Using these criteria, he says, "the only material that would qualify for usage, other than Fondu Fyre WA-1, would be Wahl WRP-3 (w/w)." But he cautions that compatibility of the two materials and their performance as patches in repair work have not been investigated. Both Wahl WRP-3 without wire and Harbison Walker 17-67 would require additional successful launch exposures, including exposures of KSC-fabricated panels, before being qualified.

Mr. Kurtz suggests future work to study cost effectiveness, compatibility, application methods, new materials, and variables in material preparation.

5.0 RECOMMENDATIONS

Mr. Kurtz's analysis seems reasonable and comprehensive. Two alternate courses are suggested:

5.1 Exposure tests have now been conducted during seven launches over a period of more than 2 years. If the need for an additional qualified vendor is urgent enough, then Wahl WRP-3 could be accepted on the basis of the criteria outlined in paragraph 4.4. In this case the assumption would be made that any problems which may arise in repairs and compatibility will be solved by appropriate application technique. Exposure tests of Harbison Walker 17-67 and Wahl WRP-3 without wire with additional panels fabricated at KSC would continue. Mr. Kurtz's suggestions should be considered in planning future work.

5.2 Alternatively, acceptance of a new product could be postponed pending repair and compatibility testing. In this case, a test plan should be made immediately, using test panels, flame deflector patches, or both. Exposure tests of Harbison Walker 17-67 and Wahl WRP-3 without wire, using panels fabricated at KSC, would continue, and future work would be planned as in the first alternative.

INVESTIGATOR: C V Moyers
C. V. MOYERS

APPROVED: C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MTB, NASA

TABLE 1

SUMMARY-LAUNCH EXPOSURES

VENDOR		NUMBER OF LAUNCH EXPOSURES	AVERAGE THICKNESS LOSS PER LAUNCH, INS.	AVERAGE MAXIMUM PIT DEPTH, INS.
DESIGNED CONCRETES	FONDU FYRE WA-1	7	0.121	0.347
	FONDU FYRE WA-1 WITH WIRE	2	0.199	0.208
HARBISON WALKER REFRACTORIES	TUFSHOT	1	0.192	0.258
	TUFSHOT WITH FIBER	2	0.151	0.501
	LI	1	0.156	0.475
	17-67	2	0.068	0.368
WAHL REFRACTORY PRODUCTS	WRP-1	2	0.190	0.246
	WRP-2	1	0.257	>1.000
	WRP-3 (WITH WIRE)	11	0.055	0.231
	WRP-3 WITHOUT WIRE	2	0.057	0.468

TABLE 2

LAUNCH EXPOSURES

VENDOR	DESIGNATION	PANEL NUMBER	LAUNCH	POSITION	AVERAGE THICKNESS LOSS, IN.	MAXIMUM PIT DEPTH IN.
DESIGNED CONCRETES	FONDU FYRE WA-1	2	STS-1	B	0.256	0.258
			STS-2	E	.087	.311
		18	STS-6	A	.041	.159
			STS-7	C	.189	.450
		11*	STS-4	B	.048	.325
			STS-5	E	(.038**)	--
		13*	STS-4	D	.178	.700
		15*	STS-4	F	.047	.227
		AVERAGE PER LAUNCH - - - - - - - -			0.121	0.347
	FONDU FYRE WA-1 WITH WIRE	3	STS-1	C	0.325	0.215
			STS-2	F	.073	.201
		AVERAGE PER LAUNCH - - - - - - - -			0.199	0.208
HARBISON WALKER	TUFSHOT	6	STS-1	F	0.192	0.258
	TUFSHOT WITH FIBER	5	STS-1	E	0.238	0.346
			STS-2	B	.063	.656
		AVERAGE PER LAUNCH - - - - - - - -			0.151	0.501
	LI	21	STS 6	C	0.156	0.475
	17-67	22	STS-6	E	0.037	0.375
			STS-7	E	.098	.360
		AVERAGE PER LAUNCH - - - - - - - -			0.068	0.368

*FABRICATED AT KSC
**ABOUT 15% OF PANEL SURFACE MISSING DOWN TO REINFORCEMENT. VALUE REPORTED MEASURED OVER REMAINING 85% - NOT INCLUDED IN AVERAGE PER LAUNCH.

TABLE 2 (CONT'D)

LAUNCH EXPOSURES

VENDOR	DESIGNATION	PANEL NUMBER	LAUNCH	POSITION	AVERAGE THICKNESS LOSS, IN.	MAXIMUM PIT DEPTH IN.
WAHL REFRACTORY PRODUCTS	WRP-1	1	STS-1	A	0.171	0.222
			STS-3	D	0.208	0.270
		AVERAGE PER LAUNCH - - - - - - - -			0.190	0.246
	WRP-2	7	STS-2	D	0.257	>1.000
	WRP-3	4	STS-1	D	0.235	0.174
			STS-2	A	0.003	0.278
		10*	STS-4	A	-.011	0.142
			STS-5	D	0.072	0.171
		12*	STS-4	C	0.077	0.361
		14*	STS-4	E	0.022	0.180
			STS-5	B	0.019	0.160
			STS-6	F	0.045	0.140
			STS-7	B	0.044	0.180
		20	STS-6	D	0.049	0.280
			STS-7	F	0.046	0.480
		AVERAGE PER LAUNCH - - - - - - - -			0.055	0.231
	WRP-3 WITHOUT WIRE	19	STS-6	B	0.019	0.600
			STS-7	D	0.095	0.335
		AVERAGE PER LAUNCH - - - - - - - -			0.057	0.468

*FABRICATED AT KSC

MTB-503-83

10

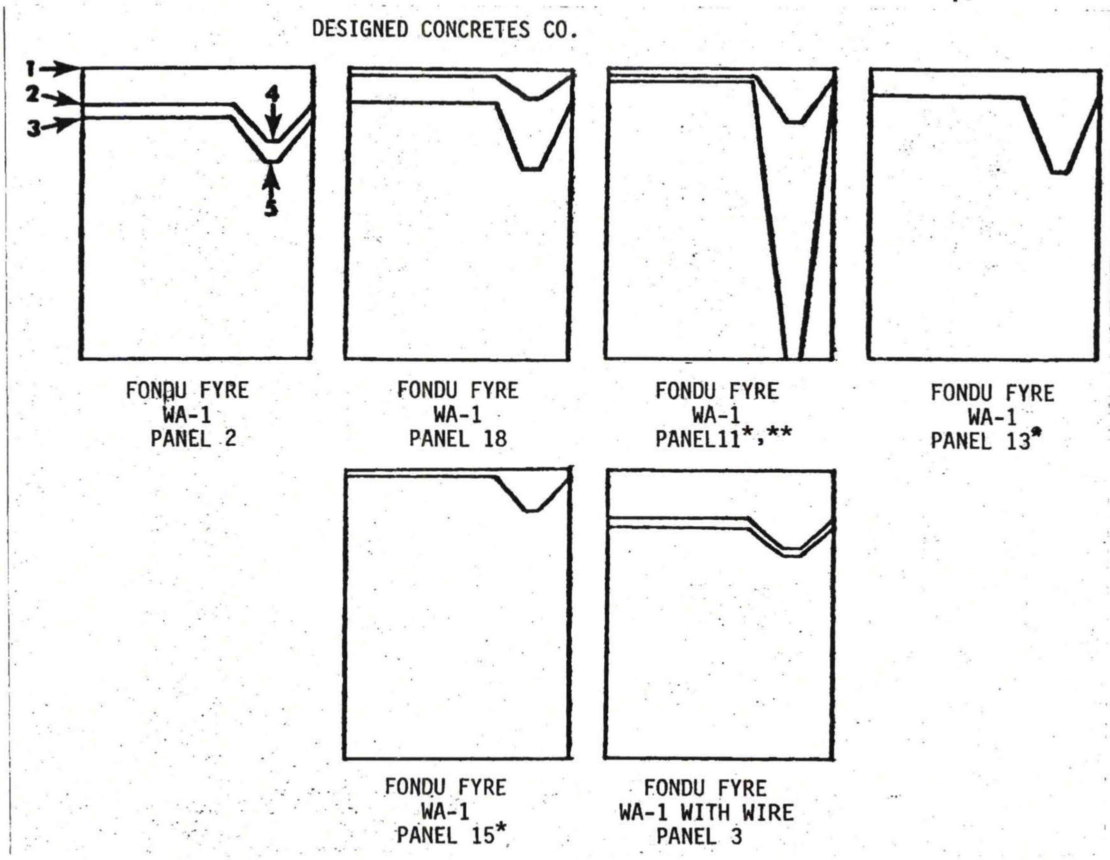

FIGURE 1

EFFECTS OF LAUNCH EXPOSURE ON REFRACTORY CONCRETE PANELS.
DESIGNED CONCRETES COMPANY
THESE GRAPHS SHOW AVERAGE THICKNESS LOSSES AND MAXIMUM PIT DEPTHS FOR INDIVIDUAL LAUNCH EXPOSURES. TYPICAL FEATURES ARE INDICATED ON PANEL 2:

1. ORIGINAL PANEL SURFACE
2. AVERAGE SURFACE LEVEL AFTER FIRST LAUNCH EXPOSURE. THE VERTICAL DISTANCE FROM 1 TO 2 IS A FULL SCALE REPRESENTATION OF THICKNESS LOSS DURING THIS EXPOSURE.
3. AVERAGE SURFACE LEVEL AFTER SECOND LAUNCH EXPOSURE. THE VERTICAL DISTANCE BETWEEN 2 AND 3 IS A FULL SCALE REPRESENTATION OF THICKNESS LOSS DURING THE SECOND EXPOSURE.

4&5 MAXIMUM PIT DEPTHS MEASURED AFTER FIRST AND SECOND EXPOSURES. AS IN "1" AND "2", DEPTHS ARE SHOWN IN FULL SCALE.

*PANEL FABRICATED AT KSC.

**SECOND EXPOSURE OF PANEL 11 NOT INCLUDED IN AVERAGES IN TABLE 1 BECAUSE OF POSSIBLE ADVENTITIOUS MECHANICAL DAMAGE AND DIFFICULTY OF EVALUATION.

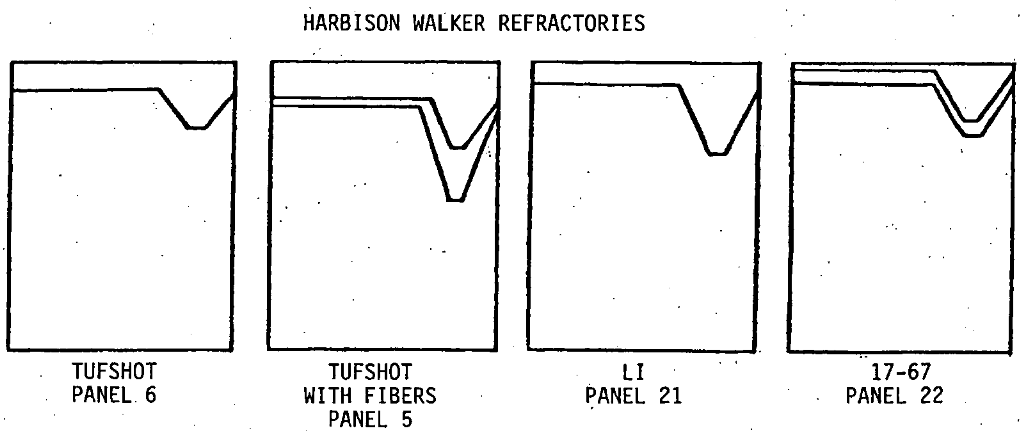

FIGURE 2

EFFECTS OF LAUNCH EXPOSURE ON REFRACTORY CONCRETE PANELS. HARBISON WALKER REFRACTORIES.

THESE GRAPHS SHOW AVERAGE THICKNESS LOSSES AND MAXIMUM PIT DEPTHS FOR INDIVIDUAL LAUNCH EXPOSURES. TYPICAL FEATURES ARE INDICATED AND EXPLAINED FOR PANEL 2, FIGURE 1, Q.V.

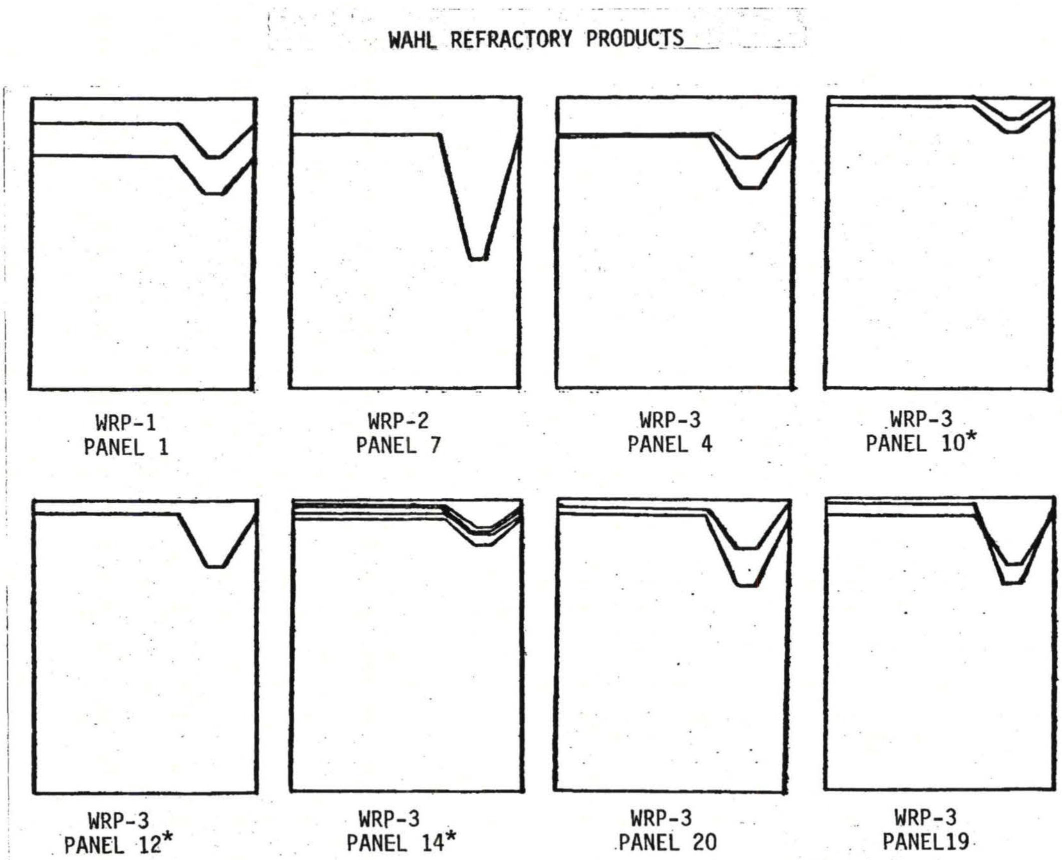

FIGURE 3

EFFECTS OF LAUNCH EXPOSURE ON REFRACTORY CONCRETE PANELS. WAHL REFRACTORY PRODUCTS.

THESE GRAPHS SHOW AVERAGE THICKNESS LOSSES AND MAXIMUM PIT DEPTHS FOR INDIVIDUAL LAUNCH EXPOSURES. TYPICAL FEATURES ARE INDICATED AND EXPLAINED FOR PANEL 2, FIGURE 1, Q.V.

*PANEL FABRICATED AT KSC.

MTB-503-83

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PRC-1372/J. WALKER	1
PRC-1211/GARY KURTZ	1
DE-MAO/C.W.HOPPESCH	1
DD-MED-33/J. F. MC INERNY	1
SL-ENG-1/WAYNE PARRIS	1
NASA, GODDARD SPACE FLIGHT CENTER GREENBELT, MARYLAND 20771 ATTN: MR. RICHARD MARRIOTT - CODE 313	1
DE-MAO-2	ALL THAT ARE LEFT

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TASK REQUEST

DATE SUBMITTED: 1/21/93	DESIRED COMP DATE: 2/4/93	AUTHORIZING DOC:

SAMPLE DESCRIPTION:
Six (6) samples of material chipped from refractory concrete test specimens:

Sample No.	Identification		
1.	Fondu Fyre	T/S 1,	MS 3
2.	Mitec 1111A05071,	T/S 2,	MS 1.
3.	Mitec A/O,	T/S 3,	MS 5.
4.	Mitec	T/S 4,	MS 6.
5.	Fondu Fyre	T/S 5,	MS 4.
6.	Mitec 11215071,	T/S 6,	MS 2.

SYSTEM: Evaluation of Refractory Concrete, Flame Deflector, LC-39A

ANALYSIS REOUESTED:

Preliminary Petrographic Analysis:

Perform Semi-quantitative analysis of particulate.

REMARKS:

REOUESTOR: P. J. Welch	PHONE: 867-1403	COMPANY: NASA	MAIL CODE: DM-MSL-24

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INVESTIGATOR	TASK NO.	SAMPLE NO.

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APPENDIX G. MTB-250-84, STS-8 AND -9

NASA
ENGINEERING DEVELOPMENT DIRECTORATE
GROUND SUPPORT OFFICE
MATERIALS ANALYSIS OFFICE
MATERIALS TESTING BRANCH
DE-MAO-2, ROOM 1218, O&C BUILDING, PHONE 867-4614
KENNEDY SPACE CENTER, FLORIDA 32899
MAY 22, 1984

MTB-250-84

SUBJECT: Exposure Tests of Refractory Concrete Test panels to Solid Rocket Booster(SRB) Exhaust During the First Nine STS Launches: Summary Report

RELATED DOCUMENTATION: MMA-1918-80, JULY 29, 1981
? → MTS-505-82, MARCH 1, 1982
MTS-142-82, MAY 6, 1982
MTS-340-82, JUNE 7, 1982
MTS-425-82, AUGUST 27, 1982
MTB-503-83, SEPTEMBER 1, 1983

1.0 FOREWORD

1.1 At the request of DD-MED-1, refractory concrete test panels have been exposed to SRB exhaust during each of the first nine STS-launches.

1.2 Panels were supplied by four vendors, except for six panels which were fabricated at KSC from vendor-supplied materials.

1.3 The purpose of the test was to qualify additional suppliers of refractory concrete for use in flame trench refurbishment.

1.4 The six reports listed above in "Related Documentation" relate procedures and results of tests conducted during the first seven launches.

1.5 This report summarizes the results of those tests, as well as the hitherto unreported tests during STS-8 and STS-9 launches.

2.0 TEST PROCEDURE

2.1 The panel thickness was measured before and after each launch exposure at 13 locations on each panel. A template was used to identify the locations to be measured. The maximum depths of pits were also determined.

2.2 For launch exposure the panels were secured in test frames at the bottom of the flame deflector in the north end of the flame trench of Launch Complex 39A. Panel positions were designated A through F in alphabetical order from east to west. Ablative coating was applied to the areas surrounding the panels to protect the fixtures used to secure the samples in place.

3.0 RESULTS

3.1 Table 1 summarizes test results for the nine launches. Table 2 is a more detailed tabulation of results.

3.2 Figures 1 through 4 show graphically the effects of launch exposure on individual panels.

4.0 DISCUSSION OF RESULTS

The material now in use in the flame trench is Designed Concretes' Fondu Fyre WA-1. The results for this material shown in Figure 1 represent five panels with a total of seven launch exposures. Three of these panels were fabricated at KSC. Four other materials show lower average thickness losses per launch than WA-1:

4.1 Harbison Walker Refractories 17-67

The average loss is low, but represents only three exposures of one panel prepared by the vendor.

4.2 Wahl Refractory Products WRP-3 (With Wire)

The average loss is low, and represents thirteen exposures of six panels, three of which were prepared at KSC.

4.3 Wahl Refractory Products WRP-3 without wire

The average loss is low, but represents only two exposures of one panel prepared by the vendor.

4.4 Sauereisen Cements Company No. 75

The average loss is low, but represents only two panels exposed to STS-9. These panels were prepared by the vendor, and contain chopped wire, but no Gridsteel reinforcement. One panel was covered with a network of fine cracks after the launch, and the other had a few cracks, but both felt solid and withstood moving by truck and forklift and being placed on inspection racks where they were supported on two opposite edges without further visible damage.

5.0 PROJECTED TESTING

Four panels are scheduled for exposure during the next launch, 41-D. The edge positions, A and F, which receive less exhaust exposure, will not by used.

5.1 Two previously exposed WA-1 panels will have a strip sawn out and will be repaired, using WA-1 for one repair and WRP 3 for the other.

5.2 An unexposed WA-1 panel will be exposed to provide the basis for a later repair test.

5.3 A Sauereisen No. 75 panel will be prepared at KSC, using wire and Gridsteel reinforcement, and will be exposed.

INVESTIGATOR: C V Moyers
C. V. MOYERS

APPROVED: C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MTB, NASA

TABLE 1

SUMMARY-LAUNCH EXPOSURES

VENDOR		NUMBER OF LAUNCH EXPOSURES	AVERAGE THICKNESS LOSS PER LAUNCH, INS.	AVERAGE MAXIMUM PIT DEPTH, INS.
DESIGNED CONCRETES	FONDU FYRE WA-1	7	0.121	0.347
	FONDU FYRE WA-1 WITH WIRE	2	0.199	0.208
	FONDU FYRE FSC-5	1	0.103	0.270
	FONDU FYRE HT-1	1	0.172	0.280
HARBISON WALKER REFRACTORIES	TUFSHOT	1	0.192	0.258
	TUFSHOT WITH FIBER	2	0.151	0.501
	L1	1	0.156	0.475
	17-67	3	0.080	0.455
WAHL REFRACTORY PRODUCTS	WRP-1	2	0.190	0.246
	WRP-2	1	0.257	>1.000
	WRP-3 (WITH WIRE)	13	0.053	0.246
	WRP-3 WITHOUT WIRE	2	0.057	0.468
SAUEREISEN COMENTS CO.	NO. 75	2	0.069	0.370

TABLE 2

LAUNCH EXPOSURES

VENDOR	DESIGNATION	PANEL NUMBER	LAUNCH	POSITION	AVERAGE THICKNESS LOSS, IN.	MAXIMUM PIT DEPTH IN.
DESIGNED CONCRETES	FONDU FYRE WA-1	2	STS-1	B	0.256	0.258
			STS-2	E	0.087	0.311
		18	STS-6	A	0.041	0.159
			STS-7	C	0.189	0.450
		11*	STS-4	B	0.048	0.325
			STS-5	E	(0.038**)	--
		13*	STS-4	D	0.178	0.700
		15*	STS-4	F	0.047	0.227
		AVERAGE PER LAUNCH - - - - - - - -			0.121	0.347
	FONDU FYRE WA-1 WITH WIRE	3	STS-1	C	0.325	0.215
			STS-2	F	0.073	0.201
		AVERAGE PER LAUNCH - - - - - - - -			0.199	0.208
	FONDU FYRE FSC-5	23	STS-9	C	0.103	0.270
	FONDU FYRE HT-1	24	STS-9	D	0.172	0.280
HARBISON WALKER	TUFSHOT	6	STS-1	F	0.192	0.258
	TUFSHOT WITH FIBER	5	STS-1	E	0.238	0.346
			STS-2	B	0.063	0.656
		AVERAGE PER LAUNCH - - - - - - - -			0.151	0.501
	LI	21	STS 6	C	0.156	0.475
	17-67	22	STS-6	E	0.037	0.375
			STS-7	E	0.098	0.360
			STS-8	C	0.105	0.630
		AVERAGE PER LAUNCH - - - - - - - -			0.068	0.368

ABRICATED AT KSC
**ABOUT 15% OF PANEL SURFACE MISSING DOWN TO REINFORCEMENT. VALUE REPORTED MEASURED OVER REMAINING 85% - NOT INCLUDED IN AVERAGE PER LAUNCH.

TABLE 2 (CONT'D)

LAUNCH EXPOSURES

VENDOR	DESIGNATION	PANEL NUMBER	LAUNCH	POSITION	AVERAGE THICKNESS LOSS, IN.	MAXIMUM PIT DEPTH IN.
WAHL REFRACTORY PRODUCTS	WRP-1	1	STS-1	A	0.171	0.222
			STS-3	D	0.208	0.270
		AVERAGE PER LAUNCH			0.190	0.246
	WRP-2	7	STS-2	D	0.257	>1.000
	WRP-3	4	STS-1	D	0.235	0.174
			STS-2	A	0.003	0.278
		10*	STS-4	A	-.011	0.142
			STS-5	D	0.072	0.171
		12*	STS-4	C	0.077	0.361
		14*	STS-4	E	0.022	0.180
			STS-5	B	0.019	0.160
			STS-6	F	0.045	0.140
			STS-7	B	0.044	0.180
			STS-8	B	0.070	0.130
		20	STS-6	D	0.049	0.280
			STS-7	F	0.046	0.480
			STS-8	E	0.017	0.530
		AVERAGE PER LAUNCH			0.053	0.246
	WRP-3 WITHOUT WIRE	19	STS-6	B	0.019	0.600
			STS-7	D	0.095	0.335
		AVERAGE PER LAUNCH			0.057	0.468
SAUEREISEN 'ENTS CO.	NO. 75	25	STS-9	B	0.103	0.410
		26	STS-9	E	0.035	0.330
		AVERAGE PER LAUNCH			0.069	0.370

*FABRICATED AT KSC

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DESIGNED CONCRETES CO.

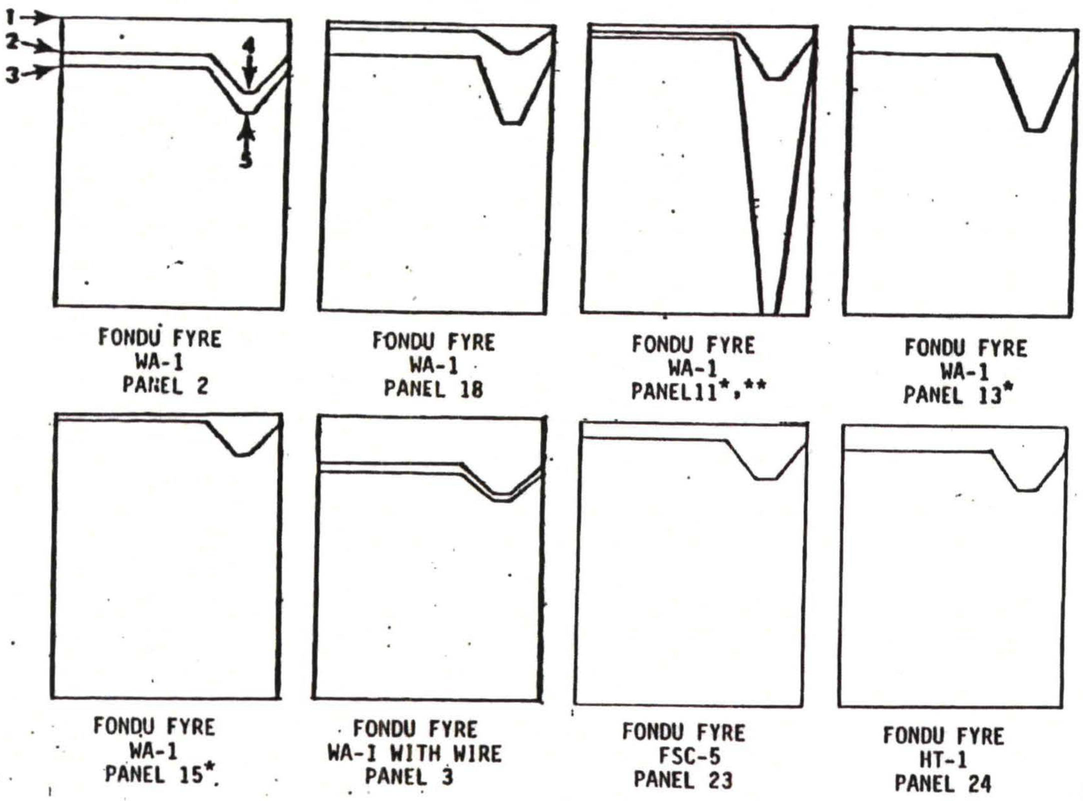


FIGURE 1

EFFECTS OF LAUNCH EXPOSURE ON REFRACTORY CONCRETE PANELS.

DESIGNED CONCRETES COMPANY

THESE GRAPHS SHOW AVERAGE THICKNESS LOSSES AND MAXIMUM PIT DEPTHS FOR INDIVIDUAL LAUNCH EXPOSURES. TYPICAL FEATURES ARE INDICATED ON PANEL 2:

1. ORIGINAL PANEL SURFACE
2. AVERAGE SURFACE LEVEL AFTER FIRST LAUNCH EXPOSURE. THE VERTICAL DISTANCE FROM 1 TO 2 IS A FULL SCALE REPRESENTATION OF THICKNESS LOSS DURING THIS EXPOSURE.
3. AVERAGE SURFACE LEVEL AFTER SECOND LAUNCH EXPOSURE. THE VERTICAL DISTANCE BETWEEN 2 AND 3 IS A FULL SCALE REPRESENTATION OF THICKNESS LOSS DURING THE SECOND EXPOSURE.

4&5 MAXIMUM PIT DEPTHS MEASURED AFTER FIRST AND SECOND EXPOSURES. AS IN "1" AND "2", DEPTHS ARE SHOWN IN FULL SCALE.

*PANEL FABRICATED AT KSC.

**SECOND EXPOSURE OF PANEL 11 NOT INCLUDED IN AVERAGES IN TABLE 1 BECAUSE OF POSSIBLE ADVENTITIOUS MECHANICAL DAMAGE AND DIFFICULTY OF EVALUATION.

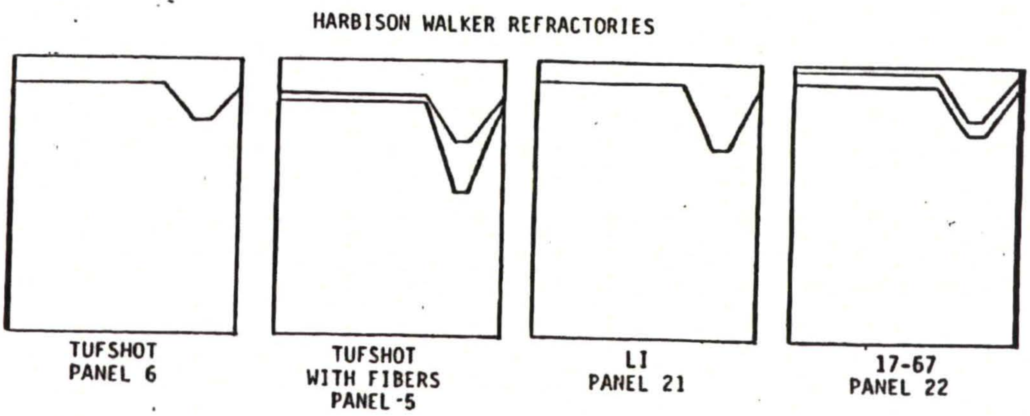


FIGURE 2

EFFECTS OF LAUNCH EXPOSURE ON REFRACTORY CONCRETE PANELS. HARBISON WALKER REFRACTORIES.

THESE GRAPHS SHOW AVERAGE THICKNESS LOSSES AND MAXIMUM PIT DEPTHS FOR INDIVIDUAL LAUNCH EXPOSURES. TYPICAL FEATURES ARE INDICATED AND EXPLAINED FOR PANEL 2, FIGURE 1, Q.V.

WAHL REFRACTORY PRODUCTS

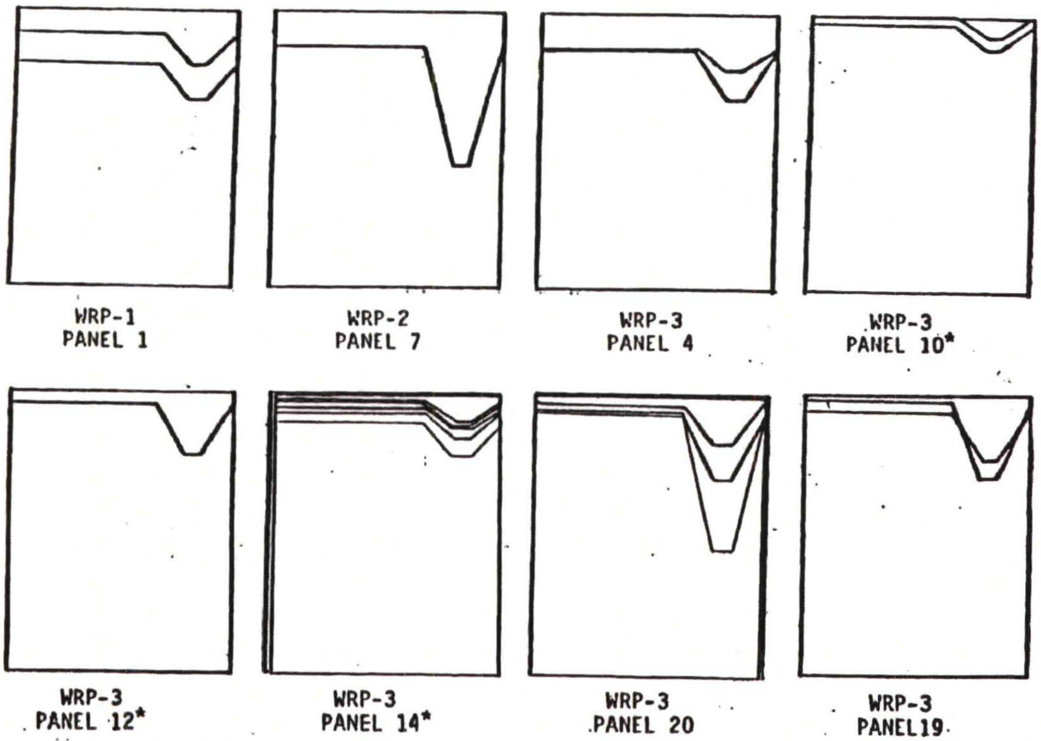


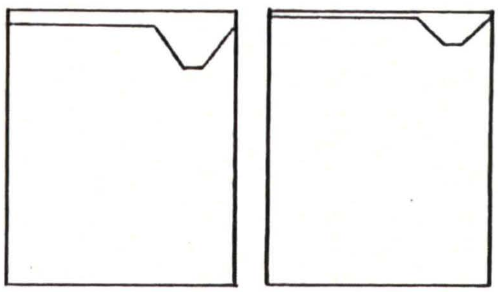
FIGURE 3

EFFECTS OF LAUNCH EXPOSURE ON REFRACTORY CONCRETE PANELS. WAHL REFRACTORY PRODUCTS.

THESE GRAPHS SHOW AVERAGE THICKNESS LOSSES AND MAXIMUM PIT DEPTHS FOR INDIVIDUAL LAUNCH EXPOSURES. TYPICAL FEATURES ARE INDICATED AND EXPLAINED FOR PANEL 2, FIGURE 1, Q.V.

*PANEL FABRICATED AT KSC.

SAUREISEN CEMENTS CO.



NO. 75
PANEL 25

NO. 75
PANEL 26

FIGURE 4

EFFECTS OF LAUNCH EXPOSURE ON REFRACTORY CONCRETE PANELS. SAUEREISEN CEMENTS COMPANY.

THESE GRAPHS SHOW AVERAGE THICKNESS LOSSES AND MAXIMUM PIT DEPTHS FOR INDIVIDUAL LAUNCH EXPOSURES. TYPICAL FEATURES ARE INDICATED AND EXPLAINED FOR PANEL 2, FIGURE 1, Q.V.

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APPENDIX H. 93-4436, STS-55

KSC-93-4436

NASA
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DIRECTOR, MECHANICAL ENGINEERING
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FAILURE ANALYSIS AND MATERIALS EVALUATION BRANCH
PHYSICAL TESTING SECTION
DM-MSL-24, ROOM 1218, O&C BUILDING
KENNEDY SPACE CENTER, FLORIDA 32899

JULY 19, 1993

REPORT NUMBER KSC-93-4436

SUBJECT: EXPOSURE TEST OF REFRACTORY CONCRETE TEST SPECIMENS TO SOLID ROCKET BOOSTER (SRB) EXHAUST DURING LAUNCH OF STS-55, LC-39A

PARTICIPANTS: J. GAY, NASA/DM-MSL-23
H. KIM, NASA/DM-MSL-1
P. PETERSEN, NASA/DM-MSL-23
P. WELCH, NASA/DM-MSL-24

RELATED DOCUMENTATION:

KSC-SPEC-P-0012, REFRACTORY CONCRETE, SPECIFICATION FOR

MTB-503-83, EXPOSURE TEST OF REFRACTORY CONCRETE TEST PANELS TO SRB EXHAUST DURING THE FIRST SEVEN STS LAUNCHES: SUMMARY REPORT

MCB-34-93 AND MCB 429-93, MICROCHEMICAL ANALYSIS REPORTS

1.0 FOREWORD

1.1 The Florida Product Innovation Center, a state university system service program, requested that the NASA Failure Analysis and Materials Evaluation Branch evaluate a refractory concrete product developed by Mitec, Inc., (Mitec) for potential applications such as the flame trenches at Kennedy Space Center (KSC).

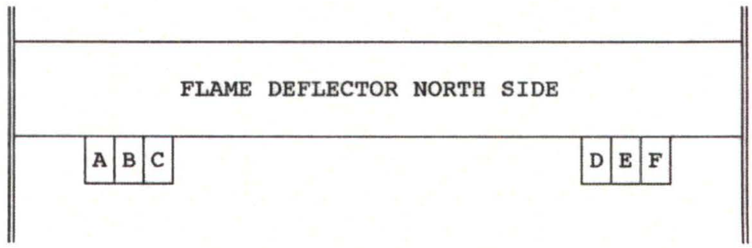
1.2 Mitec was provided with a copy of KSC-SPEC-P-0012, which contains the requirements for qualification test samples.

1.3 Six refractory concrete test specimens, 75 cm square by 10 cm thick, were provided by Mitec for testing. Reference specimens of Fondu Fyre, the refractory material currently used at KSC, were fabricated by the Shuttle Processing Contractor (SPC).

2.0 TEST PROCEDURE

2.1 Six test specimens, four Mitec and two Fondu Fyre, were selected for test. The thickness of each specimen was measured at 13 template defined locations. The test specimens were installed on the two test stands located at the north side base of the LC-39A flame deflector (see Figure 1). Each stand holds three test specimens. These locations allow the test specimens to be exposed to SRB exhaust blast during STS launches from the pad.

2.1.1 Looking south at the flame deflector, the test locations are identified alphabetically from left to right as "A" through "F".



VIEW LOOKING DOWN INTO FLAME PIT
TO IDENTIFY TEST LOCATIONS "A" THROUGH "F"

2.1.2 The reference, Fondu Fyre, test specimens were installed at Location "A" on the left side of the east stand, and at Location "E" in the center of the west stand.

2.1.3 The Mitec test specimens were installed at the remaining four locations: "B," "C," "D," and "F."

2.1.4 Samples from the test specimens were obtained for petrographic analysis.

2.2 The installed refractory test specimens were subjected to the SRB exhaust blast during the launch of STS-55 on April 26, 1993.

2.3 After the launch, the test specimens were examined and documented in place, removed, and measured for thickness changes.

2.3.1 The test specimens at Locations "A" and "B" were lost during the launch. The refractory material on the face of the flame deflector broke loose, destroying the two test specimens.

2.3.2 The Mitec specimen at Location "C" (see Figures 2 and 3) was grossly eroded and broke into numerous small pieces when removed from the stand. Post test thickness measurements were not attempted on this specimen.

2.3.3 Half of the Mitec specimen at Location "D" (see Figures 4 and 5) was missing and broke into several pieces when removed from the stand. Post test thickness measurements were not attempted on this specimen.

2.3.4 The Fondu Fyre reference test specimen at Location "E" appeared intact and was coated with a metallic material, except for the pitted areas. The test specimen was removed intact and post test thickness measurements were made of the major pieces. Chips of the metallic material were removed from the specimen to determine the layer thickness and identify the material.

2.3.5 The Mitec specimen at Location "F" (see Figures 8 and 9) appeared intact with only one noticeable crack traversing the face, and except for the pitted areas was coated with a metallic material. This specimen broke into seven major pieces when removed from the stand. Post-test thickness measurements were made of the major pieces. Chips of the metallic material were removed from the specimen to determine the layer thickness and identify the material.

3.0 <u>RESULTS</u>

The metrology data for the test specimens are presented below:

Test Location Material	"E" Fondu Fyre	"F" Mitec
Original Thickness (Avg.)	10.124 cm	10.056 cm
Post Test Thickness (Avg.)	10.056 cm	10.119 cm
Metallic Layer Thickness (Est.)	0.173 cm	0.178 cm
Post Test Thickness (Est.)	9.883 cm	9.941 cm
Thickness Loss (Est.)	0.241 cm	0.111 cm

4.0 ANALYTICAL TESTS AND RESULTS

4.1 The samples were analyzed by optical microscope, electron microprobe with energy dispersive spectrometry, and X-ray diffraction.

4.2 The four Mitec samples were similar in composition and in petrographic features, and were described collectively. The samples were moderately hard and compact. They were composed of coarse aggregate, fine sand, and cement paste.

4.2.1 The coarse aggregate appeared to be composed totally of white pumaceous material containing SiO_2 (alpha-cristoballite) and glass phase.

4.2.2 The fine sand was composed mainly of light and fine grained Si-Al rich material.

4.2.3 The cement paste was light gray in color and contained small amounts of unhydrated portland cement and was moderately carbonated throughout. The cement paste was composed of glass, unhydrated portland cement, $Ca_5Si_6O_{16}(OH)_2$ (tobermorite), $Al(OH)_3$, $CaCO_3$ (calcite), $Ca_3Al_2O_6$, and $Ca_2(SiO_3)(OH)_2$.

4.2.4 The Mitec samples were air entrained. The air content was estimated to be less than seven percent.

4.3 The Fondu Fyre samples were also moderately hard and compact. They were composed of coarse aggregate, fine sand, and cement paste.

4.3.1 The coarse aggregate appeared to be composed totally of dark coarse grained slag containing Fe_2TiO_4 (ulvospinel), $CaFe_3AlSiO_6$ (essenite), $Ca(Fe,Mg)Si_2O_6$ (augite), glass, and $Ca_5Al_2(Si_2Al_2)O_{10}(OH)_2$ (margarite).

4.3.2 The fine sand was composed mainly of light colored and fine grained Si-Al rich material.

4.3.3 The cement paste was dark gray in color, contained prominent amounts of unhydrated portland cement, and was moderately carbonated throughout. The cement paste was composed of $Ca_5Si_6O_{16}(OH)_2$ (tobermorite), $Al(OH)_3$, $CaCO_3$ (calcite), unhydrated portland cement, $Ca_3Al_2O_6$, and amorphous materials.

4.3.4 The Fondu Fyre samples were also air entrained. The air content was estimated to be less than seven percent.

4.4 The chips removed from the surface of the two refractory concrete test specimens were composed of Al_2O_3, (corundum).

5.0 CONCLUSIONS

5.1 Only two out of six test specimens survived the launch of STS-55.

5.2 The poor performance of several Mitec refractory concrete test specimen resulted from their being fabricated without the steel mesh reinforcement as required in KSC-SPEC-P-0012.

5.3 Mitec, Inc., has indicated that they will fabricate two more test specimens with steel mesh reinforcement.

INVESTIGATOR: Peter J. Welch

Peter J. Welch

APPROVAL: N. Salvail

N. Salvail, Chief, Physical Testing Section

FIGURE 1

VIEW LOOKING SOUTH IN LC-39A FLAME TRENCH AT REFRACTORY CONCRETE TEST STANDS AT BOTTOM OF FLAME DEFLECTOR. THE TEST STANDS ARE LOCATED BENEATH THE TWO SRB FLAME PITS IN THE MOBILE LAUNCH PLATFORMS.

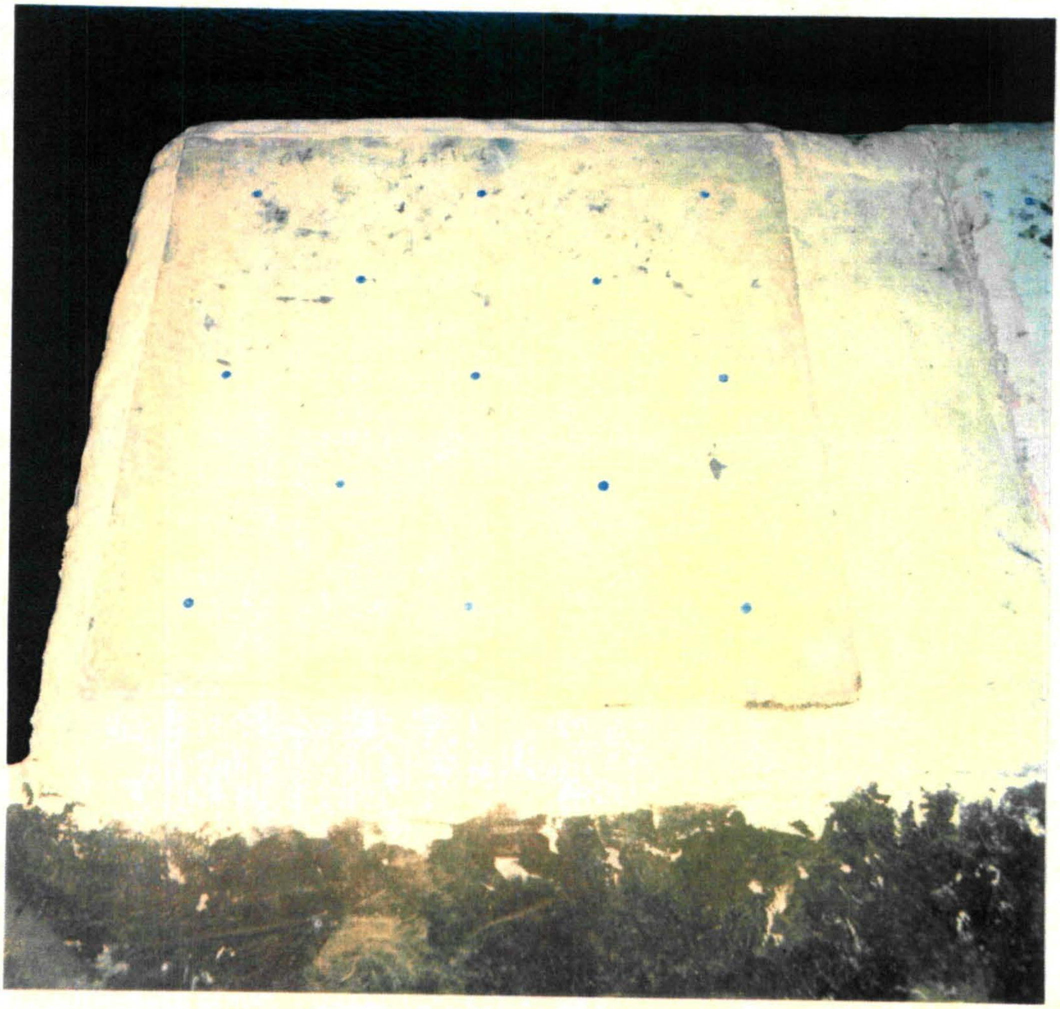


FIGURE 2

MITEC TEST SPECIMEN AT LOCATION "C" PRIOR TO LAUNCH. NOTE THE TEST SPECIMENS ARE GROUTED WITH SILICONE RUBBER TYPE ABLATIVE MATERIAL.

FIGURE 3

MITEC TEST SPECIMEN AT LOCATION "C" AFTER LAUNCH. THE TEST SPECIMEN CONTAINED NUMEROUS CRACKS AND WAS GROSSLY ERODED, ESPECIALLY ALONG THE CRACK LINES.

FIGURE 4

MITEC TEST SPECIMEN AT LOCATION "D" PRIOR TO LAUNCH.

FIGURE 5

MITEC TEST SPECIMEN AT LOCATION "D" AFTER LAUNCH. OVER HALF OF THE TEST SPECIMEN WAS MISSING AND THE REMAINDER CONTAINED NUMEROUS CRACKS. AREAS OF HEAVY EROSION PITTING WERE NOTED ON THE FACE ADJACENT TO THE FLAME DEFLECTOR. THE SURFACE OF THE SPECIMEN APPEARED TO BE COATED WITH A ROUGH METALLIC LAYER EXCEPT IN THE AREAS OF THE PITTING.

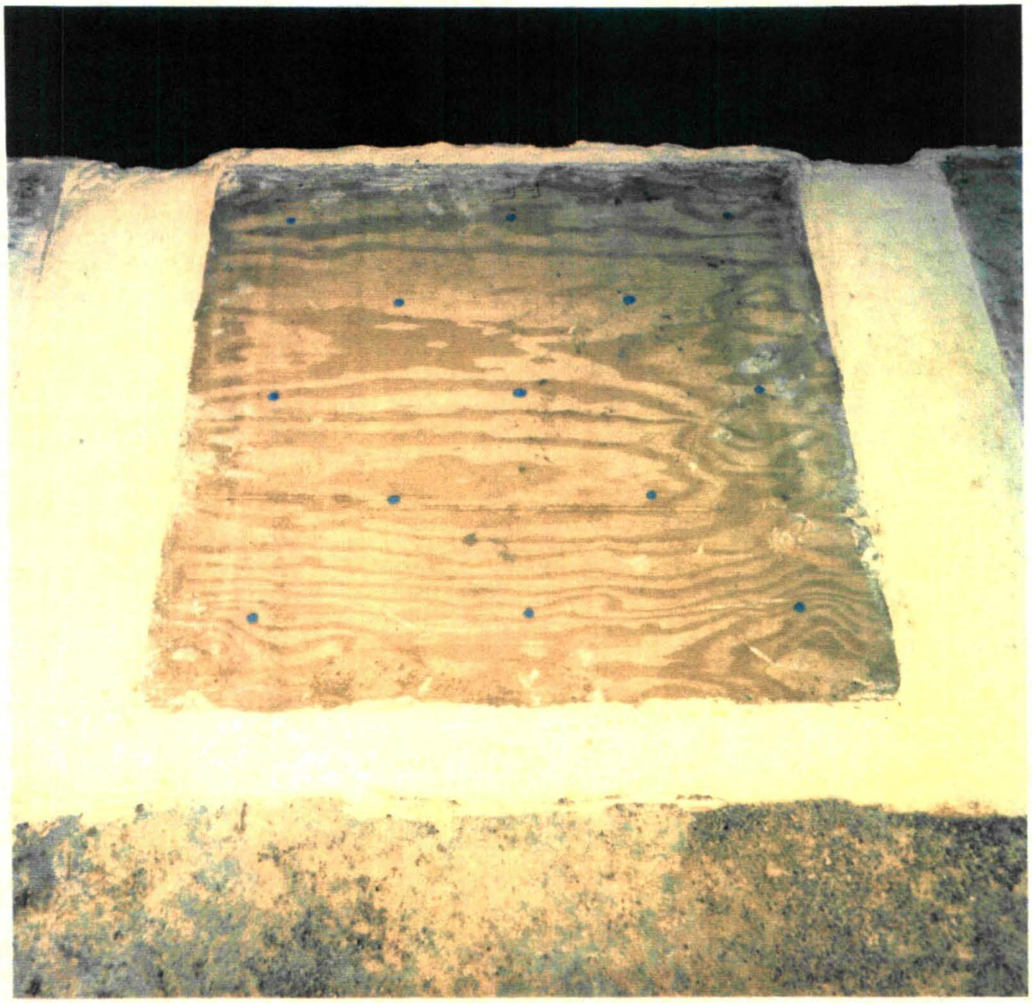


FIGURE 6

FONDU FYRE TEST SPECIMEN AT LOCATION "E" PRIOR TO LAUNCH.

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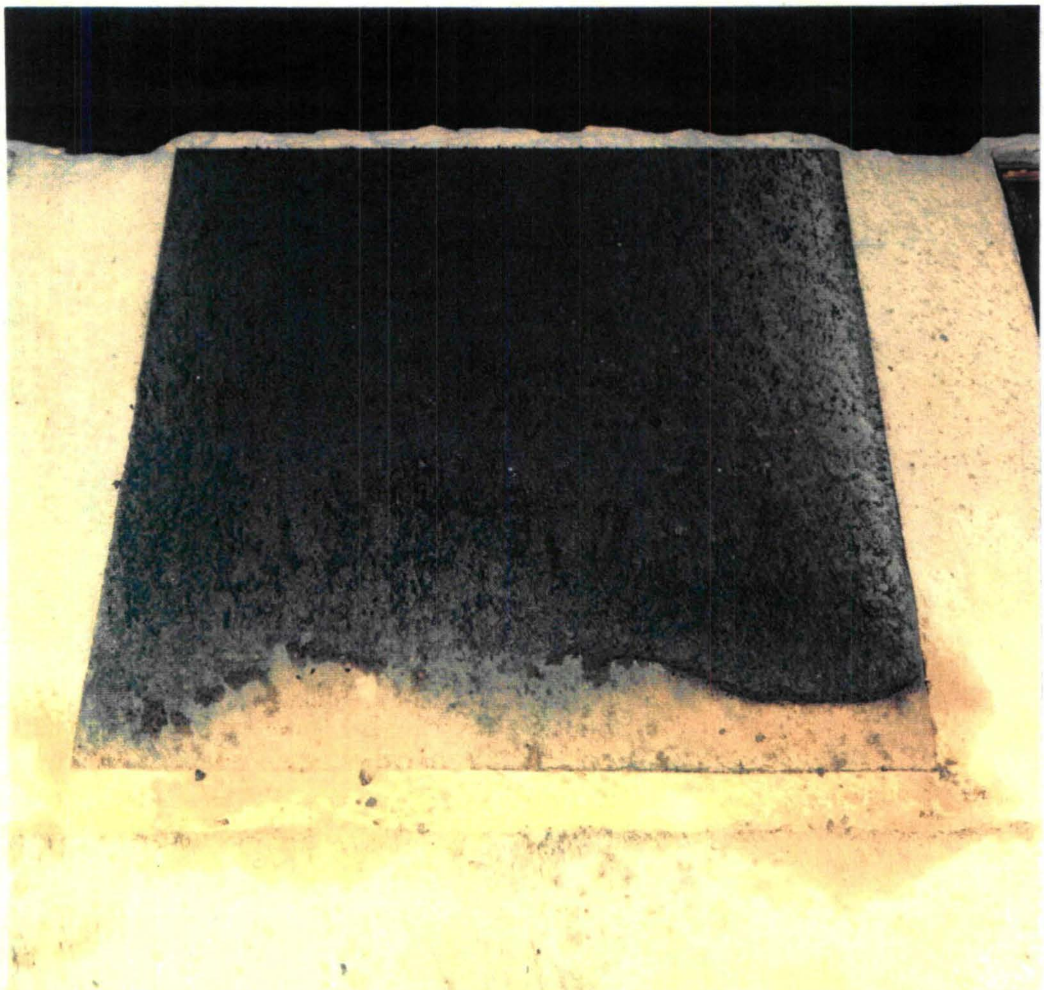

FIGURE 7

FONDU FYRE TEST SPECIMEN AT LOCATION "E" AFTER LAUNCH. AREAS OF HEAVY EROSION PITTING WERE NOTED ON THE FACE ADJACENT TO THE FLAME DEFLECTOR. THE SURFACE OF THE SPECIMEN APPEARED TO BE COATED WITH A ROUGH METALLIC LAYER EXCEPT IN THE AREAS OF THE PITTING.

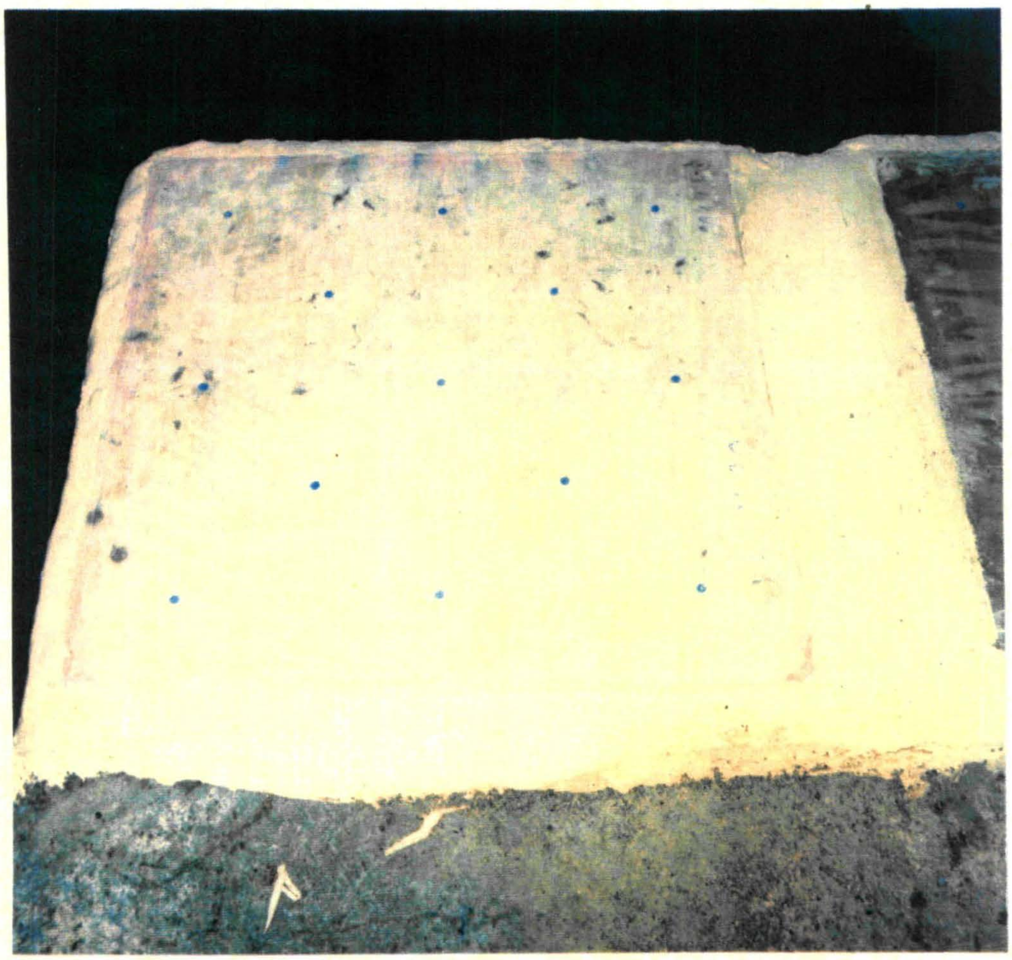

FIGURE 8

MITEC TEST SPECIMEN AT LOCATION "F" PRIOR TO LAUNCH.

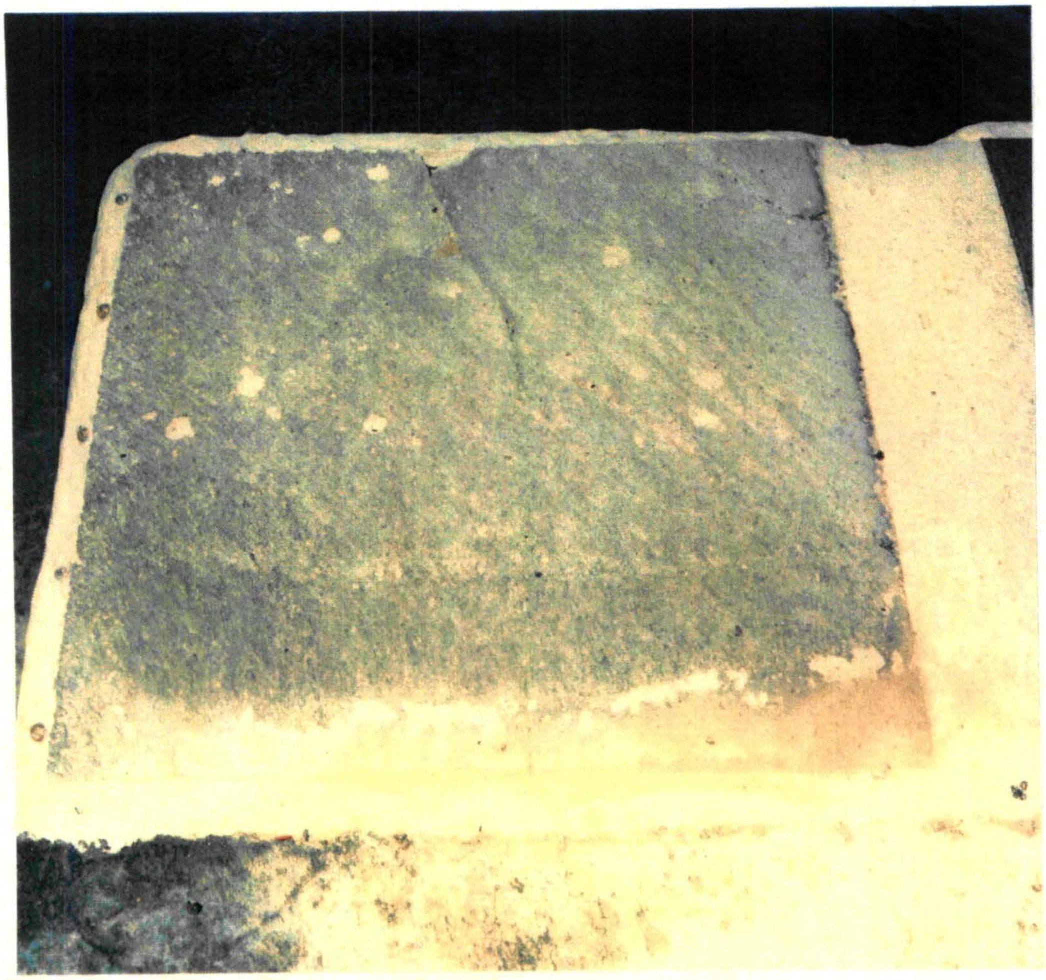

FIGURE 9

MITEC TEST SPECIMEN AT LOCATION "F" AFTER LAUNCH. SEVERAL CRACKS WERE EVIDENT IN THE FACE OF THE TEST SPECIMEN AND AREAS OF HEAVY EROSION PITTING WERE NOTED ON THE FACE ADJACENT TO THE FLAME DEFLECTOR. THE SURFACE OF THE SPECIMEN APPEARED TO BE COATED WITH A ROUGH METALLIC LAYER EXCEPT IN THE AREAS OF THE PITTING.

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This revision changes paragraph '10 days" to "14 days" in paragraph 3.2.9.

14. ABSTRACT
Launch Pads 39A and 39B currently use refractory material (Fondu Fyre) in the flame trenches. This material was initially approved for the Saturn program. This material had a lifetime of 10 years according to the manufacturer, and it has been used for over 40 years. As a consequence, the Fondu Fyre at Launch Complex 39 requires repair subsequent to almost every launch. A review of the literature indicates that the gunned Fondu Fyre refractory product (WA-1G) was never tested prior to use.
With the recent severe damage to the flame trenches, a new refractory material is sought to replace Fondu Fyre. In order to replace Fondu Fyre, a methodology to test and evaluate refractory products was developed. This paper outlines this methodology and discusses current testing requirements, as well as the laboratory testing that might be required. Furthermore, this report points out the necessity for subscale testing, the locations where this testing can be performed, and the parameters that will be necessary to qualify a product. The goal is to identify a more durable refractory material that has physical, chemical, and thermal properties suitable to withstand the harsh environment of the launch pads at KSC.

15. SUBJECT TERMS
refractory materials, Fondu Fyre, flame trench

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