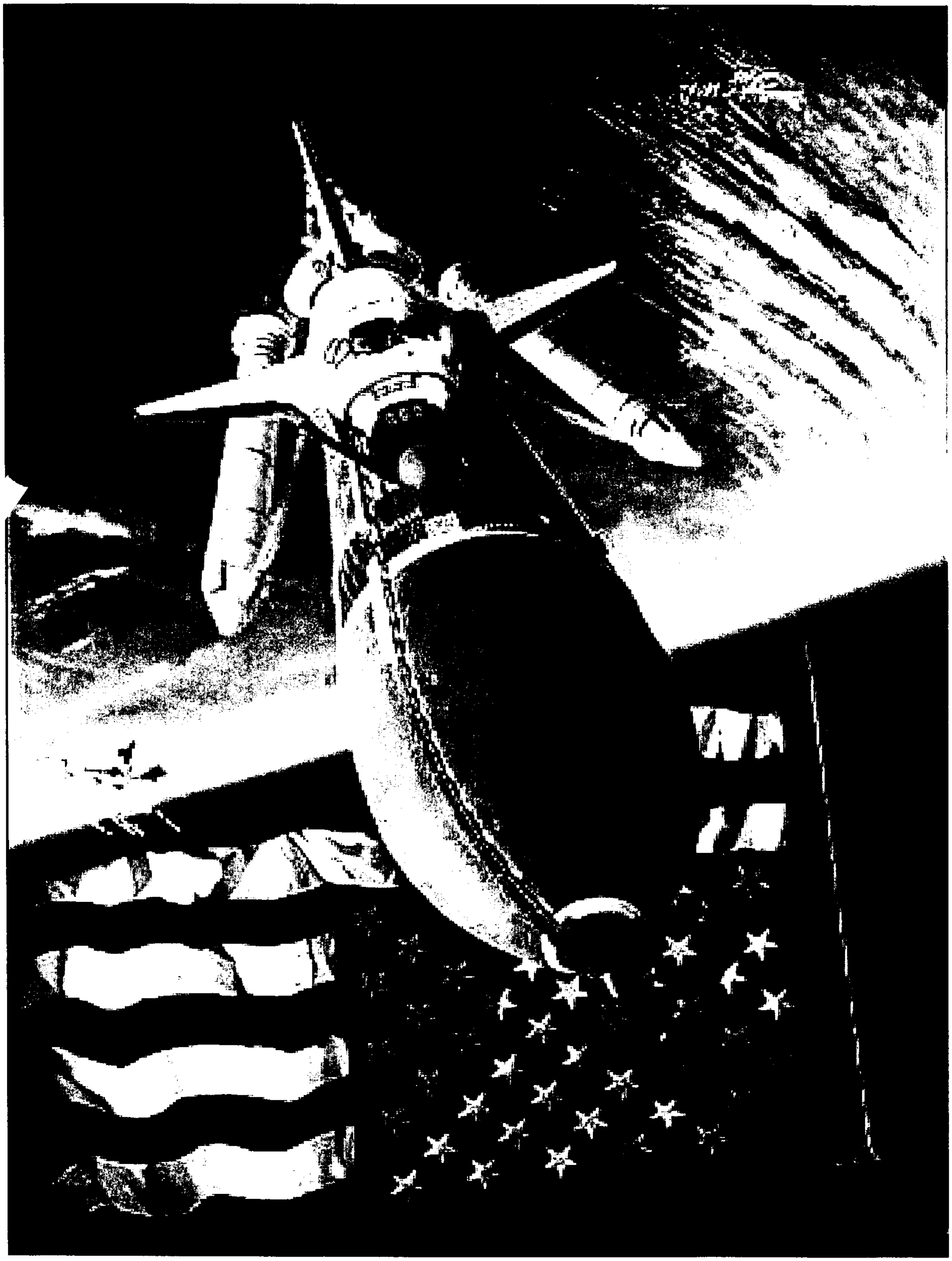

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PETITION FOR SPACE SHUTTLE PROGRAM
HCFC 141b EXEMPTION ALLOWANCE

February 4, 2003

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ACRONYMS AND ABBREVIATIONS

CAA	Clean Air Act
ECLSS	Environmental Control and Life Support System
EPA	Environmental Protection Agency
ET	External Tank
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
JSC	Johnson Space Center
KSC	Kennedy Space Center
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
MPS	Main Propulsion System
MSFC	Marshall Space Flight Center
NASA	National Space And Aeronautics Administration
ODC	Ozone Depleting Compound
ODP	Ozone Depletion Potential
OMS	Orbital Maneuvering System
PRC	Products Research Corporation
PRSD	Power Reactant Supply and Distribution
Space Act	National Aeronautics and Space Act
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program
TPS	Thermal Protection System
VOC	Volatile Organic Compound

SPACE SHUTTLE PROGRAM PETITION FOR HCFC 141b Exemption Allowance

EXECUTIVE SUMMARY

In 1987, the United States and 45 other nations adopted the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Under the Protocol, class II ozone depleting compounds (ODCs), hydrochlorofluorocarbons (HCFCs), were to be phased out of production no later than 2030. In 1992, the Environmental Protection Agency (EPA) accelerated the US phaseout of HCFC 141b to 2003. The Space Shuttle Program (SSP) requires a thermal protection system (TPS) to maintain the quality of the cryogenic propellants, provide protection from aerothermal and vehicle plume heating environments, prevent formation of ice on exterior surfaces, and maintain structural integrity. The TPS is rigid foam using HCFC 141b as the chemical blowing agent to provide the critical insulation and cell structure properties. Development and implementation of an HCFC 141b replacement cannot meet the 2003 deadline. The SSP began HCFC 141b replacement efforts far in advance of the phaseout, but no replacement has been found that meets performance requirements. Stockpiling or use of recycled or recovered HCFC 141b is not a viable long-term solution due to shelf life and environmental concerns. Continued production of HCFC 141b for use as a Space Shuttle foam blowing agent past January 1, 2003 is critical to the NASA Space Shuttle Program. Without the use of HCFC 141b, NASA's Space Shuttle Program cannot operate now or in the near future. This document constitutes a petition for an HCFC 141b Exemption Allowance as specified in 40 CFR §82.16.

The three major SSP elements requiring foam insulation are the Orbiter, the External Tank (ET), and the Solid Rocket Boosters (SRBs). The TPS is applied at various NASA and contractor sites using spray and mold techniques developed specifically for the space program's unique requirements. The details of the areas on which the insulation is used and associated process descriptions are supplied in the document, as required.

NASA has expended considerable resources to develop a TPS using an alternative blowing agent. To date, however, no viable material has been found that meets SSP criteria. The performance of Space Shuttle foam insulation in environments experienced during ascent and descent is of primary importance. The imposition of synchronous loads such as static pressure, dynamic pressure, ambient pressure, vibration loads, acoustic loads, cryoshrinkage, aeroheating, plume convective heating, and plume radiant heating on the foam proves to be the most critical aspect of determining whether a material is acceptable for Space Shuttle use. Over 200 blowing agents have been researched and tested as potential replacement candidates for HCFC 141b, including hydrofluorocarbons (HFCs), hydrofluoroethers (HFEs), hydrocarbons, and water as both a sole and co-blowing agent. Among those materials tested were the leading rigid foam industry candidates, HFC 245fa and pentanes, a type of hydrocarbon. More extensive tests, including simulated flight environments, have been conducted on TPS foams blown with HFCs, HFEs, hydrocarbons, and water. Detailed information regarding SSP experience with potential alternate materials is presented in this document.

Due to the complexity of the material and the criticality of human space flight safety, implementation of a replacement TPS will take several years. Shuttle material and process changes require extensive development and qualification programs prior to implementation. Lessons learned from replacement of CFC 11 blown foams with those using HCFC 141b demonstrate that changes in materials and processes, even when thoroughly tested, present opportunities for unforeseen problems. Minimizing these issues is critical to the Shuttle program, and is part of what makes development of the next generation TPS foams a lengthy and complex process.

As shown in this document, the use of stockpiled, recycled or recovered supplies of HCFC 141b as the source of foam blowing agent through the time anticipated to implement next generation foams poses unacceptable risk to the SSP. The stability and purity of the blowing agent is essential to viable foam insulation meeting the stringent technical requirements of manned flight hardware. Use of a non-specification foam, or utilizing stockpiled blowing agent, both threaten the Shuttle Program with launch manifest delays and safety. The conclusion to this submittal is that extended production of HCFC 141b is the only approach that will assure availability of acceptable foam for the Space Shuttle Program.

Production of HCFC 141b beyond 2002 for the SSP does not conflict with the requirements of the Clean Air Act (CAA). Section 606(a) of the CAA, as amended in 1990, provides the EPA Administrator with authority to accelerate the phaseout of ozone-depleting substances. EPA has accelerated the phaseout of class II ODCs relative to the requirements of the Montreal Protocol phaseout schedule. This accelerated date is reasonable for those applications for which acceptable substitute materials are available. The SSP, however, has identified no acceptable alternative to HCFC 141b in thermal protection foam applications. It is therefore necessary and appropriate for EPA to allow continued production and annual allowance of 40,000 lbs (18,000 kg) of HCFC 141b for Space Shuttle foam applications.

Space Shuttle Program Petition for HCFC 141b Exemption Allowance

1.0 OVERVIEW

1.1 NASA'S MISSION

The National Aeronautics and Space Act of 1958 as amended (Space Act) established the National Aeronautics and Space Administration (NASA) and laid the foundation for its mission. The Space Act directs NASA to conduct space activities devoted to peaceful purposes for the benefit of all humankind. It declares that "the general welfare and security of the United States require that adequate provision be made for aeronautical and space activities", and further states that the United States should "seek and encourage to the maximum extent possible the fullest commercial use of space." The Space Shuttle system was designed to meet NASA's strategic agency goals, and in turn has greatly benefited society.

1.2 SPACE SHUTTLE PROGRAM

The Space Shuttle Program (SSP) provides the only capability in the United States for human access to space and is the pathfinder for reusable space hardware. Conceived early in NASA's history as an integral part of a much larger program to provide logistics support to a space station, the goal of the new vehicle was to provide "routine access to space". The Shuttle is the first and only reusable space vehicle, and is the world's most reliable and versatile launch system. It can be configured to carry many different types of equipment, spacecraft, and scientific experiments. In addition to transporting people, materials, equipment, and spacecraft to orbit, the Shuttle allows astronauts to service and repair satellites and observatories in space. Since the first flight in April 1981, over 100 Space Shuttle missions have carried more than 1.5 million pounds (680,000 kilograms) of cargo and deployed over 600 major payloads serving diverse missions that include: astronomy, astrophysics, atmospheric science, geophysics, life science, materials science, microgravity science, planetary science, communications, solar physics, and national security. The Shuttle routinely takes scientific instruments into space for purposes of monitoring atmospheric conditions, including the stratospheric ozone layer and global evidence of climate change. The current focus on international cooperation involves the assembly and operational support of the International Space Station. Effective fulfillment of such SSP missions requires continued Shuttle availability with the highest attainable safety margins and without schedule interruption.

The Space Shuttle system, as shown in Figure 1.1, consists of three major elements: a reusable manned Orbiter, two reusable Solid Rocket Boosters (SRBs), and an expendable External Tank (ET) containing cryogenic propellants for the Orbiter's main engines.

The Orbiter comprises a pressurized crew compartment, which can normally carry up to seven astronauts; a large cargo bay; and three main engines mounted on its aft end that have a combined thrust of approximately 1.2 million pounds (5.3 million newtons) at sea level. It is approximately the same size as a DC-9 aircraft.

The Space Shuttle's two SRBs are the largest ever built and the first solid propellant rockets to propel a manned spacecraft. Together they provide the 5.8 million pounds (26 million newtons) of initial ascent thrust, along with the Orbiter main engines, to lift the Space Shuttle with its payload from the launch pad to a high ballistic trajectory.

The ET serves a dual role: it provides the structural backbone of the Space Shuttle during launch operations, and contains approximately 1.6 million pounds (7.3 million kilograms) of liquid hydrogen and oxygen propellants for the Orbiter's three main engines.

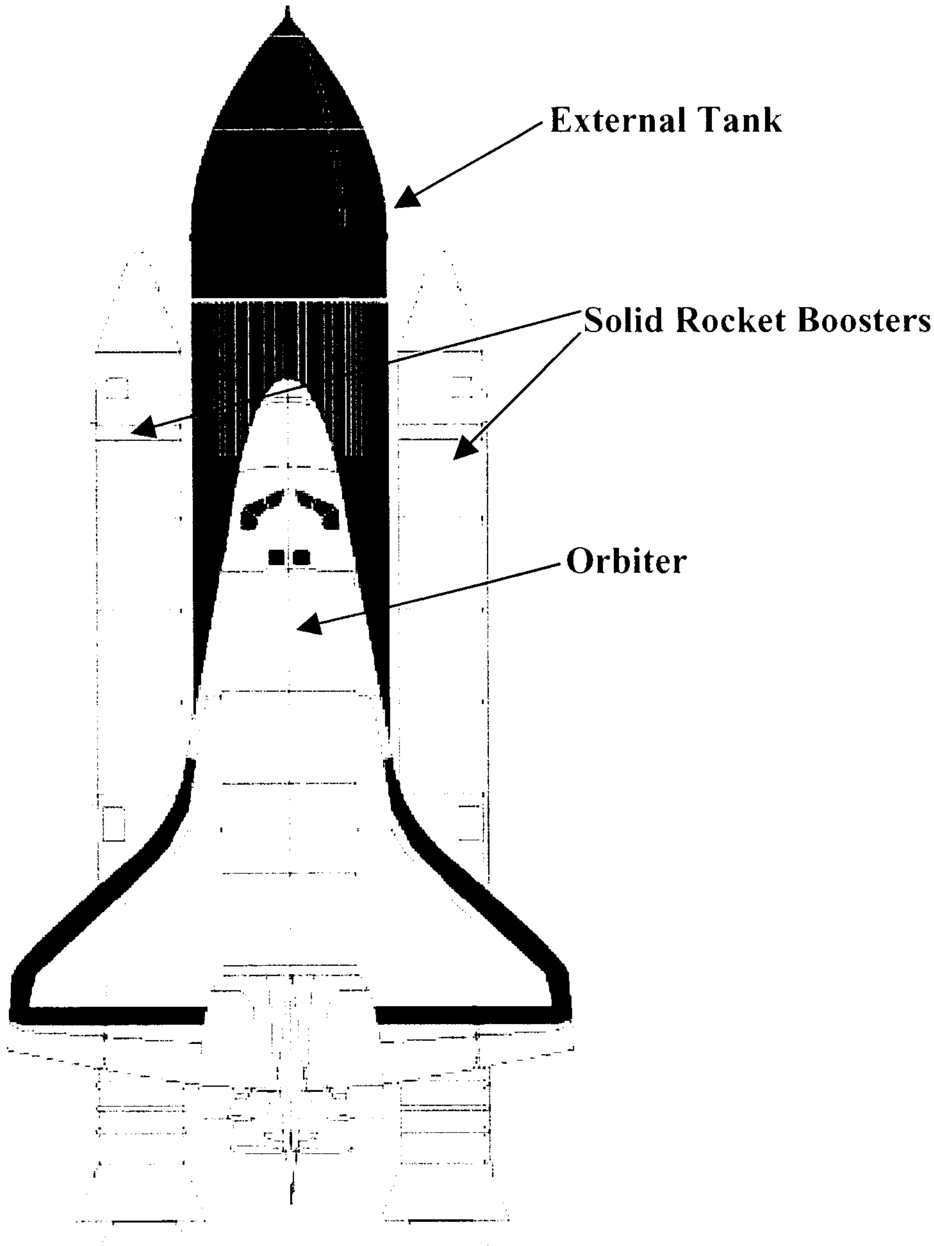

Figure 1.1 Space Shuttle Elements

The Space Shuttle is launched from a vertical position using the Orbiter's three main engines and the two SRBs. At approximately two minutes into the ascent portion of the flight, the two SRBs burn out, separate from the ET, fall into the ocean, and are recovered for reuse. The ET remains attached to the Orbiter, providing propellants to the main engines for another six to seven minutes until the velocity is just short of orbital insertion. At this time, the engines are shut down and the ET is jettisoned for a controlled reentry and disposal. During reentry, the ET flies a ballistic trajectory until it breaks up due to aerodynamic heating. Tank debris falls into an ocean area predetermined by international treaties. After ET separation, the Orbital Maneuvering System (OMS) places the Orbiter into the desired orbit (an altitude between 100 and 500 nautical miles). For de-orbit, the Orbiter is rotated tail first in the direction of flight, then the OMS engines are used to decrease the Orbiter's velocity for reentry. After reentry, the unpowered Orbiter glides to Earth and lands on a runway like an airplane. Figure 1.2 shows a typical Shuttle launch and landing scenario.

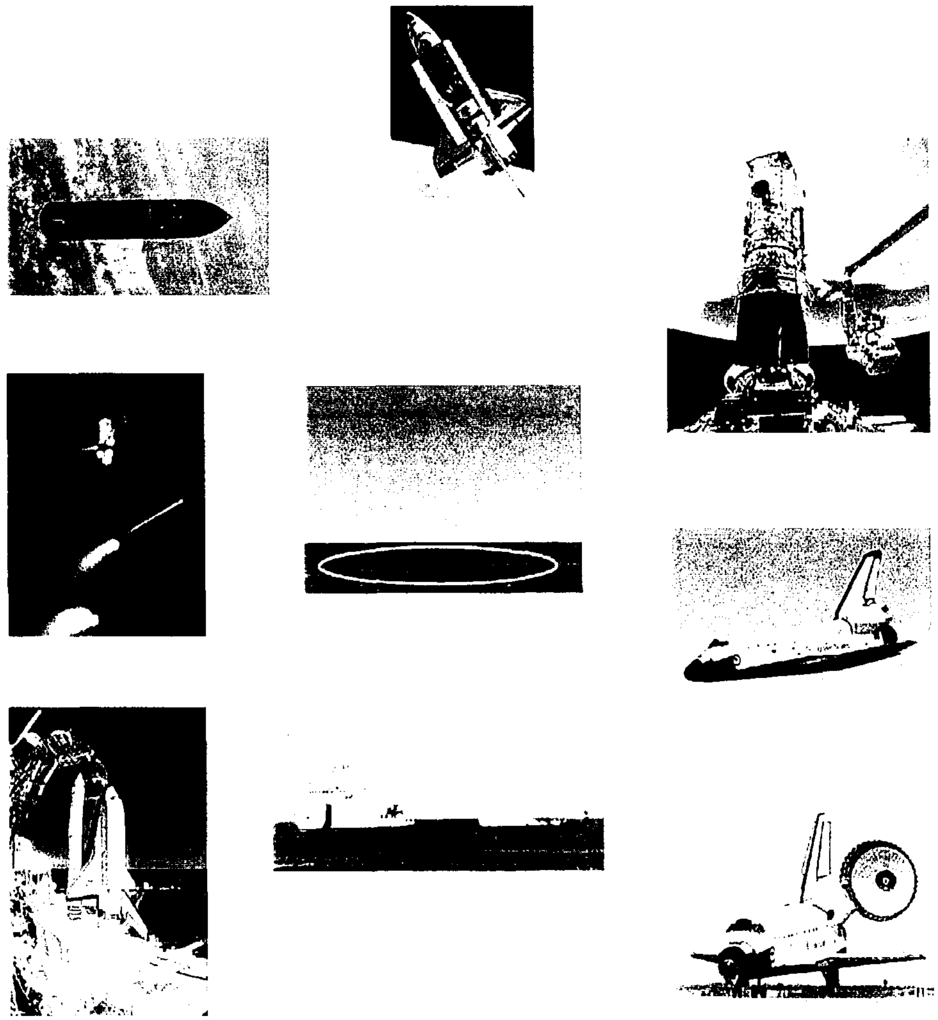

Figure 1.2 Space Shuttle Mission Sequence

2.0 SPACE SHUTTLE THERMAL PROTECTION SYSTEMS

2.1 OVERVIEW

The Space Shuttle uses a solid propellant, together with cryogenic fuels, to achieve the thrust required to lift it and its payload from the launch pad to orbit. The cryogenic fuels used are liquid oxygen (LO_2) and liquid hydrogen (LH_2). Since LO_2 and LH_2 boil at -300°F (149°C) and -423°F (-253°C) respectively, cryogenic insulation is required to support propellant loading, reduce heat input into the propellants, and maintain propellant quality. The primary structure and its subsystem components must remain within design temperature limits during prelaunch and ascent phases. As a result, major Shuttle elements require a thermal protection system (TPS).

2.2 ROLE OF THE BLOWING AGENT

Since the inception of the Shuttle program, spray and pour foam insulation systems have been used to satisfy NASA requirements for materials that can withstand the rigors of launch environments while not adding unacceptable weight. These materials utilize a chemical blowing agent to provide the critical insulation and cell structure properties of the foam. The formation of foam is due to a chemical reaction between two liquid components, an isocyanate and a polyol. The blowing agent is an integral part of this foam formulation. As the isocyanate and polyol are mixed together, a catalytic reaction generates heat, which causes the liquid blowing agent to evaporate creating an expanding cellular structure. In rigid foam insulation, the chemistry forms a closed cell structure, the properties of which vary greatly based on the type of polyol and blowing agent used. Other ingredients are added to the formulation to impart certain desirable foam characteristics. It is important to note that the extreme environments encountered during space flight require an insulation that is not typical of the commercial foam industry.

The foam blowing agent used on the ET at the inception of the SSP was CFC 11, a class I ozone depleting compound (ODC). CFC 11-based insulating foams had optimal thermal conductivity and good dimensional stability at a wide range of temperatures. Since environmental compliance and pollution prevention have been, and continue to be, ongoing priorities of the space program and the Space Shuttle production process, replacement blowing agent investigations were initiated far in advance of the December 1995 class I ODC phaseout. The SSP selected HCFC 141b to develop replacement foams for many reasons. It has a low heat of evaporation and an ideal boiling point that results in the formation of small, uniform and stable cells allowing the SSP to develop TPS capable of withstanding the rigors of space flight. It was both commercially available and proposed by major fluorocarbon manufacturers and polyurethane manufacturers. HCFC 141b proved to be viable in existing SSP foams and foam application processes, although significant challenges presented themselves in the development and implementation phases of material replacement.

2.3 ROLE OF THE FOAM

The TPS design is driven by a number of design requirements for natural environments and induced environments including pre-launch, ascent, and ET reentry environments. The role of the TPS in each environment is described below.

2.3.1 Natural Environments

After manufacture, SSP elements are transported to and within Kennedy Space Center (KSC) where they are stored, some for up to six years, until mated with the other Shuttle components. Once elements are mated and the vehicle is transported to the launch pad, Shuttle TPS foams must be able to endure a 180-day stay without performance degradation. The unsheltered environment to which these components may be exposed includes temperatures up to 115°F (46.1°C), humidity ranging from 8-100%, sand, dust, salt fog, rain, ozone, solar radiation and fungus.

2.3.2 Induced Environments

SSP foam is designed to withstand the induced environments imposed during transportation, ground operations, handling, storage, and flight operations. The environments, illustrated in Figure 2.1, include both thermal and mechanical loads from prelaunch, ascent, and reentry.

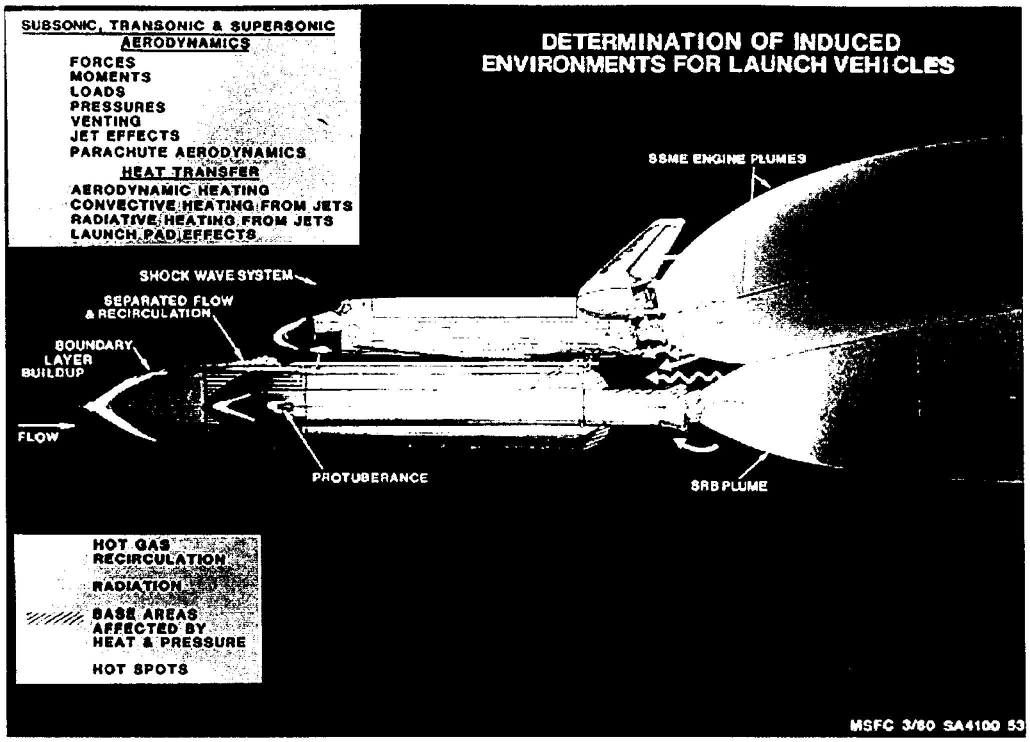

Figure 2.1 Space Shuttle Induced Environments

2.3.2.1 Prelaunch

The foam insulation thickness is primarily defined by the prelaunch requirements. Maintaining good quality/stable propellants and minimizing ice formation on the vehicle exterior are the primary considerations. In summary, prior to launch the TPS serves the following critical functions:

- Maintains LO_2 and LH_2 boil-off rates below the ET vent valve capabilities;
- Contributes to propellant loading accuracy and increased propellant densities;
- Maintains LO_2 and LH_2 at specified temperatures at the Orbiter/ET interface to ensure flow of propellant to shuttle main engines;
- Eliminates air liquefaction on the LH_2 tank;
- Minimizes ice formation on the ET exterior surfaces;
- Maintains environmental integrity of various assemblies and sensitive components.

2.3.2.2 Ascent

In the ascent phase, the TPS must maintain the primary structures and subsystem components within design temperature limits. For example, the Orbiter/ET umbilical 17-inch disconnect must be protected from the intense heat of ascent. The SRB strut assembly TPS must maintain a uniform crush condition to capture the ET/SRB connecting bolts as they are hurled by an explosive charge during the SRB separation maneuver. In the ET Attach Rings, the foam must endure the heat load of flight and remain in place to mitigate descent environments. The insulation must adhere firmly to the cryogenic tank surfaces under the synchronous loads induced during ascent to orbit. All SSP insulative foams must withstand the following loads:

- Static, dynamic and ambient pressures;
- Acoustic and vibrational loads;
- Cryoshrinkage;
- Ascent aerodynamic heating;
- SRB and main engine plume radiant and recirculation heatings;
- SRB separation motor plume heat impingement;
- Autogenous tank pressurization gas heating.

2.3.2.3 Reentry

Following ET separation from the Orbiter, the TPS is required to protect the ET structure from aerodynamic heating to prevent premature fragmentation at high altitudes. Another function of the TPS occurs during ET reentry when external temperatures and tank pressurization contribute to the ET fragmentation process. The residual TPS material must be adequate to provide the entry function to maintain the desired break-up footprint over a remote ocean location, protecting the population and avoiding established shipping lanes.

In the event of an emergency mission abort, the ET foam must ensure that structural temperatures are maintained to prevent ET break-up during emergency landing. Current flight rules require an intact ET and Orbiter to descend to 50,000 feet (15,000 meters). Separation of the ET occurs at 50,000 feet (15,000 meters) or above to prevent crew endangerment.

2.4 SPACE SHUTTLE TPS REQUIREMENTS

In order to survive hostile Shuttle service environments, insulating foams must meet stringent requirements. The following properties have been identified as critical to producing foam that satisfies these requirements.

Thermal Conductivity and Density

The most important material property that SSP insulating foams must meet is low thermal conductivity at a given density. This is achieved by increasing the percentage of blowing agent trapped in the foam cells, resulting in lower foam density. The density and the required foam thickness determine the weight of the foam on the ET, which also must be limited. The amount of space that foam on the Shuttle Orbiter can occupy is limited and hence, the foam must provide adequate thermal insulation while minimizing foam thickness.

Changes in these properties could have unacceptable consequences in the flight environments. An increase in density would increase the impact energy of ET foam debris; increased thermal conductivity would increase ice formation on the tank. Foam or ice debris emanating from critical areas of the ET would compromise Orbiter tile and windshield integrity and flight crew safety on ascent and reentry. Increased weight of the ET would compromise Shuttle performance reserves required to achieve high inclination trajectories for docking with the International Space Station. It is therefore necessary for material properties to be optimized within the constraints imposed by mission requirements. The required properties necessitate a foam formulation that can be consistently applied within critical application processes and stringent tolerances.

Recession Rate

Recession rate is the rate at which foam material decomposes and ablates from the foam surface at elevated temperatures. Foam recession rates must be controlled to protect the Shuttle vehicle during ascent. Shuttle TPS must withstand extreme radiant heating environments from the 3000°F (1650°C) SRB and 6000°F (3300°C) Space Shuttle Main Engine (SSME) plumes, as well as ascent aerodynamic heating temperatures of up to 2000°F (1100°C) during peak heating. It must also provide protection from SRB/SSME plume convective recirculation temperatures of up to 4000°F (2200°C). In addition to ascent requirements, resistance to reentry heating is necessary to maintain a limited ET debris footprint over an isolated ocean area.

Material Properties

SSP TPS possesses material properties that are unique to space launch vehicle requirements. The foam must not delaminate internally or debond from the substrate when the substrate is stressed to its yield point under Shuttle flight loads at -423°F (-253°C), while the external surface is exposed to temperatures in excess of 3000°F (1650°C). This requirement is necessary to prevent debris that could impact the Orbiter creating a Safety of Flight issue, or cause structural failure of the launch vehicle components. Foam insulation on all cryogenic surfaces must withstand expansion and contraction stresses associated with prelaunch and flight.

Structural material properties such as tensile strength and bond strength must be maintained over a substrate temperature range of -423°F (-253°C) to +300°F (149°C) to meet flight requirements. TPS must meet flammability and outgassing requirements for SSP materials specified in NASA Handbook 8060.1. Cured foams must be stable for six years under natural conditions.

Additionally, all TPS foams must be compatible with surrounding materials under all natural and induced environments. For example, SRB pour foams must have comparable density and thermal ablative properties as the surrounding spray foam. It must also adhere to substrates such as sealed cork, rubber, painted steel, painted aluminum and silicone sealants.

These properties are interdependent and are all related to the ability to perform under synchronous Shuttle loads during ascent and descent. The imposition of loads (shown in Figure 2.2) such as static pressure, dynamic pressure, ambient pressure, vibration loads, acoustic loads, cryoshrinkage, aeroheating, plume convective heating, and plume radiant heating on the foam proves to be the most critical aspect of determining whether a material is acceptable for Space Shuttle use. Unfortunately, no test facility can simultaneously recreate and accurately synchronize these load profiles. The complete suite of synchronous loads, and the materials' response to those loads, can only be experienced during actual Shuttle flights. Modifying SSP TPS is a complex process that cannot be fully anticipated by the qualification testing program, posing risks to the SSP.

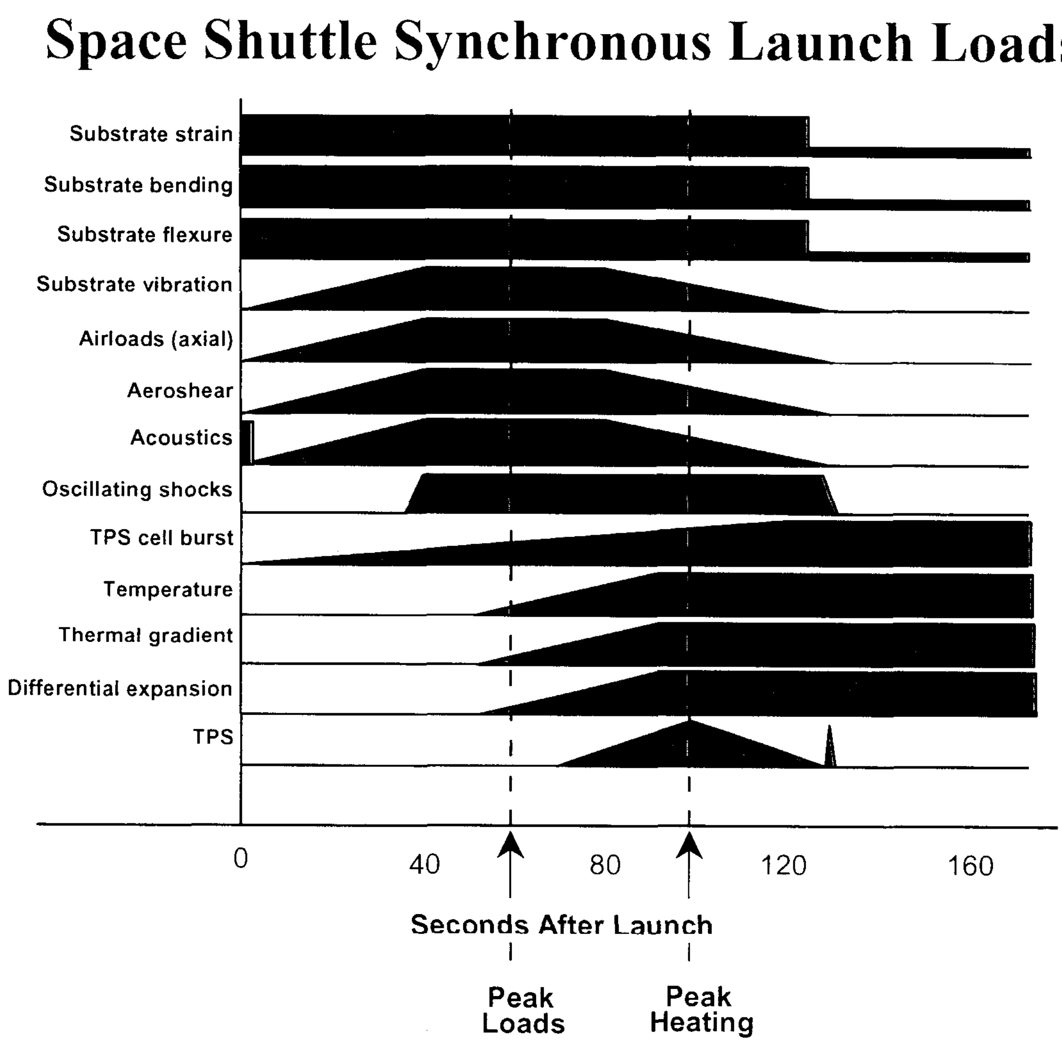

Figure 2.2 Space Shuttle Synchronous Launch Loads

3.0 Shuttle Use of Foam Insulation

The three major Space Shuttle system elements require TPS. Table 3.1 shows the amount of HCFC 141b procured for the Shuttle as part of TPS foam systems for the years 2000 - 2002. Foam usage is flight rate dependent. The HCFC 141b amounts listed in the table supported an average of five flights annually. The SSP must maintain the capability to increase the flight rate to 9 flights per year if necessary to support the International Space Station and other missions. An annual allowance of 40,000 lbs (18,000 kg) of HCFC 141b would provide that capability.

Year	HCFC 141b Procured *Pounds (Kilograms)*
2000	28,001 lbs (12,701 kg)
2001	17,015 lbs (7,718 kg)
2002	27,905 lbs (12,657 kg)

Table 3.1 Space Shuttle Procurement of HCFC 141b, 2000 – 2002

Although the entire Shuttle system is subjected to the loads described in Section 2.4, each element has unique characteristics that must be reflected in TPS formulations. The sections below present a technical description of each area requiring HCFC 141b blown foam and the application processes. A more detailed description of areas and specific parts requiring foam is given in the Appendix.

3.1 ET USES OF HCFC 141B BLOWN FOAM

At 154 feet (47 meters) in length and nearly 28 feet (9 meters) in diameter, the ET is the largest element of the Space Shuttle system and requires the most foam insulation. As shown in Figure 3.1, it is made up of three primary structures: a LO_2 tank, a LH_2 tank, and an intertank that connects the two and provides the forward attachment points for the SRBs. As mentioned in the Shuttle overview, the ET has two major roles: to contain and deliver liquid propellants to the main engines, and to serve as the structural backbone for the attachment of the Orbiter and SRBs. It must accommodate the complex stresses created by its own weight and that of the Orbiter prior to launch, then the thrust generated by the Orbiter and SRBs during launch. When loaded with propellants at launch, the ET alone weighs approximately 1,674,000 pounds (759,300 kilograms).

The ET requires a TPS to maintain the cryogenic propellant quality, to protect the structure from ascent and plume heating, and to minimize ice/frost formation. The TPS is applied to most of the exterior surface, covering 16,750 square feet (1,556 square meters) and accounting for approximately 4,000 pounds (1,800 kilograms) of the ET weight. This TPS system consists of four low-density polyurethane and polyurethane-modified isocyanurate foams that are specialty products engineered to meet numerous stringent technical requirements so as to perform flawlessly in the adverse and unique Space Shuttle environments.

Three of the four insulating foams are spray foams; the fourth is poured in place. The primary spray foam material is an HCFC 141b blown closed cell rigid sprayed foam system with higher temperature stability than conventional urethane foams. It accounts for approximately 77% of the total foam insulation used on the ET. Another sprayed foam, used on approximately 7% of the tank, provides improved radiant recession properties for the aft dome engine plume heat environment. These foam materials are low density, two-component liquid high-index urethane modified isocyanurate systems that are applied to the ET structure by automated spray equipment. The application is tightly controlled to meet requirements for finish, thickness, roughness, waviness, density, strength and adhesion. They are applied in specially designed, environmentally-controlled spray cells. The third spray foam is also a two-part liquid urethane system, but does not require the same high temperature processing constraints. Although there are prescribed temperature parameters for this foam, application can be accomplished in most of the ET factory temperature and humidity environments. The fourth foam, a manually mixed pour foam, is used to make small repairs, close out small areas, and to manufacture ice/frost prevention ramps.

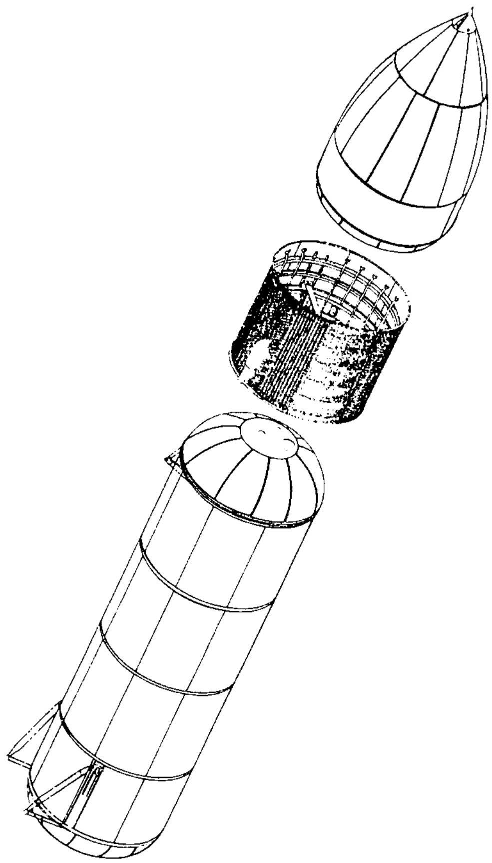

Figure 3.1 Structure of the External Tank

Processing of the large acreage foam requires controlled spray cell temperature and relative humidity. For this application, the tank structure is positioned vertically on a turntable, rotated at the appropriate speed. The "A" and "B" urethane components are heated and supplied to a spray gun. Mixing of the two heated components occurs inside the spray gun mixing chamber. Within seconds of being mixed, the two liquid components begin an exothermic reaction that causes the blowing agent to boil, resulting in a foam mixture that is sprayed onto the rotating tank structure. The entire process of foam application to these large structures is automated and computer controlled.

The second spray foam is used only on the aft LH_2 dome. This is the most difficult application process. The rotation speed of the tank, the speed of the spray gun, and the spray foam flow rate are all interrelated and computer controlled. After the foam application process, the major ET structures are mated together, as illustrated in Figure 3.2.