Reusable TPS
Space Shuttle Orbiter

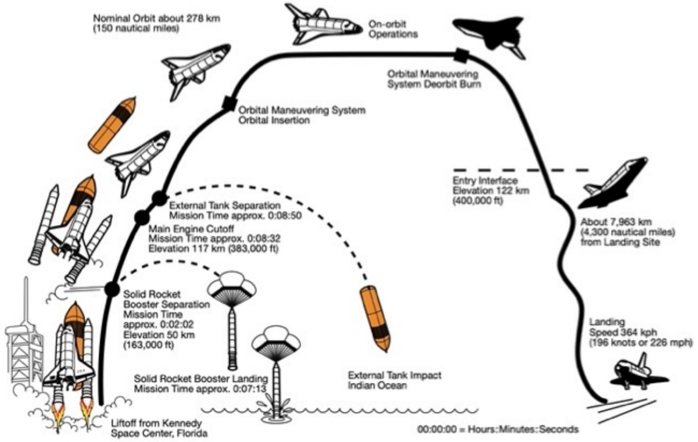
Prepared in Support of AM TPS Workshop

E. Venkatapathy and S. Bouslog

2/2/2022

First Reusable Reentry System - Space Shuttle Orbiter

- The first reusable system
- Original requirements were:
  - Reusable for up to 100 flights
  - Rapid turn around
  - High reliability and low vulnerability to orbital debris
  - Mass efficient, low maintenance and cost-effective refurbishment
- Two most significant technology developments required were:
  - Propulsion
  - Thermal Protection System
  - −121 °C (−186 °F) in space - 1,649 °C (3,000 °F) to during entry



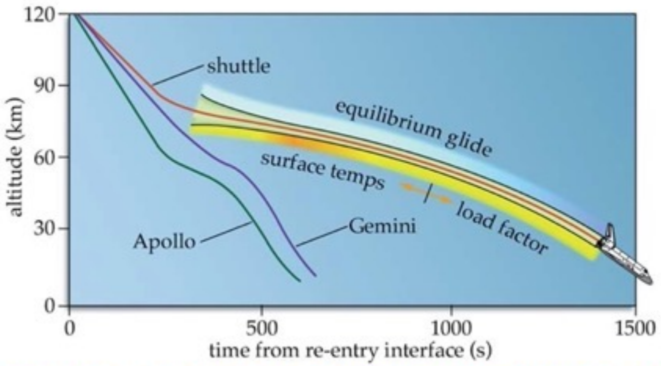


Figure 4.1.7-25. Re-entry Profiles for the Shuttle Versus Gemini and Apollo. This graph shows the difference between re-entry profiles for Apollo, Gemini, and the Space Shuttle. Notice Gemini and Apollo re-entered much more steeply than the Space Shuttle. The Shuttle's re-entry profile must stay within a tight corridor between equilibrium glide, which ensures it will slow enough to avoid skipping out and not over shoot the runway, and surface temperature/load factor requirements, which determine maximum heating and deceleration.

https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/cami/library/online_libraries/aerospace_medicine/tutorial/media/III.4.1.7_Returning_from_Space.pdf

Shuttle Lifting Entry Trajectory and Reusable TPS Challenge

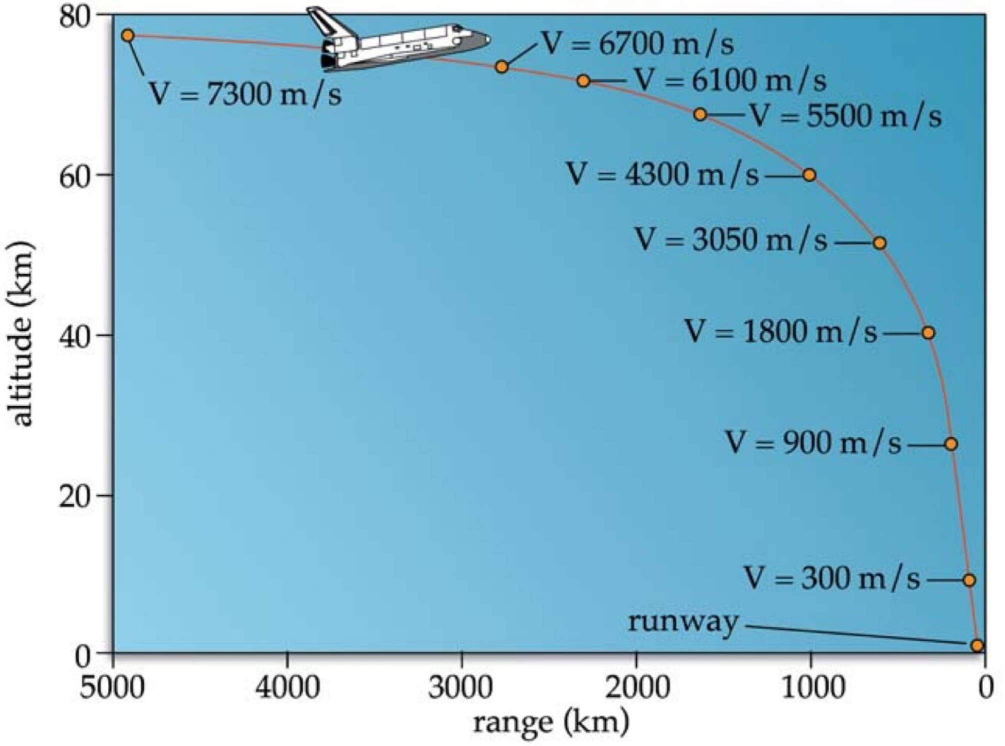
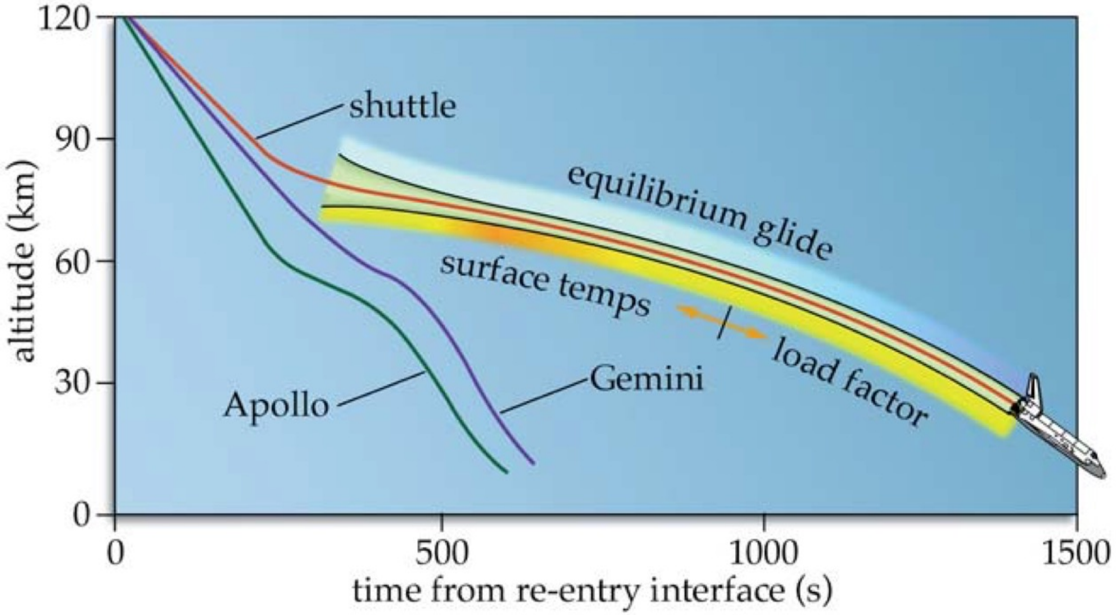


Figure 4.1.7-24. Re-entry Profile for the Space Shuttle. This graph shows the Space Shuttle's altitude and velocity profile for a typical re-entry.



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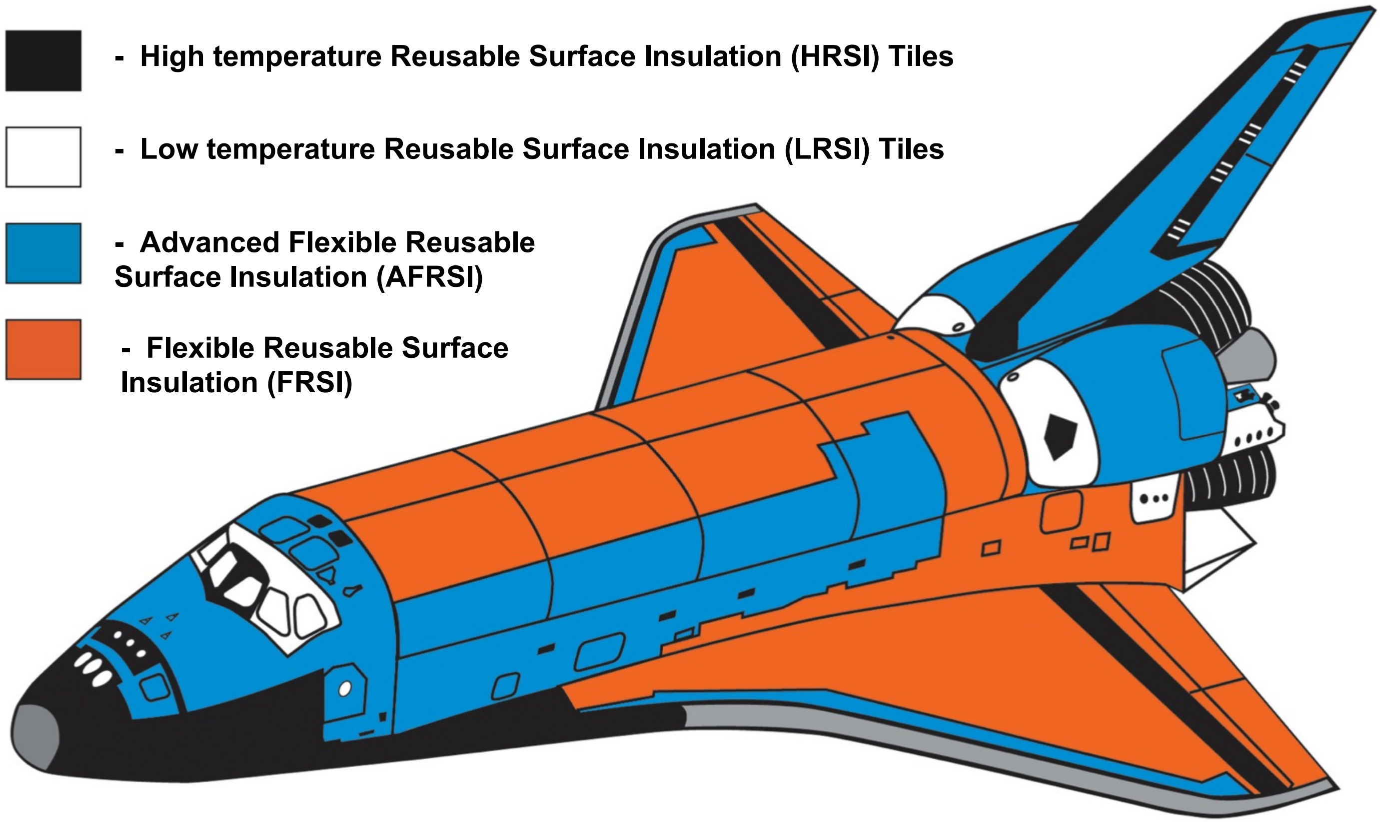
Shuttle TPS

- Reinforced Carbon-Carbon (RCC)
- High temperature Reusable Surface Insulation (HRSI) Tiles
- Low temperature Reusable Surface Insulation (LRSI) Tiles
- Advanced Flexible Reusable Surface Insulation (AFRSI)
- Flexible Reusable Surface Insulation (FRSI)



Number of Tiles and Blankets

High-Temperature Reusable Surface Insulation (HRSI) tiles

22-pound-per-cubic-foot =	525
9-pound-per-cubic-foot =	20,000

Reinforced Carbon-Carbon (RCC) panels or segments 57

Fibrous Refractory Composite Insulation (FRCI) tiles*

12-pound-per-cubic-foot =	2,950

Low-Temperature Reusable Surface Insulation (LRSI) tiles

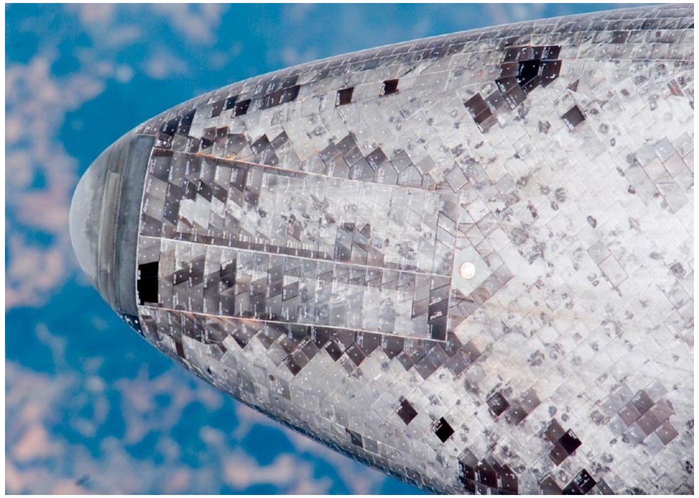
9-pound-per-cubic-foot =	725
12-pound-per-cubic-foot =	77**

Flexible Insulation Blankets (FIBs) = 2,300

Felt Reusable Surface Insulation (FRSI) = 975***

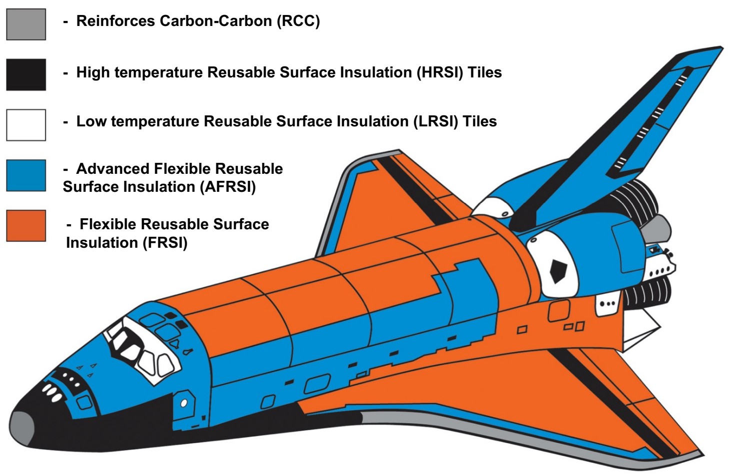
* Not shown is FRCI. The tiles are limited to isolated areas.

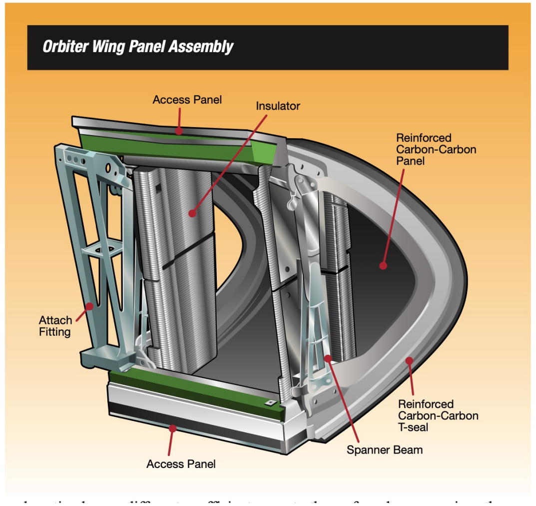
Shuttle TPS: Complex in many ways



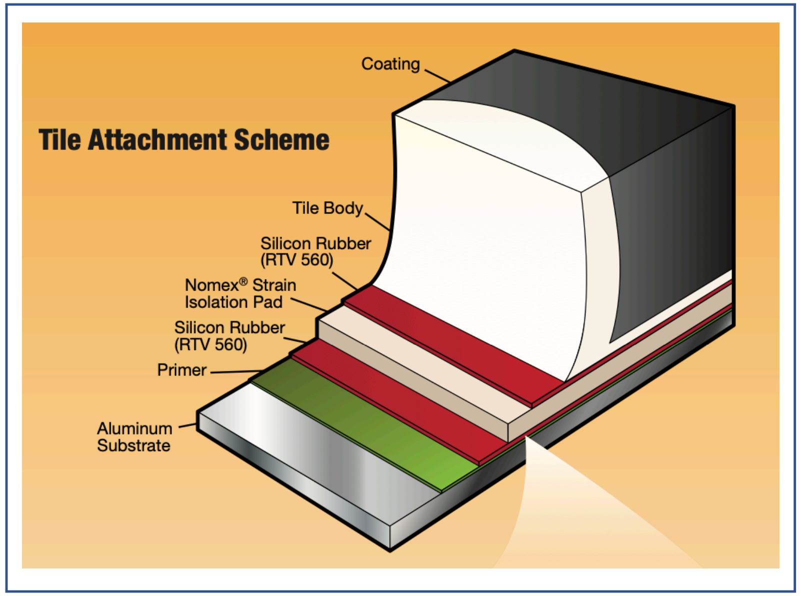
Reinforced Carbon-Carbon - Nose and Wing Sections

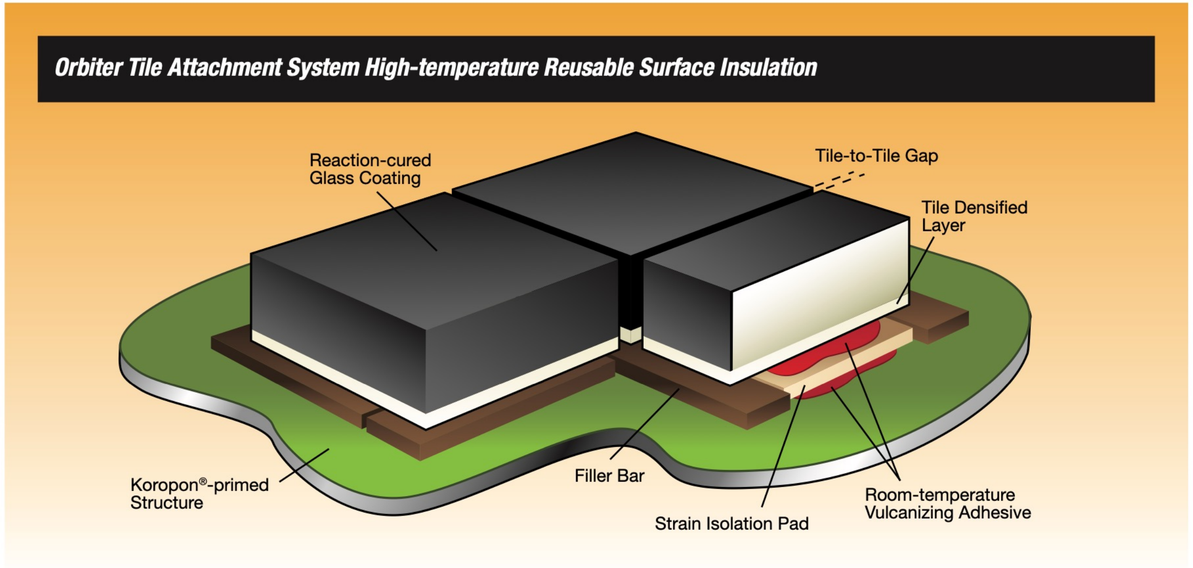
- Nose cap and Wing leading edge needed to withstand extreme temperature of reentry, maintain its shape and **be reusable**.
- Vought Corporation, Dallas, Texas, in collaboration with NASA, developed the reinforced carbon-carbon (RCC)
- Reinforced carbon-carbon is a composite made by curing graphite fabric that has been pre-impregnated with phenolic resin laid up in complex shaped molds. The resin polymer is converted to carbon by pyrolysis.
- Since carbon oxidizes at elevated temperatures, a silicon carbide coating is used to protect the carbon substrate.
- The parts are designed as a shell section with an open interior cavity that promotes cross-radiation from the hotter bottom to the top surface.
- RCC with excellent surface emissivity can reject heat by radiating to space.





Shuttle HRSI LI-900 & LI 2200 (same as AIM-9, 12, 22)



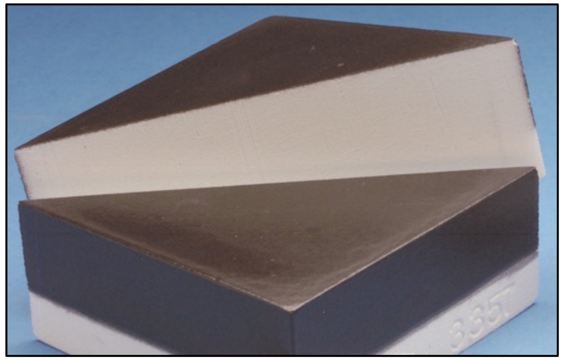


Shuttle era HRSI LI-900 tile

Coatings (RCG) and Surface Treatment (TUFI)

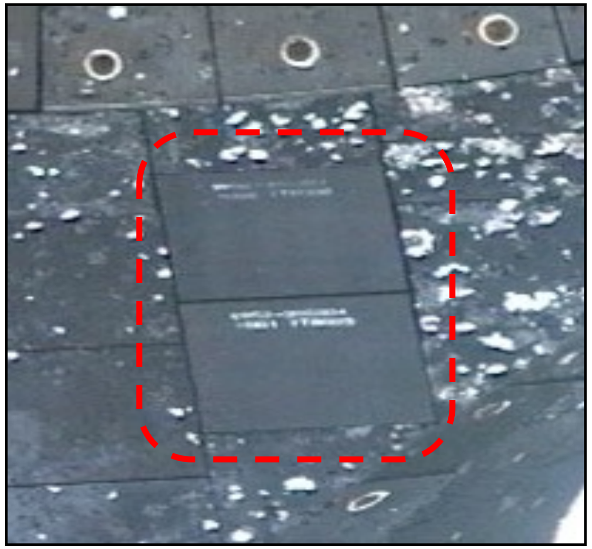
Coatings and Surface Treatments improve performance and for water proofing.

- **Coatings:** Applied on top of a material, forming a separate layer
- **Surface Treatments:** Applied into a material, forming an integrated or composite material



Reaction Cured Glass (RCG):

- Black coating consisting of silicon boride and borosilicate glass. Typically applied to all but one side of the tile to protect the porous silica. RCG is very effective on silica-based tiles up to ~2800° F.



Toughened Uni-piece Fibrous Insulation:

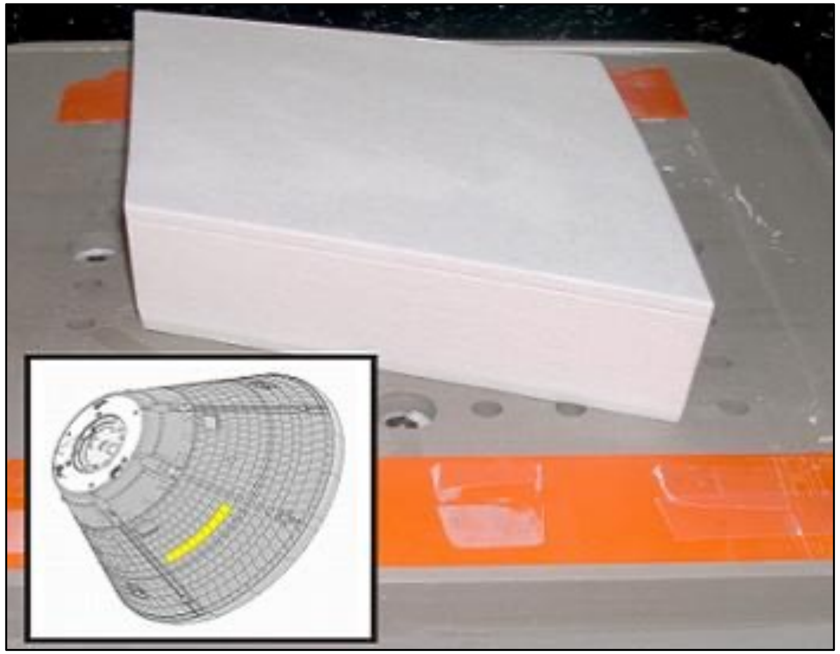
- Consists of borosilicate glass (B_2O_3/SiO_2), silicon boride (SiB_x), and molybdenum disilicide ($MoSi_2$), yielding a stronger, tougher silica tile.
- Standard TUFI tiles were used on the Shuttle Orbiter's underside. White variants with higher impact resistance and conductivity were used on the upper body.

Fibrous Refractory Composite Insulation [FRCI-8, -12, -20]
FRCI replaced HRSI tiles where damage had been an issue.

- **Reusable, higher strength aluminoborosilicate tile.**
- Improved durability and resistance to coating cracking and weight reduction.
- Good insulator consisting of Nextel® fibers, and silica fibers.
- Substrate has 95% - 96% porosity.
- Low density –
  - FRCI-12 has a density of 0.17-0.21 g/cc.
- Acreage areas expecting low to moderate heat fluxes where high strength is required.
- Leading edge candidate for lower heat flux sub-orbital missions. Use up to ~2400 °F.

Alumina Enhanced Thermal Barrier [AETB-8, -12, -17, -20]

- Reusable, higher temperature capable, stronger & dimensionally stable
- Consists of Nextel® fibers, alumina fibers, silica fibers, and silicon carbide.
- Very tunable to complex geometries.
- Substrate has 94 - 95% porosity.
- AETB-8 (0.13-0.15) g/cc.
- AETB-12 (0.17-0.21) g/cc.
- Acreage areas for moderate heat fluxes.
- Leading edge candidate for sub-orbital missions with low to moderate heat flux. Use up to ~2600 °F.
- Substrate for TUFI tiles on Space Shuttle and Orion Backshell.



Blankets and Felts

Advanced Flexible Reusable Surface Insulation (AFRSI)

- AFRSI consists of a low-density fibrous silica batting that is made up of high-purity 99.8-percent amorphous silica fibers (1 to 2 mils thick).
- This batting is sandwiched between an outer woven silica high-temperature fabric and an inner woven lower temperature fabric.
- The blankets are cut to the planform shape required and bonded directly to the orbiter by RTV silicon adhesive. Quilted blankets replaced most of the white tiles on the topside of the vehicle. Protects most of the Space Shuttle fuselage, upper wings, and vertical tail.

Felt Reusable Surface Insulation (FRSI)

- FRSI is a felt material made from needled polyaramid fibers and used in upper payload bay doors, portions of the mid-fuselage, aft-fuselage sides, portions of the upper wing surface and portions of the OMS/RCS pods.
- The FRSI blankets protect areas where temperatures are below 700 F.