



**SLOVENSKI STANDARD**  
**kSIST-TP FprCEN/CLC/TR 17603-31-16:2021**  
**01-maj-2021**

---

**Vesoljska tehnika - Priročnik za toplotno zasnovno - 16. del: Sistem toplotne zaščite**

Space Engineering - Thermal design handbook - Part 16: Thermal Protection System

Raumfahrttechnik - Handbuch für thermisches Design - Teil 16: Wärmeschutzsystem

Ingénierie spatiale - Manuel de conception thermique - Partie 16: Protection Thermique des véhicules spatiaux

**(standards.iteh.ai)**

**Ta slovenski standard je istoveten z: FprCEN/CLC/TR 17603-31-16**

[kSIST-TP FprCEN/CLC/TR 17603-31-16:2021](https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-f1dec5f1ea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021)

<https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-f1dec5f1ea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021>

---

**ICS:**

49.140 Vesoljski sistemi in operacije Space systems and operations

**kSIST-TP FprCEN/CLC/TR 17603-31-16:2021** en,fr,de

**iTeh STANDARD PREVIEW**  
**(standards.iteh.ai)**

[kSIST-TP FprCEN/CLC/TR 17603-31-16:2021](https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-fdec5fdea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021)  
<https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-fdec5fdea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021>

TECHNICAL REPORT  
RAPPORT TECHNIQUE  
TECHNISCHER BERICHT

**FINAL DRAFT**  
**FprCEN/CLC/TR 17603-31-16**

March 2021

ICS 49.140

English version

## Space Engineering - Thermal design handbook - Part 16: Thermal Protection System

Ingénierie spatiale - Manuel de conception thermique -  
Partie 16: Protection Thermique des véhicules  
spatiaux

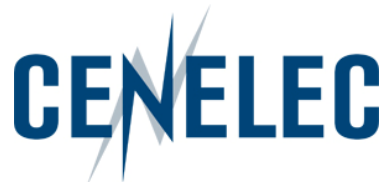
Raumfahrttechnik - Handbuch für thermisches Design -  
Teil 16: Wärmeschutzsystem

This draft Technical Report is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

**Warning** : This document is not a Technical Report. It is distributed for review and comments. It is subject to change without notice and shall not be referred to as a Technical Report.



**CEN-CENELEC Management Centre:  
Rue de la Science 23, B-1040 Brussels**

## Table of contents

<b>European Foreword</b> .....	<b>5</b>
<b>1 Scope</b> .....	<b>6</b>
<b>2 References</b> .....	<b>7</b>
<b>3 Terms, definitions and symbols</b> .....	<b>8</b>
3.1 Terms and definitions .....	8
3.2 Abbreviated terms.....	8
<b>4 Introduction</b> .....	<b>9</b>
4.1 General.....	9
4.2 Classification of thermal protection systems .....	10
<b>5 Ablative systems</b> .....	<b>14</b>
5.1 General.....	14
5.2 Ablative materials .....	14
5.3 Basic analysis .....	15
5.3.1 Surface equilibrium .....	16
5.4 Existing systems.....	19
5.4.1 Galileo probe.....	19
<b>6 Radiative systems</b> .....	<b>23</b>
6.1 General.....	23
6.2 Radiative materials .....	23
6.3 Existing systems.....	24
6.3.1 Space shuttle .....	24
6.4 Other developments .....	35
6.4.1 X-38 .....	35
<b>Bibliography</b> .....	<b>54</b>
<b>Figures</b>	
Figure 4-1: Velocity-altitude map for the Space Shuttle. Lifting re-entry from orbit.....	9
Figure 4-2: Summary of re-entry trajectories. From East (1991) [6]. .....	10

Figure 4-3: Sketch of an ablative thermal protection system.....	11
Figure 4-4: Sketch of a radiative thermal protection system.....	11
Figure 4-5: Sketch of a transpiration thermal protection system. ....	12
Figure 4-6: Typical transpiration cooling system .....	13
Figure 5-1: Surface energy balance.....	17
Figure 5-2: Galileo entry probe. ....	20
Figure 5-3: Physical model and phenomena considered in material response analysis .....	20
Figure 5-4: Temperature history at interfaces. ....	22
Figure 5-5: Comparison of mass loss fluxes. ....	22
Figure 6-1: Worst case peak predicted surface temperatures. [K] for STS-1. From Dotts et al. (1983) [5]. ....	25
Figure 6-2: Worst case peak predicted structure temperatures. [K] for STS-1. From Dotts et al. (1983) [5]. ....	25
Figure 6-3: Thermal protection subsystems. From Dotts et al. (1983) [5]. ....	26
Figure 6-4: RCC system components. From Curry et al. (1983) [3]. ....	27
Figure 6-5: Nose cap system components. From Curry et al. (1983) [3]. ....	27
Figure 6-6: Wing leading-edge system components. From Curry et al. (1983) [3]. ....	28
Figure 6-7: Tile attachment and gap filler configuration. From Dotts et al. (1983) [5]. ....	29
Figure 6-8: Nose cap RCC surface comparison between prediction and flight data. From Curry et al. (1983) [3]. ....	30
Figure 6-9: Nose cap access door tile surface comparison between prediction and flight data. From Curry et al. (1983) [3]. ....	30
Figure 6-10: Wing leading-edge panel (stagnation area). Comparison between prediction and flight data. From Curry et al. (1983) [3]. ....	31
Figure 6-11: STS-1 flight data analysis comparison for lower mid-fuselage location. From Dotts et al. (1983) [3]. ....	31
Figure 6-12: STS-1 flight data analysis comparison for lower wing location. From Dotts et al. (1983) [3]. ....	32
Figure 6-13: STS-1 flight data analysis comparison for lower inboard elevon location. From Dotts et al. (1983) [3]. ....	32
Figure 6-14: STS-1 flight data analysis comparison for lower mid-fuselage side location. From Dotts et al. (1983) [3]. ....	33
Figure 6-15: Comparison of STS-2 data with analytical predictions. From Normal et al. (1983) [11]. ....	33
Figure 6-16: Comparison of STS-2 data with analytical predictions. From Normal et al. (1983) [11]. ....	34
Figure 6-17: Comparison of STS-2 data with analytical predictions. From Normal et al. (1983) [11]. ....	34
Figure 6-18: In-depth comparison of STS-2 data with analytical predictions for maximum temperatures. From Normal et al. (1983) [11]. ....	35
Figure 6-19: X-39 TPS Configuration.....	36
Figure 6-20: X-38 Reference Heating .....	36

**FprCEN/CLC/TR 17603-31-16:2021 (E)**

Figure 6-21: CMC Side Panels together with lower CMC Chin Panel .....	37
Figure 6-22: Stand-off Position and Global Design .....	38
Figure 6-23: Stand-off Positions and Global Design .....	39
Figure 6-24: Max. Pressure Load .....	40
Figure 6-25: Max. Thermal Load at Panel Surface .....	40
Figure 6-26: Nose Skirt Assembly with Insulation Blankets .....	41
Figure 6-27: Max. and min. Heat flux time lines applied on the NSK.....	41
Figure 6-28: Simplified description of heat transfer modes within the nose skirt assembly.....	42
Figure 6-29: Temperature distribution over a NSK side panel at t = 1100s.....	44
Figure 6-30: Carrier Panel TPS Design .....	45
Figure 6-31: X-38 Aeroshell Panel and Blanket Distribution .....	46
Figure 6-32: X-38 Parafoil System.....	46
Figure 6-33: Parafoil Line Routing and Acreage Blankets.....	46
Figure 6-34: FEI-450 Blanket equipped with Gray FEI-1000High Emittance Coating.....	47
Figure 6-35: Typical look of FEI-650 and Blanket with Gray High Emittance .....	47
Figure 6-36: Allocation of Blanket Types to the X-38 Lee-Side Surface.....	49
Figure 6-37: Qualification Test Sequence for X-38 .....	50
Figure 6-38: Parameters and Results of the Qualification Tests .....	50
Figure 6-39: Computer controlled sewing of FEI blankets.....	52
Figure 6-40: FEI-1000 blankets of the Forward Fuselage.....	52
Figure 6-41: FEI Blankets Integrated on the X-38 V-201 .....	53

## European Foreword

---

This document (FprCEN/CLC/TR 17603-31-16:2021) has been prepared by Technical Committee CEN/CLC/JTC 5 "Space", the secretariat of which is held by DIN.

This document is currently submitted to the Vote on TR.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-31.

This Technical report (FprCEN/CLC/TR 17603-31-16:2021) originates from ECSS-E-HB-31-01 Part 16A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

<https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-f1e5f1ea09a/kSIST-TP-FprCEN-CLC-TR-17603-31-16-2021>

**This document is currently submitted to the CEN CONSULTATION.**

# 1

## Scope

---

The thermal protection system (TPS) of a space vehicle ensures the structural integrity of the surface of the craft and maintains the correct internal temperatures (for crew, electronic equipment, etc.) when the vehicle is under the severe thermal loads of re-entry. These loads are characterised by very large heat fluxes over the relatively short period of re-entry.

The design of thermal protection systems for re-entry vehicles is very complex due to the number and complexity of phenomena involved: the flow around the vehicle is hypersonic, tridimensional and reactive, and its interaction with the vehicle's surface may induce chemical reactions which are not fully understood.

Two TPS concepts for re-entry vehicles, ablative and radiative are examined and there is also an analysis of existing systems using them.

iteh STANDARD PREVIEW  
(standards.iteh.ai)

The Thermal design handbook is published in 16 Parts

TR 17603-31-01	Thermal design handbook – Part 1: View factors
TR 17603-31-02	Thermal design handbook – Part 2: Holes, Grooves and Cavities
TR 17603-31-03	Thermal design handbook – Part 3: Spacecraft Surface Temperature
TR 17603-31-04	Thermal design handbook – Part 4: Conductive Heat Transfer
TR 17603-31-05	Thermal design handbook – Part 5: Structural Materials: Metallic and Composite
TR 17603-31-06	Thermal design handbook – Part 6: Thermal Control Surfaces
TR 17603-31-07	Thermal design handbook – Part 7: Insulations
TR 17603-31-08	Thermal design handbook – Part 8: Heat Pipes
TR 17603-31-09	Thermal design handbook – Part 9: Radiators
TR 17603-31-10	Thermal design handbook – Part 10: Phase – Change Capacitors
TR 17603-31-11	Thermal design handbook – Part 11: Electrical Heating
TR 17603-31-12	Thermal design handbook – Part 12: Louvers
TR 17603-31-13	Thermal design handbook – Part 13: Fluid Loops
TR 17603-31-14	Thermal design handbook – Part 14: Cryogenic Cooling
TR 17603-31-15	Thermal design handbook – Part 15: Existing Satellites
TR 17603-31-16	Thermal design handbook – Part 16: Thermal Protection System



## 2 References

---

EN Reference	Reference in text	Title
EN 16603-00-01	ECSS-S-ST-00-01	ECSS System - Glossary of terms

All other references made to publications in this Part are listed, alphabetically, in the **Bibliography**.

### iTeh STANDARD PREVIEW (standards.iteh.ai)

[kSIST-TP FprCEN/CLC/TR 17603-31-16:2021  
https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-  
fdec5fdea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021](https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-fdec5fdea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021)

## Terms, definitions and symbols

---

### 3.1 Terms and definitions

For the purpose of this Standard, the terms and definitions given in ECSS-S-ST-00-01 apply.

### 3.2 Abbreviated terms

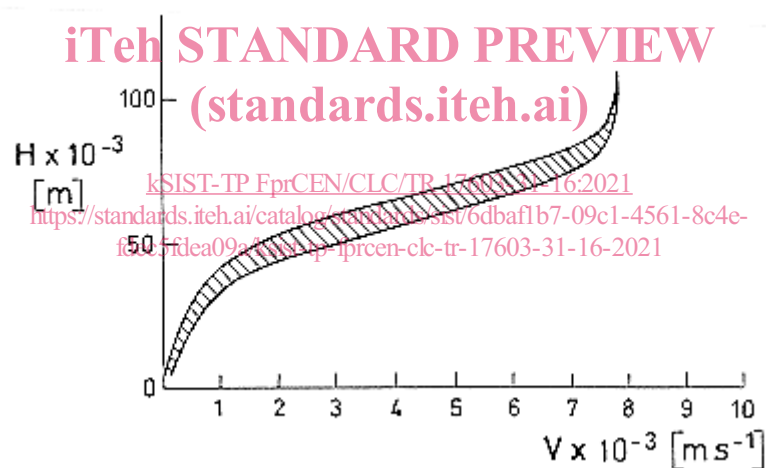
The following abbreviated terms are defined and used within this Standard.

<b>CAD</b>	computer aided design
<b>CFD</b>	computational fluid dynamics
<b>CMC</b>	ceramics matrix composite
<b>C/SiC</b>	carbon reinforced silicon carbide
<b>FEI</b>	flexible external insulation
<b>FRSI</b>	flexible reusable surface insulation
<b>HTI</b>	high temperature insulation
<b>HRSI</b>	high-temperature reusable surface insulation
<b>IFI</b>	internal flexible insulation
<b>LRSI</b>	low-temperature reusable surface insulation
<b>RCC</b>	reinforced carbon-carbon
<b>RSI</b>	reusable surface insulation
<b>SIP</b>	strain isolation pad
<b>SOML</b>	structural outer mold line
<b>TOML</b>	TPS outer mold line
<b>TPS</b>	thermal protection system

## 4.1 General

The thermal protection system (TPS) of a space vehicle consists of those elements needed to protect the structural integrity of the vehicle's surface and maintain the appropriate internal temperatures (for crew, electronic equipment, etc.) when the vehicle is under the severe thermal loads of re-entry. These loads are mainly characterised by very large heat fluxes during relatively short times.

The heat fluxes acting on the TPS are so large because of the great speeds of re-entry vehicles. The velocity-altitude map for the Space Shuttle is represented in Figure 4-1.



**Figure 4-1: Velocity-altitude map for the Space Shuttle. Lifting re-entry from orbit.**

The heat fluxes and the time of re-entry are basically determined by the re-entry orbit. These orbits are designed so that the vehicle is captured by the planet and the payload is not damaged by the accelerations; these factors greatly restrict the number of valid trajectories. However, for lifting vehicles which can be manoeuvred those restrictions are alleviated, and re-entry trajectories, other than ballistic, can be achieved. In Figure 4-2 the heat fluxes and re-entry times for different trajectories are summarised.

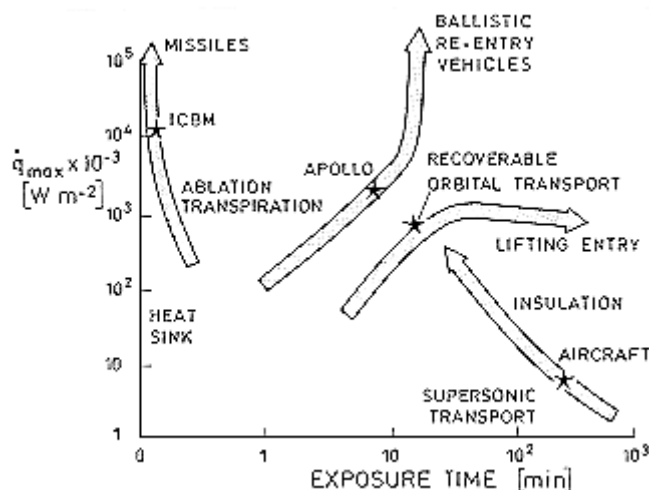


Figure 4-2: Summary of re-entry trajectories. From East (1991) [6].

The design of thermal protection systems for re-entry vehicles is a very complex problem due to the number and complexity of phenomena involved. It suffices to mention here that the flow around the vehicle is hypersonic, tridimensional and reactive, and its interaction with the vehicle's surface may induce chemical reactions which are not fully understood.

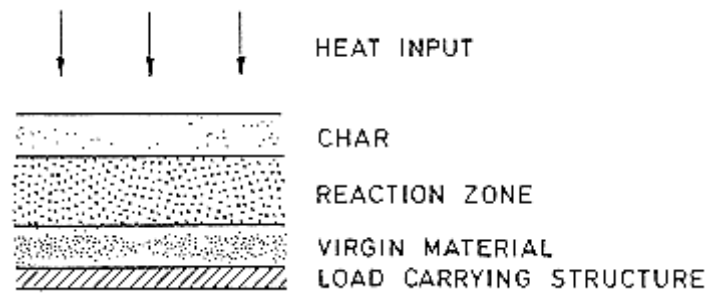
## 4.2 Classification of thermal protection systems

Generally speaking the TPS consists of a material system (shield and/or load carrying member) operating on a given heat dissipation principle. There are several TPS concepts for re-entry vehicles (Hurwicz & Rogan (1973a) [9]):

- Ablative thermal protection
- Radiative thermal protection
- Heat sinks
- Transpiration cooling

### ABLATIVE SYSTEMS

Ablative systems operate dissipating the incident thermal energy through the loss of material: these systems lose mass as a consequence of the ablation of the external surface material. They have good thermal characteristics since phase changes absorb a large amount of energy. These systems are not reusable. See Figure 4-3 for a sketch of an ablative system.

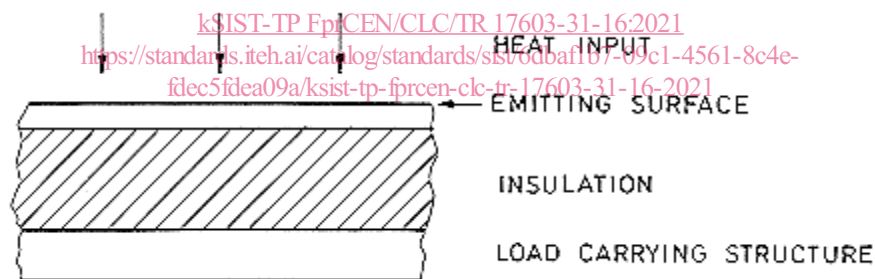


**Figure 4-3: Sketch of an ablative thermal protection system.**

The ablation process is quite complex and is described in some detail in clause 5.2. One important consequence of the analysis of these systems is that their efficiency is particularly sensitive to material performance. Therefore, it is necessary to treat the subject of materials in detail. In the absence of a universally acceptable ablative material a wide variety of ablative compositions and constructions have been produced, usually tailored to satisfy the requirements of a specific vehicle for a specific mission. A detailed description of ablative materials is given in clause 5.3.

#### RADIATIVE SYSTEMS

Radiative systems operate re-emitting by radiation the energy received from the surrounding environment. They are composed of two layers: an outer layer which consists of a material that can stand the radiation equilibrium temperature and an inner layer which insulates the outer layer from the structure in order to minimise the heat flow between the two, see Figure 4-4.



**Figure 4-4: Sketch of a radiative thermal protection system.**

It will be seen in clause 6.1 that the effectiveness of a radiative system increases very rapidly with increasing surface temperature and surface emissivity. Consequently, the primary development efforts have been concerned with the improvement of high emissivity, high temperature coatings, and with increasing the material service temperatures (including that of the internal insulation). A detailed description of materials used in radiative systems is given in clause 6.2.

These systems can be designed including a cooling subsystem: this is a fluid loop where the working fluid transports heat from the areas where the heat flux is stronger to those where the heat flux is weaker. The actual mechanism for heat transport can be the same as in heat pipes, the fluid is vaporised in areas of higher temperatures, and it is condensed in areas of lower temperatures. However, even though the characteristics of these systems are good, they are not used in practice.

**FprCEN/CLC/TR 17603-31-16:2021 (E)****HEAT SINK THERMAL PROTECTION SYSTEM**

A heat sink is the simplest type of absorptive thermal protection system. It was used in the design of the early re-entry vehicles (e.g. the first two manned Mercury vehicles).

These systems are composed of an outer layer, comparatively thick, which consists of a material of high conductivity and capacitance. The function of this layer is to absorb the heat input. Since the material heats up, the storage capability is limited by the melting temperature.

Its use is limited to relatively low heating rates and therefore may not be practical for the high heat loads encountered in short re-entry times.

Heat sinks have the advantages of simplicity, dependability, and for reusable vehicles, ease of refurbishment. Their outstanding disadvantage is their low efficiency, this would cause a heat sink sized to satisfy most current re-entry missions to be excessively heavy.

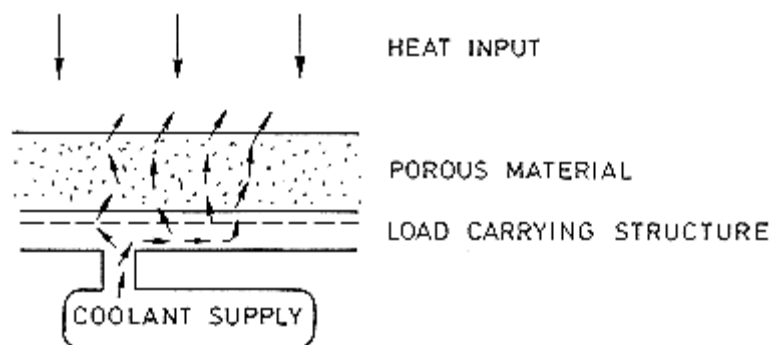
Materials commonly used as heat sinks are

- beryllium
- beryllium oxide (beryllia)
- copper.

Graphite has many desirable heat sink characteristics, but begins to oxidise at temperatures far below those required for best efficiency.

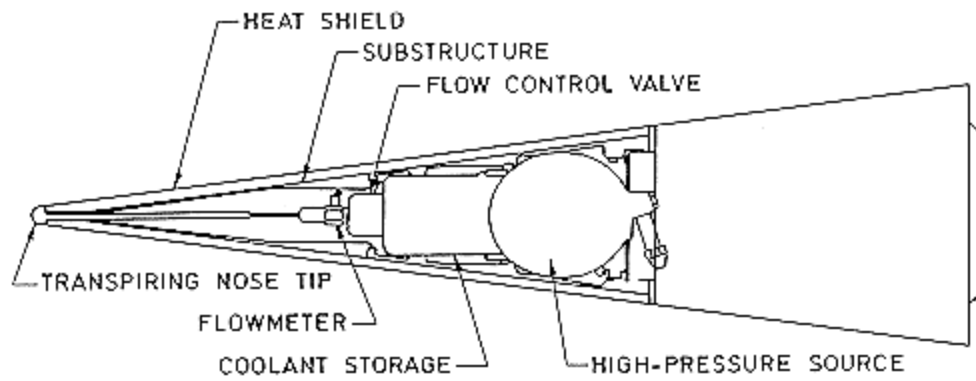
**TRANSPIRATION COOLING**

Transpiration systems are systems where fluid is injected through a porous medium into the boundary layer. The structure is maintained cool by two basic mechanisms: heat is conducted to the coolant as it flows through the structure, and as the coolant is ejected out the surface it reduces the surface heat transfer rate by cooling and thickening the boundary layer. See Figure 4-5 for a sketch.



**Figure 4-5: Sketch of a transpiration thermal protection system.**

In some applications, the shape change caused by the surface recession of an ablating surface is not acceptable for aerodynamic performance reasons. In such cases, if the environment is too severe for radiative or heat sink systems, transpiration cooling may be the only practical solution. This TPS makes possible performance in environments that could not otherwise be withstood. However, its mechanical complexity (see Figure 4-6), with the associated reliability problems, tend to limit its use.



**Figure 4-6: Typical transpiration cooling system**

For re-entry application, the most acceptable coolants are:

- H<sub>2</sub>O
- NH<sub>3</sub>
- CF<sub>4</sub>
- CO<sub>2</sub>

## iTeh STANDARD PREVIEW (standards.iteh.ai)

[kSIST-TP FprCEN/CLC/TR 17603-31-16:2021](https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-fdec5fdea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021)

<https://standards.iteh.ai/catalog/standards/sist/6dbaf1b7-09c1-4561-8c4e-fdec5fdea09a/ksist-tp-fprcen-clc-tr-17603-31-16-2021>