Standardization Training Program
Level 2 ECSS Standards

Training Course in ECSS-E-ST-31C
“Space Engineering - Thermal Control General Requirements”

5 October 2015

Wolfgang Supper
TEC-MT

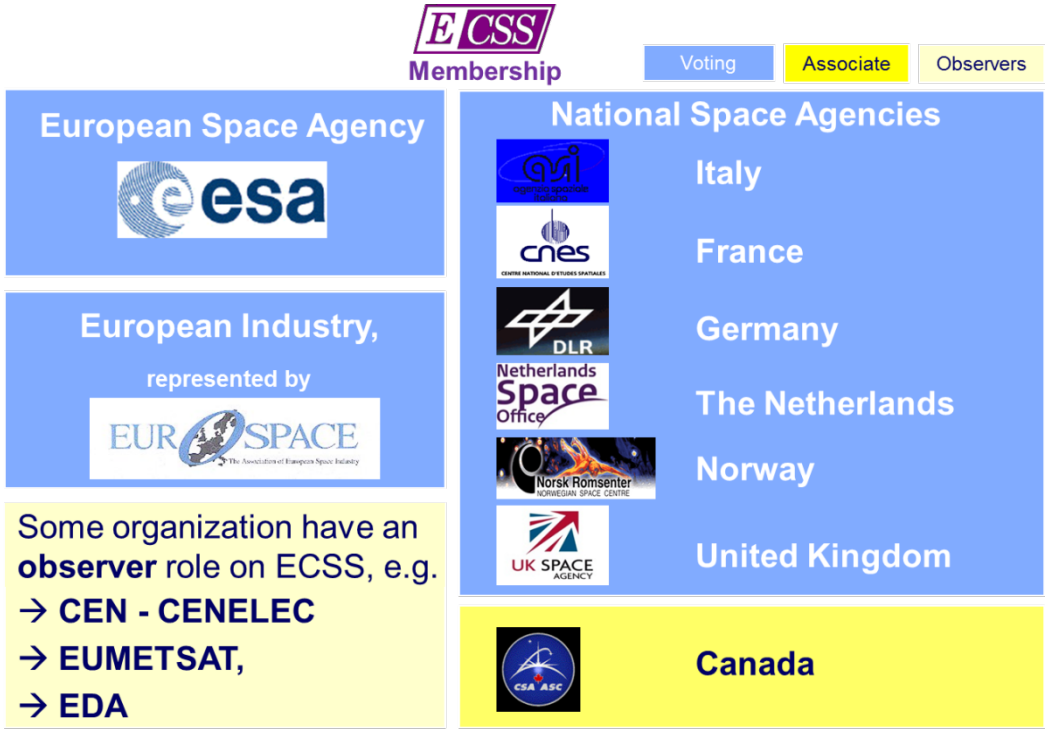
Content of Course

- Introduction
  - Characteristics of the ECSS system (7 pages)
  - ECSS Documents for Thermal Control (4 Pages)
  - Types of requirements (3 pages)
  - Relation of Standard to a specific project (2 pages)
- Structure of ECSS document (1 page)
- Clause 1: Scope of Document (3 pages)
- Clause 2: Normative References (1 Page)
- Clause 3: Terms, definitions and abbreviated terms (13 Pages)
- Clause 4: Requirements (14 pages)
- Clause 5: Document requirements definition (DRD) list (3 pages)
- DRD Annexes (normative) (4 pages)
- Tailoring (4 Pages)
- Conclusion (1 Pages)

Characteristics of ECSS System (1)

- **ECSS** = European Cooperation for Space Standardization
- Established in 1993, it is an organization which works to develop a **single coherent set of space standards** within the European space community

- Cooperative effort between **ESA**, National Space Agencies (**ASI, UKSA, CNES, DLR, NSO,** and **NSC**) and European industry (represented by **Eurospace**)



Characteristics of ECSS System (2)

ECSS

- Is driven by a partnership of **industries and space agencies**
- Is written in **consensus** by industry and agency experts
- Is a **consistent** set of documents
- Makes **maximum use of existing** and commonly used international standards
- Has flexibility through **tailoring**
- Is replacing ESA's PSS and other standards
- Is recognized by the European Space Community as:
  - the **single** developing body for European Space standards
  - the source of requirements for its Space activities
- Standards define the **requirements** rather than the means

Characteristics of ECSS System (3)

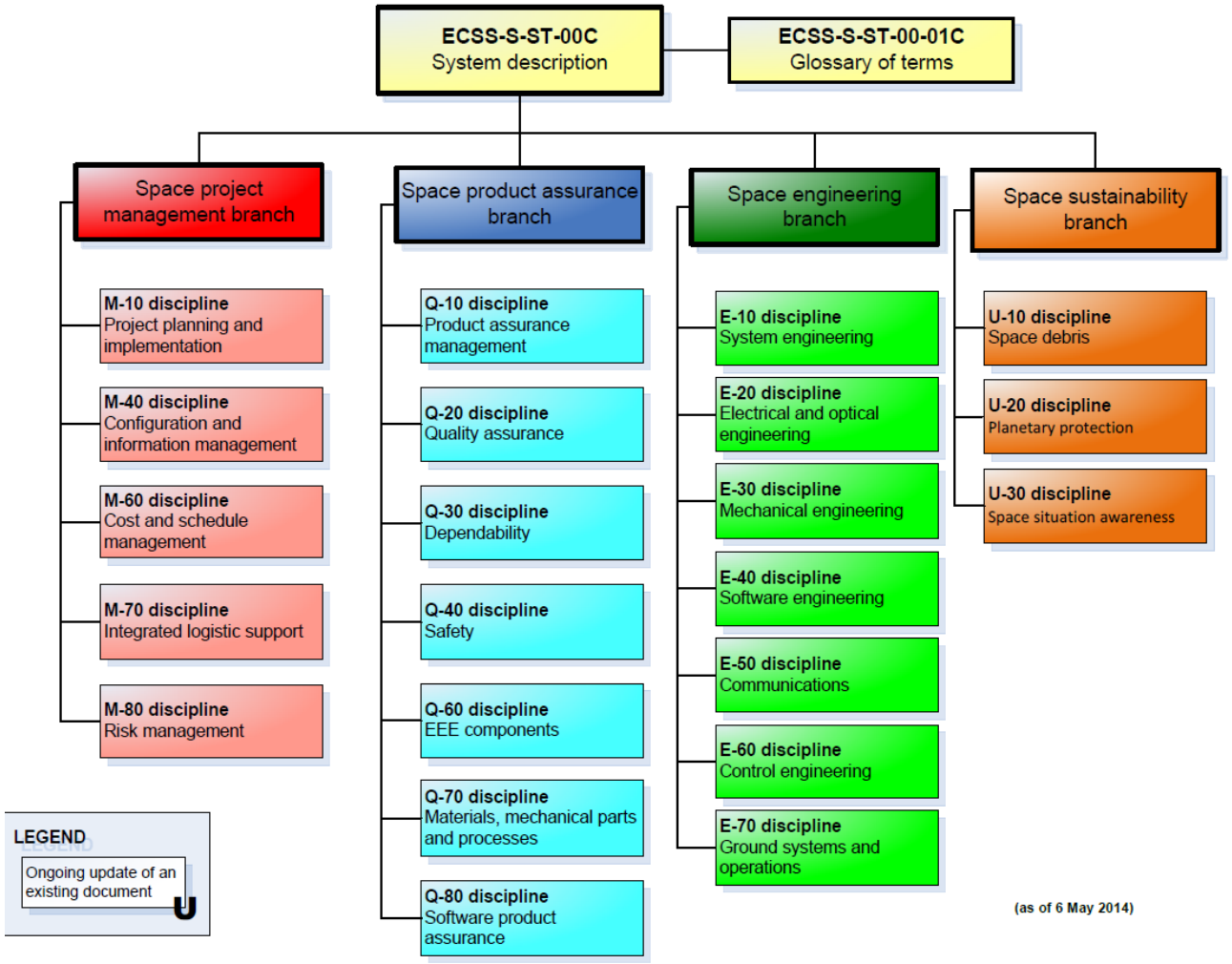
- Key aspect of ECSS is the documentation architecture, designed to facilitate the organisation and retrieval of information within the ECSS system (see next slides).
- Basically four main branches: Management (M), Product Assurance (Q), Engineering (E), and Sustainability (U) and four hierarchical levels
  - **Level 0 (ECSS-P-00) - Describes the policy and objectives of the ECSS system and its architecture together with the principle rule for the creation, validation and maintenance of documents.**
  - **Level 1 (ECSS-M-00, ECSS-Q-00, ECSS-E-00) - Describe the strategy in the specific domain by giving a global view of the requirements and interfaces between the elements at Level 2.**

Characteristics of ECSS System (4)

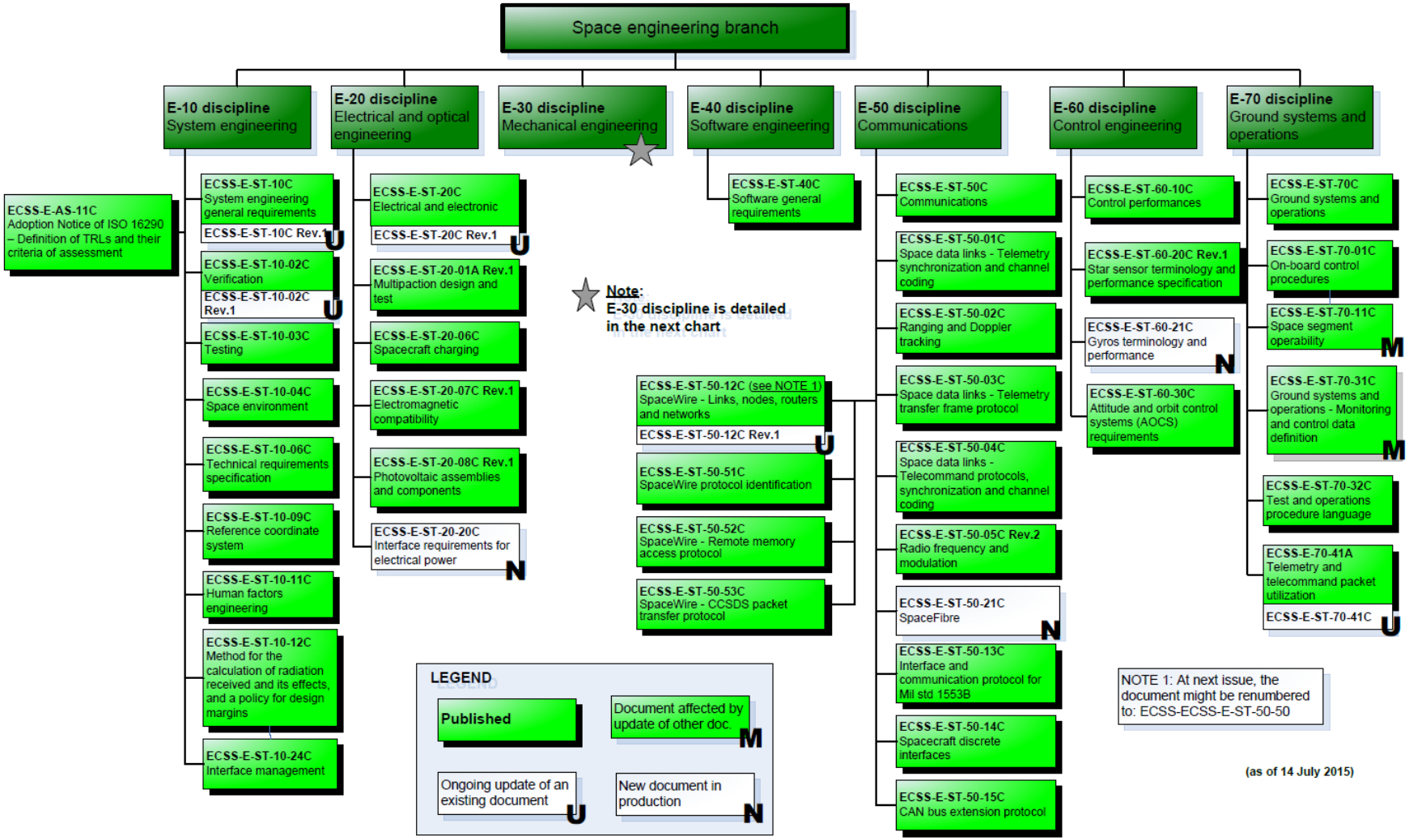
- **Level 2 (ECSS-M-10, ECSS-Q-10 ...) - Describe the required objectives and functions for all aspects in the individual domain (project organization, quality assurance, system engineering, etc.)**
  ➔The Thermal Control Standard ECSS-E-ST-31C is located here
- **Level 3 - Describe methods, procedures and recommended tools to achieve the requirements of Level 2 documents. Define the requirements for interfaces and performance of the specified product.**
  ➔ ECSS-E-ST-31-02C "Two-phase heat transport equipment" is located here.

In addition, there are different handbooks providing guidelines, typical/recommended engineering methods, etc.

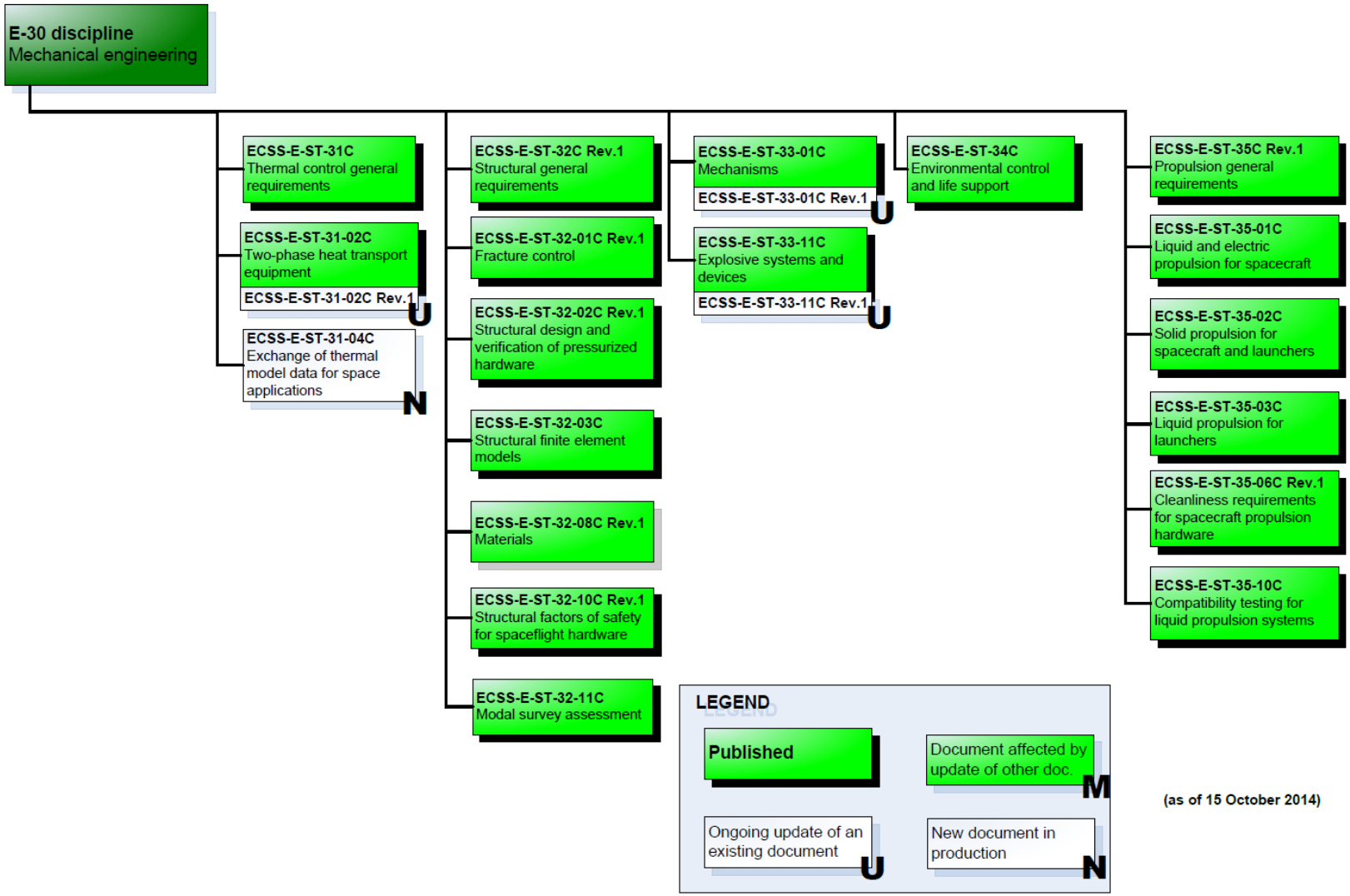
Characteristics of ECSS System (5)



Characteristics of ECSS System (6)



Characteristics of ECSS System (7)



ECSS Documents for Thermal Control (1)

In the ECSS system there are several documents related to thermal control:

- **Existing standards: ECSS-E-ST-31C, ECSS-E-ST-31-02C**
- **Existing Handbooks: ECSS-E-HB-01**
- **Standard in preparation: ECSS-E-ST-31-04C**

ECSS-E-ST-31C: Thermal control general requirements

- **To be used on subsystem level**
  - **Typical user: responsible subsystem engineer in a system team and thermal design engineer in a thermal functional department**
  - **Useful to responsible engineers of other subsystems to understand thermal interfaces**
- **Document includes requirements for**
  - **All mission phases**
  - **Interfaces to equipment thermal control**
  - **Interfaces to other subsystems**
  - **The entire temperature range**

ECSS Documents for Thermal Control (2)

ECSS-E-ST-31-02C: Two-phase heat transport equipment (TPHTE)

- To be used on equipment level (heat pipe, loop heat pipe,…)
  - Typical user: responsible thermal design engineer for TPHTE in a thermal functional department
  - Useful to responsible thermal subsystem engineers in system teams to understand TPHTE interfaces
- Document includes requirements for
  - Design and verification of the different TPHTE
  - Qualification process of TPHTE
  - Detailed qualification test program
  - Necessary development and verification documents (DRD)
- Applicable to all flight hardware of space projects, covering spacecraft and launchers

➔ First issue was addressing qualification of TPHTE; update is currently on-going to also address the acceptance of TPHTE

ECSS Documents for Thermal Control (3)

ECSS-E-HB-31-01, Part 1A to 16A: Thermal design handbook

Part 1: View factors

Part 2: Holes, Grooves and Cavities

Part 3: Spacecraft Surface Temperature

Part 4: Conductive Heat Transfer

Part 5: Structural Materials: Metallic and Composite

Part 6: Thermal Control Surfaces

Part 7: Insulations

Part 8: Heat Pipes

Part 9: Radiators

Part 10: Phase-Change Capacitors

Part 11: Electrical Heating

Part 12: Louvers

Part 13: Fluid Loops

Part 14: Cryogenic Cooling

Part 15: Existing Satellites

Part 16: Thermal Protection System

- **Intended to be used as supporting material in space projects and applications**
- **Collection of data gathered from many projects and technical journals which provides descriptions and recommendation to be considered in the thermal design process**
- **Handbook has unfortunately not been updated for some time**

ECSS Documents for Thermal Control (4)

- ***ECSS-E-ST-31-04C: Exchange of thermal model data for space applications***

The objective of this document is to define and describe the standard protocol for Exchange of Thermal Model Data for Space Applications (commonly known as STEP-TAS protocol). It will also include accompanying documents, as a getting started guide, as well as the supporting libraries for the creation of the data exchange files that comply with the protocol.

Types of requirements (1)

- The task force for pre-tailoring has identified three types of requirements:
  - **Documentation Requirements**
    - Requirements for production and use of project documents
  - **Process Oriented Requirements**
    - Requirements related to processes, stating how to perform a certain task
    - Usually not quantifiable, and not possible to verify on the product
    - Compliance to these requirements is performed by reviewing and accepting plans (e.g. DDVP) or analyses (e.g. FMECA)
    - Closure is done by reviewing the completed process (a way of working), i.e. accepting how something has been designed, manufactured, or analysed. This can be made by reviewing the associated documentation (Plan, Analysis), or by an audit process.
  - **Product Oriented Requirements**
    - Requirements related to specific technically related issues, describing a product property or functionality
    - Always quantifiable, and can be verified on the product
    - Compliance of these requirements is illustrated by verification of the requirements (by Test, Analysis, Inspection or Review of Design)
    - Closure is performed by checking the actual verification of the individual requirement (i.e. VCD)

Types of requirements (2)

- **Examples for documentation requirements:**
  - Clause 4.9.3b: The TCS supplier shall deliver the documentation as detailed in Table 5-1
  - Clause 4.9.3c: The TCS shall provide following inputs to higher level documents: AIV plan, DDP, drawings, interface requirement document, etc.
- **Examples for process oriented requirements**:
  - Clause 4.2.1a: TCS performance requirements for all mission phases shall be specified and agreed with the system authority
  - Clause 4.2.1b: The mission phases shall be represented by a coherent set of thermal design cases covering the extreme range of conditions experienced by an item during its lifetime
  - Clause 4.5.2.1a: Verification by analysis shall be performed through thermal analytical modelling and corresponding prediction
- **Examples for product oriented requirements:**
  - Clause 4.1.1a: The design of the TCS shall meet requirements of all mission phases up to the end of the operating lifetime
  - Clause 4.1.8a: The TCS shall be designed for heat flux effects as well as transient phenomena during decent, entry and landing
  - Clause 4.2.1g: The TCS shall conform to the following requirements to be specified in the TCS specification: 1. Temperature gradients, 2. Temperature stability, 3. Temperature uniformity, 4. Heat flux, etc.

Types of requirements (3)

- These requirement type definitions have not been systematically implemented into the ECSS system, but would have several advantages:
  - Easy distinction between requirement types (when listed in dedicated sections of the Standard)
  - Process requirements may be easily introduced in SOW and product requirements into technical specifications
  - Requirement verification can be more easily traced. Product requirements are most often tracked through VCD (Verification Control Document) and documentation / process requirements through compliance status lists
  - The thermal control Standard contains only few product related requirements (temperature, environment, lifetime requirements, etc.). Most of the requirements are process related (how to do verification, modelling, analysis, testing, etc.)

Relation of Standard to a specific project (1)

- Due to the generic nature of the specified requirements, detailed specifications for a thermal subsystem in a specific project are not included.

The procurement of a specific thermal subsystem cannot be based on this ECSS document alone.

- Documentation and process requirements, called out in this Standard, are generally introduced into the Statement of Work (SOW) of a specific project
- Technical or product requirements need to be translated into a technical subsystem specification dedicated to a specific project. (Standard can be seen as a “guideline” for writing a detailed, project dedicated, technical specification.)
- In different places references to the need for a technical specification are already given, for example:
  - Clause 4.2.1a: TCS performance requirements for all mission phases shall be specified and agreed with the system authority
  - Clause 4.2.1g: The TCS shall conform to the following requirements to be specified in the TCS specification
  - Clause 4.2.2a: Temperatures… shall not exceed values … specified in the TCS specification

Relation of Standard to a specific project (2)

Examples for translation of

ECSS requirement ⇨ Subsystem specification

ECSS	Specification
Cl. 4.2.1e: Minimum and maximum design temperatures shall be provided (defined)	Quantitative values for design temperatures are specified for all units
Cl. 4.2.1f: Acceptance and qualification margins shall be defined	Quantitative values for margins are specified for all units
Cl. 4.2.1g: The TCS shall conform to required temperature gradients, stability, uniformity, heat flux, etc.	Quantitative values for temperature gradients, stability, uniformity, heat flux, etc. are specified for all units
Cl. 4.2.2b3: A TPS shall support mechanical and thermo-mechanical loads	Quantitative load values are specified for relevant parts of the TPS
Cl. 4.4.5a: The TCS shall conform to the total lifetime covering expected combinations of mission phases	Lifetime is quantitatively specified. Mission phases are specified in detail.

Structure of ECSS document

In order to facilitate the use of the ECSS system, the breakdown of main clauses is the same for all ECSS standards:

- **Clause 1: Scope**
- **Clause 2: Normative References**
- **Clause 3: Terms, definitions and abbreviated terms**
- **Clause 4: Requirements**
- **Clause 5: Documentation requirements**
- **DRDs as normative annexes**
- **Any informative text as informative annexes**

The following slides summarizes and discusses the main clauses of Thermal Standard ECSS-E-ST-031C

Clause 1: Scope of ECSS-E-ST-031C (1)

In general: The purpose of the Scope clause is to describe, in a few lines, the standard as a whole in such a way that the reader can assess if the standard is applicable or not to a particular case.

Scope of ECSS-E-St-031C:

ECSS-E-ST-31 defines requirements for the discipline of thermal engineering.

This Standard defines the requirements for the definition, analysis, design, manufacture, verification and in-service operation of thermal control subsystems of spacecraft and other space products.

For this Standard, the complete temperature scale is divided into three ranges: Cryogenic temperature range, Conventional temperature range and High temperature range.

The requirements of this Standard are applicable to the complete temperature scale. However, where applicable, requirements are stated to be applicable only for the cryogenic or high temperature range. References to these specific requirements have been summarized in Annex G and Annex H.

This standard is applicable to all flight hardware of space projects, including spacecraft and launchers.

This standard may be tailored for the specific characteristic and constrains of a space project in conformance with ECSS-S-ST-00.

The document is a generic technical specification, to be tailored (see later)

Clause 1: Scope of document (2)

The Standard covers requirements for the entire life cycle of the subsystem:

- Ground and pre-launch (Clause 4.1.2)
- Launch and ascent (Clause 4.1.3)
- Planetary orbital phases (Clause 4.1.4)
- Interplanetary phases (Clause 4.1.5)
- Planetary natural environment (Clause 4.1.6)
- Docking, docked and separation phases (Clause 4.1.7)
- Descent, entry and landing (Clause 4.1.8)
- Post-landing phases (Clause 4.1.9)

Clause 1: Scope of document (3)

- Standard is applicable for the complete temperature range (as defined in the standard)
  - Cryogenic temperature range (below 200 K)
  - Conventional temperature range (200 to 470 K)
  - High temperature range (above 470 K)
  - Specific requirements related to the extreme temperature ranges are called out in the following clauses (see also Annex G and H):
    - Clause 4.2.2 for requirements in the high temperature range
    - Clause 4.2.3 for requirements in the cryogenic temperature range
    - Clause 4.5.2.2 for verification by test in the cryogenic temperature range
    - Clause 4.5.2.3 for verification requirements of thermal protection system (TPS)

Clause 2: Normative References

The purpose of the "Normative references" clause is to list the documents referred to in requirements.

- For the Thermal Control Standard the references include ECSS documents for
  - Glossary of terms
  - Verification, testing, space environment
  - Project management (configuration and information management)
  - Space product assurance
    - Quality assurance, safety
    - Materials, mechanical parts and processes
    - Cleanliness and contamination control
- All referenced documents are undated, meaning that the latest issue / revision of a referenced document is applicable

Clause 3: Terms, definitions and abbreviated terms (1)

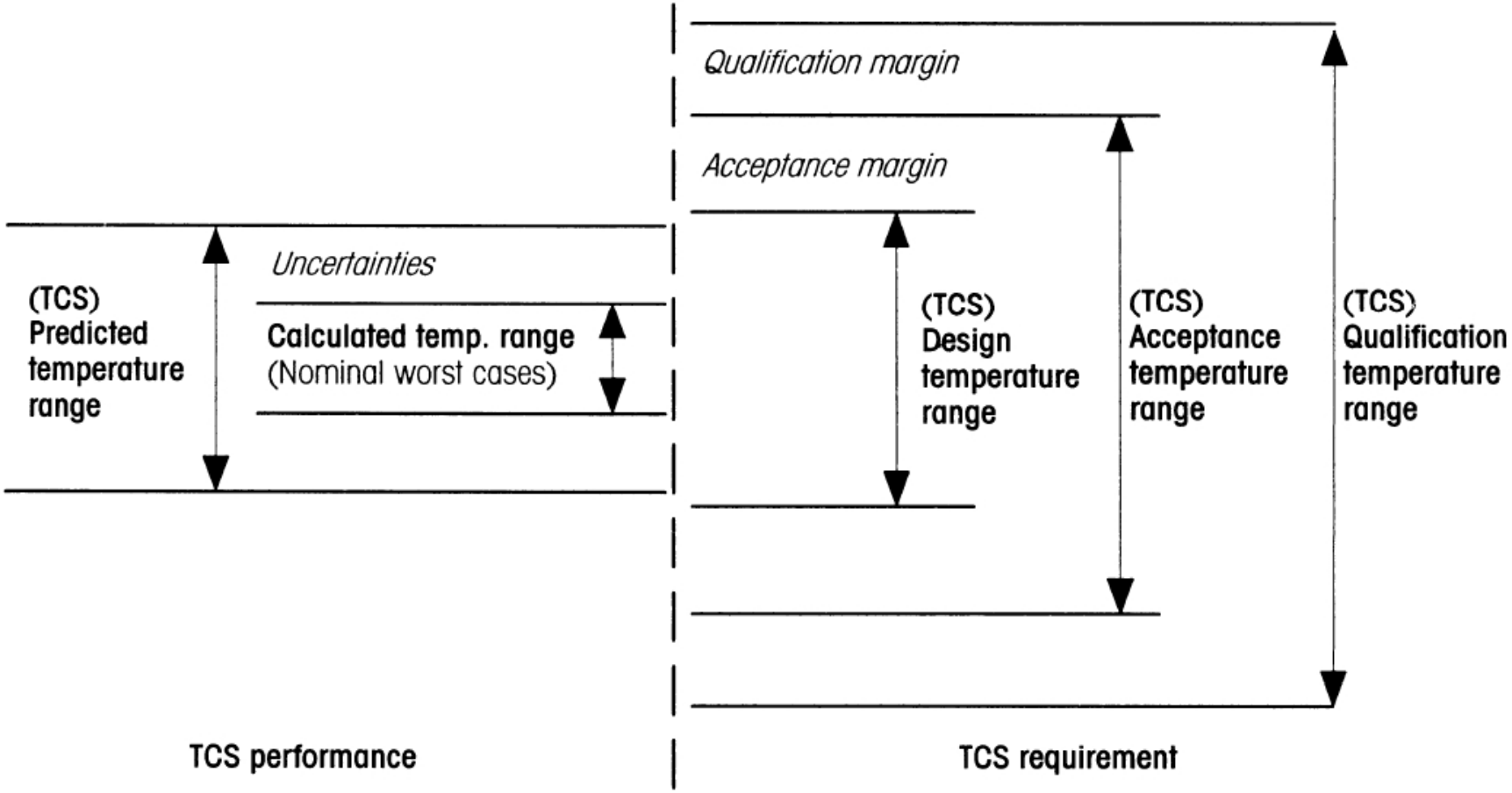
Clause 3 has the following purpose:

- to list the terms defined in other standards which are applicable to the thermal control standard (definition of terms shall not be repeated throughout the ECSS system)
- to present the terms specific to the thermal control standard together with their definitions (these terms are unique in the ECSS system and appear only in the thermal control standard)
- to list the abbreviation used in the standard, and their expanded meaning

- The clause is very important in the sense that experts will have the same understanding of specific terms used in thermal control engineering
- For example the clause lists 26 temperature-related terms
- Most important temperature definition and the relation to each other are explained in the following slide (Figure 3.1 from the standard)

Clause 3: Terms, definitions and abbreviated terms (2)

Temperature definitions for thermal control system (Figure 3-1 in Standard)



Clause 3: Terms, definitions and abbreviated terms (3)

General definitions related to temperature ranges:

3.2.1.2 acceptance temperature range

temperature range obtained from the qualification temperature range after subtraction of qualification margins specified for the operating and non-operating mode and the switch-on condition of a unit

NOTE 1 The acceptance temperature range is the extreme temperature range that a unit can reach, but never exceed, during all envisaged mission phases (based on worst case assumptions).

NOTE 2 Temperature range used during acceptance tests to verify specified requirements and workmanship

3.2.1.3 calculated temperature range

temperature range obtained by analysis or other means for the operating and non-operating mode and the minimum switch-on condition of a unit, based on worst case considerations (i.e. an appropriate combination of external fluxes, materials properties and unit dissipation profiles to describe hot and cold conditions) excluding failure cases

NOTE The calculated temperature range plus any uncertainties is limited to the specified design temperature range. During the course of a project these uncertainties change from initial estimates into a value determined by analysis.

Clause 3: Terms, definitions and abbreviated terms (4)

General definitions related to temperature ranges (cont):

3.2.1.7 design temperature range

temperature range specified for the operating and non-operating mode and the switch-on condition of a unit, obtained by subtracting acceptance margins from the acceptance temperature range

NOTE 1 Temperature range representing the temperature requirement for the TCS design activities.

NOTE 2 The terms “operating temperature range” or “operational temperature range” should not be used for the design temperature range. The term “operating or non-operating temperature limits” is acceptable.

3.2.1.18 predicted temperature range

temperature range obtained from the calculated temperature range increased by the uncertainties

3.2.1.20 qualification temperature

temperature range specified for the operating and non-operating mode and the switch-on condition of a unit, for which this unit is guaranteed to fulfil all specified requirements

Clause 3: Terms, definitions and abbreviated terms (5)

Definitions related to margins:

3.2.1.1 acceptance margin

contingency agreed between system authority and TCS to account for unpredictable TCS-related events

NOTE The acceptance margin is the difference between the upper or lower acceptance temperature and the upper or lower design temperature (for both operating and non-operating mode).

3.2.1.19 qualification margin

contingency approved by the system authority to account for any unexpected events

NOTE For temperatures, the qualification margin is the difference between the upper or lower qualification temperature and the upper or lower acceptance temperature (for operating and non-operating mode).

Clause 3: Terms, definitions and abbreviated terms (6)

General definitions related to temperature:

3.2.1.16 minimum switch-on temperature

minimum temperature at which a unit can be switched from the non-operating mode to the operating mode and functions nominally when the unit temperature is brought back to the relevant operating mode temperatures

NOTE Also referred to as start-up temperature.

3.2.1.22 radiative sink temperature

virtual black body radiation temperature used to define the equivalent radiative thermal load on an item

NOTE 1 The radiative sink temperature includes both the natural environment load (solar, planetary albedo and infrared fluxes) and the radiative exchanges with other items.

NOTE 2 The radiative sink temperature is typically used to provide a simplified interface for an item, to provide a means for parameter studies thus avoiding extensive calculations or to define adequate radiative boundary conditions for thermal tests.

See NOTE 3 and 4 in Standard for formula for calculation of sink temperature

3.2.1.27 system interface temperature point

physical point appropriately located on the structure of the system which can be used to evaluate the heat exchanged by conduction between a unit and the spacecraft system

Clause 3: Terms, definitions and abbreviated terms (7)

General definitions related to temperature (cont):

3.2.1.28 temperature difference

difference in temperature of two points at a given time

3.2.1.29 temperature gradient

spatial derivation of temperature in a point at a given time

NOTE It is expressed by a temperature divided by unit length.

3.2.1.30 temperature mean deviation (ΔT_{mean})

sum of temperature differences (measured minus analysed values) divided by the number of correlated temperatures

NOTE ΔT_{mean} can be positive or negative.

where

ΔT_{mean}	=	temperature mean deviation
T_{Mi}	=	measured temperature
T_{Pi}	=	temperature predicted by analysis
N	=	number of samples

Clause 3: Terms, definitions and abbreviated terms (8)

General definitions related to temperature (cont):

3.2.1.31 temperature reference point (TRP)

physical point located on a unit and defined in the unit ICD to provide a simplified representation of the unit temperature

NOTE 1 The TRP is used for coherent verification at unit, subsystem and system level.

NOTE 2 Depending on the unit dimensions and interface complexity, more than one temperature reference point can be defined.

3.2.1.32 temperature stability

condition when the temperature variation for a defined period of time is less than a defined (small) value

3.2.1.34 temperature uniformity

condition when the temperature difference or the temperature gradient at a given time is less than a defined (small) value

3.2.1.35 temperature variation

change of temperature at a given point with respect to time

NOTE It is expressed by a temperature divided by time.

Clause 3: Terms, definitions and abbreviated terms (9)

Definitions related to temperature in the cryogenic temperature range:

3.2.3.4 maximum cryogenic temperature

temperature of a defined item when the total heat load flowing into the CCS is the maximum cryogenic heat load and considering the worst case performance of the CCS

3.2.3.6 nominal cryogenic temperature

temperature of a defined item when the total heat load flowing into the CCS in nominal steady state conditions is the nominal cryogenic heat load and considering a nominal performance of the CCS

3.2.3.8 ultimate cryogenic temperature

maximum cryogenic temperature increased by the temperature margins agreed by the system authority and depending on the design status

Clause 3: Terms, definitions and abbreviated terms (10)

Definitions related to temperature in the high temperature range:

3.2.4.4 allowable temperatures

maximum temperatures specified for thermally protected items to ensure the structure integrity

NOTE For example: Protected items are primary and secondary structures.

3.2.4.9 limit temperatures

maximum or minimum local temperatures of an exposed surface for a defined item resulting from the application of the least favourable heat fluxes histories expected on nominal missions inside the boundaries of limit fluxes

3.2.4.11 nominal temperatures

local temperatures of an exposed surface for a defined item resulting from the application of the nominal heat flux histories

3.2.4.16 ultimate temperature

local instantaneous temperature of an exposed surface for a defined item resulting from the application of ultimate flux histories

Clause 3: Terms, definitions and abbreviated terms (11)

Definitions related to heat:

3.2.1.1 heat dissipation

thermal energy divided by time produced by a source

3.2.1.2 heat flux

thermal energy (heat) divided by time and unit area perpendicular to the flow path

NOTE Heat flux is also referred to as heat flow rate density.

3.2.1.3 heat leak

unwanted heat exchange between a thermally protected item and the environment

NOTE The heat leak can be a heat gain or a heat loss depending of the environmental temperature

3.2.1.4 heat lift

transfer of a specified heat flow rate from a lower to a higher temperature

NOTE For example: Heat pump.

3.2.1.5 heat storage

capability to store heat at a defined temperature or within a defined temperature range

NOTE For example: Heat storage can be performed by sensible heat, latent heat as a PCM, by heat conversion into chemical energy.

Clause 3: Terms, definitions and abbreviated terms (12)

Other Definitions:

3.2.1.8 geometrical mathematical model (GMM)

mathematical model in which an item and its surroundings are represented by radiation exchanging surfaces characterized by their thermo-optical properties

NOTE The GMM generates the absorbed environmental heat fluxes and the radiative couplings between the surfaces.

3.2.1.38 thermal mathematical model (TMM)

numerical representation of an item and its surroundings represented by concentrated thermal capacitance nodes or elements, coupled by a network made of thermal conductors (radiative, conductive and convective)

- NOTE 1 For thermo - hydraulic modelling enthalpy and fluidic conductors are used in addition.
- NOTE 2 A TMM generates for all nodes / elements a temperature history, an energy balance; in addition pressure drops and mass flow rates for thermo - hydraulic modelling.
- NOTE 3 Numerical representation can be performed by lumped parameter, finite difference or finite element methods.

Clause 3: Terms, definitions and abbreviated terms (13)

Other Definitions:

3.2.1.39 thermal node

representation of a specific volume of an item with a representative temperature, representative material properties and representative pressure (diffusion node) used in a mathematical lumped parameter approach

3.2.1.23 sensitivity analysis

analysis, which uses a variation of input parameters in order to evaluate the influence of inaccuracies on the analysis results

3.2.1.41 uncertainties

inaccuracies in temperature calculations due to inaccurate physical, environmental and modelling parameters

Clause 4: Requirements (1)

All requirements for the TCS are listed in Clause 4 and broken down in the following sub-clauses:

- Clause 4.1: Mission
- Clause 4.2: Performance
- Clause 4.3: Requirements towards other subsystems
- Clause 4.4: Design
- Clause 4.5: Verification
- Clause 4.6: Production ad manufacturing
- Clause 4.7: In-service requirements
- Clause 4.8: Product assurance
- Clause 4.9: Deliverables

The next slides give an overview over the requirements

Clause 4: Requirements (2)

Clause 4.1: Mission -> includes requirements for all mission phases:

- ground and pre-launch,
- launch and ascent,
- planetary orbital phases,
- interplanetary phases,
- planetary natural environment,
- docking, docked and separation phases,
- decent, entry and landing,
- post-landing phases

- Requirements are mostly generic and related to meet the requirements for different mission phases
- The distinction between process and product related requirements is sometimes difficult

Tailoring to specific project mission phases and translation into specific project requirements necessary

Clause 4: Requirements (3)

Clause 4.2: Performance

- The most important TCS product performance requirements are given in Clause 4.2.1:
- Clause 4.2.1g: The TCS shall conform to the following requirements to be specified in the TCS specification:
  1. Temperature gradients
  2. Temperature stability
  3. Temperature uniformity
  4. Heat flux
  5. Heat storage
  6. Heat lift
  7. Electrical power allocation for heating and cooling
  8. TM/TC allocation for TCS parameter
  9. Mass allocation for TCS
- Specific requirements for the high and cryogenic temperature range (if different from the nominal range) as well as TCS functional requirements are given in Clauses 4.2.2, 4.2.3 and 4.2.4

Tailoring and translation into specific project requirement necessary

Clause 4: Requirements (4)

Clause 4.3: Requirements **towards other subsystems**

- **General (4.3.1)** states that requirements
  - from other subsystems affecting TCS
  - from TCS on other subsystems

  shall be issued in a TCS interface control document
- **Mechanical (4.3.2)** -> requirements related to ICD (e.g. dimensions, mass, fixation, materials, heat capacities, alignment, forbidden zones, etc.); respect mechanical loads; issue thermal ICD
- **Electrical (4.3.3)** -> requirements related to heat dissipation, harness, TCS power budget, voltage, EMC
- **AOCS (4.3.4)**
  - 4.3.4.1 Propulsion -> thrusters temperature, plume interaction, heat soak back; possible modification of thruster operation, if predicted temperatures are too high
  - 4.3.4.2 Attitude control -> respect attitude requirements; agreement for thermally unacceptable attitudes

Clause 4: Requirements (5)

- **TM/TC (4.3.5)** -> command and telemetry allocation to TCS
- **OBDH and S/W (4.3.6)** -> TCS related software requirements (heater control, sensors)
- **Launcher (4.3.7)** -> launcher requirements affecting TCS (e.g. launcher envelope, venting requirements, depressurization profile, accessibility, launch pad air-conditionning, heat fluxes from fairing, etc.)
- **GSE (4.3.8)** -> requirements affecting TCS interfaces; TCS specific GSE requirements
- **ECLS (4.3.9)** -> interface requirements to ECLS

Tailoring and translation into specific project requirement necessary

Clause 4: Requirements (6)

Clause 4.4: Design -> Broken down in the following sub clauses:

- **General (4.4.1)** -> design shall
  - Meet requirements of 4.1, 4.2. 4.3
  - Use materials compatible to environment
  - Be documented in design description
- **Budget allocation (4.4.2)** -> TCS shall define budgets for mass, size, power, energy, TM/TC, operational aspects
- **Parts, materials and processes (4.4.3)** -> Use of space qualified parts, materials and processes
- **EEE components (4.4.4)** -> Use of space qualified EEE components
- **Lifetime (4.4.5)** -> TCS design shall conform to the total lifetime
- **Predictability and testability(4.4.6)** -> Design shall enable the demonstration of performance requirements (Cl. 4.2) by analysis and test

Clause 4: Requirements (7)

Clause 4.4: Design -> Broken down in the following sub clauses (cont):

- **Flexibility(4.4.7)** -> the design shall be able to accommodate modifications of TCS requirements and shall offer trimming capabilities
- **Integration and accessibility (4.4.8)** -> Accessibility to allow for integration, (de-) mounting, inspection, maintenance
- **Reliability (4.4.9)** -> TCS shall demonstrate required reliability figures by analysis and test, meet system requirements (i.e. single point failure avoidance)
- **Interchangeability (4.4.10)** -> TCS shall meet system interchangeability requirements
- **Maintenance (4.4.11)** -> TCS shall specify maintenance procedures, no in-orbit maintenance
- **Safety (4.4.12)** -> Reference to ECSS-Q-ST-40 and ECSS-Q-ST-40-02
- **Availability (4.4.13)** -> Plan for in-time availability of resources and items with limited lifetime

Clause 4: Requirements (8)

Clause 4.5: Verification (1)

- Verification requirements are by definition process requirements (not related to product properties)
- General verification requirements are contained in
  - ECSS-E-ST-10-02 (Verification)
  - ECSS-E-ST-10-03 (Testing)
- The thermal Standard contains requirements specific to TCS
  - Clause 4.5.2.1: Requirements for analysis, modelling, TCS testing and documentation
    - Cases to be verified to be agreed with the system authority
    - Thermal balance, thermal vacuum and climatic tests are required (the latter one may be tailored away)
  - Clause 4.5.2.2: Requirements related to cryogenic control system (CCS)
  - Clause 4.5.2.3: Requirements related to High temperature TPS

Clause 4: Requirements (9)

Clause 4.5: Verification (2)

- Clause 4.5.3: Requirements dedicated to Thermal Balance Test (TBT)
  - Regarded as TCS performance verification and (when applicable) as TCS qualification test
  - Clause 4.5.3.1: Requirements related to test performance
    - Documentation: Test specification, procedures, test report
    - Purpose of TBT to verify
      - Thermal mathematical model
      - Suitability of TCS design
      - Performance of TCS hardware
      - Sensitivity of TCS with respect to parameter changes
    - Two different steady-state test cases + transient case
    - Solar simulation, when behaviour is governed by solar environment
    - Critical hardware flight representative

Clause 4: Requirements (10)

Clause 4.5: Verification (3)

- Clause 4.5.3.2: Requirements related to test success criteria
  - Steady-state conditions, when temperature sensor readings meet predefined temperature variation over a predefined time period
- Clause 4.5.3.3: Requirements related to correlation success criteria
  - Test correlation for steady-state and transient modes based for units on unit temperature reference points (TRP)
  - Correlation is successful, when
    - Deviations between measured and predicted temperatures as specified
    - Temperature mean deviation as specified
    - Temperature standard deviation as specified
    - Deviations between measured and predicted heating / cooling power within specification

Clause 4: Requirements (11)

Clause 4.6: Production and manufacturing -> Broken down in the following sub clauses:

- **Procurement (4.6.1)** -> procurement shall
  - be performed against purchase orders
  - in accordance with ECSS-Q-ST-70 (cl. 5.6) addressing in detail procurement of materials and ECSS-Q-ST-70 (cl 6.6) addressing procurement of mechanical parts
  - in accordance with ECSS-Q-ST-20 (cl. 5.4) addressing QA requirements for procurement
  - and in accordance with specifications provided by TCS
- **Manufacturing process (4.6.2)** -> procedures to be approved by customer
  - Number of samples, prototypes, components to be agreed with customer
  - in accordance with QA requirements as specified in ECSS-ST-Q-20 (cl. 5.5)
- **Quality management (4.6.3)** -> according to ECSS-Q-ST-20 (cl. 5.1.1)
- **Cleanliness and contamination (4.6.4)** -> according to ECSS-Q-ST-70-01 (cl. 5.1 & 5.2)
  - TCS shall define cleanliness requirements for TCS H/W

Clause 4: Requirements (12)

Clause 4.6: Production and manufacturing -> Broken down in the following sub clauses (cont'd):

- **Integration (4.6.5)** -> Procedures for all levels of integration to be defined
- **Identification and marking (4.6.6)** -> according to ECSS-M-ST-40 (cl. 5.3.1.5)
- **Packing, handling, transportation (4.6.7)** -> requirements shall be defined
  - Items containing hazardous material or those subjected to special packaging, handling and transportation shall be identified
- **Storage (4.6.8)** ->
  - Storage conditions shall not to cause degradation to thermal H/W
  - Storage devices and storage procedures shall be defined
- **Repair (4.6.9)** -> Repair procedures, tools and material shall be defined

Clause 4: Requirements (13)

Clause 4.7: In-service requirements ->

- Support the system during S/C commissioning, operational phases, special events, in-orbit anomalies; provide input to operational documentation

  Examples: Thermal simulation of S/C

  De-freezing of fluid systems

- Support Cryogenic Control System (CCS) by
  - adjusting operational parameters to compensate for degradation
  - De-contamination of cryogenic areas

Clause 4.8: Product assurance -> requirements for TCS are specified at system level and based on ECSS-Q-ST-20 Quality assurance, ECSS-Q-ST-40 Safety qand ECSS-Q-ST-70 Materials, mechanical parts and processes

Clause 4: Requirements (14)

Clause 4.9: Deliverables

- All deliverables (hardware, documents, software, mathematical models) shall be specified in the Statement of Work (SOW)
- TCS shall deliver all H/W in accordance with the specifications
- TCS shall deliver subsystem documents as listed in Table 5-1
  - Document requirements definitions (DRD) exist for each required document
  - DRD defines the expected content for each document
- TCS shall provide inputs to higher level system documents (AIV and test plans, DDP, drawings, interface documentation, budgets, design definition / justification, etc.)

Clause 5: Document requirements definition (DRD) list (1)

- Document requirements definitions (DRD) serve to ensure:
  a. completeness and consistency of information within the documents,
  b. that the information contained in the document conforms to its defined scope, and correctly implements its interfaces with other documents, and
  c. that portions of a document can be generated or maintained by separate organizational groups and seamlessly integrated into a coherent whole.
- Table 5-1 lists and summarizes the DRDs that are called up in the previous clauses and that are defined in annexes of this Standard or other relevant Standards.
- The first issue of a document is created in the project phase as indicated in the following list and delivered for the indicated project review.
- The document is then updated in additional issues for follow-on project phases and reviews. The creation of a completely new document shall be avoided.

Clause 5: Document requirements definition (DRD) list (2)

Table 5-1: ECSS-E-ST-31 DRD List

Document title	Summary	Phase								DRD ref.	Remarks
		0	A	B		C	D		E	F	
		MDR	PRR	SRR	PDR	CDR	QR	AR		MCR	
Mathematical Model Specification	Specifies requirements for development and delivery of thermal mathematical models to be used for thermal analysis at system level				X	X					E-ST-31	
Thermal and geometrical model description	Describes the TMM and GMM to be used as input for the sub-system thermal analysis cases		X	X	X	X	X	X			E-ST-31	To be updated before each analysis campaign
TCS analysis report	Contains a full mathematical analysis of the thermal control system leading to the thermal subsystem definition including redundancy strategy, operational concept and hardware definition		X	X	X	X	X	X	X		E-ST-31	Document to be updated or re-issued for CDR, AR, TBT prediction, TBT evaluation, Flight prediction
TCS interface control document	Describes the thermal control subsystem interfaces to other subsystems and to the system		X	X	X	X	X	X			E-ST-31	To be updated at CDR and AR
TCS thermal balance test specification	Describes the requirements applicable for the thermal balance test including purpose, test approach and test article					X					E-ST-31	Can be combined with the system thermal vacuum (TV) test specification
TCS detailed design description	Describes the detailed design of the thermal control subsystem			X	X	X					E-ST-31	Possible update for phase D
TCS thermal balance test procedure	Gives directions for conducting the thermal balance test in terms of description, resources, constraints and step-by-step procedure					X					E-ST-10-02	Before TBT
TCS thermal balance test report	Describes the execution of the thermal balance test and the results obtained					X					E-ST-10-02	After TBT

Clause 5: Document requirements definition (DRD) list (3)

Table 5-1: ECSS-E-ST-31 DRD List (cont.)

Document title	Summary	Phase								DRD ref.	Remarks
		0	A	B		C	D		E	F	
		MDR	PRR	SRR	PDR	CDR	QR	AR		MCR	
TCS declared materials list	Establishes the detailed record of all the materials used to produce the products of the thermal control subsystem		X	X	X	X					Q-ST-70	First formal delivery at PDR
TCS declared mechanical parts list	Establishes the detailed record of all the mechanical parts used to produce the products of the thermal control subsystem		X	X	X	X					Q-ST-70	First formal delivery at PDR
TCS declared process list	Establishes the detailed record of all the processes used to produce the products of the thermal control subsystem		X	X	X	X					Q-ST-70	First formal delivery at PDR

DRD's are given in normative annexes to the Standard:

Annex A, Annex B, etc.

"normative" means: these annexes are part of the list of requirements to be met

"informative" Annexes contain information

DRD Annexes (normative) (1)

The structure of each DRD is equal for all documents:

1. DRD identification

- **1.1 Requirement identification and source document**
- **1.2 Purpose and objective**

2 Expected response

- **2.1 Scope of content**
- **<1> Introduction**
- **<2> Applicable and reference documents**
- **<3> Definitions and abbreviations**
- **<4> and following sections: Content is document specific**
- **2.2 Special remarks**

DRD Annexes (normative) (2) - Example

Annex A (normative)

TCS mathematical model specification

A1. DRD identification

A1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-31, requirement 4.5.2.1d.

A1.2 Purpose and objective

The TCS mathematical model specification specifies requirements for development and delivery of mathematical models to be used for thermal analysis.

A2 Expected response

A2.1 Scope of content

<1> Introduction

a. The TCS mathematical model specification shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

DRD Annexes (normative) (3) – Example

<2> Applicable and reference documents

a. The TCS mathematical model specification shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The TCS mathematical model specification shall list the applicable directory or glossary and the meaning of specific terms or abbreviations utilized in this document.

<4> Definition of subassemblies, interfaces and nodal breakdown

a. The TCS mathematical model specification shall specify the subassemblies, for which mathematical models are required.

b. The TCS mathematical model specification shall define conductive, convective and radiative interface nodes and their characteristics.

<5> Node number and node identification

a. The maximum number of nodes for a subassembly model shall be given.

b. A method of identification and numbering of nodes shall be presented.

DRD Annexes (normative) (4) - Example

<6> Modelling rules

a. The model hierarchy shall be described.

b. The document shall describe the applied modelling rules for thermal items

c. Control algorithms for thermal components shall be described.

<7> Software tools

a. The software tools to be used for development of the mathematical models shall be described.

<8> Test cases

a. The thermal mathematical model shall be delivered together with the definition and results of representative test cases.

A2.2 Special remarks

None

Tailoring (1)

- The ECSS document contains requirements
  - for a variety of thermal products (spacecraft and launcher subsystems, equipment, units)
  - related to different missions (Earth orbiting spacecraft, exploration spacecraft …), different temperature ranges
- Requirements are of generic nature and therefore not defined for a specific project
- Consequently, it is necessary to select from the ECSS document a set of suitable requirements for each project case => this selection process is called tailoring

ECSS definition of tailoring (ECSS P-001B):

- Process by which individual requirements of specifications, standards and related documents are evaluated and made applicable to a specific project by selection, and in some exceptional cases, by modifications of existing or by addition of new requirements.
- Tailoring is, according to ECSS rules, a task of the customer.
- In most cases tailoring is performed by the contractor and approved by the customer
- The exact process of tailoring is not yet clearly defined and is still improving.

Tailoring (2)

- **Examples for ECSS requirements tailoring**
  - **Project A**
    - Tailoring performed by ESA (as Customer). Reference: AAA.ESA.SA.RS.0074, “Tailoring of ECCS-E Engineering Standards“

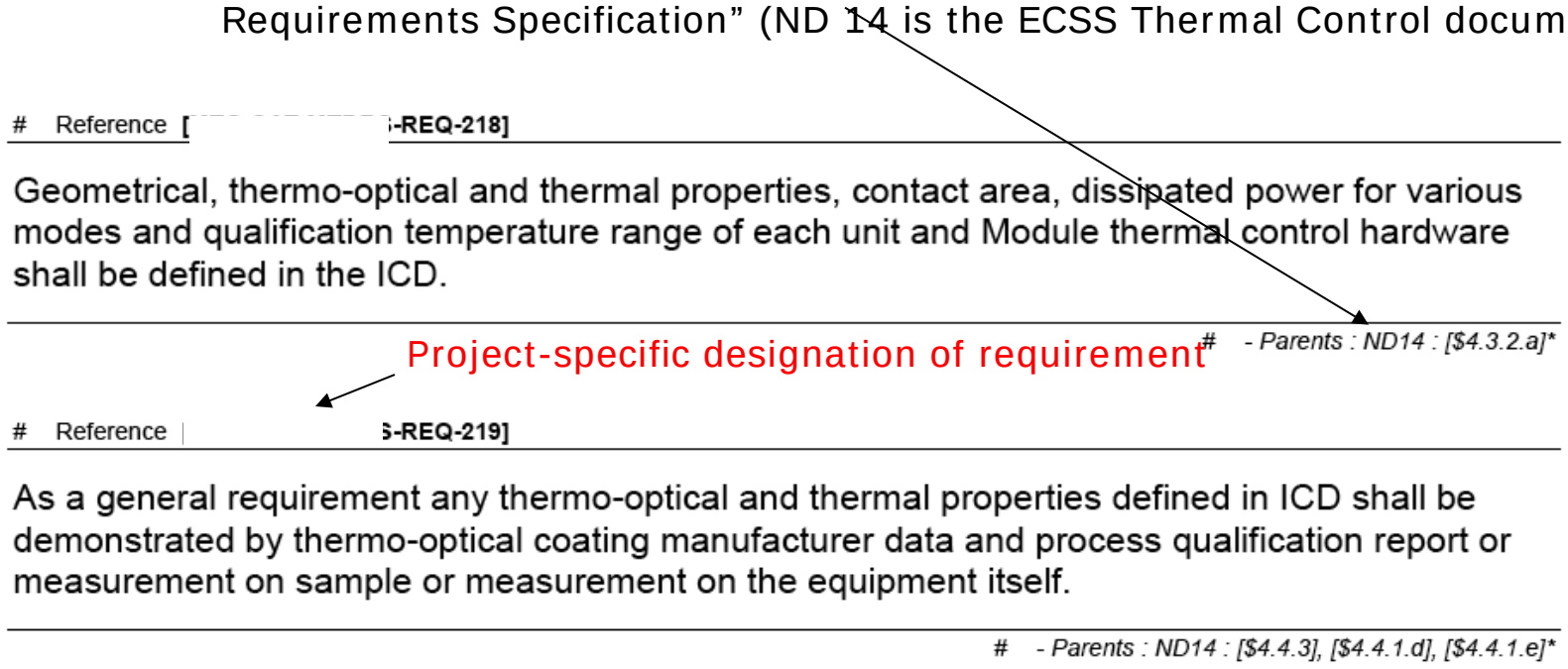
E-ST-31C Thermal control general requirements

Clauses removed	4.1.5	Interplanetary phases
	4.1.7	Docking, docked and separation phases
	4.1.8	Descent, re-entry and landing
	4.1.9	Post-landing phases
	4.2.2	High temperature range
	4.3.9	ECLS
	Annex H	High temperature range
	Reason:	Relates to events and environment not encountered by MTG

- The table lists requirements which are not applicable for Project A
- All other thermal requirements of E-ST-31C are then applicable

Tailoring (3)

- Project A (cont)
  - ECSS requirements are implemented into project document as shown in the following example:
    - Document: AAA-BBB-SA-SS-0166 “Mechanical and Thermal Design Requirements Specification” (ND 14 is the ECSS Thermal Control document)



- Some ECSS requirements have been modified before introduction into project specific documents
- A check whether all relevant ECSS requirements are used is, however, not performed

Tailoring (4)

- Examples for ECSS requirements tailoring (cont)
  - Project B
    - ECSS requirements are implemented into project document as shown in the following Document: BBB-XXX-SP-0046 “Thermal Control System Specification” (RD2 is the ECSS Thermal Control document)

Req #	Requirement	Source	Verif. Method
TCS-GEN-4.4-0200	The TCS shall conform to the specified launcher envelope(s) both for static and dynamic conditions, and shall consider accessibility requirements.	[RD2]	A
TCS-GEN-4.4-0210	The TCS shall be compatible with launch-pad air-conditioning requirements as defined in [AD4]	[RD2]	R
TCS-GEN-4.4-0220	The TCS shall conform to the launcher depressurization profile and the heat fluxes from the fairing and the launcher interface as defined in [AD4].	[RD2]	A

Project-specific designation of requirement

- All applicable ECSS requirements are introduced into the project specific specification (unchanged or modified, if noted)
- A cross reference to the applicable ECSS clause is not given
- A check whether all relevant ECSS requirements are used is, however, not performed

Conclusion

- ECSS-E-ST-31C defines a set of requirements, which are applicable for thermal control design and verification tasks in all spacecraft projects
- In addition technical terms are defined, which shall be used by all ECSS users to avoid misunderstandings in technical discussions
- The document covers requirements for the entire temperature range and includes requirements for all mission phases, for interfaces to equipment thermal control and other subsystems
- Requirements are mostly generic and need to be translated into project specific (quantitative) requirements
- A set of requirements specific to a project must be generated by a tailoring process
- When introducing requirements into project specific documents it is recommended to differentiate between product oriented and process oriented requirements. Most of the process requirements could be part of project specific Statement of Work (SOW)