Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

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Supplement to document ST/SG/AC.10/C.3/2012/8

Transmitted by the expert from Spain

EUROPEAN COOPERATION

ECSS

FOR SPACE STANDARDIZATION

Space engineering

Qualification of Two-Phase Heat Transport Systems

To be updated after ECSS-E-ST-03C “Testing” has been issued.

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

The formulation of this Standard takes into account the existing ISO 9000 family of documents.

Standard has been prepared by the ECSS-E-31-02 Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Change log

Issue	Implemented changes
A	Initial issue Transformation of PSS-49 into an ECSS document
Draft 4	Discussed in WG 170608
Draft 5	Prepared for WG 08 July 2008
WG3 Draft	Comments made during WG3 – 08.07.2008
Draft 6	Clean copy after WG3 meeting, Chapter 4 “Qualification Principles” subdivided in sub-chapters Introduction of Chapter 4.5 “Temperature and performance range” Inclusion of text for Chapter “Introduction”
Draft 7	Clean copy after WG 4 meeting (29/30 September 2008) Update of qualification test flow (as separate document for this draft) Inclusion of pressure cycle test Inclusion of leak-before-burst requirement Subdivision of thermal performance tests in “generic” “for HP” and “for CDL”
Draft 8	Clean copy after WG 5 meeting (21/22 April 2009) Changes marked in blue
Draft 9a	Clean copy after WG 6 on September 2 / 3 2009
Draft 10	Changes implemented during WG 10 discussions
Draft 11	Clean up of document with comments after WG 7, including comments from Enrique Conzales. Draft to be presented to TA.

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Introduction

This Standard is based on ESA PSS-49, Issue 2 "Heat pipe qualification requirements", written 1983, when the need for heat pipes in several ESA projects had been identified. To that time a number of European development activities were initiated to provide qualified heat pipes for these programmes, which culminated in a first heat pipe application on a European spacecraft in 1981 (MARECS, BR-200, ESA Achievements - More Than Thirty Years of Pioneering Space Activity, ESA November 30, 2001), followed by a first major application on a European communication satellite in 1987 (TV-SAT 1, German Communication Satellites).

ESA PSS-49 was published to a time, when knowledge of heat pipe technology started to evolve from work of a few laboratories in Europe (IKE, University Stuttgart, EURATOM Research Centre, Ispra). Several wick designs, material combinations and heat carrier fluids were investigated and many process related issues remained to be solved. From today's view point the qualification requirements of ESA PSS-49 appear therefore very detailed, exhaustive and in some cases disproportionate in an effort to cover any not yet fully understood phenomena. As examples the specified number of qualification units (14), the number of required thermal cycles (800) and the extensive mechanical testing (50 g constant acceleration, high level sine and random vibration) can be cited.

The present Standard takes advantage of valid requirements of ESA PSS-49, but reflects at the same time today's advanced knowledge of two-phase cooling technology, which can be found with European manufacturers. This includes experience to select proven material combinations, reliable wick and container designs, to apply well-established manufacturing and testing processes, and develop reliable analysis tools to predict in-orbit performance of flight hardware. The experience is also based on numerous successful two-phase cooling system application in European spacecraft over the last 20 years.

Besides stream-lining the ESA PSS-49, to arrive at today's accepted set of heat pipe qualification requirements, the following features have also be taken into account:

- Inclusion of qualification requirements for two-phase loops (CPL, LHP),
- Reference to applicable requirements in other ECSS documents,
- Formatting to recent ECSS template in order to produce a document, which can be used in business agreements between customer and supplier.

1 Scope

This standard defines requirements for two-phase heat transportation systems (TPHTS), for use in spacecraft thermal control.

This standard is applicable to new hardware qualification activities.

This standard is not applicable to already existing TPHTS hardware at the date of the publication.

2
Normative references

The following dated normative documents are called by the requirements of this ECSS Standard and therefore constitute requirements to it. Subsequent amendments to, or revisions of any of these publications do not apply.

NOTE However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below.

ECSS-E-ST-10-02	Space engineering - Verification
ECSS-E-ST-10-03	Space engineering – Testing
ECSS-E-ST-10-06	Space engineering - Technical requirements specifications
ECSS-E-ST-31	Space engineering - Thermal control general requirements
ECSS-E-ST-32-02	Space engineering - Structural design and verification of pressurized hardware
ECSS-E-ST-32-01	Space engineering - Fracture Control
ECSS-E-ST-32	Space engineering - Structural general requirements
ECSS-S-ST-00-01	ECSS system – Glossary of terms
BS EN 9100:2009-08-31	Aerospace series - Quality management systems - Requirements (based on ISO 9001:2000) and Quality systems - Model for quality assurance in design, development, production, installation and servicing (based on ISO 9001:1994)

3 Terms, definitions and abbreviated terms

3.1 Terms defined in other standards

For the purpose of this Standard, the terms and definitions from the following standards apply in particular from

ECSS-S-ST-00-01:

calibration

characteristic

customer

design

development

environment

equipment

failure

function

infrastructure

inspection

lifetime

model

performance

procedure

product

qualification process

requirement

risk

safety critical function

specification

standard

supplier

system

technical specification

test

traceability

validation

verification

ECSS-E-10-02B:

analysis

qualification stage

review-of-design (ROD)

ECSS-E-10-03B

burst pressure

proof pressure

thermal cycle

ECSS-E-32-02

differential pressure

external pressure

internal pressure

leak-before-burst

pressure vessel

pressurized hardware

proof pressure

proof test

3.2 Terms specific to the present standard

3.2.1. capillary pumped loop (CPL)

CDL with the fluid reservoir separated from the evaporator and without a capillary link to the evaporator

NOTE See CDL definition in 3.2.2.

3.2.2. capillary driven loop (CDL)

TPL, in which fluid circulation is accomplished by capillary action (capillary pump)

NOTE See TPL definition in 3.2.21.

3.2.3. constant conductance heat pipe (CCHP)

heat pipe with a fixed thermal conductance between evaporator and condenser at a given saturation temperature

NOTE See heat pipe definition in 3.2.6

3.2.4. dry-out

depletion of liquid in the evaporator section at high heat input when the capillary pressure gain becomes lower than the pressure drop in the circulating fluid

3.2.5. effective length

heat pipe length between middle of evaporator and middle of condenser for configurations with one evaporator and one condenser only

NOTE Used to determine the heat pipe transport capability (see 3.2.10)

3.2.6. exposure temperature range

maximum temperature range to which a TPHTS is exposed during its product life cycle and which is relevant for thermo-mechanical qualification

NOTE 1 The internal pressure at the maximum temperature of this range defines the MDP for the pressure vessel qualification of a TPHTS

NOTE 2 The extreme temperatures of this range can be below freezing and / or above critical temperatures of the working fluid

NOTE 3 In other technical domains, this temperature range is typically called non-operating temperature range (see clause 4 for additional explanation).

3.2.7. heat pipe (HP)

TPHTS consisting of a single container with liquid and vapour passages arranged in such a way that the two fluid phases move in counter flow

NOTE 1 See TPHTS definition in 3.2.20

NOTE 2 The capillary structure usually extends over the entire container length

3.2.8. heat pipe diode (HPD)

heat pipe , which transports heat based on evaporation and condensation only in one direction

NOTE See heat pipe definition in 3.2.7

3.2.9. loop heat pipe (LHP)

CDL with the fluid reservoir as integral part of the evaporator

NOTE 1 See CDL definition in 3.2.2

NOTE 2 The reservoir can be separated, but has a capillary link to the evaporator

3.2.10. heat transport capability

maximum heat pipe transport capability expressed in [Wm] (transported heat x effective length)

3.2.11. maximum design pressure (MDP)

maximum allowed pressure inside a TPHTS during product life cycle

NOTE The product life cycle starts after acceptance of the product for flight

3.2.12. mechanical pump driven loop (MPDL)

TPL, in which fluid circulation is accomplished by a mechanical pump

NOTE See TPL definitions in 3.2.21

3.2.13. product life cycle

product life starting from the delivery of the TPHTS hardware until end of service live

3.2.14. reflux mode

operational mode, where the liquid is returned from the condenser to the evaporator by gravitational forces and not by capillary forces

3.2.15. start-up

operational phase starting with initial supply of heat to the evaporator until nominal operational conditions of the device are established

3.2.16. sub-cooling

temperature difference between average CDL reservoir temperature and the temperature of the liquid line at the inlet to the reservoir

NOTE The average CDL reservoir temperature represents the saturation temperature inside the reservoir.

3.2.17. thermal performance temperature range

temperature range for which a TPHTS is thermally qualified

NOTE In the thermal performance temperature range a thermal performance map exists.

3.2.18. tilt for HP

height of the evaporator (highest point) above the condenser (lowest point) during ground testing

NOTE This definition is valid for a configuration with one evaporator and one condenser (see Figure 3-1)

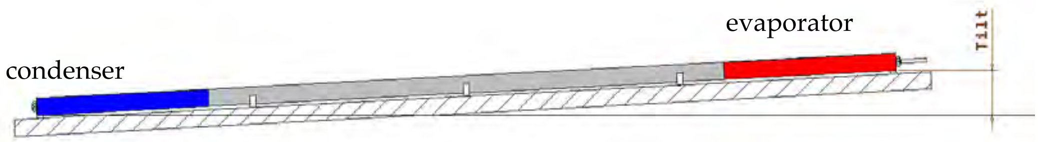


Figure 3-1: Tilt definition for HP

3.2.19. tilt for LHP

height of the evaporator (highest point) above the reservoir (lowest point) during ground testing (see Figure 3-2)

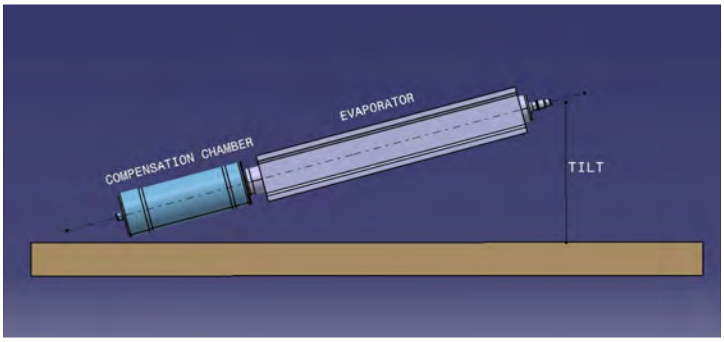


Figure 3-2: Tilt definition for LHP

3.2.20. two-phase heat transport system (TPHTS)

hermetically closed system filled with a working fluid and transporting thermal energy by a continuous evaporation/condensation process using the latent heat of the fluid

NOTE 1 A fluid evaporates in the heat input zone (evaporator) and condenses in the heat output zone (condenser)

NOTE 2 This is in contrast to a single-phase loop where the sensible heat of a liquid is transported (a liquid heats up in the heat input zone and cools down in the heat output zone)

3.2.21. two-phase loop (TPL)

TPHTS with physically separated vapour and liquid transport lines forming a closed loop

NOTE See TPHTS definition in 3.2.20.

3.2.22. useful operational temperature range

temperature range between freezing and critical point of a working fluid, for which a meaningful heat transport capability can be determined

NOTE The useful operational temperature range is generally the operational qualification temperature range

3.2.23. variable conductance heat pipe (VCHP)

heat pipe with an additional non-condensible gas reservoir allowing a variable thermal conductance between evaporator and condenser

NOTE 1 See heat pipe definition in 3.2.7

NOTE 2 The variation in thermal conductance is generally accomplished by regulating the volume of a non-condensable gas plug reaching into the condenser zone, which in turn varies the effective condenser length

NOTE 3 The variation of the gas volume can be performed by active or passive means

3.3 Abbreviated terms

The following abbreviations are defined and used within this standard:

Abbreviation	**Meaning**

Abbreviation	Meaning
CCHP	Constant conductance heat pipe
CDL	Capillary driven loop
CPL	Capillary pumped loop
DRD	Document Requirement Definition
DUL	Design ultimate load
DYL	Design yield load
FOSU	Factor of safety ultimate
FOSY	Factor of safety yield
HP	Heat pipe
HPD	Heat pipe diode
LBB	Leak before burst
LHP	Loop heat pipe
MDP	Maximum design pressure
MPC	Metallic pressurized component
MPDL	Mechanical pump driven loop
MSPE	Metallic special pressurized equipment
NDI	Non-destructive inspection
ROD	Review-of-design
SPE	Special pressurized equipment
TPHTS	Two-phase heat transport system
TPL	Two-phase loop
VCHP	Variable conductance heat pipe

4 Qualification Principles

4.1 TPHTS categorization

The TPHTS are categorized in Figure 4-1 according to their design and functional principle.

Heat pipes consist in general of a single container with a capillary structure extending over the entire container length. Liquid and vapour passages are arranged in such a way that the two fluid phases move in counter flow.

Capillary driven loops (CDL) have separate evaporator and condenser sections, which are connected by dedicated vapour and liquid tubing. At least one capillary structure is located in the evaporator section, which serves as capillary pump to circulate the fluid in a true loop configuration.

The mechanically pumped two-phase loop (MPDL) has a configuration, which is similar to the CDL, except that the circulation of the fluid is accomplished by a mechanical pump.

NOTE Requirements for MPDL are not included in version C of this Standard

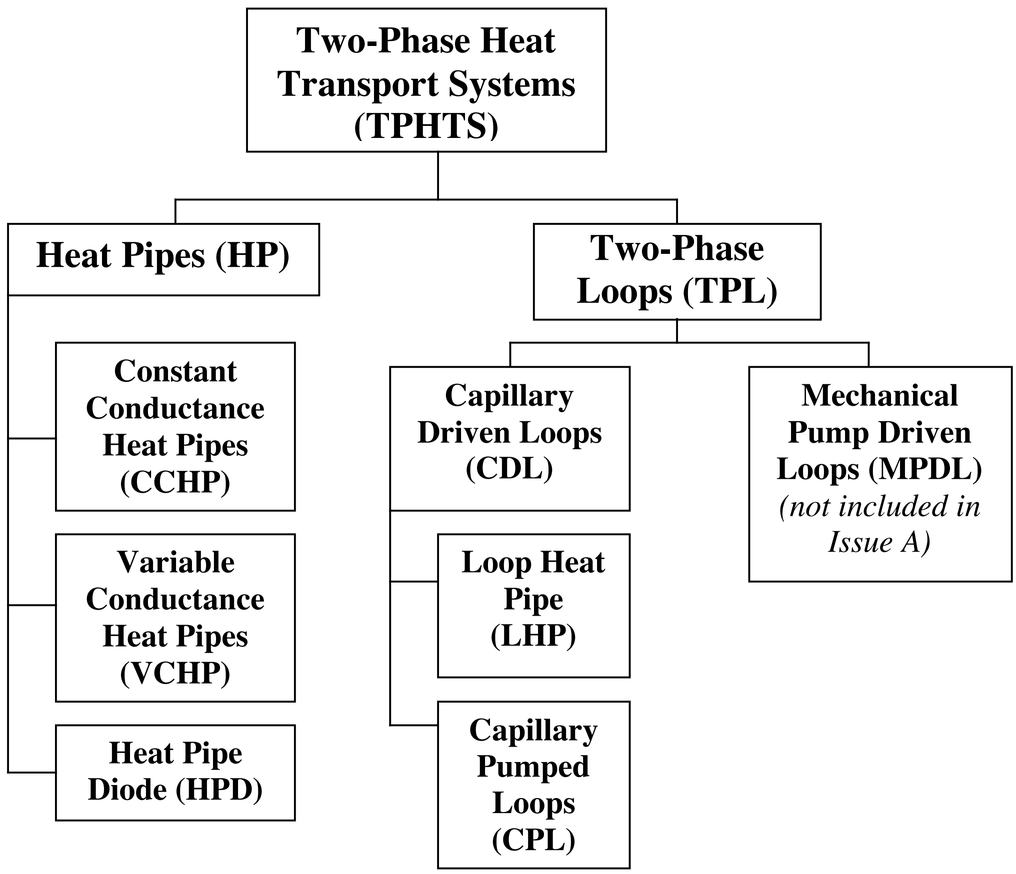


Figure 4-1: Categories of Two-Phase Heat Transportation Systems

4.2 Involved organizations

The qualification process of TPHTS is generally carried out by a specialized equipment manufacturer (called in this document "supplier") and controlled by the qualification authority, which is in most cases and called in this document the "customer".

The qualification activity is embedded in the supplier's product assurance and quality organization and in most cases the supplier's quality assurance plan has been established and approved for space activities independently from the TPHTS qualification process specified in this document. It is the task of the supplier's PA authority to introduce / approve adequate product assurance provisions at his subcontractor(s). The existence of an approved PA Plan is precondition for commencing qualification activities.

4.3 Generic requirements

The present document provides generic, i.e. not project specific requirements for formal qualification of TPHTS. It is therefore important to select overall and enveloping qualification requirements in order to support a maximum of spacecraft application without the need for delta qualification.

4.4 Processes, number of qualification units

The qualification of TPHTS is based on qualified manufacturing processes (e.g. cleaning, surface treatment, welding and leak testing) and covers in general the following areas:

- Performance over long operation time (compatibility between fluid and wall material, space radiation, leak tightness)
- Mechanical performance (strength, pressurized hardware)
- Thermal performance (heat transport capability, start-up behaviour, heat transfer coefficients, etc.)

In this context the number TPHTS units to be produced for the qualification program are evaluated and selected by the supplier. There are no general applicable sources, which specify the minimum of units to be used to undergo identical qualification testing in order to arrive at a successful qualified product. The question to be answered for each TPHTS configuration is: How many identical units needs to be built and tested in order to verify that production processes provide reproducible performance results.

The following are possible selection criteria:

- Experience of the manufacturer in production of similar products,
- Simplicity of the configuration,
- TPHTS design features, which have inherent capability for good repeatability of the production processes (simple axial grooved heat pipes).

This Standard specifies the number of needed units submitted to the qualification process for configurations, which are currently used in several spacecraft applications. It is expected that the supplier performs the selection for other configurations and provide argumentation to the customer for agreement of his choice.

Compared to full qualification of a new product the number of units can be reduced for delta qualification of an existing but modified product.

4.5 Thermal and mechanical qualification

4.5.1 Temperature range

In contrast to most of electronic equipment the performance of a TPHTS varies with its operating temperature, because properties of the used heat carrier are temperature dependent. For heat pipes as an example, important fluid properties can be grouped into a figure-of-merit (G), which is the product of surface tension, heat of vaporization and liquid density divided by the liquid viscosity (for more information see references in Bibliography). G is plotted for some fluids over the temperature in Figure 4-2. The heat transport capability of a capillary pumped loop is proportional to these curves.

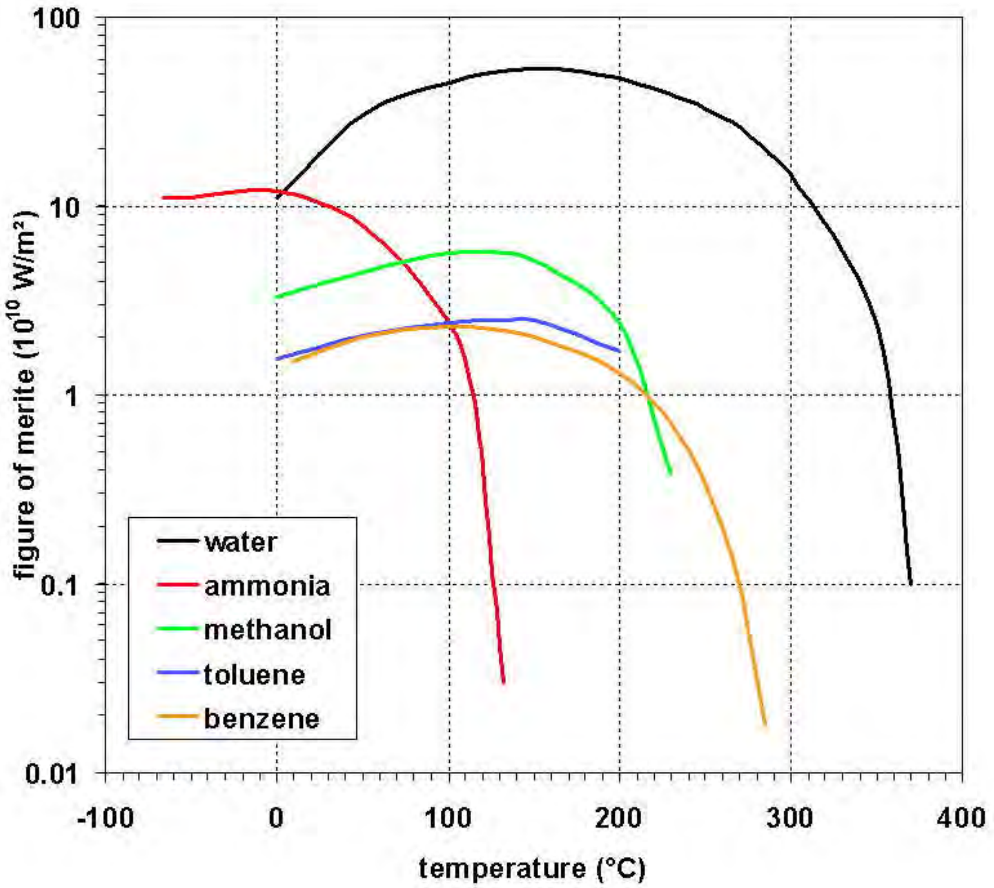


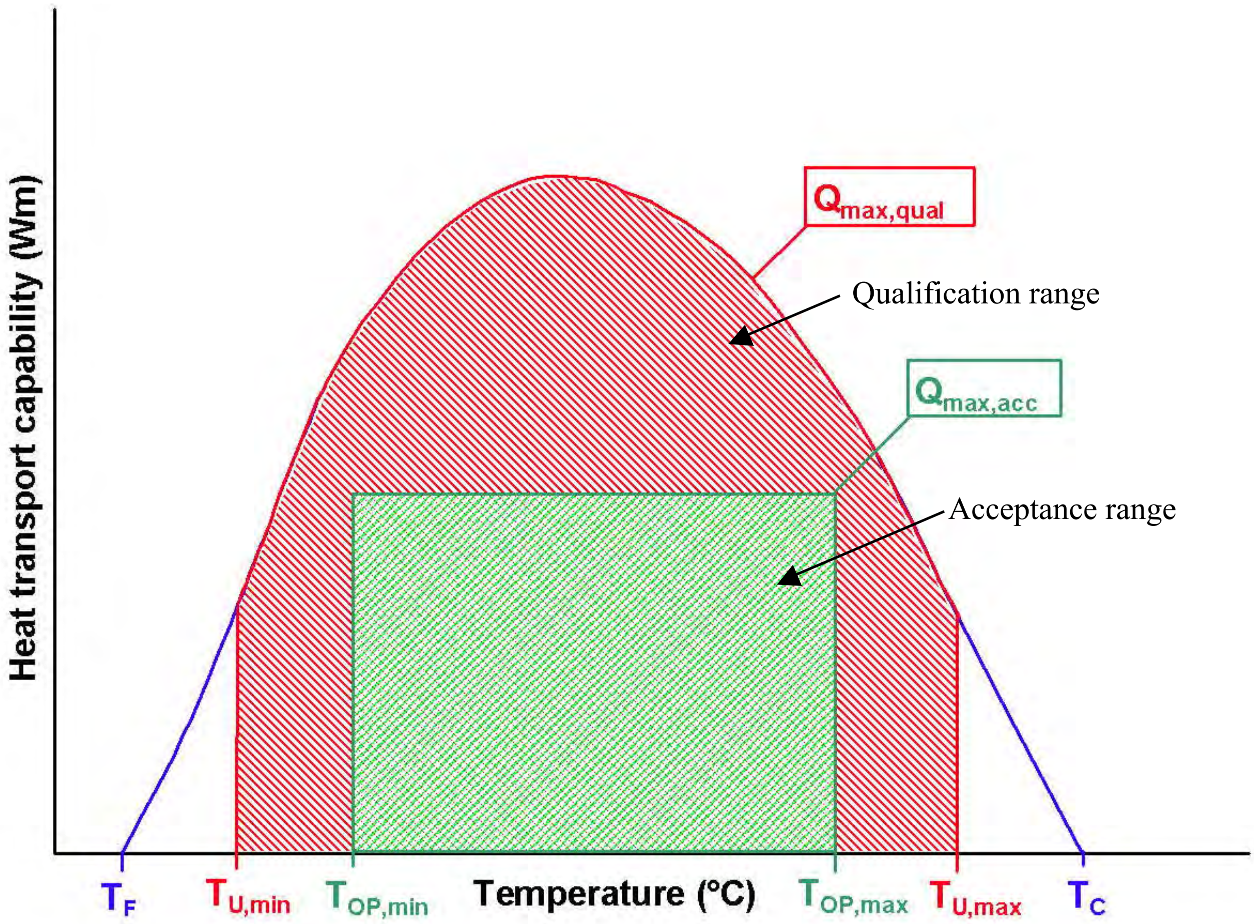
Figure 4-2: Figure-of-merit (G) for some TPHTS fluids

Generally, the **applicable temperature range** of a TPHTS is subdivided into a thermally and a mechanically relevant regime.

The **thermal performance temperature range**, for which qualification is performed, is defined within the theoretical operating temperature range, confined by the freezing and the critical temperature of the used fluid. Lower and upper temperature limits of the qualification range are selected in such a way that a useful map of thermal performance data can be established. Within this range the maximum transport capability for qualification will be determined. For a specific space application the operating temperature range (within the thermal performance temperature range) and the maximum required heat transport capability are specified.

For thermo-mechanical qualification the temperature range is relevant, to which the device is exposed to during the life cycle. In most cases this **exposure temperature range** is wider than the above-mentioned thermal performance temperature range. The minimum temperature of this range can be below the freezing temperature of the used heat carrier and it is important to take into account possible damage caused by the frozen liquid. The upper exposure temperature can be even above the critical temperature of the heat carrier. This temperature determines in general the maximum internal pressure for design and qualification of the device.

The mentioned temperature ranges and associated heat transport capabilities are illustrated in Figure 4-3.



$Q_{max,qual}$	Maximum transport capability for qualification
$Q_{max,acc}$	Maximum transport capability for acceptance (specified for a specific project)
T_F, T_C	Freezing and critical temperature of a selected fluid
ΔT-Expose	exposure temperature range
ΔT-Perform	thermal performance temperature range
ΔT-Accept	acceptance and nominal operating temperature range (specified for a specific project)

Figure 4-3: Definition of Temperature and performance ranges for a HP

4.5.2 Mechanical qualification

TPHTS are classified as pressurized component and relevant mechanical requirements are specified in ECSS-STD-E-32-02 and are applied in the present Standard for all TPHTS types.

For qualification of a TPHTS as pressurized component the main characteristic is the internal pressure, which varies in relation to the exposure temperature of the unit (temperature dependent saturation pressure of the heat carrier liquid).

ECSS-STD-E-32-02 specifies qualification requirements for TPHTS, which undergo either proof pressure tests ≥ 1,5 MDP or <1,5 MDP. However units, which have seen proof pressures < 1,5 MDP, are generally not accepted by customers. The present Standard selects therefore qualification requirements for TPHTS, which have seen proof pressure tests ≥ 1,5 MDP. As a rule, qualification by pressure testing is the preferred method rather then qualification by fracture control analysis.

For qualifying a TPHTS with respect to external mechanical environment the following mechanical tests are considered:

- Constant or static acceleration
- Sine vibration
- Random vibration

For these tests the qualification unit needs to be rigidly mounted to the test equipment (vibration table). However, such mounting provisions can have only reduced similarity to real applications in spacecrafts and the meaningfulness of such tests is, therefore, very often reason for discussion under experts. For heat pipes it is common understanding not to perform these tests on long heat pipe profiles for the following reasons:

- The length of the test heat pipe is adapted to the test equipment and is therefore shorter as in many realistic spacecraft applications
- The application of heat pipe is often for embedding them in sandwich structures. Mechanical loads for these applications are quite different as can be simulated with a rigidly fixed single heat pipe profile.
- Several capillary structures, in particular axial groove heat pipes, are quite insensitive to mechanical loads and tests as suggested in existing procedures can be unnecessary.

For many TPHTS applications (in particular for devices with simple capillary structures, e.g. axial grooves) the formal mechanical qualification can be therefore performed with the first structural model on satellite level. In case the risk for such a late qualification is high, pre-qualification can be performed on unit or part level in particular for the following cases:

- The TPHTS, in particular a heat pipe, has a capillary structure, which is sensitive towards mechanical loads, e.g. arterial wick. In such a case a short piece of the heat pipe profile is selected for mechanical qualification testing (sine, random vibration).
- An evaporator of a LHP or CPL can be separately tested (sine, random vibration) to verify that mechanical requirements are met.
- Equally this can be true for a two-phase loop condenser, in particular for configurations where the condenser tubing is embedded into a structural panel.

The Standard will therefore not specify at which model level vibration testing is to be performed. The supplier and customer are asked to agree on a logical qualification plan, which may include testing at higher then equipment level.

5 Requirements

5.1 Technical specification

a. The qualification process shall be based on a technical specification approved by the customer.

NOTE Usually the technical specification evolves from the functional requirements of the customer and defines the technical performances for the proposed solution as part of a business agreement.

b. The technical specification specified in 5.1a shall be drafted according to ECSS-E-ST-10-06 “Technical requirements specifications”.

NOTE A tailoring guide is provided in Table A 1.

5.2 General qualification requirements

5.2.1 Qualification process requirements

a. The qualification process shall meet requirements of ECSS-E-ST-10-02C "Verification".

NOTE 1 A tailoring guide is provided in Annex Table A 2.

NOTE 2 It is important to note that ECSS-E-ST-10-02 clause 5.2.4.1b requires that the qualification stage is completed before launch.

5.2.2 Supporting infrastructure

a. The infrastructure to support the qualification process shall meet requirements of ECSS-E-ST-10-03.

NOTE 1 A tailoring guide is provided in Annex Table A 4.

NOTE 2 Requirements are in particular related to tool and test equipment validation, calibration, re-verification after modification, avoidance of adverse effects of facilities, tools and instrumentation on qualification objectives.

5.3 Qualification process selection

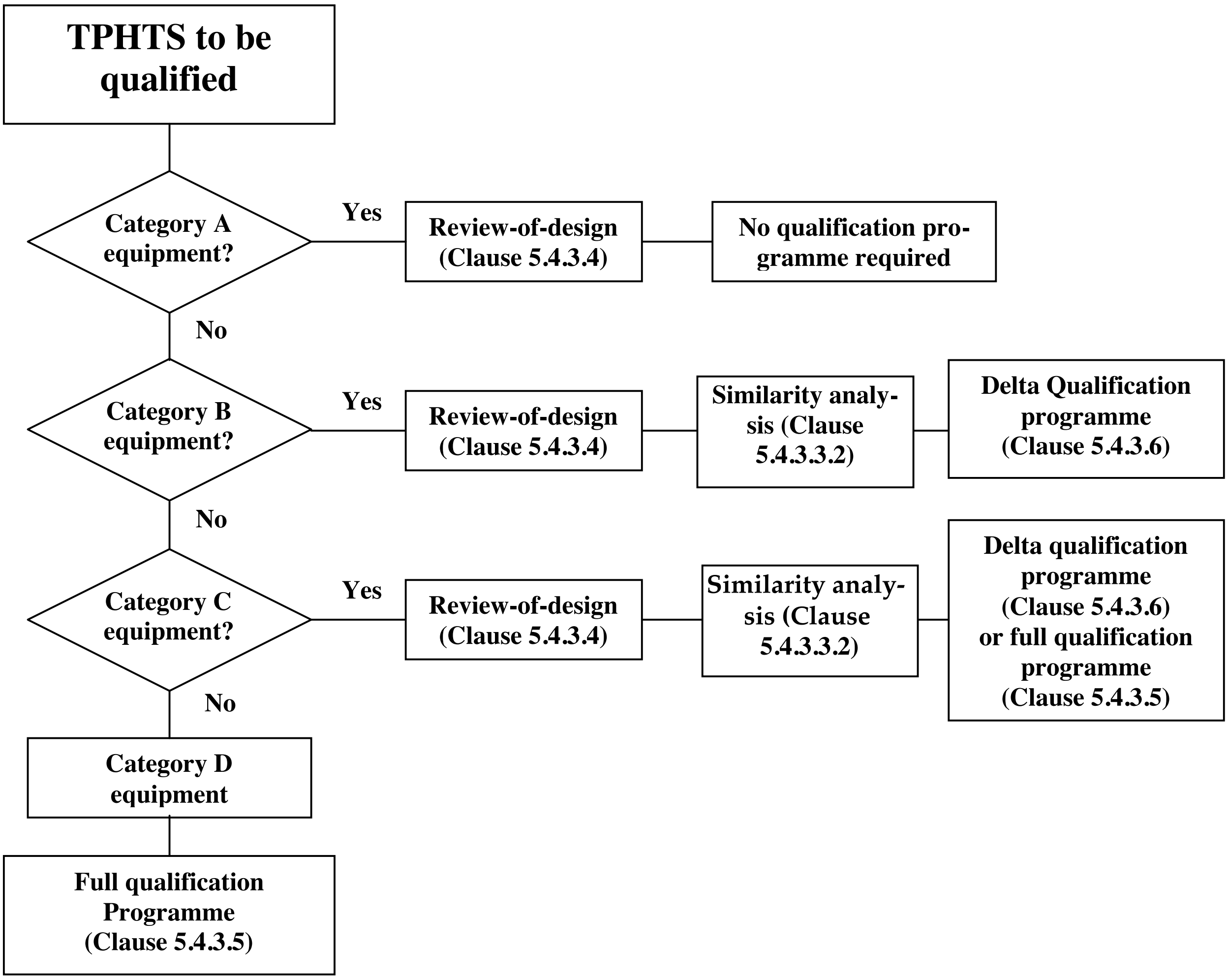
a. The scope of the qualification process shall meet requirements of ECSS-E-ST-10-02.

NOTE 3 A tailoring guide is provided in Annex A.2.

NOTE 4 It is important to note that ECSS-E-ST-10-02 requires that the qualification process is to be adapted to the qualification heritage of the product.

b. The qualification process shall be structured according to Figure 5-1.

NOTE Tailoring of categories in E-10-02 for application to TPHTS are shown in Annex Table A 3.



For category definition see Annex Table A 3.

Figure 5-1: Selection of qualification process

5.4 Qualification stage

5.4.1 General

a. The qualification stage shall meet requirements of ECSS-E-10-02.

NOTE 1 A tailoring guide is provided in Annex A.2.

NOTE 2 In particular ECSS-E-10-02 specifies that the qualification demonstrates that the design meets requirements of the specification, that traceability to lower level verification exists, that lower level qualification to be closed-out prior to close-out at higher level.

NOTE 3 The qualification can be supported by in-orbit demonstration to verify requirements, which are affected by zero-g environment.

5.4.2 Quality audits

a. The supplier shall allow quality audits in support to the qualification process in accordance with EN 9100-2009 Clause 4.6.4.2.

b. Quality audits shall be conducted such that the supplier's know-how and proprietary data are protected

NOTE As a general rule audits should be performed by quality assurance personnel of the customer and not by experts in the field.

5.4.3 Qualification methods

5.4.3.1 Overview

a. The qualification stage shall meet requirements of ECSS-E-10-02.

NOTE 1 A tailoring guide is provided in Table A 2.

NOTE 2 In particular ECSS-E-10-02 specifies that the qualification methods by test, analysis (including similarity, review-of-design and inspection.

NOTE 3 Generally, all new TPHTS are qualified by test

b. The selected qualification methods shall be defined in a verification plan (see RN 3 of Table 5-1).

c. The verification plan shall be agreed with the customer.

5.4.3.2 Test

a. Qualification testing shall meet requirements of ECSS-E-10-02.

NOTE 1 A tailoring guide is provided in Table A 2.

NOTE 2 In particular ECSS-E-10-02 specifies verification by test for safety critical functions and on hardware, which is representative of the end item in terms of design, materials, tooling and methods.

b. TPHTS subject to qualification test shall be manufactured applying qualified processes.

5.4.3.3 Analysis

5.4.3.3.1 General

a. Analysis shall be performed to predict specified performance parameter of the TPHTS.

b. Analytical prediction results shall be correlated with qualification test results.

NOTE Result correlations lead to software tool validation, which can reduce follow-on qualification processes.

c. Discrepancies between analytical prediction and test results shall be analysed in order to demonstrate that the objective of the qualification is not compromised.

5.4.3.3.2 Similarity

a. Verification by similarity shall meet requirements of ECSS-E-10-02.

NOTE 1 A tailoring guide is provided in Annex A.2.

NOTE 2 In particular ECSS-E-10-02 specifies for a product that is similar to already qualified products that a delta qualification programme is being identified by similarity analysis.

5.4.3.4 Review-of-design and inspection

a. Verification by review-of-design (ROD) shall meet requirements of ECSS-E-10-02.

NOTE 1 A tailoring guide is provided in Annex A.2.

NOTE 2 In particular ECSS-E-10-02 specifies to use for ROD existing records and evidence for demonstration that requirements are met.

NOTE 3 Existing records and evidence are validated design documents, approved design reports, technical description, engineering and manufacturing drawings.

5.4.3.5 Full qualification programme

a. Category C and D equipment (see Table A 3) shall be qualified by test according to Clause 5.4.3.2 and 5.5 and by analysis according to Clause 5.4.3.3.

NOTE In agreement with the customer a reduced qualification programme can be selected for Category C equipment

5.4.3.6 Delta qualification programme

a. Category B equipment (see Table A 3) shall undergo a delta qualification programme, which is a subset of the full qualification programme of Clause 5.4.3.5

b. The delta qualification programme shall be selected on a case-by-case basis and based on the modifications to existing qualified hardware

c. The delta qualification programme shall be agreed with the customer

5.4.3.7 Performance requirements

5.4.3.8 Generic requirements

a. The following generic performance characteristics of a TPHTS shall be determined and verified against specified data:

1. Ability to sustain the combination of the predicted worst mechanical loads:
   (a) External mechanical loads,
   (b) Internal loads due to the saturation pressure of the heat carrier fluid within the TPHTS exposure temperature range,
   (c) Thermo-mechanical loads due to temperature cycling and CTE mismatch within the TPHTS exposure temperature range,
   (d) Loads imposed by volume change due to freezing/thawing of the heat carrier within the TPHTS exposure temperature range.
2. Thermal parameters:
   (a) Minimum and maximum heat transport capability over the TPHTS thermal performance temperature range,

   NOTE For heat pipes only the maximum heat transport capability is of interest

   (b) Evaporator heat flux over the TPHTS thermal performance temperature range,
   (c) Heat transfer coefficient in the evaporator and condenser,
   (d) Overall thermal resistance of the device,
3. Operational requirements
   (a) Maximum heat load applied in one step over the specified temperature range, under which start-up will successfully occur
   (b) Start-up behaviour from frozen conditions, if the exposure temperature range includes freezing of the working fluid
   (c) For cryogenic TPHTS, start-up from the super-critical state of the working fluid
4. Leak-before-burst
5. Lifetime performance
   (a) Long-term compatibility between fluid and wetted materials (materials in contact with the fluid)
   (b) Space radiation effects in order to demonstrate that fluid decomposition will not adversely affect specified TPHTS performance during the product life cycle.

5.4.3.9 Specific requirements

a. For CCHP the following specific performance characteristics shall be determined and verified against specified data:

1. Reduction of transport capability due to heat pipe bending at the minimum specified radius

   NOTE The minimum bending radius is defined by the supplier

2. Reduction of transport capability due to tilt (see Figure 3-1)

b. For VCHP in addition to Clause 5.4.3.9.a

1. Maximum transport capability in fully-on conditions
2. Heat leak from condenser to evaporator in off-mode
3. Thermal resistance between condenser and reservoir
4. Ability to regulate the evaporator temperature with passive and active methods.

NOTE Passive methods include devices with non-heated gas reservoirs, active methods include devices with heated/cooled gas reservoirs

c. For Diode HP in addition to Clause 5.4.3.9.a

1. Maximum heat transport capability in forward mode
2. Time and energy to move from forward to reverse mode and vice versa
3. Hest leak from condenser to evaporator in reverse mode
4. Time-to-shutdown
5. The energy needed for shutdown for each of the above tests.
6. The time to start-up the unit.

d. For CDL

1. Minimum heat load applied under which start-up is possible over the specified temperature range.
2. Sensitivity of the minimum heat load in relation to the thermal mass attached to the evaporator
3. Minimum heat load applied under which nominal operation is possible over the specified temperature range.
4. Sub-cooling conditions to guarantee specified performance
5. Impact on performance due to tilt (see Figure 3-2) and adverse elevation (evaporator above condenser)
6. Heat leak from condenser to evaporator in off-mode
7. Ability to regulate the evaporator temperature with passive and active methods.

NOTE Passive methods include devices with passive regulation (by-pass) valves in TPL. Active methods include devices with heated/cooled liquid reservoirs, heated regulation valves and TPL's with thermo-electric cooler (TEC) on the liquid reservoir.

5.5 Qualification test programme

5.5.1 Number of qualification units

a. The number of TPHTS units submitted to the qualification programme test units shall be in accordance with Figure 5-2 and Figure 5-3.

5.5.2 Test sequence

a. TPHTS of category D as defined in Table A 3 shall be verified by qualification testing according to the test sequence as defined in Figure 5-2 for HP and Figure 5-3 for CDL .

b. For TPHTS of category B and C as defined in Table A 3 the supplier shall derive from the test sequence of Figure 5-2 and Figure 5-3 a reduced test sequence for delta qualification.

c. The delta qualification program shall be agreed with the customer.

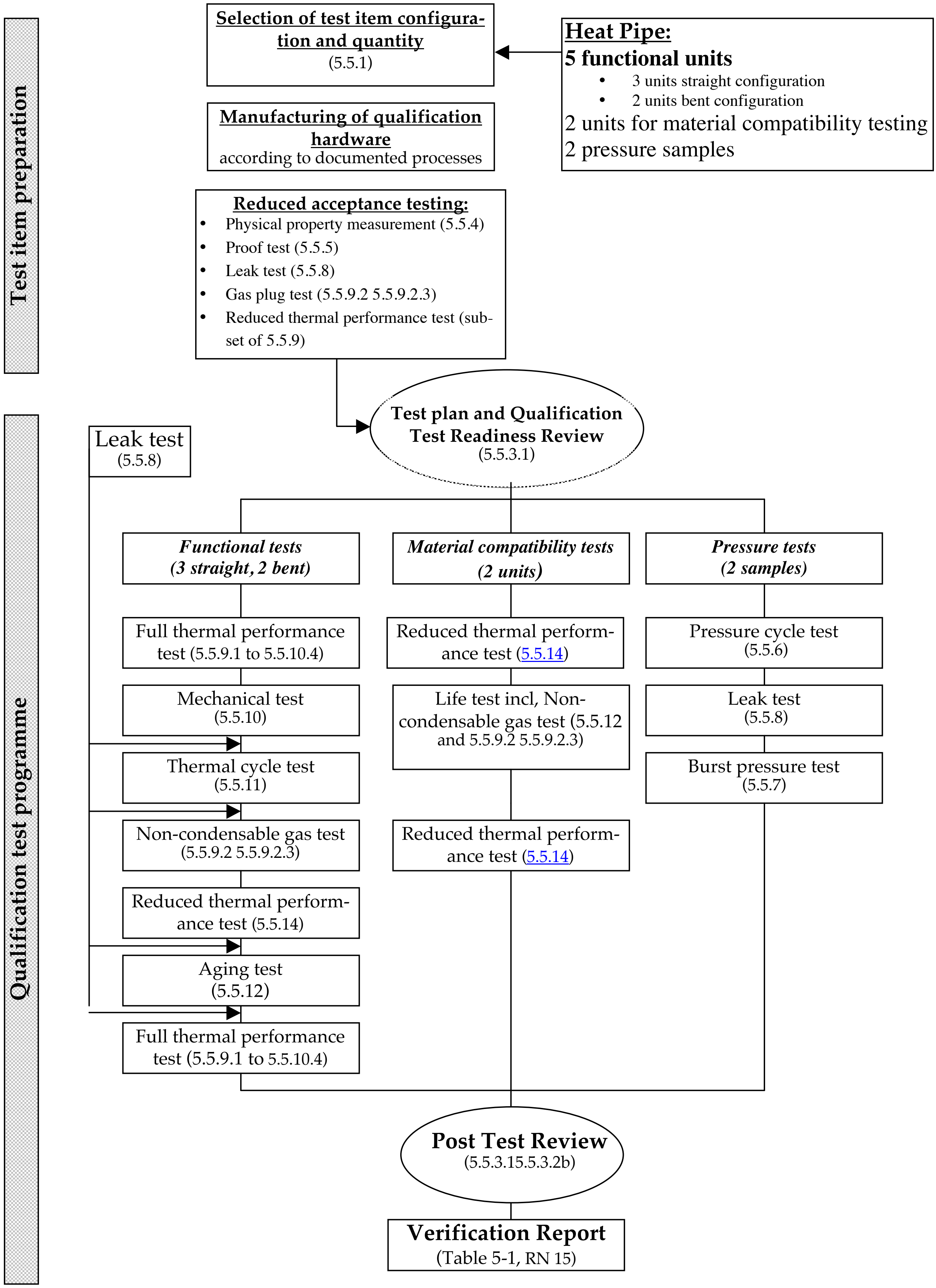


Figure 5-2: Qualification test sequence for HP

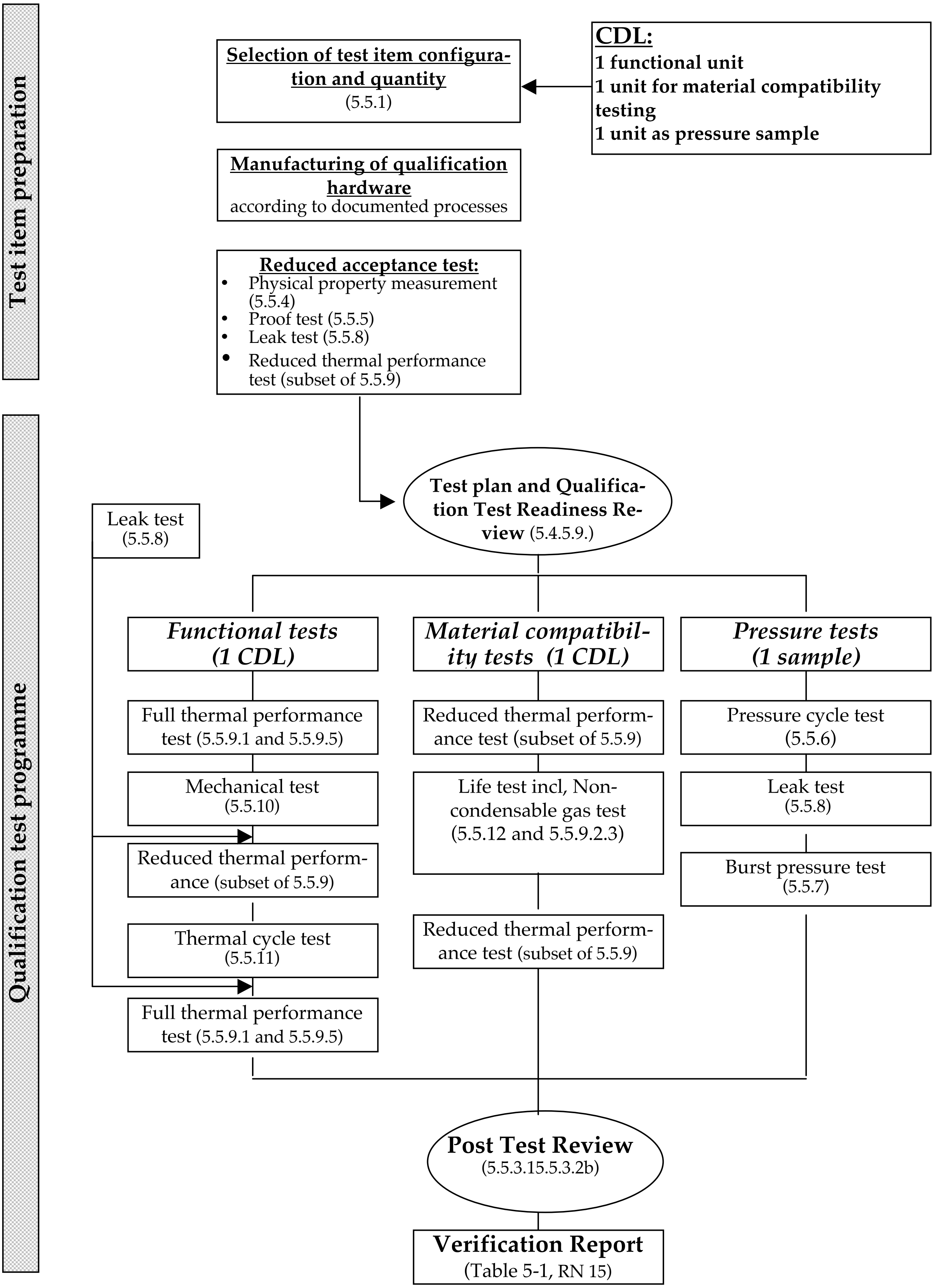


Figure 5-3: Qualification test sequence for CDL

5.5.3 Test requirements

5.5.3.1 General

a. The qualification testing process shall meet requirements of ECSS-E-ST-32-02 "Structural design of pressurized hardware".

NOTE A tailoring guide is provided in Table A 5.

5.5.3.2 Test plan and reviews

a. Before starting the qualification test campaign the following preconditions shall be met:

1. Establishing of a test specification according to Table 5-1 RN 9.
2. Establishing of detailed test procedures according to Table 5-1 RN 10.
3. Conductance of test readiness review.

b. At completion of the test sequence a post - test review shall be conducted.

c. Test documentation shall be agreed with the customer.

5.5.3.3 Test conditions

a. Test conditions to support the qualification process shall meet requirements of ECSS-E-ST-10-03.

NOTE 1 A tailoring guide is provided in Annex Table A 4.

NOTE 2 Requirements are in particular related to tolerances, calibration / measurement accuracies.

5.5.3.4 Test data management

a. Test data management shall meet requirements of ECSS-E-ST-10-03.

NOTE 1 A tailoring guide is provided in Annex Table A 4.

NOTE 2 Requirements are in particular related to trend analysis of test results to detect long-term gradually increasing defects and failures during performance, leak and long duration tests.

5.5.4 Physical properties measurement

a. Physical properties measurement shall meet requirements of ECSS-E-ST-10-03.

NOTE 1 A tailoring guide is provided in Annex Table A 4.

NOTE 2 Requirements are in particular related to the measurement of important physical properties and comparing them to specifications in relevant drawings.

b. In addition to relevant requirements of ECSS-E-ST-10-03 the following specific properties of TPHTS test unit shall be measured, recorded and compared to specification in relevant drawings:

1. Flatness of heat input and heat output zones,
2. Fluid amount (from manufacturing records),

5.5.5 Proof pressure test

a. Proof pressure test shall be performed applying 1.5 times MDP as specified in ECSS-E-32-02 for duration of 15 minutes.

NOTE 1 The factor of 1.5 can be relaxed/reduced to 1.1 for cases where MDP is based on a manufacturing process (e.g. curing of panels with embedded heat pipes) as long as the unit material stays in the elastic domain

NOTE 2 For items where, in the final configuration, the proof pressure level cannot be achieved by temperature increase (hot proof pressure), proof pressure verification can be performed at lower level.

b. Pressure shall be generated on the sealed unit by increasing the temperature of the unit and thus the saturation pressure of the heat carrier fluid (hot proof pressure test).

NOTE When the pressure target leads to a temperature higher than the critical temperature than the cold pressure test (before unit sealing) can be added to reach the pressure target and a safety factor is then not applied for the hot pressure test on the sealed unit.

c. In cases where proof pressure test is not feasible, margins against mechanical failure shall be verified by analysis in accordance with to ECSS-E-32-02.

5.5.6 Pressure cycle test

a. The pressure cycle test shall consist of 2000 cycles between 1 bar and MDP at ambient temperature

5.5.7 Burst pressure test

a. Burst pressure test shall be performed applying 2.5 times MDP for duration of 15 minutes.

NOTE The factor of 2.5 can be relaxed/reduced to 1.5 for cases where MDP is based on a manufacturing process (e.g. curing of panels with embedded heat pipes).

b. No rupture or leak shall occur during burst pressure test.

c. Burst pressure test shall be carried out with burst pressure samples manufactured from the same material batch and according to processes, which are identical to the ones used for the functional qualification unit.

d. Burst pressure samples shall include all features of the flight configuration.

NOTE For example representative bends, welds and joints.

e. Burst pressure test shall be performed at the maximum exposure temperature by increasing the internal pressure until the required burst pressure is reached.

f. After the 15 minutes hold-time, the pressure shall be further increased until rupture occurs and the pressure at rupture shall be recorded.

g. If burst pressure tests are performed at sub-unit level, the burst pressure test processes shall include all parts of the product including all joints, welds, end fittings.

NOTE For example, if it is performed at the level of the evaporator or reservoir of a TPL.

5.5.8 Leak test

a. Leak test shall be performed at ambient temperature sing an detection method agreed with the customer.

5.5.9 Thermal performance test

5.5.9.1 General

a. Thermal performance test results, obtained under 1-g conditions, shall be correlated to predict 0-g (on-orbit) performance

b. For thermal performance tests at ambient conditions, it shall be demonstrated that the conditions specified in 5.5.9.1a do not have an influence on in-orbit performance.

NOTE For a specific application the Customer can require a thermal performance test in vacuum

c. During ground test the unit shall be insulated and the remaining heat exchange with the environment shall be determined.

d. When establishing the maximum heat transport capability, the vapour temperature shall be varied in increments within the specified operational temperature range such that a performance over temperature curve is generated.

e. For each temperature step, the temperatures along the length of the unit shall be measured and recorded.

f. Maximum performance shall be declared, when temperature excursions in the evaporator indicate the beginning of a non-nominal operational condition.

NOTE Temperature excursions are generally caused by dry-out conditions in the evaporator

g. Temperature readings during performance testing in combination with the applied heat load (corrected for heat exchange with the environment) shall be used to determine heat transfer coefficients in the evaporator and the condenser.

h. Performance shall be measured as function of the orientation of evaporator vs. condenser in the gravitational field

5.5.9.2 Specific tests for HP

5.5.9.2.1 General

a. Maximum heat transport capability shall be measured with

1. straight HP
2. bent HP
3. uniform heat input and output,
4. one-sided heat input and one-sided heat output,
    (a) combination of heat input on top of the HP and heat output on bottom of the HP (with respect to gravity),
    (b) combination of heat input on bottom of the HP and heat output on top of the HP (with respect to gravity).
    (c) side heat input and opposite side heat output

b. The supplier shall define performance degradation a the minimum allowed bending radius.

5.5.9.2.2 Performance under tilt

a. The maximum heat transport capability shall be measured for tilt heights from zero to a value at which the heat transport capability falls to zero.

b. Measurement shall be performed at sufficient tilt intervals as to create a smooth curve of performance over tilt height.

c. Test results at different tilt heights shall be extrapolated to zero tilt.

NOTE The graphical extrapolation of tilt performance to zero tilt (horizontal position) is assumed to be the zero-g (in-orbit) performance.

5.5.9.2.3 Determination of gas plug

a. The gas plug test shall be performed during aging and life tests under the following condition:

1. Heat pipe mounted in reflux mode (vertical orientation with evaporator at the lower end),
2. Heat pipe operation at maximum operating temperature,
3. Condenser is instrumented with temperature sensors (axial distance 10 mm),
4. Periodic check of axial temperature profile of the condenser end at lower temperature

b. The non-condensable gas content shall be determined based on the measured temperature profile

c. It shall be demonstrated that non-condensable gas generation over the life-time meets the specified gas plug length

5.5.9.2.4 Start-up test

a. A start-up test at the minimum thermal performance temperature by applying 50% of the maximum heat load specified at that temperature shall be performed and the time until nominal operation shall be determined

5.5.9.2.5 Start-up procedure

a. After a full depriming (emptying the capillary structure), a start-up procedure shall be determined

5.5.9.2.6 Performance in reflux mode

a. The heat transfer coefficients in the evaporator and condenser areas shall be measured as a function of power input and temperature

b. Test shall be performed by applying power at to the bottom of the liquid pool and measuring the temperature profile along the pipe.

5.5.9.3 Specific tests for VCHP

a. In addition to the tests under clause 5.5.9.2.1 to 5.5.9.2.4, the following tests shall be performed.

1. Aging tests before charging the device with the control gas.

2. Maximum heat transport capability with the gas front located outside the condenser (between condenser and reservoir)

3. Residual conductance with the gas front outside the condenser (between condenser and evaporator)

5.5.9.4 Specific tests for Diode HP

a. The time-to-shutdown of the Diode HP shall be tested by applying pre-defined heat loads to the nominal condenser.

b. When establishing the time-to-shutdown, the vapour temperature shall be varied in suitable increments within the specified operational temperature range in order to generate a smooth performance over temperature curve.

c. The pre-defined heat loads shall be 10%, 30%, 50% and 80% of the derived Qmax in nominal mode for the specific heat pipe profile.

d. The energy needed for shutdown shall be derived for each of the above tests.

e. The time to start-up the heat pipe diode shall be established by applying pre-defined heat loads to the nominal evaporator.

f. The pre-defined heat loads shall be 10%, 30%, 50% and 80% of the derived Qmax in nominal mode for the specific heat pipe profile.

5.5.9.5 Specific tests for CDL

a. Start-up with low power shall be verified by testing with and without thermal inertia on the evaporator heater system

b. The specified performance of a CDL shall be verified under the following test conditions:

1. simulation of large heat load variations (increase and decrease of heat load)

2. simulation of large condenser temperature variations

3. different orientations with respect to gravity including tilt for LHP (see fig.3)

4. different parasitic heat inputs in the liquid line and into the reservoir

5.5.10 Mechanical tests

5.5.10.1 General

a. Mechanical tests shall be performed in accordance with requirements of ECSS-E-ST-10-03.

NOTE 1 A tailoring guide is provided in Table A 4.

NOTE 2 Sinusoidal, random vibration and shock tests are generally not meaningful for long heat pipe profiles, for heat pipes, which are later embedded in structural panels and for CDL, for which the configuration in the intended application can not be represented on unit level (for example: large distance between evaporator and condenser).

NOTE 3 A deflection test to replace sinusoidal and random testing can be agreed with the customer.

NOTE 4 For example, capillary structures, which have an inherent characteristic to be damaged by mechanical loads.

5.5.10.2 Sinusoidal and random vibration

a. Sinusoidal and vabration tests shall be performed in accordance with requirements of ECSS-E-ST-10-03.

NOTE A tailoring guide is provided in Table A 4.

5.5.11 Thermal cycle test

a. The thermal cycle test shall consist of 8 full cycles over the exposure temperature range with a hold-time of 1 hour.

NOTE Cycle tests of TPHTS can be performed under ambient conditions.

5.5.12 Aging and life tests

5.5.12.1 Generic test requirements

a. TPHTS shall be operated in a long duration life test as specified in 5.5.12.1b in order to confirm the specified performance over the product life cycle.

b. For qualification purpose of the device the duration of the life test shall be ≥ 8000 hours.

NOTE The life test should be extended beyond the formal qualification programme.

c. Aging tests shall be performed in the functional test sequence as given in Figure 5-2

NOTE Aging test is a reduced life test with a duration of 300 hours

d. Life and aging tests shall be performed at the maximum specified operation temperature.

e. Trend analyse according to ECSS-E-ST-10-03 #5.3.2i shall be performed in order to determine the non-condensable gas content at the end of the product life cycle.

f. The TPHTS supplier shall demonstrate that the non-condensable gas content expected at end of product life cycle does not violate the specified performance.

5.5.12.2 Specific test requirements for HP

a. Life and aging tests shall be performed in reflux mode.

b. The amount of produced non-condensable gas shall be determined according to Clause 5.5.9.2.3 in periodic intervals, with shorter intervals especially at the beginning for the life test and only at the end for the aging test.

NOTE Periods and intervals are to be agreed between the TPHTS supplier and the customer

5.5.12.3 Specific test requirements for CDL

a. During life tests the impact of possible non-condensable gas generation on the performance shall be determined in periodic intervals.

NOTE 1 The period is to be agreed between the TPHTS supplier and the customer

NOTE 2 The quantitative determination of non-condensable gas generation is difficult and generally not required

b. Life testing shall be declared as failed when the performance degrades to a level, which is outside of relevant performance specification

5.5.13 Reduced Thermal Performance Test

5.5.13.1 Generic

Tests according to clause 5.5.9.1 shall be performed.

5.5.13.2 Specific HP

a. Tests according to clauses 5.5.9.2.1a.1, 5.5.9.2.1a.2, 5.5.9.2.1a.3 and 5.5.9.2.1a.4 shall be performed in one selected configuration

b. The maximum heat transport capability shall be measured for one tilt between 2.5 and 4 mm at two temperatures to be agreed with the customer.

5.5.13.3 Specific VCHP

a. In addition to tests according to 5.5.13.1 and 5.5.13.2: thermal performance at fully on condition

5.5.13.4 Specific Diode-HP

a. Tests shall be performed as specified in clause to 5.5.9.4 at one vapour temperature and with a heat load of 50% of Qmax.

NOTE It is recommended to perform these tests at 20 °C

5.5.13.5 Specific CDL

a. Start-up with low and maximum power shall be verified for one condenser sink temperature and by simulation of flight-representative thermal inertia on the evaporator heater system.

5.6 Documentation requirements

a. The documents listed in Table 5-1 shall be prepared and configuration controlled.

b. The following documents shall be written and agreed with the customer before starting the qualification process

1. technical requirements specification

2. verification plan

c. The design and manufacturing file of the qualification hardware shall be under configuration control and available for customer review.

d. The final outcome of the qualification process as documented in the verification report (RN 14 of Table 5-1) shall be agreed with the customer

NOTE A customer statement on the successful completion of the qualification process is recommended.

Table 5-1: Required documentation

RN	Title	DRD reference	Remarks
1	Technical requirements specification	ECSS-E-ST-10-06C, Annex A	Customer approval needed before starting the qualification process
2	Verification plan	ECSS-E-ST-10-02C, Annex A	
3	Review-of-design report	ECSS-E-ST-10-02C, Annex D	
4	Inspection report	ECSS-E-ST-10-02C, Annex E	
5	Declared materials list	ECSS-Q-ST-70, Annex B	
6	Declared mechanical parts list	ECSS-Q-ST-70, Annex C	
7	Declared processes list	ECSS-Q-ST-70, Annex D	
8	Mechanical and thermal performance analysis and test prediction	ECSS-E-ST-31, Annex C	May be split in two documents
9	Test specification	ECSS-E-ST-10-03, Annex B	
10	Test procedures	ECSS-E-ST-10-03, Annex C	One procedure for each test. Procedures may be grouped in one document as appropriate.
12	Test Reports	ECSS-E-ST-10-02C, Annex C	One test report for each test. Reports may be grouped in one document as appropriate.
13	Test Evaluation and data correlation	ECSS-E-ST-31, Annex C	
14	Verification report	ECSS-E-ST-10-02, Annex F	For agreement with the customer.

Annex A (informative) Tailoring guidelines of ECSS-E-ST-10-06, ECSS-E-ST-10-02, ECSS-E-ST-10-03 and ECSS-E-ST-32-02 for application to TPHTS

Annex A provides tailoring guidelines for ECSS Standards, which are in general applicable to the qualification process of TPHTS. In case of contradiction the requirement definitions of this Standard have priority.

A.1 Tailoring guidelines for ECSS-E-ST-10-06

Table A 1 presents the ECSS-E-ST-10-06 tailoring guidelines for application to TPHTS. Requirements of ECSS-E-ST-10-06 not referenced in this table are not applicable to TPHTS.

Table A 1: ECSS-E-ST-10-06 tailoring guidelines for application to TPHTS

Clause	Subject	Remarks related to present Standard
7.2.1 b.	The specification shall be identifiable, referable and related to a product or a system	
7.2.2 a.	An entity shall be identified to be responsible for the specification.	The entity is the **supplier** for a generic TPHTS specification and the **customer** for a specific TPHTS specification
7.2.3	b. Each technical requirement shall be separately stated. c. Abbreviated terms used in requirements shall be defined in a dedicated section of the specification. d. The technical requirements shall be consistent (e.g. not in conflict with the other requirements within the specification). e. The technical requirements shall not be in conflict with the other requirements contained in business agreement documents.	
7.2.4 a.	The specification shall be complete in terms of	

Clause	Subject	Remarks related to present Standard
	applicable requirements and reference to applicable documents.	
7.1.3 c.	Requirements are consistent and not in conflict to other requirement of the specification	
7.2.5 a.	The specification shall be under configuration management.	
7.2.8 a.	Specification does not contain non-technical requirements (cost, method of payment, quantity required, time or place of delivery)	Except quantity of units required for the qualification process
8.2.1 a.	Requirement described in quantifiable terms	
8.1.1 b.	Include method to be used to determine the required performance	
8.2.2 a.	Justification of technical requirement	Only requirements that are not specified by the customer needs to be justified
8.2.4 a.	The technical requirements shall be unambiguous.	
8.2.5 a.	Each technical requirement shall be unique.	
8.2.3 a.	Each technical requirement shall be under configuration management.	
8.2.4	The technical requirements shall be unambiguous.	
8.2.5	Each technical requirement shall be unique.	
8.2.6 b.	A unique identifier shall be assigned to each technical requirement.	
8.2.7	Each technical requirement shall be separately stated.	
8.2.8	A technical requirement shall not require additional data or explanation to express the need	
8.2.9	A technical requirement shall be verifiable using one or more approved verification methods.	
8.2.10	The tolerance shall be specified for each parameter/variable.	
8.3.1 a.	Verifiable requirement using one or more verification methods	
8.3	Requirements and recommendations for the wording	

A.2 Tailoring guidelines for ECSS-E-ST-10-02

Table A 2 and Table A 3 present the ECSS-E-ST-10-02 tailoring guidelines for application to TPHTS. Requirements of ECSS-E-ST-10-02 not referenced in this table are not applicable to TPHTS.

Table A 2: ECSS-E-ST-10-02 tailoring guidelines for application to TPHTS

Clause	Subject
5.2.2.1 a.	Application of verification methods test (including demonstration), analysis (including similarity), ROD, inspection.
5.2.2.1 b	Verification of safety critical functions by test.
5.2.2.3. c.	Constraints for verification by similarity
5.2.2.3. d.	Similarity analysis defines any difference for additional verification activities
5.2.2.4. a.	Verification by ROD by using existing records and evidence
5.2.2.5. a.	Verification by inspection by determination of physical characteristics
5.2.3. b.	Traceability to lower level verification
5.2.3. c.	Close-out of verification at lower level before close-out at higher level
5.2.4.1 b.	Completion of qualification before launch
5.2.4.2 a.	Qualification demonstrates that technical requirements are met
5.2.4.2 b.	Hardware is representative to end item
5.2.4.2 c.	Qualification according to product heritage
5.2.6.1 and 5.2.6.2	Requirements with respect to tools and test equipment

Table A 3: Categories of two-phase cooling systems according to heritage (derived from ECSS-E-10-02C, Table 5.1)

Category	Description	Qualification programme	*Remarks related to the present Standard*
A	Off-the-shelf product without modifications and The product is qualified to requirements at least as severe as those imposed by the actual technical specification The product is produced by the same manufacturer and using identical tools and manufacturing processes	None	
B	Off-the-shelf product without modifications. However: The product is qualified to requirements less severe or different to those imposed by the actual technical specification Or The product is produced by a different manufacturer or using different tools and manufacturing processes Or The product has substitution parts and materials with equivalent reliability	Delta qualification programme, decided on a case-by-case basis.	*This category relates for example to TPHTS hardware, which is identical to already qualified hardware but has been qualified to lower mechanical loads or narrower operating temperature ranges as required by an actual project.* *The category relates also to situations, where TPHTS manufacturing technology is transferred from a qualified supplier to a new manufacturer.*
C	Off-the-shelf product with design modifications	Delta or full qualification programme, decided on a case-by-case basis depending on the impact of the modification.	*Examples for category C are:* *Heat pipes with identical capillary structure but different diameters, smaller bent radius,* *CDL with different fluid line configurations or dimensions or different condenser configurations (radiator lay out).*
D	New designed and developed product.	Full qualification programme.	*Applicable for any new developed TPHTS, including existing systems with new capillary structures or material combinations.*

A.3 Tailoring guidelines for ECSS-E-ST-10-03 and ECSS-E-32-02

For the qualification process, dedicated requirements can be found in ECSS-E-ST-10-03 "Testing" and ECSS-E-ST-32-02 "Structural design of pressurized hardware" as defined in Table A 4 and Table A 5. Clauses not listed in these tables, are not applicable to TPHTS.

NOTE Some requirements are indicated as modified to adapt to the specific characteristics of TPHTS.

Table A 4: ECSS-E-ST-10-03 tailoring guidelines for application to TPHTS (to be updated after issue of ST-10-03C)

Clause	Subject
4.2.2.1., 4.2.2.2., 4.2.2.3.	Test programme includes test readiness review (TRR) and post-test review (PTR)
4.5.2.1 and Table 1	Test tolerances
4.5.2.2 and Table 2	Measurement accuracy
4.6. b.	Comparison of test data during test sequences to detect trends for anomalous behaviour
5.1. c.	No adverse effects of facilities, tools and instrumentation on qualification test objectives.
5.2. e. and Table 3	Qualification test level and duration
5.3.2. i., k.	Creation of test result database to perform trend analysis.
5.3.3	Physical properties measurements
5.3.6	Leakage test
5.3.7.1.	Proof pressure
5.3.7.2	Burst pressure
5.3.9. and Table 6	Sinusoidal vibration
5.3.10. and Table 8	Random vibration
5.3.15	Thermal cycle test (requirements modified in this Standard to meet TPCS characteristics)
5.3.17.	Life test (requirements modified in this Standard to meet TPCS characteristics)

See also applicable DRD's of ECSS-E-ST-10-03 as listed in Table 5-1 RN 11, 12 and 13.

Table A 5: ECSS-E-ST-32-02 tailoring guidelines for application to TPHTS

Clause	Comment
3.2.45 special pressurized equipment	Heat pipes are defined as "special pressurized equipment" and relevant requirements apply NOTE. It is assumed that requirements related to "special pressurized equipment" are valid for all TPHTS
4.2.1 Leak tightness a. The maximum leak rates of the pressurized hardware versus pressure values shall be established through a detailed analysis of the pressurized system to which the pressurized hardware belongs. b. Leak rate of all pressurized hardware shall conform to the level defined in 4.2.1a c. Leak rate of all pressurized hardware shall be such that operation of the system is ensured throughout the specified lifetime. NOTE Pressurized hardware containing hazardous fluids reach end of safe-life when leakage occurs.	
4.2.2 Classification of fracture critical parts a. Fracture critical item classification shall be performed in conformance with ECSS-E-ST-32-01. NOTE When pressurized hardware is classified as fracture critical, it is subjected to the implementation of the fracture critical item tracking, control and documentation procedures specified in ECSS-E-ST-32-01.	Heat pipes are generally classified as non fracture critical (because they are LBB)
4.2.3 Operation and maintenance **4.2.3.1 Operating procedures** a. Operating procedures shall be established for all pressurized hardware. b. The procedures specified in 4.2.3.1 b. shall be compatible with the safety requirements and personnel control requirements at the facility where the operations are conducted. c. Step-by-step directions shall be written with such a detail to unambiguously describe the operation.	
4.2.3.2 Safe operating limit a. Safe operating limits shall be established for pressurized hardware based on analysis and testing employed during its design, development and qualification.	

Clause	Comment
qualification. b. The safe operating limits specified in 4.2.3.2a shall be summarized in a format providing visibility of the structural characteristics and capability. c. The information in the format specified in 4.2.3.2b shall include the following data: 1. In a general case (a) fabrication materials; (b) critical design conditions; (c) MDP; (d) nominal operating pressure; (e) proof pressure; (f) design burst pressure; (g) N/A; (h) operational cycle limits; (i) operational system fluid; (j) N/A; (k) NDI techniques employed; (l) N/A; (m) N/A; (n) minimum margin of safety; (o) potential failure mode. 2. For pressurized hardware with a non LBB failure mode, additionally to the data included in 4.2.3.2.c.1: (a) the critical flaw sizes; (b) the maximum acceptable flaw sizes.	TPHTS have generally a LBB failure mode
4.2.3.5 Storage a. When pressurized hardware is put into storage: 1. they shall be protected against exposure to adverse environments that can cause corrosion or degrade the material; 2. they shall be protected against mechanical damages; 3. induced stresses due to storage fixture constraints shall be avoided by storage fixture design. b. If 4.2.3.5a is not met, the hardware shall be submitted to re-acceptance as specified in clause 4.2.4.3 prior to acceptance for use.	
4.2.4 Service life extension, reactivation and re-acceptance **4.2.4.1 Service life extension**	

Clause	Comment
a. N/A b. In case of fatigue life demonstration, required for the hardware, the service life may be extended without additional test or inspection, if there is available data including at least actual pressure, loads, and environments from the past period of service life, and the evaluation exhibits that the cumulative damage does not reach the specified service life. c. The new service life shall be determined by safe-life demonstration as required for this type of pressurized hardware.	
4.6.1 Metallic special pressurized equipment **4.6.1.1 Factors of safety** a. The values in Table 4-8 shall be applied as minimum values of factors of safety for internal pressure. NOTE For heat pipes: 1.5 proof, 2,5 burst	Factor of safety are valid for all Two-Phase Heat Transport Systems
4.6.1.2 Development approach a. Clause 5.2 on structural engineering shall be applied. NOTE Thermal, stress and strain analyses and stiffness, strength and stability demonstrations are sometimes substituted with certification from qualified aerospace suppliers, with customer approval. b. N/A c. N/A d. N/A e. Qualification tests shall be conducted according to 4.6.1.3 to demonstrate the structural adequacy of the design. f. N/A g. Fatigue-life demonstration shall be performed by analysis or test or both in conformance with ECSS-E-ST-32. h. N/A i. N/A j. For material selection, material design allowable and their characterisation, requirements shall be applied in conformance with ECSS-E-ST-32. k. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70. l. Inspections shall be applied according to clause 5.7.	For all TPHTS a proof pressure with proof factor of ≥ 1,5 is generally required

<table>
<tr><th>Clause</th><th>Comment</th></tr>
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NOTE 3 The development approach for heat pipes is illustrated in Figure 4-12

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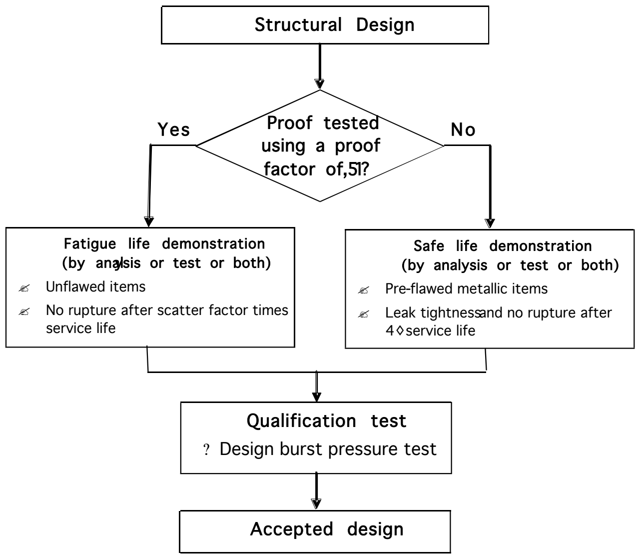

Figure 4-12: Development approach of heat pipes

</td><td>Generally for all TPHTS units a proof factor ≥0.5 is required.</td></tr>
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4.6.1.3 Qualification tests

a. N/A

b. All heat pipes and hazardous fluids containers shall be submitted to a design burst pressure test.

c. N/A

d. N/A

e. N/A

f. Clauses 5.4.1, 5.4.2, 5.4.4 and 5.4.6, shall be applied to the qualification tests.

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4.6.1.4 Acceptance tests

a. The following SPE shall be submitted to a proof pressure test:

1. heat pipes;

b. N/A

c. Fusion joints shall be 100 % inspected by means of a NDI method, defined with customer approval, prior and after the proof pressure test.

d. N/A

e. N/A

f. Clauses 5.5.1, 5.5.2, and 5.5.3 shall be applied to the acceptance tests.

NOTE Proof and leak tests can be performed at the assembled pressurized system level.

</td><td>Acceptance tests are performed before the hardware is submitted to the qualification process.</td></tr>
<tr><td>

5. 2 Structural engineering

</td><td></td></tr>
</table>

Clause	Comment
a. The structural design of pressurized hardware shall be in conformance with ECSS-E-ST-32. b. N/A c. Proof pressure and design burst pressure shall be derived from the MDP using the factor of safety given in Table 4-8. d. N/A e. As a minimum, any item of pressurized hardware shall possess, throughout the respective service life of the hardware in the expected operating environments, a strength such to withstand: 1. proof pressure without detrimental deformation; 2. design burst pressure without experiencing rupture or fibre failure; 3. N/A; 4. MDP multiplied by FOSY for internal pressure and simultaneous loads multiplied by FOSY for mechanical and thermal loads, without detrimental deformation; 5. N/A; 6. MDP multiplied by FOSU for internal pressure and simultaneous loads multiplied by FOSU for mechanical and thermal loads, without experiencing rupture or fibre failure; 7. N/A. f. N/A. g. N/A. h. A scatter factor of five (5) shall be used in fatigue analysis.	Generally TPHTS units are not designed as load carrying structural elements.
5.3 Failure mode demonstration **5.3.1 General**	
a. The failure mode demonstration (i.e. demonstration of LBB or no LBB) can be ensured by analysis or test or both b. N/A c. N/A d. N/A e. N/A f. Areas where the LBB failure mode is not demonstrated shall be designed according to safe-life requirements as per clause 5.3 g. For composite and composite over-wrapped pressurized hardware, potential degradation of the	Generally all TPHTS are LBB, which is demonstrated by test.

Clause	Comment
composite strength by the leaking fluid shall be accounted for in the failure mode demonstration.	
5.4 Qualification tests	
5.4.1 General	
a. 'General requirements' and 'Qualification testing' requirements shall apply in conformance with ECSS-E-ST-10-03.	
b. N/A.	
c. N/A	
d. When NDI is performed in the qualification tests, it shall meet clause 5.7.	Generally NDI is performed during manufacturing process before the qualification process commences.
e. N/A.	
f. N/A.	
g. When the strength design allowable of the materials depends on the fluid to be stored in the flight hardware (e.g. when the stored fluid is liquid hydrogen), the change of material properties shall be verified: ▪ by using this specific fluid to pressurize the test specimens, or ▪ by analysis, supported by tests on samples or sub-scale articles and providing material strength design allowable versus fluid characteristics.	
h. In case of changing the manufacturing process, the qualification tests shall be repeated unless it is demonstrated that the new manufacturing process maintains or improves material and geometrical characteristics.	
5.4.3 Leak test	
a. During the leak test, the pressure level shall be maintained at MDP or greater for 30 minutes as a minimum.	
b. For qualification 'leakage test', requirements shall be in conformance with ECSS-E-ST-10-03. **NOTE** Exceptions to the values provided in 5.4.3a and 5.4.3b are sometimes specified by the customer or granted with customer approval.	
5.4.4 Vibration test	
a. Vibration testing shall be conducted at the pressure condition corresponding to the maximum predicted vibration environment.	
b. N/A.	
5.4.5 Pressure cycling test	
a. Pressure cycles shall range from zero differential pressure to MDP and back to zero differential pressure for at least 50 cycles or four times the number of planned pressure cycles expected in one	The number of cycles for TPHTS are specified in clause 5.5.6 of the present Standard.

<table>
<tr><th>Clause</th><th>Comment</th></tr>
<tr><td>service life, whichever is greater.

5.4.7 Burst test
a. The pressure shall be increased until burst occurs.
b. The burst pressure shall be recorded.</td><td></td></tr>
<tr><td>5.5 Acceptance tests
5.5.1 General
a. ‘General requirements’ and ‘Accepting testing’ requirements shall apply in conformance with ECSS-E-ST-10-03.
b. When an acceptance test is conducted at temperature other than temperature expected for the design loads, the change of material properties at this temperature shall be verified:
▪ by adjustment of the pressure and load level, or
▪ by analysis, supported by tests on samples or sub-scale articles and providing material strength design allowable versus temperature.
c. When NDI is performed in the acceptance tests, it shall meet clause 5.7.
d. When the strength design allowable of the materials depends on the fluid to be stored in the flight hardware (e.g. when the stored fluid is liquid hydrogen), the change of material properties shall be verified:
▪ by using this fluid to pressurize the test specimens, or
▪ by analysis, supported by tests on samples or sub-scale articles and providing material strength design allowable versus fluid characteristics.
5.5.2 Proof pressure test
a. During the proof pressure test, the load level (i.e. pressure level, external load level) shall be maintained for 5 minutes as minimum.
5.5.3 Leak test
b. During the leak test, the pressure level shall be maintained at MDP or greater for 30 minutes as minimum.
c. For acceptance ‘leakage test’, requirements shall be in conformance with ECSS-E-ST-10-03.
NOTE Exceptions to the values provided in 5.5.3a and 5.5.3b are sometimes specified by the customer or granted with customer approval.</td><td>Generally acceptance testing for all TPHTS is performed on hardware before the qualification process commences.</td></tr>
<tr><td>5.7 Inspection
5.7.1 General
a. An inspection plan shall be established prior to the</td><td></td></tr>
</table>

Clause	Comment
start of fabrication. b. For 'Inspection' plan, requirements shall be in conformance with ECSS-Q-ST-20. c. For 'Inspection of PFCI', requirements shall be in conformance with ECSS-E-ST-32-01. d. The inspection plan shall specify inspection points throughout the program, beginning with material procurement, continuing through fabrication, assembly, acceptance proof test and operation, and using the following techniques: 1. procurement of raw materials, in conformance with ECSS-Q-ST-70; 2. procurement of mechanical parts in conformance with ECSS-Q-ST-70; 3. NDI for detecting mechanical damage or flaw, in conformance with clauses 5.7.2 and ECSS-E-ST-32-08. e. Acceptance and rejection criteria shall be established within the inspection plan for each phase of inspection and for each type of inspection. f. For 'Detected defects' outside of the acceptance criteria defined in 5.7.1e, requirements shall be in conformance ECSS-E-ST-32-01.	

Applicability matrix

Identifier	Requirement	Applicable (A/M/N)	Modified requirement

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