

BS EN 16603-32-02:2014



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Space engineering — Structural design and verification of pressurized hardware

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National foreword

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A list of organizations represented on this committee can be obtained on request to its secretary.

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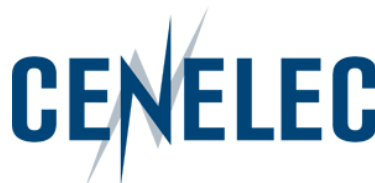
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Foreword

This document (EN 16603-32-02:2014) has been prepared by Technical Committee CEN/CLC/TC 5 “Space”, the secretariat of which is held by DIN.

This standard (EN 16603-32-02:2014) originates from ECSS-E-ST-32-02C Rev. 1.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2015, and conflicting national standards shall be withdrawn at the latest by February 2015.

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

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

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1

Scope

This Standard defines the structural design verification of metallic and non-metallic pressurized hardware which includes pressure vessels, pressurized structures, pressure components (such as valves, pumps, lines, fittings, and hoses), and special pressurized equipment (e.g. batteries, heat pipes, cryostats, sealed containers, hazardous fluids container). External supports and structural interfaces of pressurized hardware are not covered by this standard. Solid propellant motor cases are not covered by this standard.

Objectives of the associated verification process are primarily to demonstrate the qualification of design and performance, as meeting all specified requirements, and to ensure that the flight hardware is free from workmanship defects and acceptable for flight.

This Standard applies to all space products and in particular to launch vehicles, transfer vehicles, re-entry vehicles, spacecraft, space station, landing probes and rovers, sounding rockets, payloads and instruments.

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

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications, do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms
EN 16603-10-02	ECSS-E-ST-10-02	Space engineering – Verification
EN 16603-10-03	ECSS-E-ST-10-03	Space engineering – Testing
EN 16603-32	ECSS-E-ST-32	Space engineering – Structural general requirements
EN 16603-32-01	ECSS-E-ST-32-01	Space engineering – Fracture control
EN 16603-32-08	ECSS-E-ST-32-08	Space engineering – Materials
EN 16603-32-10	ECSS-E-ST-32-10	Space engineering – Reliability based mechanical factors of safety
EN 16602-20	ECSS-Q-ST-20	Space product assurance – Quality assurance
EN 16602-70	ECSS-Q-ST-70	Space product assurance – Materials, mechanical parts and processes

Terms, definitions, and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01, ECSS-E-ST-32, and ECSS-E-ST-32-01 apply.

3.2 Terms specific to the present standard

3.2.1 autofrettage

vessel sizing operation where pressure driven deflection is used to plastically yield the metal liner into the overlying composite in order to induce initial compressive stress states in the metal liner

NOTE Autofrettage is considered to be part of the manufacturing process and is conducted prior to acceptance test.

3.2.2 boss

zone of a pressure vessel or a pressurized structure ensuring functional interfaces (e.g. fluid connections and mechanical interfaces) of the hardware with the pressurized system

3.2.3 burst factor (j_{burst})

multiplying factor applied to the maximum design pressure (MDP), to obtain the design burst pressure

NOTE The burst factor corresponds to an ultimate factor of safety.

3.2.4 burst pressure

pressure level at which collapse, rupture or unstable fracture of the pressurized hardware occurs

3.2.5 composite over-wrap

layers of fibre-based composite material applied onto a liner, sustaining significant pressure and environmental loads

3.2.6 composite over-wrapped pressure vessel (COPV)

pressure vessel with a fibre-based composite structure fully or partially encapsulating a liner

NOTE For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

3.2.7 composite over-wrapped pressurized component (COPC)

pressurized component with a fibre-based composite system fully or partially encapsulating a liner

NOTE For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

3.2.8 composite over-wrapped pressurized structure (COPS)

pressurized structure with a fibre-based composite system fully or partially encapsulating a liner

NOTE For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

3.2.9 composite over-wrapped special pressurized equipment (COSPE)

special pressurized equipment with a fibre-based composite system fully or partially encapsulating a liner

NOTE For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

3.2.10 composite pressure vessel (CPV)

pressure vessel whose structural wall is fully composed with fibre based composite material

NOTE For example:

- the permeation barrier can be ensured by a coating on the internal or the external shape of the composite wall, or by the composite wall itself, or by both.
- low-pressure liquid hydrogen tank without liner.

3.2.11 composite pressurized structure (CPS)

pressurized structure whose structural wall is fully composed with fibre based composite material

NOTE For example:

- the permeation barrier can be ensured by a coating on the internal or external shape of the composite wall, or by the composite wall itself, or by both.
- low-pressure liquid hydrogen structural tank without liner.

3.2.12 critical flaw

specific flaw with a size such that unstable growth occurs under the specific operating load and environment

3.2.13 cryostat

vacuum-jacketed container designed to keep its contents at a low (cryogenic) temperature

NOTE Cryostat is also known as a Dewar, named after its inventor.

3.2.14 design burst pressure

differential pressure to be withstood by the pressurized hardware without burst in the applicable operating environment

NOTE The design burst pressure is equal to the product of the MDP and the burst factor.

3.2.15 differential pressure

internal pressure minus external pressure

3.2.16 external pressure

absolute pressure outside the pressurized hardware

3.2.17 fibre failure

rupture or kinking of a bundle of filaments

NOTE There are two fibre failure modes: under tension (fibre rupture) and under compression (kinking).

3.2.18 fitting

pressure component of a pressurized system utilized to connect lines, other pressure components or pressure vessels within the system

3.2.19 hazardous fluid container

pressurized container, compartment or housing that is individually sealed to contain a fluid, which can create a hazard if released

3.2.20 hydrogen embrittlement

mechanical and environmental process that results from the initial presence or absorption of excessive amounts of hydrogen in metals

NOTE Usually it occurs in combination with residual or applied tensile stresses.

3.2.21 impact damage

induced defect caused by an object strike on the pressurized hardware or pressurized hardware strike on an object

NOTE Delamination in the composite over-wrap of a COPV, dent in the metallic liner of a COPV.

3.2.22 inter-fibre failure

micro-cracking in the matrix of a composite material, or at the interface filament-matrix of a composite material

3.2.23 internal pressure

absolute pressure inside the pressurized hardware

3.2.24 leak-before-burst (LBB)

fracture mechanics design concept, showing that any potentially critical flaw grows through the wall of a pressurized system and cause pressure relieving leakage at MDP without burst (catastrophic failure)

3.2.25 liner

part of pressurized hardware serving as a mandrel during the manufacturing of the over-wrap and as fluid permeation barrier when in contact with the stored fluid

NOTE For example:

- when the liner is made of metallic material, it can carry significant pressure and environmental loads.
- when the liner is made of homogeneous non metallic material, it usually does not carry significant pressure and environmental loads.

3.2.26 line

tubular pressurized hardware of a pressurized system provided as means for transferring fluids between components of the system

NOTE Flex hoses are included.

3.2.27 maximum design pressure (MDP)

See ECSS-E-ST-32.

3.2.28 maximum expected operating pressure (MEOP)

See ECSS-E-ST-32.

3.2.29 mechanical damage

induced flaw in pressurized hardware item which is caused by surface abrasions, cuts or impacts

NOTE The pressurized hardware item can be a metallic, homogeneous non metallic or composite item.

3.2.30 metallic pressure vessel (MPV)

pressure vessel fully composed of metallic material

3.2.31 metallic pressurized structure (MPS)

pressurized structure fully composed of metallic material

3.2.32 metallic pressurized component (MPC)

pressurized component fully composed of metallic material

3.2.33 metallic special pressurized equipment (MSPE)

special pressurized equipment fully composed of metallic material

3.2.34 non-hazardous LBB failure mode

leak-before-burst (LBB) behaviour that does not result in a hazard

NOTE For example: LBB behaviour with a leak of liquid or gas that is not toxic, reactive or flammable.

3.2.35 pressure component (PC)

component in a pressurized system, other than a pressure vessel, pressurized structure, or special pressurized equipment that is designed largely by the internal pressure

NOTE For example:

- lines, fittings, gauges, valves, bellows, and hoses.
- batteries not meeting the pressure vessel definition.

3.2.36 pressure vessel (PV)

pressurized hardware designed primarily for the storage of pressurized fluid with an energy level greater than or equal to 19310 Joules, or with a pressure greater than or equal to 0,69 MPa, or which can create a hazard if released

NOTE E.g. the stored energy can be calculated by the formula for the reversible adiabatic (isentropic) expansion of the confined gas:

$$E = \frac{P_1 V}{\gamma - 1} \left[1 - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

where:

E is the stored energy;

P_1 is the internal pressure;
 P_2 is the external pressure;
 V is the pressurized volume;
 γ is the ratio of specific heat of the gas.

3.2.37 pressurized hardware (PH)

hardware item that primarily contains internal pressure

NOTE E.g. included are pressure vessels, pressurized structures, pressure components and special pressurized equipments.

3.2.38 pressurized structure (PS)

structure designed to carry both internal pressure and vehicle structural loads

NOTE E.g. launch vehicle main propellant tanks, crew cabins and manned modules.

3.2.39 pressurized system

system which consists of pressure vessels, or pressurized structures, or both, and other pressure components, that are exposed to and structurally designed largely by the acting pressure

NOTE For example:

- a pressurized system is often called a pressure system.
- electrical or other control devices for system operations are not included.

3.2.40 proof factor (j_{proof})

multiplying factor applied to MDP to obtain design proof pressure

3.2.41 proof pressure

product of MDP and proof factor

3.2.42 proof test

test of flight hardware under proof load or pressure to give evidence of satisfactory workmanship and material quality or to establish the initial crack sizes in the hardware

3.2.43 sealed container

pressurized container, compartment or housing that is individually sealed to contain a fluid or to maintain an internal gaseous environment

NOTE E.g. electronics housing

3.2.44 sizing pressure

pressure to which composite over-wrapped pressurized hardware is subjected with the intent of yielding its metallic liner or a portion of the liner

NOTE E.g. the sizing pressure also refers to the pressure applied during autofrettage.

3.2.45 special pressurized equipment

pressurized hardware that meets the pressure vessel definition, but which is not feasible or cost effective to conform to the requirements applicable to pressure vessels

NOTE For example:

- pressurized hardware may be classified as special pressurized equipment with customer approval.
- heat pipes, cryostats, sealed containers and hazardous fluids container.
- sealed nickel-hydrogen batteries meeting the definition of a pressure vessel.

3.2.46 visual damage threshold (VDT)

lowest impact energy level applied to a composite item that creates an indication that is detectable by an inspector using an unaided visual technique

NOTE No quantitative reliability nor confidence level is associated with this technique.

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
BAI	residual burst strength after impact
COPC	composite over-wrapped pressurized component
COPS	composite over-wrapped pressurized structures
COSPE	composite over-wrapped special pressurized equipment
COPV	composite over-wrapped pressure vessel
CPS	composite pressurized structure
CPV	composite pressure vessel
DLL	design limit load
DUL	design ultimate load
DYL	design yield load
FCI	fracture critical item
FLLI	fracture limited life item
FOS	factor of safety
ISS	international space station

LBB	leak-before-burst
MDP	maximum design pressure
MEOP	maximum expected operating pressure
MPC	metallic pressurized component
MPS	metallic pressurized structure
MPV	metallic pressure vessel
MSPE	metallic special pressurized equipment
NDI	non-destructive inspection
PFCI	potential fracture-critical item
PC	pressure component
PH	pressurized hardware
PV	pressurized pressure vessel
PS	pressurized structure
SPE	special pressurized equipment
VDT	visual damage threshold

3.4 Symbols

j_{burst}	value of burst factor
j_{proof}	value of proof factor
FOSU	value of ultimate factor of safety
FOSY	value of yield factor of safety

General requirements

4.1 Overview

4.1.1 Content

Clause 4 presents requirements which are general requirements in the sense that:

- requirements for all categories of pressurized hardware are specified in clause 4.2;
- requirements for all pressure vessels are specified in clause 4.3;
- requirements for all pressurized structures are specified in clause 4.4;
- requirements for all pressure components are specified in clause 4.5;
- requirements for all special pressurized equipments are specified in clause 4.6.

4.1.2 Categories of pressurized hardware

The pressurized hardware treated in this Standard are categorized in Figure 4-1. A flowchart describing the classification of pressurized hardware is in Figure 4-2.

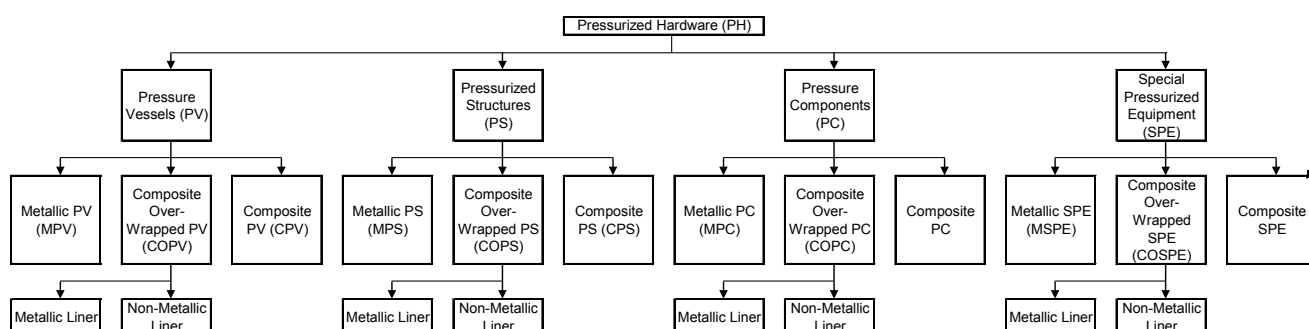
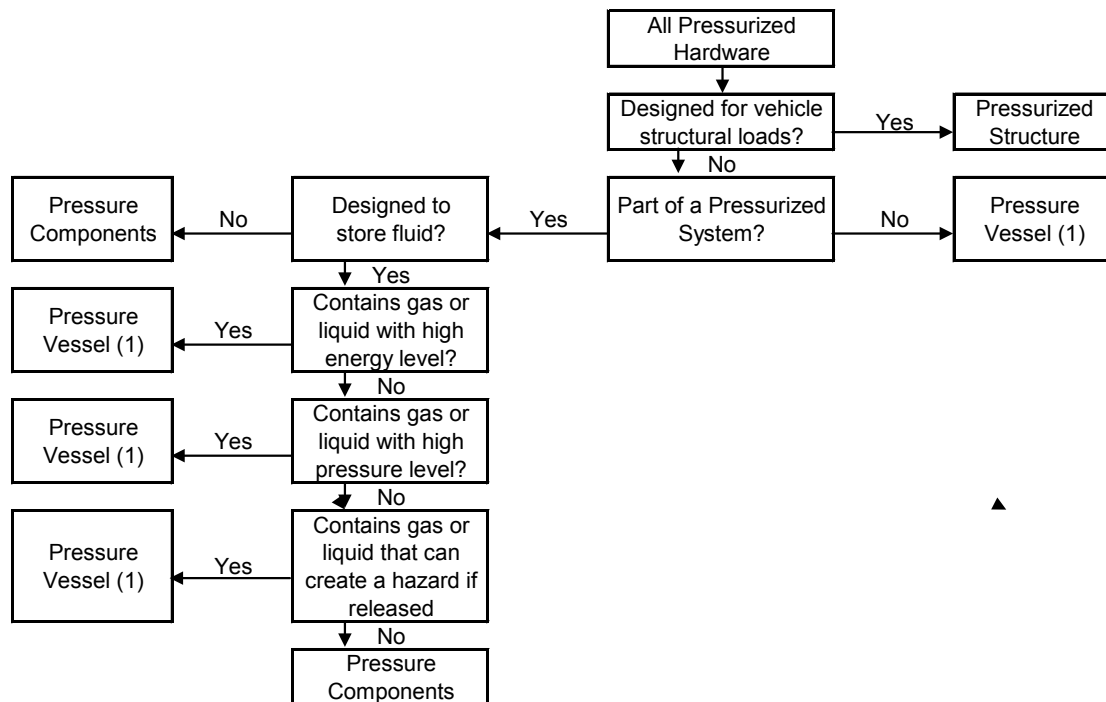


Figure 4-1: Breakdown of PH types covered by this Standard



Notes:

1. Subclause 4.6 describes Special Pressurized Equipment that meets the pressure vessel definition, but which is not feasible or cost effective to conform to the requirements applicable to pressure vessels.

Figure 4-2: Flowchart describing PH classifications covered by this Standard

4.2 General

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.

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 4.2.3.1a 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.
- d. Schematics identifying the location and pressure limits of a relief valve and burst disc, shall be provided.
- e. Procedures to ensure compatibility of the pressurizing system with the structural capability of the pressurized hardware shall be established.
- f. Prior to initiating or performing a procedure involving hazardous operations with pressure systems, practice runs shall be conducted on non-pressurized systems.
- g. Initial tests shall then be conducted at pressure levels not to exceed 50 % of the nominal operating pressure until operating characteristics can be established.
- h. Warning signs with the hazard identified shall be posted at the operations facility prior to pressurization.

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.
- 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 as a minimum 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) pressurization and depressurization sequence;
 - (h) operational cycle limits;
 - (i) operational system fluid;
 - (j) cleaning agent;
 - (k) NDI techniques employed;
 - (l) extreme thermal and chemical environments;
 - (m) maximum leakage levels versus pressure values;
 - (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 4.2.3.2c.1:
- (a) the critical flaw sizes;
 - (b) the maximum acceptable flaw sizes.
- d. Back-up documentation, including at least applicable references to design drawings, detail analyses, inspection records, and test reports, shall be indicated.
- e. The minimum internal pressure to guaranty structural stabilization shall be identified and included in the acceptance data package.

4.2.3.3 Inspection and maintenance

- a. The results of stress and safe-life analyses shall be used in conjunction with the results from the structural development and the qualification tests to define quantitative acceptance criteria for inspection and repair.
- b. Damage limits shall be established by the supplier for pressurized hardware so that the inspection interval and repair schedule can be established.
- c. Analyses of operational data developed per clause 5.7 shall include forecast of remaining life and reassessment of inspection intervals.

4.2.3.4 Repair

- a. All repaired or refurbished hardware shall be submitted to re-acceptance, as specified in clause 4.2.4.3, after each repair and refurbishment to verify their structural integrity.

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.

4.2.3.6 Documentation

- a. Inspection, maintenance, and operation records shall be kept and maintained throughout the life of the pressurized hardware.
- b. As a minimum, the records specified in 4.2.3.6a shall contain the following information:
 - 1. temperature, pressurization history, and pressurizing fluid for both tests and operations;
 - 2. number of pressurization cycles experienced as well as the maximum number in safe-life analysis or test;
 - 3. results of any inspection conducted, including: inspector, inspection dates, inspection techniques employed, location and character of flaws, flaw origin and cause;
 - 4. storage condition;
 - 5. maintenance and corrective action performed from manufacturing to operational use, including refurbishment;
 - 6. sketches and photographs to show areas of structural damage and the extent of repair;
 - 7. acceptance and re-acceptance test performed, including test condition and results;
 - 8. analyses supporting the repair or modification which can influence future use capability.

4.2.4 Service life extension, reactivation and re-acceptance

4.2.4.1 Service life extension

- a. In case of safe-life demonstration, required for the hardware, the service life may be extended after performing a complete NDI, and leak test.
- 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 fatigue-life or safe-life demonstration as required for this type of pressurized hardware.

4.2.4.2 Reactivation

- a. Pressurized hardware which is reactivated for use after an extensive period in either an unknown, unprotected, or unregulated storage environment shall meet the requirements specified in clause 4.2.4.3 to ascertain their structural integrity before commitment to flight.
- b. A specific inspection for corrosion and incidental damage prior to re-acceptance tests shall be performed.

4.2.4.3 Re-acceptance

- a. All refurbished pressurized hardware shall undergo the same acceptance tests as specified for new hardware in clauses 4.3 to 4.6, in order to verify their structural integrity before commitment to flight.
- b. If the demonstration specified in 4.2.4.3a is not performed, it shall be demonstrated that the refurbished parts of the pressurized hardware are not affected by the corresponding tests.
- c. Pressurized hardware exceeding the specified storage environment (e.g. temperature, humidity, time and storage fixture constraints) shall undergo the acceptance tests specified in clauses 4.3 to 4.6 for new hardware.
- d. If the demonstration specified in 4.2.4.3c is not performed, it shall be demonstrated that all concerned parts of the pressurized hardware are not affected by the exceeded storage environment.

4.3 Pressure vessels

4.3.1 Factors of safety

- a. The values in Table 4-1 shall be applied as minimum values of factors of safety for internal pressure.
- b. For loads different from internal pressure, minimum values of factors of safety for 'pressurized hardware' shall be applied in conformance with ECSS-E-ST-32-10.

NOTE 1 Exceptions to the values provided in Table 4-1 are sometimes specified by the customer or granted with customer approval.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$$j_{\text{proof}} = (1 + j_{\text{burst}}) / 2 \quad \text{when } j_{\text{burst}} < 2,0$$

$$j_{\text{proof}} = 1,5 \quad \text{when } j_{\text{burst}} \geq 2,0$$

Table 4-1: Factors of safety for PV (unmanned and manned missions)

Load	FOSY	Proof factor	FOSU	Burst Factor
Internal pressure	1,0	1,25	1,0	1,5
Mechanical loads (including external pressure)	Values specified in ECSS-E-ST-32-10			

4.3.2 Metallic pressure vessels

4.3.2.1 Development approach

- a. Clause 5.2 on structural engineering shall be applied.
- b. The failure mode shall be demonstrated by analysis or test or both according to clause 5.3.
- c. Except in the case specified in 4.3.2.1d, 'safe life item' demonstration shall be performed by analysis or test in conformance with ECSS-E-ST-32-01.
- d. For pressure vessels with a non-hazardous LBB failure mode, the safe-life demonstration specified in 4.3.2.1c may be replaced by a fatigue life demonstration by analysis or test or both.

NOTE This can have an impact on the mission reliability.

- e. In the case specified in 4.3.2.1d, requirements for 'fatigue analysis' shall be applied in conformance with ECSS-E-ST-32.
- f. Qualification tests shall be conducted according to clause 4.3.2.2 to demonstrate the structural adequacy of the design.
- g. For corrosion effects (control and prevention), the requirements in ECSS-E-ST-32 shall apply.
- h. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.
- i. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with ECSS-E-ST-32.
- j. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.
- k. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-3.