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Systèmes spaciaux — Dispositifs et équipements explosifs

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 26871 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Space systems — Explosive systems and devices

1 Scope

This International Standard specifies requirements for the use of explosives on spacecraft and other space products, including launch vehicles. It addresses the aspects of design, analysis, verification, manufacturing, operations and safety.

NOTE Specific requirements for man-rating are not addressed.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14300-1, *Space systems — Programme management — Part 1: Structuring of a project*

ST/SG/AC.10/1, UN Recommendations on the transport of dangerous goods (Model Regulations)

UNO Manual of Tests and Criteria. United Nations, Fifth Edition, 2010

Mil-std 1576, *Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems*, USAF, 1992

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
actuator
component that performs the moving function of a mechanism

NOTE An actuator can be either an electric motor, or any other mechanical (e.g. spring) or electric component or part providing the torque or force for the motion of the mechanism.

3.1.2
all-fire level
lowest level of the fire stimulus (including rise time, shape, duration), which results in initiation of a first element (initiator) within a specific reliability and confidence level as determined by test and analysis

NOTE 1 The stimulus duration shall be compliant with the system.

NOTE 2 It is recommended that the test sequence be carried out at the lowest temperature of the operating range.

NOTE 3 The probability of functioning should be equal to or better than 0,999 at the 95 % confidence level.

3.1.3
armed
condition that allows the probability of a wanted event to be above an agreed limit

3.1.4
cartridge
explosive device designed to produce pressure for performing a mechanical function

NOTE A cartridge is called an initiator if it is the first or only explosive element in an explosive train.

3.1.5
catastrophic failure
failure resulting in loss of life, loss of mission or loss of launch capability

3.1.6
charge
explosive loaded in a cartridge, detonator or separate container for use in a explosive device

3.1.7
component
smallest functional item in a explosive subsystem

3.1.8
deflagration
reaction of combustion through a substance at subsonic velocity in the reacting substance

3.1.9
detonation
chemical decomposition propagating through the explosive at a supersonic velocity such that a shock wave is generated

3.1.10
detonator
first element whose output is a high-order detonation

NOTE Detonators are generally used to effect detonation transfers within explosive trains.

3.1.11
dud
explosive charge or component that fails to fire or function upon receipt of the prescribed initiating stimulus, after an external effect (human failure, manufacturing failure, environmental, chemical, ageing, etc.)

3.1.12
electro-explosive device
explosive cartridge that is electrically actuated

3.1.13
end user
person who, or organization that, actually uses a product

NOTE The end user is not necessarily the owner or buyer.

3.1.14
explosive US
energetic material GB
material which is capable of undergoing an explosion when subjected to heat, impact, friction, detonation or other suitable initiation

3.1.15
explosive actuator
mechanism that converts the products of explosion into useful mechanical work

3.1.16
explosive component
any discrete item containing an explosive substance

3.1.17
explosive function
any function that uses energy released from explosive substances for its operation

3.1.18
explosive system
collection of all the explosive trains on the spacecraft or launcher system, and the interface aspects of any on-board computers, launch operation equipment, ground support and test equipment and all software associated with explosive functions

3.1.19
explosive train
series of explosive components, including initiating and igniting elements, explosive transfer assembly and explosive actuator, arranged to realise the pyro effect required

3.1.20
extreme envelope
positive margin over the conditions of the qualification envelope

NOTE The device or system design is based on the conditions that define the extreme envelope.

3.1.21
gas generator
explosive device that produces a volume of gas or exothermic output or both

EXAMPLE Pyrotechnic igniters for solid propulsion applications, gas generator for inflatable structures.

3.1.22
initiator
first explosive element in an explosive train which, upon receipt of the proper mechanical, optical or electrical impulse, produces a deflagrating or detonating action

NOTE 1 The initiator is divided into three categories: 1) igniter, a first element whose output is hot gases and hot particles (igniters may be initiators for solid or liquid propellant); 2) squib, a first element whose output is primarily gas and heat (squibs may be initiators for gas generators and igniters or may be cartridges for actuated devices); 3) detonator, a first element whose output is a high-order detonation (detonators are generally used to effect detonation transfers within explosive trains).

NOTE 2 The deflagrating or detonating action is transmitted to the elements following in the train.

NOTE 3 Initiators can be electrically (EEDs), optically or mechanically actuated.

3.1.23
launcher
launch vehicle
system used to transport a payload into orbit

3.1.24
lifetime
period over which any properties are required to be within defined limits

3.1.25
lot
batch
group of components produced in homogeneous groups and under uniform conditions

3.1.26
lot acceptance
demonstration by measurement or test that a lot of items meet its requirements

3.1.27
no-fire level
maximal level of input energy with an ignition stimulus (including nominal rise time and shape as required by the system, but with a 5 min extended duration), to a first element (initiator) at which initiation will not occur within a specific reliability and confidence level as determined by test and analysis

NOTE 1 It is recommended that the test sequence be carried out at the hottest temperature of the operating range.

NOTE 2 The probability of functioning should be less than or equal to 0,001 at the 95 % confidence level.

NOTE 3 A first element tested at this level shall remain safe and functional and shall guarantee the level of performances required after the no-fire level test.

3.1.28
operational envelope
set of conditions in which the device or system meets its requirements

3.1.29
packaged charge
explosive material in a closed container

3.1.30
primary explosive
substance or mixture of substances used to initiate a detonation or burning reaction

NOTE In their intended role, these materials are sensitive to a range of thermal, mechanical and electrical stimuli, including exposures during processing.

3.1.31
pyrotechnic device
device or assembly containing, or actuated by, propellants or explosives, with the exception of large rocket motors

NOTE Initiators, ignitors, detonators, squibs, safe and arm devices, booster cartridges, pressure cartridges, separation bolts and nuts, pin pullers, linear separation systems, shaped charges, explosive guillotines, pyrovalves, detonation transfer assemblies (mild detonating fuse, confined detonating cord, confined detonating fuse, shielded mild detonating cord, etc.), through-bulkhead initiators, mortars, thrusters, explosive circuit interrupters, and other similar items.

3.1.32
qualification envelope
positive margin over the conditions of the operational envelope

3.1.33
safe
condition that renders the probability of an unwanted event below an agreed limit

3.1.34
scoop-proof connector
connector shell design in which the male contacts are recessed into the connector body to prevent mismating damage to pins (especially in blind mating applications)

3.1.35
secondary characteristic
any characteristic other than the function

3.1.36
secondary explosive
substance or mixture which will detonate when initiated by a shock wave, but which normally does not detonate when heated or ignited

3.1.37
sequential firing
application of the firing pulses to initiators separated in time

3.1.38
spacecraft
satellite or other orbiting vehicle with self-propulsion

3.1.39
space vehicle
any satellite or launch vehicle

3.1.40
success
simultaneous achievement by all characteristics of required performance

3.1.41
sympathetic firing
firing of other explosive devices due to the output of any other

3.1.42
transfer line
linear explosive assembly for propagation of deflagration or detonation

3.1.43
through-bulkhead initiator
TBI
device for transfer of detonating input to detonating or deflagrating output across a hermetically sealed barrier

3.1.44
user manual
document provided by the supplier to describe all the appropriate rules of operations

3.2 Abbreviated terms

AIT	Assembly, integration and test
AIV	Assembly, integration and verification
A/N	As necessary
CDR	Critical design review
DC	Direct current
DKP	Design key point documentation
DMPL	Declared materials and processes list
DRB	Delivery review board
DRD	Document requirements definition
DSC	Differential scanning calorimetric
DTA	Differential thermal analysis
EED	Electro-explosive device
EMC	Electromagnetic compatibility

EMI	Electromagnetic interference
ESD	Electrostatic discharge
FMECA	Failure modes, effects and criticality analysis
FTA	Fault tree analysis
FOSU	Ultimate design factor of safety
FOSY	Yield design factor of safety
GSE	Ground support equipment
ICD	Interface control document
MEOP	Maximum expected operating pressure
MRR	Manufacturing readiness review
N/A	Not applicable
NC	Normally closed
NO	Normally open
PDR	Preliminary design review
PUM	User manual
R	Reliability
RAMS	Reliability, availability, maintainability, safety
RF	Radio frequency
RFP	Request for proposal
S/C	Spacecraft
SRS	Shock response spectrum
TBI	Through-bulkhead initiator
TBPM	To be provided by manufacturer
TBPU	To be provided by user
TGA	Thermo-gravimetric analysis
TRR	Test readiness review
UM	User manual
UNO	United Nations Organization
VDC	Voltage direct current
VTS	Vacuum thermal stability

3.3 Symbols

A	Ampere
F	Force
F_D	Inertial resistance force
F_L	Deliverable output force
g	Standard surface gravity (9,806 65 m/s^2)
h	Drop height (m)
He	Helium
I_F	Inertial force
I_T	Inertial torque
K_E	Explosive factor
K_{LD}	Local design factor
K_M	Model factor
KMP	Margin policy factor
K_P	Project factor
KO	Kick-off
K_P	Project factor
M	Mass of drop weight (kg)
scc	Square centimetre cubic
T	Torque
T_D	Inertial resistance torque
T_L	Deliverable output torque
V	Volt
σ	Standard deviation

4 Requirements

4.1 General

4.1.1 Background information

Since an explosive item used for flight can function only once, it can never be fully tested before its crucial mission operation. The required confidence can only be established indirectly by testing identical items. Test results and theoretical justification are essential to demonstrate fulfilment of the requirements. The requirement for repeatability shows that product assurance plays a crucial role in support of technical aspects.

The need for statistics requires that the explosive components used in an explosive system be tested and characterized extensively. The variability in components means it is essential that manufacturers provide customers with proof that the delivered items are identical to those qualified.

Failure or unintentional operation of an explosive item can be catastrophic for the whole mission and life-threatening. Specific requirements can exist for the items associated with it. As all explosives, whatever their use, are to be treated in a similar fashion, the same requirements, regulations, practices and standards need to be applied, which will help to avoid human error.

If there is sufficient data to establish the reliability and confidence level for any given performance against any given condition, this should be done. Subsequently, all margins should be converted into standard deviations (σ) and be incorporated into the reliability and confidence analysis.

When viewed from the perspective of a specific project context, the requirements defined in this International Standard should be tailored to match the genuine requirements of the particular profile and circumstances of a project.

NOTE 1 Tailoring is a process by which individual requirements of specifications, standards and related documents are evaluated, and made applicable to a specific project by selection and, in some exceptional cases, modification of existing or addition of new requirements.

The requirements of this International Standard are drawn from the more detailed specifications of AIAA S-113[1] and ECSS-E-ST-33-11C[3].

4.1.2 Overview

Being generally applicable, the requirements stated in this section apply throughout and are not repeated in the sections relating to specific topics.

Explosive systems and devices use energetic materials (explosives, propellants, powder) initiated by mechanical, electrical, thermal, or optical stimuli, for unique (single-shot) functions, e.g. solid booster initiation, structure cutting, stage distancing, pressurized venting, stage neutralization, valve opening or closing, release of solar arrays, antennas, booms, covers and instruments.

The properties of the initiator govern the major part of the behaviour of the system.

The requirements for initiators and their derivatives, such as cartridges and detonators, are defined in specific requirements related to the specific types.

Properties of explosive components and systems, which cannot be covered by requirements for the initiators alone, are defined in specific requirements relating to the types of actuator.

Other components of the explosive system, which can be tested and do not need specific requirements, are subject to the general technical and product assurance requirements. Detailed aspects of these components are included where they have a significant influence on the success of the system.

Single-shot items can never be tested in advance. Particular care is needed in their development, qualification, procurement and use, in accordance with the development phases specified in ISO 14300-1.

Safe handling and usage of explosive components are not governed by individual users or the suppliers.

4.1.3 Applicability

This International Standard applies in addition to any existing standards and requirements applicable to spacecraft or launchers.

4.1.4 Properties

a) The two states of the properties of the explosive system (before firing and after firing) shall be identified and listed in a specific document for shipper and user.

b) For every explosive component, the function, primary stimulus, unwanted stimuli and secondary characteristics shall be identified and quantified.

c) Only qualified and lot-accepted items shall be used in flight systems.

d) The properties for the two states of the explosive system (before firing and after firing) referred to in item a) of this list shall remain stable over time when subjected to external loads or environmental conditions, within the qualification values.

4.2 Design

4.2.1 General

a) Redundant trains shall be designed such that the first component to fire does not adversely affect the second.

b) The system lay-out should facilitate the replacement of subsystems or components.

c) Parts of the explosive system and devices identified as critical on the basis of a RAMS analysis shall be replaceable.

d) Replaceable parts and substitutes shall be listed in the user manual of the explosive system and devices.

4.2.2 Reliability and confidence levels

a) It shall be agreed between the customer and the supplier which performance parameters are to be defined as mean values with associated standard deviation [see g) below].

b) The explosive system shall achieve the specified properties within defined levels of reliability and confidence agreed between the customer and the supplier.

NOTE 1 All components are contributors.

NOTE 2 This International Standard specifies critical safety and performance properties.

c) The reliability of components shall be equal to or better than 0,999 with a confidence level equal to or better than 95 %.

d) The probability of unwanted functioning of components shall be less than or equal to 0,001 with a confidence level equal to or better than 95 %.

e) The performance characteristics of components at any level of assembly shall be specified at the specified level of reliability and confidence [see b) above].

f) The safety characteristics of items at any level of assembly shall be specified at the specified level of reliability and confidence [see c) above].

g) The supplier shall provide documentation, for customer approval, justifying the validity of statistical methods used to determine the product performances.

4.2.3 Performance

a) Except as specified in b) below, all performances shall be quantified by measurement versus time of initial, transitional, and final values of the specified properties.

NOTE Specified properties are listed in 4.11 and 4.12.

b) The specified time interval [defined in a)] shall be identified and measured between either

1) a clear reproducible initiation event and the attainment of the performance value, or

2) an initiation event and 90 % of the measured performance value.

c) For performance that cannot be quantified based on measurements, an acceptance procedure shall be agreed between the supplier and the customer.

d) The basis of the time shall be specified and justified.

4.2.4 Wanted and unwanted response

a) For wanted response, the response of any component, when subjected to the specified minimum probable stimulus, shall be demonstrated to be more than the specified lower limit agreed between the customer and the supplier.

b) For unwanted response, the response of any component, when subjected to the specified maximum possible disturbance, shall be demonstrated to be less than the specified upper limit agreed between the customer and the supplier.

NOTE This applies to safety and failure.

4.2.5 Dimensioning

4.2.5.1 Strength

The explosive system shall sustain, before, during and after firing:

— the internal loads due to operation, and

— the external loads defined by the user.

NOTE These loads represent the sum of pre-load, static, dynamic, thermal and any other load seen in service.

4.2.5.2 Explosive charge dimensioning

a) The methodology for dimensioning the charge of the explosive devices (using or not the modelling) shall be justified.

NOTE 1 Dimensioning is done at the worst case (e.g. temperature of the qualification envelope).

b) Design factors and additional factor values defined in this clause shall be agreed with the customer.

c) For determination of the explosive charge, the design factor K shall be used, as defined hereinafter:

$$K = K_{MP} \times K_E \times K_P \times K_M$$

d) A “margin policy factor”, K_{MP}; shall be defined, justified and applied in accordance with the methodology given in Annex A.

NOTE 2 This factor, used to give confidence to the design, covers (non-exhaustive list)

— the lack of knowledge on the failure modes and associated criteria,

— the lack of knowledge on the effect of interaction of loadings, and

— the non-tested zones.

NOTE 3 Justification can be performed based on relevant historical practice and analytical or experimental means.

NOTE 4 K_{MP} can have different values according to the technology used for the device (e.g. expanding tube, cutter, pyrotechnic actuator).

NOTE 5 While going through the design refinement loops, K_{MP} can be progressively reduced down to 1,0 after justification.

e) When modelling is performed, a “model factor”, K_M, shall be applied to account for uncertainties in mathematical models when used for prediction of behaviour and induced load.

NOTE 6 K_M is applied in cases where uncertainty exists in the model.

NOTE 7 While going through the design refinement loops, K_M can be progressively reduced down to 1,0 after the demonstration of satisfactory correlation between model and test measurements.

f) A specific “project factor”, K_P, shall be defined, justified and applied to account for the programme maturity and the confidence in the specification given to the project.

NOTE 8 K_P is generally defined by the project and can be reduced during the development.

NOTE 9 K_P can also cover a growth potential for some further development (e.g. generic product).

g) An “explosive factor”, K_E, shall be applied for uncertainties on the behaviour of explosive materials in the mission profile (e.g. ageing and temperature influences, batch influence, material compatibility).

NOTE 10 Typical values are given in Table 1.

Table 1 — Explosive factor

Explosive materials	K_E
Pyrotechnic compositions	≥1,1
Propellants (e.g. NC; NC/NG, composite)	≥1,2
HE (pure)	≥1,1
HE (composite)	≥1,2

At any step, a minimization of the explosive charge shall be taken into account.

An ageing programme and manufacturing qualification process (e.g. batch influence, wear of manufacturing tool) shall be used to reduce the K_E factor.

h) For phases C and D of the component, when all requirements are totally set up, the reliability demonstration shall be used to justify design margins, including the influence of ageing, temperature and explosive batch.

NOTE 12 See Figure 1.

NOTE 13 R is the estimated reliability, R^+ and R^- are the limits according to the confidence level required.

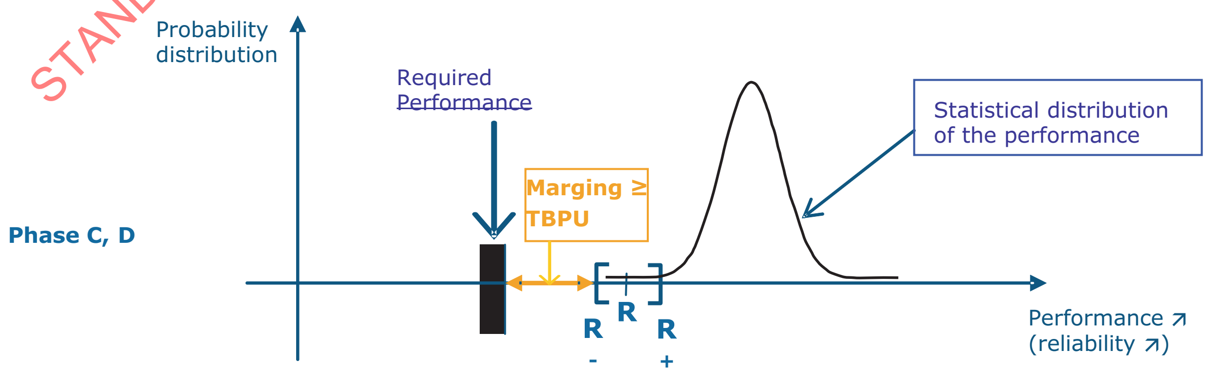

Figure 1 — Margin and reliability relationship

4.2.5.3 Integrity of the explosive system

a) The explosive system shall maintain its integrity and position during its lifetime.

b) A "margin policy" shall be defined, justified and applied in accordance with the methodology given in Annex A.

c) Components that are intended not to rupture during operation, when installed into their explosive system interfaces, shall be able to withstand the maximum expected operational loads times a factor FOSU.

d) The factors FOSY and FOSU shall be consistent with the values given in Annex B depending on the materials used.

e) The deformation of a component shall not

1) reduce its specified performance,

2) affect any part of the system,

3) cause leakage.

f) During the development phase, a dedicated margin policy shall be defined, justified and applied for each case identified in FMECA, from major to catastrophic.

4.2.5.4 Motorization

The following motorization factor requirements are applicable to explosively actuated devices:

a) to provide throughout the operational lifetime and over the full range of travel actuation torques (or forces) according to provision d) or e);

b) to derive the factored worst-case resistive torques (or forces), the components of resistance, considering in-orbit worst-case conditions (environmental effects, e.g. vacuum, temperature, zero G) shall be multiplied by the minimum uncertainty factors specified in Table 2;

Table 2 — Minimum uncertainty factors

Component of resistance	Symbol	Theoretical factor	Measured factor
Inertia	I_T (or I_F)	1,1	1,1
Spring	S	1,2	1,2
Motor magnetic losses	H_M	1,5	1,2
Friction	F_R	3	1,5
Hysteresis	H_Y	3	1,5
Other (harness)	H_A	3	1,5
Adhesion	H_D	3	3

c) The theoretical uncertainty factors in Table 2 may be reduced to the measured factors providing the worst-case measured torque or force-resistive components are determined by measurement according to a test procedure approved by the customer and demonstrate the adequacy of the uncertainty factor with respect to the dispersions of the resistive component functional performances.

d) The minimum actuation torque (T_{min}) shall be derived from the following equation:

$$T_{min} = 2,0 \times (1,1I_T + 1,2S + 1,5H_M + 3F_R + 3H_Y + 3H_A + 3H_D) + 1,25T_D + T_L$$

where

I_T is the inertial torque applied to a device subjected to acceleration in an inertial frame of reference (e.g. spinning spacecraft, payload or other);

T_D is the inertial resistance torque caused by the worst-case acceleration function specified by the customer at the device level;

T_L is the deliverable output torque, when specified by the customer.

e) The minimum actuation force (F_{min}) shall be derived using the following equation:

$$F_{min} = 2{,}0 \times (1{,}1 I_F + 1{,}2 S + 1{,}5 H_M + 3\ F_R + 3\ H_Y + 3\ H_A + 3\ H_D) + 1{,}25\ F_D + F_L$$

where

I_F is the inertial force applied to a device subjected to acceleration in an inertial frame of reference (e.g. spinning spacecraft, payload or other);

F_D F_D is the inertial resistance force caused by the worst-case acceleration function specified by the customer at the device level;

F_L is the deliverable output force, when specified by the customer.

f) The kinetic energy of the moving components shall not be taken into account to meet the specified motorization factor.

4.3 Mission

a) The use of explosive functions, including those for flight termination and range safety, during all phases of the mission, shall be specified.

b) The environmental conditions, life cycle and functions being activated shall be specified.

EXAMPLE Ground storage, transport, launcher ignition, staging and safety functions, payload separation, motor ignition, solar array, antenna, boom or cover release, propulsion system branch opening or closing, de-orbiting.

c) Mission-related requirements placed on the explosive system shall be specified.

4.4 Functionality

a) The timing of each function of the explosive system shall be specified.

b) The explosive system shall react only to a specified stimulus (e.g. nature, range of values) and shall be insensitive to all others.

c) The explosive system shall ensure that the correct stimulus arrives at the specified place at the specified time.

d) The explosive system shall prevent the stimulus from reaching the initiator at any other time.

e) Unwanted functions or malfunctions shall be prevented.

f) The firing sequence (simultaneous or sequential) shall cause no anomaly.

NOTE This applies to secondary characteristics as well as to explosive functions.

g) Explosive systems shall be single-fault tolerant.

h) Explosive systems shall be two-fault tolerant, if premature initiation causes a catastrophic failure.

i) If loss of function is safety-critical or catastrophic, the explosive system shall avoid single-point failures and include at least two initiators.

j) Provision shall be made within the explosive system to protect its components against unwanted operation or degradation.

4.5 Safety

4.5.1 General

a) The system, including software and procedures, shall be Fail-Safe.

b) For a catastrophic risk, the explosive system shall be Fail-Safe/Fail-Safe or Fail-Operational/Fail-Safe.

c) The response of any explosive device to conditions outside the conditions specified shall be reported by the manufacturer to the user.

d) An explosive subsystem shall only respond to commands intended for that explosive subsystem.

4.5.2 Prevention of unintentional function

4.5.2.1 General

a) The firing pulse (e.g. detonating shock, electrical pulse, light pulse) shall be prevented from reaching any explosive initiator at any time except the correct instant by means of switchable barriers (e.g. electrical, mechanical, plugs, pins).

b) Provision shall be made to prevent firing in response to radio frequency, lightning, a magnetic field and electrostatic discharge.

c) If the explosive system contains two or more barriers, then at least two of these barriers

   1) shall be independent,

   2) shall not be subject to common cause failure, and

   3) shall each provide complete disconnection of the firing circuit.

d) For explosive systems involving a potential catastrophic risk, the barrier close to the source of the risk shall be a mechanical barrier.

e) The primary and redundant EEDs shall not be activated through the same electrical firing circuit.

f) Stray circuits or coupling, which can result in unintentional firing, shall be avoided.

4.5.2.2 Safe and arm device pre-arm function

a) The pre-arm function shall be the fourth last in a sequence of functions.

b) The pre-arm function shall be independent and respond only to a unique action.

c) The pre-arm function shall remain in its switched state after operation until the fire function has reverted to its initial state.

d) The pre-arm function can include the select function.

NOTE A safe and arm device is not always included.

4.5.2.3 Select function

a) The select function shall be the third last in a sequence of functions.

b) The select function shall select the explosive devices.

c) The select function shall be independent and respond only to a unique command.

d) The select function shall be used to control only one explosive function.

e) It shall revert to its initial state after the fire command within an interval agreed with the customer.

4.5.2.4 Arm function

a) The arm function shall be the second-last action in the sequence.

b) The arm function shall be independent and respond only to a unique command.

c) The arm function shall be used to control only one explosive function.

d) It shall be possible to restore its initial (disarmed) state after the arm command within an interval agreed with the customer.

4.5.2.5 Fire function

a) The fire function shall be the last action in the sequence.

b) The fire function may be used to activate a number of explosive devices.

c) The fire function shall be independent and respond only to a unique command.

d) The fire function shall revert to its initial state after the firing command within an interval agreed with the customer.

4.6 Survival and operational conditions

a) The explosive system shall survive the specified sequence of conditions without malfunctioning or degrading beyond the specified limits.

b) The explosive system shall operate between the extremes of the ranges and combinations of specified conditions.

c) The limits used for the qualification of elements and interfaces shall comply with the specified reliability and confidence.

d) End users shall specify the characteristics of the expected environment.

e) The end user shall specify the explosive system constraints.

f) The explosive system shall limit the mechanical, electrical and thermal effects of its operation within limits agreed with the user to avoid disturbance (e.g. shock, electrical short circuits, magnetic fields) or damage to other sensitive elements on the space vehicle.

NOTE For verification tests, see 4.14.

4.7 Interface requirements

4.7.1 General

The natures of the interfaces are

— geometry, including the analysis of the dimensions for all phases of life (e.g. assembly, transport, flight);

— mechanical, including induced loads, static and dynamic;

— fluids, including venting;

— thermal loads;

— electrical, including ensuring electrical continuity and EMC;

— materials, including ensuring compatibility.

4.7.2 Functional

a) Each interface shall

   1) ensure no assembly errors can be made, and

   2) prevent damage during assembly or dismantling.

b) While separated, protection shall be provided to each interface.

   NOTE 1 This is to prevent activation or damage by external loads and environmental conditions.

c) When closed, each interface shall establish stable continuity of properties between the joined elements.

   NOTE 2 This is to prevent disturbance of, or being disturbed by, external loads and environmental conditions.

d) Each interface shall sustain, without degradation in both coupled and separated states,

   1) the assembly and dismantling duty-cycle, and

   2) the operational and environmental conditions of the application.

4.7.3 Internal

a) Each element in the explosive system shall be compatible with its neighbour.

b) Each element shall provide outputs (e.g. electrical, mechanical, thermal, optical) at each interface with margins over the input requirements of the next element or the explosive system output requirements.

4.7.4 External

a) The explosive system shall be compatible with the requirements of all other subsystems on board, external loading and environmental conditions.

b) If case a) of this list cannot be met, it shall be agreed with the user that

   1) either the on-board system requirements be changed, or

   2) protection against the environmental conditions be provided or the external loads on the explosive system be reduced.

4.8 Mechanical, electrical, and thermal requirements

4.8.1 Mechanical

4.8.1.1 Inertial properties

The supplier shall provide the customer with

a) the mass,

b) the centre of mass,

c) the inertial properties, and

d) the numerical model, upon request of the user,

of the components before and after firing.

4.8.1.2 Main fixings

Each element of the explosive system shall be provided with an interface compatible with the methods of attachment to the structure or appendage agreed with the customer.

4.8.1.3 Modularity of the system

a) The explosive system shall be assembled from modular components.

b) It shall be possible to test the components separately.

c) It shall be ensured that attachment, installation, repair and replacement can be done without affecting the surrounding equipment.

4.8.1.4 Avoidance of confusion

a) It shall be ensured, using dedicated marking, that components intended for different applications cannot be confused.

   EXAMPLE Inert components (dummies, etc.) versus live items (test models, flight models, qualification models, etc.)

b) For launchers, the colour code (see Annex C) can be applied.

   NOTE This is to prevent confusion and to ensure incorrect items are not used for flight or qualification.

4.8.1.5 Accessibility

a) Access shall be provided, throughout the space vehicle integration,

   1) to the initiators, safe, test, and arm plugs for connection,

   2) for measurements of properties, and

   3) to all elements for inspection.

b) Access shall be safe and convenient, as agreed with the customer.

4.8.2 Electrical

4.8.2.1 General

a) The explosive system firing sources shall have their own power distribution points.

b) The explosive system shall provide power pulses to initiators at the times required by the application.

c) The power pulse, shape, amplitude and duration shall be as specified in the initiator input requirements. This shall be demonstrated by testing.

d) If the firing source circuit takes power from the host vehicle, either

   1) the return side shall not be grounded on the payload side of the interface, and shall be isolated from payload structure by at least 10 kΩ, or

   2) isolation converters shall be used to provide at least 10 kΩ isolation between payload return circuit and host vehicle return circuit,

   when measured at a minimum of 1,5 times the bus voltage.

4.8.2.2 Circuit independence

a) EEDs shall not be connected in series or parallel with each other.

b) A separate command shall activate each component for launch vehicles.

c) If case a) in this list cannot be met, the alternative circuit shall be justified and agreed between the customer and the supplier.

d) It shall be verified by test or analysis that the circuits meet the requirements on reliability and on the prevention of unintentional function.

   NOTE See 4.2.2 and 4.5.2.

4.8.2.3 Power system overload

The power supply shall ensure that the power subsystem is not overloaded before, during or after the actuation of any explosive device, even in the case of a single-point failure together with a short-circuit (both pin-to-pin and pin-to-ground).

4.8.2.4 Electromagnetic compatibility (EMC)

a) The explosive system power, command and control electrical circuitry shall limit the generation of electromagnetic fields or conducted noise to a level at least 20 dB below the no-fire power rating.

b) The explosive system shall provide shielding to the same levels noted in a) when exposed to externally generated electromagnetic fields.

c) Control circuits shall limit the power level at any barrier to at least 20 dB below the minimum activation power.

4.8.2.5 Electrostatic discharge

a) Explosive systems and components shall

   1) survive,

   2) not be degraded by specified electrostatic discharges,

   3) be tested to verify survivability.

b) Protective features shall

   1) be provided to prevent initiation,

   2) be provided to prevent change of state of barriers,

3) be provided to prevent parasitic paths,

4) be tested to verify effectiveness.

c) Electrostatic discharge to ground through the explosive elements shall be prevented.

d) Build-up of electrostatic charges shall be prevented.

e) Measures to satisfy requirement d) of this list shall not violate single-point grounding requirements.

f) All ESD-sensitive components shall be identified and listed.

g) Unplanned electrostatic discharges shall be avoided.

4.8.2.6 Voltage drop

The voltage drop in the electrical circuit shall be taken into account when providing the required firing pulse.

4.8.2.7 Electrical bonding

a) The resistance to electrical ground shall not exceed the specified value according to the bonding requirements given in Figure 2.

b) The metallic parts of the explosive components shall be bonded by direct contact.

c) The shielding of the firing circuits shall be bonded at least at both ends.

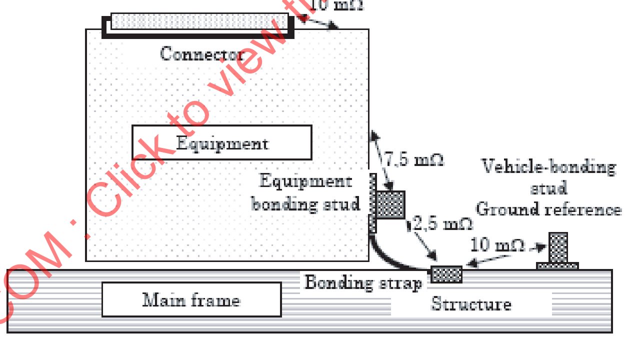

Figure 2 — Bonding requirements

4.8.2.8 Isolation

a) Every electrical firing circuit and monitoring circuit shall be electrically independent.

b) The explosive system shall isolate the function to prevent power drain or parasitic paths before and after firing.

c) Provision shall be made to isolate power lines and return lines of the explosive system from electrical ground.

NOTE This is to prevent continued drain on the power system after firing, when, for example, a short circuit to ground can occur.

d) Provisions for redundancy shall not prevent fulfilment of requirement a) of this list.

e) Safe and arm device control and check-out circuits shall

1) be independent of the firing circuits, and

2) use separate non-interchangeable connectors.

4.8.2.9 Insulation resistance

The explosive system shall neither function nor degrade as a result of the potential difference between the firing circuits and the shielding or the ground within specified limits.

4.8.2.10 Dielectric strength

The explosive system shall neither function nor degrade as a result of leakage current of electrical firing circuits to ground.

4.8.2.11 Sensitivity to RF energy

a) When exposed to RF conditions, the induced current shall not exceed the greater of the following:

   1) 20 dB below the no-fire current;

   2) 20 dB below the RF sensitivity threshold (any reaction of the component, even a non-nominal one — reliability and confidence levels are given in Table 2).

   NOTE If no RF limit is known, the DC limit can be used.

b) When exposed to RF conditions, the explosive system shall not be degraded.

4.8.2.12 Magnetic cleanliness

a) The maximum level of residual magnetism shall be agreed with the end user.

   NOTE Reduced levels can be achieved by the choice of suitable materials.

b) The supplier shall provide the customer with the magnetic properties of the components.

c) The explosive system shall not generate magnetic fields exceeding the electromagnetic interference safety margins level required (TBPU).

4.8.2.13 Lightning

a) Explosive systems shall preclude activation due to electrical potential differences, or current generated within the explosive system by exposure to lightning.

b) Explosive systems should preclude degradation by exposure to lightning.

4.8.3 Thermal

4.8.3.1 Sensitivity

a) Explosive systems and components shall

   1) survive,

   2) not be degraded by defined thermal loads in terms of intensity, duration and cycling, and

   3) be tested to verify survivability.

b) Protective features shall

   1) be provided to prevent unintended initiation,

   2) be provided to prevent loss of performance, and

3) be tested to verify effectiveness.

c) Build-up of heat shall be prevented.

d) All thermally sensitive components shall be shielded or otherwise protected from the environment.

e) Explosive systems and components shall not ignite at temperatures more than 30 C higher than the maximum expected environmental temperature.

NOTE This is to ensure no auto-ignition or “cook-off”.

4.8.3.2 Heat generation

The explosive system shall not generate heat causing temperatures which exceed the specified limits.

4.8.4 Status check

4.8.4.1 General

a) The explosive system shall provide for

1) measurements of electrical or optical properties during the integration of any circuit before and after firing, without inducing firing, unintentional status changes or degradation, and

2) the indication of at least the status of the pre-arm and select barriers during the mission.

b) It shall be possible to verify the status of the barriers protecting the initiator before inserting the arming plug.

c) Check-out circuits shall not allow current flow or electrostatic discharge causing unintentional effects in the explosive system.

NOTE This applies also after any single failure.

d) Any checking out of the status of electrical initiators shall limit the check-out current to 10^{-2} times the “no-fire” current on the bridge wire.

e) Any checking-out of the status of optical initiators shall limit check-out energy to 10^{-4} times the “no-fire” power density at the fire wavelength on the optical interface if the fire wavelength is used.

f) The checking-out power or current or optical wavelength or frequency shall cause no unintentional effects or hazards, even after any single failure.

g) Any checking-out of the insulation resistance of the explosive system shall limit the voltage to 50 V DC.

h) Provision shall be made for an immediate warning signal to be given for any unplanned change of status of any explosive system control or check-out device.

EXAMPLE Thermal control requirements or material temperature limits.

4.8.4.2 Initiator status

a) Provision shall be made for on-ground checking of the initiator status.

b) Provision shall be made for access to the interface.

c) Requirements for access shall be communicated to the user and facilities authorities.

NOTE Range safety sometimes prohibits the use of these features.

4.9 Materials

a) All materials, including explosive substances, shall be compatible with those materials with which they can come into contact.

NOTE 1 Outgassing can occur during, for example, polymerization or degradation of polymers.

NOTE 2 Explosive systems use materials (e.g. explosives, propellants, powder, binders, cleaning agents, cements) that can be toxic, corrosive, highly reactive, flammable, dangerous with direct contact.

b) Continued exposure to the expected environmental conditions shall not cause degradation or increased sensitivity in excess of agreed limits.

c) Any sealing system used to prevent degradation shall be demonstrated to be effective.

d) No cracking shall be allowed due to shock loads.

NOTE 3 Materials can become brittle at low temperatures.

e) Age-sensitive materials shall only be used where degradation causes no loss of explosive system performance beyond the limits agreed with the end user.

f) The nature and condition of age-sensitive materials shall be identified and documented in the DMPL.

g) The nature and condition of explosive materials shall be identified and documented in the DMPL.

h) Explosives that can react in response to normal environmental stimuli shall only be used in agreement with the user.

i) The properties of the explosives shall be reported and shall be compared with the mission requirements.

j) Degradation of the explosives shall not exceed agreed limits.

k) Degradation of explosive characteristics shall be determined by testing.

NOTE 4 Test methods can be DTA, DSC, TGA, VTS.

4.10 Non-explosive components and equipment

4.10.1 Connectors

a) There shall be only one connection per pin.

b) The requirements of 4.7.2 shall apply.

c) Mismating of connectors shall be impossible (e.g. geometry, lay-out, dimensions, harness length).

d) The insert polarization and contact arrangement of the connectors used in the explosive system shall not be used elsewhere on the space vehicle.

e) Source circuits shall be terminated by female contacts.

f) Spare or un-terminated contacts shall not be allowed.

g) Prime and redundant circuits for the same function shall not pass through the same connector.

h) Electrical connectors shall provide continuous shielding in all directions.

i) Electrical connectors shall provide continuous shielding during

1) engagement before the pins connect,

2) disengagement after the pins disconnect.

j) Connector savers shall be used in agreement with AIT requirements.

NOTE This is to prevent the receptacle and contacts from wear and damage.

4.10.2 Wiring

a) Electrical supply for each initiator, optical source and safe and arm device shall be by a separate shielded, twisted-pair, line or coaxial cable (with double braid).

b) All connections between conductors shall be made by

1) soldering,

2) crimping,

3) connectors.

NOTE See 4.10.1.

c) Wiring used for explosives should be visibly and uniquely identifiable.

4.10.3 Shielding

a) The firing circuit, including the initiator, shall be shielded.

b) The shield shall provide 20 dB attenuation at the specified electromagnetic frequencies.

c) Cable shielding shall provide ≥90 % optical coverage.

d) Double-layer cable shielding should be used.

e) For all other element shielding, there should be shielding at 100 % optical coverage (e.g. no gaps or discontinuities, full shielding at the back faces of the connectors, no apertures in any container housing elements of the firing circuit), in order to be compliant with the electromagnetic environment severity.

f) Shields shall not be used for current carrying.

NOTE Shields can be grounded by multiple points to the structure.

4.10.4 Faraday cap

Faraday caps shall be used and shall prevent EEDs from being initiated by electromagnetic fields.

4.10.5 Safety cap

a) Safety caps shall be used and shall contain the products of initiation of an explosive device.

b) It shall not be possible to install an explosive device with the safety cap mounted.

4.10.6 Power

a) The explosive system shall make use of the available voltage and current supplies from the power subsystem to produce power pulses of suitable size, duration and timing for each of the functions.

b) The firing pulse requirements in Table 4, row 5, and Table 6 shall apply for EEDs and laser initiators respectively.

c) The power provided at the power distribution points shall be adequate to fulfil the requirements of 4.8.2.6, allowing for losses.

4.10.7 Safe and arm connector

a) A connector shall be provided on the exterior surface of the space vehicle for use with manually inserted plugs to enable

   1) isolation,

   2) coupling of any explosive system, and

   3) testing of any explosive system.

b) Provision shall be made for access to the interface.

c) Requirements for access shall be communicated to the user, the customer and facilities authorities.

d) The safe and arm connector shall be visibly identifiable.

e) The safe and arm connector shall be qualified for the number of required connection cycles (e.g. to cover integration, testing and use).

f) The receptacle shall meet the requirements of 4.10.1.

   NOTE 1 A sub-D connector, self-locking bayonet or triple-start thread type can be used.

g) A connector saver shall be used.

   NOTE 2 This is to prevent the receptacle and contacts from wear and damage.

4.10.8 Safe plug

a) For electrical initiators, the safe plug shall

   1) short-circuit each initiator,

   2) ground each shorted initiator circuit,

   3) short-circuit each firing circuit, and

   4) ground each firing circuit.

b) For optical initiators, the safe plug shall be capable of absorbing or redirecting n times the maximum power the laser can generate, where n is defined by the user.

c) The safe plug shall be

   1) compatible with the safe and arm connector receptacle,

   2) suitable for use with flight hardware,

   3) suitable for the number of connection cycles necessary to cover integration, testing and use,

   4) scoop proof,

   5) lockable (e.g. sub-D connector, bayonet or triple-start thread type),

   6) visibly identified, and

   7) shall carry a “Remove before Flight” banner.

4.10.9 Arming plug

The arming plug shall

a) provide electrical continuity between the supply and firing circuits with electrical properties (including resistance, isolation, bonding, and Faraday protection) in any line, and be compliant with the requirements,

b) be compatible with the safe and arm connector,

c) be scoop-proof,

d) be lockable (e.g. sub-D connector, bayonet or triple-start thread type), and

e) be visibly identified.

4.10.10 Test plug

The test plug shall

a) provide electrical access to the firing circuits with electrical properties (including resistance, isolation, bonding measurements, Faraday protection and firing current pulse verification, including its correct distribution) in any line, and be compliant with the requirements,

b) be compatible with the safe and arm connector,

c) not carry any potential or current at the time of insertion or removal,

d) be suitable for the number of connection cycles necessary to cover integration, test and use,

e) be suitable for use with flight hardware,

f) be scoop-proof, and

g) be lockable (e.g. sub-D connector, bayonet or triple-start thread type).

4.10.11 Safe and arm device

4.10.11.1 General

a) Electrically actuated safe and arm devices should be used.

b) A safe and arm device shall

   1) be used in applications where unplanned initiation of the explosive system can cause injury, death, or severe damage to property,

   2) prevent the mounting of initiators in the armed position,

   3) provide means of remote arming,

   4) provide means of remote safing,

   5) provide safing without passing through the armed position,

   6) prevent manual arming,

   7) provide manual safing and prevent unwanted return to arm

   8) remain in the selected position under all conditions except when intentionally activated,

   9) prevent the device from remaining in any state between “safe” and “arm”,

10) arm within a time interval agreed with the user,

11) not require a force or torque to safe, exceeding the specified value, and

12) if actuated remotely, shall be safe within the specified time interval.

c) It shall not be possible to arm the safe and arm device if an initiator has been activated with the safe and arm device in safe position.

d) The safe and arm device shall be capable of being manually positioned to “safe” during any phase of this cyclic life.

e) The barrier shall be removable, or a reconnection shall allow propagation when required (“armed” condition).

f) Remote operation and status indication shall be provided.

g) Local visible unambiguous status indication shall be provided.

h) All additional blocks shall be flagged “Remove before flight”.

NOTE Safe and arm devices can use initiator-simulator resistors.

4.10.11.2 Electrically actuated

The electrically actuated safe and arm device

a) shall not have current flow exceeding 2 mA in the disarm or safe command circuit during the arming cycle nor in the arm command circuit during disarm or safing,

b) shall have a demonstrated cyclic life of 1 000 safe-to-arm-to-safe transitions, or five times the number of transitions predicted during its lifetime, whichever is greater, without failure or degraded performance.

4.10.11.3 Mechanically actuated

The mechanically actuated safe and arm device shall have a demonstrated cyclic life of 300 safe-to-arm-to-safe transitions without failure or degraded performance.

4.10.11.4 Safing

a) Safing shall prevent detonation or initiation transfer by

1) the placement of a barrier between the initiator and next explosive element, or

2) misalignment of the initiator and the next explosive element.

b) Safing shall disconnect power and return firing lines.

c) Safing shall short the EEDs.

d) Safing should ground the shorted EEDs through a resistance agreed with the end user.

e) Safing shall have one or several resistors with a resistance exceeding 10 kΩ if the resistors remain connected to the firing circuit in the arm position.

f) 4.1.3 a) applies.

4.10.11.5 Arming

a) Arming shall enable detonation or initiation transfer by

1) the removal of a barrier between the initiator and next explosive element, or

2) alignment of the initiator and the next explosive element.

b) Arming shall

1) connect firing power lines and return lines to EEDs,

2) remove the short from the EEDs, and

3) disconnect the EEDs from the ground.

c) During transition from “safe” to “arm”, each electrical switch shall disconnect before connecting to the next circuit.

d) 4.1.3 a) applies.

4.10.11.6 Status indicators

a) The device shall

1) provide remote status indications,

2) provide local status indications,

3) indicate an “arm” status with a black “A” on a red background or a red “A”,

4) indicate a “safe” status with a white “S” on a green background or a green “S”.

b) The status indications shall be unambiguous.

c) Visibility of the status indicators when installed on the spacecraft or launcher shall be ensured.

4.10.11.7 Initiator-simulator resistors

Application of operational voltages for at least 20 s shall not degrade the safe and arm performance or cause initiation of explosives.

4.10.12 Initiator harness connector

The initiator harness connector

a) shall comply with the interface requirements of the integral connector of the initiator, and

b) shall not be used for other purposes on the space vehicle.

4.10.13 Initiator test substitute

Any initiator test substitute shall be representative with respect to properties which affect the results of the test.

4.11 Explosive components

4.11.1 General

4.11.1.1 Applicability

Subclause 4.11 applies to explosive components that cannot be fully tested before flight. For other elements of the system, which can be fully tested before flight, the equipment environmental test conditions of the user apply.

The requirements for explosive components are given below as measurements to be made after specific preconditioning and under survival and operational conditions identified in 4.5.

4.11.1.2 Identification

a) Each part, material or product shall be identified by a unique and permanent part or type number.

b) In addition, parts, materials and products shall be identified as individual entities or groups by means of one or more of the following methods:

   1) date codes indicating date of manufacture, to identify items made by a continuous process or subject to degradation with age;

   2) lot or batch numbers, to identify items produced in homogeneous groups and under uniform conditions; this identification applies when the items need not be individually distinguishable;

   3) serial numbers, to identify individual items for which unique data shall be maintained.

c) The method of marking shall be compatible with the nature of the item and its use.

d) Identification should include

   — manufacturer,

   — part number, lot number,

   — serial number, and

   — manufacturing date.

e) For launchers, colour coding shall be used on components to indicate behaviour.

f) Colour coding should be in accordance with Annex C.

4.11.1.3 Contamination

a) Contamination shall be prevented during all the phases of the product life.

   EXAMPLE By the use of approved materials and by design to contain products of the operation of explosive components.

b) If requirement a) of this list cannot be met, a component shall not be accepted unless the limits of the amount and type of contamination are identified by the manufacturer and agreed with the end user.

   NOTE The contamination to be analysed is

   — from the environment to the components,

   — from the components to the environment, and

   — related to the innocuousness of the component during and after functioning.

4.11.1.4 After functioning

After functioning, no explosive component shall cause

a) any disturbance beyond specified limits,

b) contamination beyond specified limits.

4.11.2 Initiators

4.11.2.1 General

Properties of initiators shall be in accordance with Table 3 and shall be quantified.

Under the conditions given in column E of Table 3, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 3 — Common requirements for initiator (igniter, squib, detonator, cartridge, packaged charge) properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	AC leakage current	mA	TBPM	TBPM		
2	Bonding resistance	mΩ	10	N/A	To next-level assembly	
3	Thermal response	V/t	TBPM	TBPM		
4	Leak rate	scc He/s	10^{-6}	N/A	@ Δp= 0,1 MPa before and after firing	
5	Structural integrity	MPa		TBPM		Applies to MEOP according to 4.2.5.2
6	Temperatures					
a)	Auto-ignition	°C	N/A	TBPM		
b)	Non-operating	°C	TBPM	TBPM		
c)	Operating	°C	TBPM	TBPM	Duration TBPM	
d)	Storage	°C	TBPM	TBPM	Duration TBPM	
e)	Transport	°C	TBPM	TBPM	Duration TBPM	
7	Generated					
a)	Pressure	MPa	TBPM	TBPM	TBPM	Only the known and relevant output parameter shall be provided.
b)	Heat	J	TBPM	TBPM	TBPM	Only the known and relevant output parameter shall be provided.
c)	Light	lm	TBPM	TBPM	TBPM	Only the known and relevant output parameter shall be provided.
d)	Shock pressure	GPa	TBPM	TBPM	TBPM	Only the known and relevant output parameter shall be provided.
8	Probability of ignition of a reference charge			99,8 %	95 % confidence.	

Table 3 *(continued)*

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
9	No. of mating/de-mating cycles		TBPM	TBPU	With/without change of seals.	
10	Lifetime	Year	TBPM	N/A	For transport, storage and operation.	

4.11.2.2 1 W/1 A no-fire initiators

Properties of 1 W/1 A no-fire initiators shall be in accordance with Table 4 and shall be quantified.

Under the conditions given in column E of Table 4, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

a) The minimum no-fire rating shall be 1 A (current) or 1 W (power) for 5 min.

b) The firing probability when subjected to the no-fire current or no-fire power for 5 min shall be less than 0,001 at a 95 % confidence level.

c) After exposure to the no-fire current or no-fire power, the EED shall be capable of functioning according to its requirements.

Table 4 — Requirements for low-voltage initiator properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	DC insulation resistance	M Ω	N/A	2	@ ≥250 V, ≥60 s	
2	Breakdown voltage	kV	11	N/A		
3	ESD survival	kV	N/A	25	@ 500 pF and 5 000 Ω for pin to pin test @ 500 pF and 0Ω for pin to case test	
4	Dielectric strength	µA	500	N/A	@ 200 V (AC) ≥60 s	
5	All-fire current	A	TBPM	TBPM	≥99,9 % of the units function with a confidence level of 95 % @ specified conditions	
6	All-fire power	W	TBPM	TBPM	≥99,9 % of the units function with a confidence level of 95 % @ specified conditions	
7	Response time	ms	TBPM	N/A	for all-fire current or power	
8	No-fire current	A	N/A	1	≤0,1% of the units function with a confidence level of 95 % @ 5 min, at specified conditions.	

Table 4 *(continued)*

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
9	No-fire power	W	N/A	1	≤0,1% of the units function with a confidence level of 95% @ 5 min, at specified conditions.	
10	Bridge wire resistance	Ω	TBPM	TBPM	@10 mA, ≤60 s, number of applications TBPM	

4.11.2.3 High-voltage initiators

Properties of high-voltage initiators shall be in accordance with Table 5 and shall be quantified.

Under the conditions given in column E of Table 5, the properties given in column A, expressed in the unit specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 5 — Requirements for high-voltage initiator properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	All-fire voltage	V	TBPM	TBPM	≥99,9 % of the units function with a confidence level of 95%	
2	No-fire voltage	V	TBPM	TBPM	≤0,1 % of the units function with a confidence level of 95% @ 5 min, test temperature TBPM	
3	Operating voltage	V		>500		

4.11.2.4 Laser initiators

Properties of laser initiators shall be in accordance with Table 6 and shall be quantified.

Under the conditions given in column E of Table 6, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 6 — Requirements for laser initiator properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	All-fire power density	W/mm^2	TBPM	TBPM	≥99,9 % of the units function with a confidence level of 95 %	
2	No-fire power density	W/mm^2	TBPM	TBPU	≤ 0,1 % of the units function with a confidence level of 95 % @ 5 min, at specified conditions (wavelength TBPM)	Factor of safety for spurious lights (TBPU).
3	Pulse width	ms	N/A	TBPM		
4	Wavelength	nm	TBPM	TBPM		Depending on optical source: solid laser, laser diode.

4.11.2.5 Mechanical initiators

Properties of mechanical initiators shall be in accordance with Table 7 and shall be quantified.

Under the conditions given in column E of Table 7, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 7 — Requirements for mechanical initiator properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	All-fire energy	J	TBPM	TBPM	≥99,9 % of the units function with a confidence level of 95 %	
2	No-fire energy	J	≤0,1 × min. all-fire energy	TBPM	≤0,1 % of the units function with a confidence level of 95 %	
3	Test energy	J	N/A	TBPM		

4.11.2.6 Packaged charges

Properties of packaged charges shall be in accordance with Table 8 and shall be quantified, except for structural integrity and those of Table 3.

Under the conditions given in column E of Table 8, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 8 — Requirements for packaged charge properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Structural integrity		N/A	N/A	Handling and transport loads	
2	Detonation? Yes/No		TBPM	N/A	Intended operational mode	
3	Deflagration? Yes/No		TBPM	N/A	Intended operational mode	

4.11.3 Integral initiator connectors

4.11.3.1 General

a) The configuration of the connector shall be used only for initiators.

NOTE This is the integral (upper) part of the initiator.

b) The interface shall allow for sealing.

4.11.3.2 Electrical initiator connector

a) The connector thread or closing mechanism shall be self-locking.

b) The connection shall have electrical continuity with a resistance <10 mΩ.

c) The connector shall be able to undergo 50 mating/de-mating cycles without degradation.

d) The connection shall be able to undergo specified shocks without degradation.

4.11.3.3 Laser initiator connector

a) The initiator shall incorporate an interface to match the interfaces on the fibre-optic connector and the adaptor used to join the two items.

b) The connector interface shall not be used for any purpose other than explosive devices.

c) The connector thread or closing mechanism shall be self-locking.

d) The connection shall have electrical continuity with a resistance <10 mΩ.

e) The connector shall be able to undergo 50 mating/de-mating cycles while meeting its requirements.

4.11.4 Transfer devices

4.11.4.1 General

Properties of transfer devices shall be in accordance with Table 9 and shall be quantified.

Under the conditions given in column E of Table 9, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 9 — General requirements for transfer device properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Critical diameter	mm	N/A	TBPM		Information about explosive to be provided.
2	Temperatures:					
a)	Auto-ignition	°C	N/A	TBPM		
b)	Non-operating	°C	TBPM	TBPM		
c)	Operating	°C	TBPM	TBPM	Duration TBPM	
d)	Storage	°C	TBPM	TBPM	Duration TBPM	
e)	Transport	°C	TBPM	TBPM	Duration TBPM	
3	Probability of ignition of a reference charge			99,8 %	95 % confidence	
4	No. of mating/de-mating cycles		TPBM	TBPU	With/without change of seals	
5	Life time	Year	N/A	TBPU	For transport, storage and operation	

4.11.4.2 Transfer line assemblies

Properties of transfer line assemblies shall be in accordance with Table 10 and shall be quantified.

Under the conditions given in column E of Table 10, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 10 — Requirements for transfer line assembly properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Propagation velocity	m/s	TBPM	TBPM		
2	Deflagrating lines					
a)	Pressure	MPa	TBPM	TBPM		
b)	Heat	J	TBPM	TBPM		
3	Detonating lines					
a)	Shock transmission capability	GPa	TBPM	TBPM	Standard material	
b)	Flyer characteristics	mm	TBPM	TBPM	Flyer thickness, diameter, material, and jitter	
c)	Flyer velocity	m/s	TBPM	TBPM	Best estimate	
d)	Ignition gap	mm	TBPM	TBPM	By initiator type: TBPM	
4	End-to-end transmission gap	mm	TBPM	TBPM		
5	Electrical continuity	mΩ	TBPM	N/A	From end to end	
6	Leak rate (together with interfaces)	scc He/s	10^{-6}	N/A	@ Δp= 0,1 MPa before firing	
7	Leak-tightness (together with interfaces)	scc He/s	10^{-3}	N/A	@ Δp= 0,1 MPa after firing (ends implemented in the specified interface) + no debris	
8	Organic contamination of surfaces	mg/m^2	2	N/A	TBPU	
9	Radius of curvature	m	N/A	TBPM	Bending	
10	No. of times can bend		TBPM	TBPU	Bending	
11	Twist angle	rad/m	TBPM	N/A		
12	Tension	daN	TBPM	N/A		
13	Overall mass	g/m	TBPM	N/A	Linear mass of flexible part (g/m) + ends (g)	
14	Explosive mass	g/m	TBPM	N/A	Linear mass of flexible part (g/m) + ends (g)	

4.11.4.3 Through-bulkhead transfer devices

Properties of through-bulkhead transfer devices shall be in accordance with Table 11 and shall be quantified.

Under the conditions given in column E of Table 11, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 11 — Requirements for through-bulkhead transfer device properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Output					
a)	Pressure	MPa	TBPM	TBPM	In TBPM cm^3 at 20 °C	
b)	Energy	J	TBPM	TBPM	TBPM	
c)	Leak rate	scc He/s	10^{-6}	N/A	@ Δp= 0,1 MPa before firing	
2	Barrier tightness leak rate	scc He/s	10^{-5}	N/A	@ Δp= 0,1 MPa before firing	
3	Barrier tightness leak rate	scc He/s	10^{-3}	N/A	@ Δp= 0,1 MPa after firing	
4	Structural integrity	MPa	TBPM	TBPM		Barrier resistance after firing.

4.11.4.4 Shaped charges

Properties of shaped charges shall be in accordance with Table 12 and shall be quantified.

Under the conditions given in column E of Table 12, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 12 — Requirements for shaped charge properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Cutting capabilities					
a)	Structure thickness	mm	TBPM	N/A	Associated with material properties	
b)	Structure loads	MPa	TBPM	TBPM		
c)	Cutting delay	ms	TBPM	TBPM		
2	Debris/contamination/ induced					
3	Temperatures					
a)	Auto-ignition	°C				
b)	Survival non-operating	°C	TBPM	TBPM		
c)	Operational operating	°C	TBPM	TBPM		
d)	Storage	°C	TBPM	TBPM		

Table 12 *(continued)*

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
e)	Transport	°C	TBPM	TBPM		
4	Lifetime	Year	TBPM	N/A	During transport, storage and mission	

4.11.4.5 Expanding tube devices

Properties of expanding tube devices shall be in accordance with Table 13 and shall be quantified. These devices include separation systems based on detonation (shock and deformation) and inflation (pressure-generated) a combination of these.

Under the conditions given in column E of Table 13, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 13 — Requirements for expanding tube device properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Cutting capabilities					
a)	Structure thicknesses, position of the cutting area	TBPM	TBPM	TBPM	Associated with material properties (e.g. ductility, elongation, strain rate)	
b)	Cut structure loads during cutting	kN	TBPU	TBPU	Associated with material properties (e.g. ductility, elongation, strain rate, plasticity)	
c)	Type of impulse	N s	TBPM	TBPU	Radial or axial	
2	Explosives: quantity and type	g	TBPM	TBPM	Associated with tube materials properties	
3	Redundancy				TBPM	
4	Expanding tube unsupported length	m	TBPM	N/A	Number and size of windows for the expanding tube assembly	
5	Cutting conditions					
a)	Response time	ms	TBPM	TBPM	Between first input and completion of cutting	
b)	Generated shock	g/ms	TBPM	N/A	Time history and TBPU sampling rate. Test configuration TBPU	
6	Device leak rate	scc He/s	10^{-6}	N/A	@ Δp= 0,1 MPa before firing	
7	Device leak rate	scc He/s	10^{-3}	N/A	@ Δp= 0,1 MPa after firing	
8	Particle generation		TBPU	N/A	Test method TBPU	
9	Temperatures					
a)	Auto-ignition	°C	N/A	TBPM		
b)	Non-operating	°C	TBPM	TBPM		

Table 13 *(continued)*

	A	B	C	D	E	F
	Property	Unit	Max. value	Min. value	Condition	Other
c)	Operational	°C	TBPM	TBPM		
d)	Storage	°C	TBPM	TBPM		
e)	Transport	°C	TBPM	TBPM		
10	Lifetime	Year	TBPM	N/A		

4.11.4.6 Distribution boxes

Properties of distribution boxes shall be in accordance with Table 14 and shall be quantified.

Under the conditions given in column E of Table 14, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 14 — Requirements for distribution box properties

	A	B	C	D	E	F
	Property	Unit	Max. value	Min. value	Condition	Other
1	Input/output					
a)	Number		TBPM	TBPM		
b)	Interface type		TBPM	TBPM	Design TBPM	
2	Explosives					
a)	Quantity and type	g	TBPM	TBPM		
b)	Response		TBPM	TBPM	e.g. detonating, deflagrating	
3	Redundancy				TBPM	
4	Response time	ms	TBPM	TBPM	Between first input and all outputs	
a)	Generated shock	g/ms	TBPM	N/A	Time history and TBPU sampling rate. Test configuration TBPU	
b)	Device leak rate	scc He/s	10^{-6}	N/A	@ Δp = 0,1 MPa before firing	
c)	Device leak rate	scc He/s	10^{-3}	N/A	@ Δp = 0,1 MPa after firing	
5	Temperatures					
a)	Auto-ignition	°C	TBPM	TBPM		
b)	Non-operating	°C	TBPM	TBPM		
c)	Operating	°C	TBPM	TBPM		
d)	Storage	°C	TBPM	TBPM		
e)	Transport	°C	TBPM	TBPM		
6	Lifetime	Year	TBPM	N/A	During transport, storage and mission	

4.11.4.7 Explosive delays

Properties of explosive delays shall be in accordance with Table 15 and shall be quantified.

Under the conditions given in column E of Table 15, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 15 — Requirements for explosive delay properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Delay type		TBPM	TBPM		With or without gas generation.
2	Delay time	ms	TBPM	TBPM	Mean value, standard deviation at temperatures	
3	Temperature sensitivity	%/°C	TBPM	TBPM	Temperature range to be provided	
4	Initiation		TBPM	TBPM	To be provided: mechanical (e.g. percussion), electrical, thermal, detonation	
5	Output		TBPM	TBPM	To be provided: pressure versus time, calorific energy, detonation	
6	Leak rate	scc He/s	10^{-6}	TBPM	@ Δp= 0,1 MPa before firing	
7	Leak rate	scc He/s	TBPM	N/A	@ Δp= 0,1 MPa after firing	
8	Temperatures:					
a)	Auto-ignition	°C	TBPM	TBPM		
b)	Non-operating	°C	TBPM	TBPM		
c)	Operating	°C	TBPM	TBPM		
d)	Storage	°C	TBPM	TBPM		
e)	Transport	°C	TBPM	TBPM		
9	Lifetime	Year	TBPM	N/A	During transport, storage and mission	

4.11.5 Safe and arm devices containing explosive

Subclause 4.10.11 applies. Only secondary explosives with less or equal sensitivity to hexogen shall be used.

4.11.6 Gas generators

Properties of gas generators shall be in accordance with Table 16 and shall be quantified.

Under the conditions given in column E of Table 16, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 16 — Common requirements for gas generator properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Bonding resistance	mΩ	10	N/A	To next level assembly	
2	Leak rate	scc He/s	10^{-6}	N/A	@ Δp= 0,1 MPa before and after firing at initiator interface	
3	Structural integrity	MPa		TBPM	Applies on MEOP according to 4.2.5.2	
4	Temperatures					
a)	Auto-ignition	°C	N/A	TBPM		
b)	Non-operating	°C	TBPM	TBPM		
c)	Operating	°C	TBPM	TBPM	Duration TBPM	
d)	Storage	°C	TBPM	TBPM	Duration TBPM	
e)	Transport	°C	TBPM	TBPM	Duration TBPM	
5	Generated					
a)	pressure	MPa	TBPM	TBPM		Only the known and relevant output parameters shall be provided.
b)	heat	J	TBPM	TBPM		Only the known and relevant output parameters shall be provided.
c)	no. of mating/de-mating cycles		TBPM	TBPU	With/without change of seals	
d)	shock	g/ms	TBPM	N/A	Time history and TBPU sampling rate. Test configuration TBPU.	
6	lifetime	Year	TBPM	N/A	For transport, storage and operation	

4.12 Explosively actuated devices

4.12.1 General

Properties of explosively actuated devices which incorporate initiation and explosive charges shall be in accordance with Table 17 and 4.11 and shall be quantified.

No released part shall cause damage.

Under the conditions given in column E of Table 17, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 17 — General requirements for explosively actuated device properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Leak rate	scc He/s	TBPU	N/A	@ Δp= 0,1 MPa before firing	
2	Leak rate for spacecraft	Pa/l	2,5.10-2		@10^{-2} Pa during firing	
3	Leak rate	scc He/s	TBPU	N/A	@ Δp= 0,1 MPa after firing	
4	Temperatures					
a)	Non-operating	°C	TBPM	TBPM		
b)	Operating	°C	TBPM	TBPM	Duration TBPM	
c)	Storage	°C	TBPM	TBPM	Duration TBPM	
d)	Transport	°C	TBPM	TBPM	Duration TBPM	
5	Functional delay	ms	TBPM	TBPM		
6	No. of assemblies/ disassemblies		TBPM TBPM	TBPU TBPU	To the maximum load of the device attachments	
7	Generated shock	g/ms	TBPM	N/A	Time history and TBPU sampling rate. Test configuration TBPU.	
8	Lifetime	Year	TBPM	N/A	During transport, storage and mission	

4.12.2 Separation nuts and separation bolts

Properties of separation nuts and bolts shall be in accordance with Table 18 and shall be quantified.

a) Resettable separation nuts shall include a means of verifying that the nut is properly reset before and after its mating bolt or stud installation and torqueing.

b) The pre-load shall be specified and shall exceed the maximum expected amplitude of the dynamic tension in the bolt and effects of thermal variations.

Under the conditions given in column E of Table 18, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 18 — Requirements for separation nut and bolt properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Screw pre-load tension				Screw properties to be provided	
a)	By pure tension	kN	TBPM	TBPM		
b)	By torque	kN	TBPM	TBPM		
2	Load capabilities				Worst-case temperatures	
a)	Axial load	kN	TBPM	TBPM		
b)	Transverse load	kN	TBPM	TBPM		
c)	Bending moment	Nm	TBPM	TBPM		
d)	Torsion	Nm	TBPM	TBPM		
3	Stiffness				Worst-case temperatures	
a)	Axial	N/m	TBPM	TBPM		

Table 18 *(continued)*

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
b)	Transverse	N/m	TBPM	TBPM		
c)	Bending moment	Nm/rad	TBPM	TBPM		
d)	Torsion	Nm/rad		TBPM		

4.12.3 Pullers

Properties of pullers shall be in accordance with Table 19 and shall be quantified.

a) The puller shall be capable of withdrawing the pin under maximum shear and bending loads.

b) The retractable pin shall not rebound.

Under the conditions given in column E of Table 19, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 19 — Requirements for puller properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Pin pre-loads			N/A		
a)	Axial	N	TBPM	N/A		
b)	Shear	N	TBPM	N/A		
c)	Bending moment	Nm	TBPM	N/A		
2	Traction force	N	TBPM	TBPM	Minimum at end of stroke	
3	Pulling stroke	mm	TBPM	TBPM		

4.12.4 Pushers

Properties of pushers shall be in accordance with Table 20 and shall be quantified.

Pushers shall be able to withstand the expected loads (e.g. compression, shear and bending moment) during operation.

Under the conditions given in column E of Table 20, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 20 — Requirements for pusher properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Rod axial load	kN	TBPM	N/A		
2	Push force	N	TBPM	TBPM	Minimum at end of stroke	
3	Pushing stroke	mm	TBPM	TBPM		

4.12.5 Cutters

Properties of cutters shall be in accordance with Table 21 and shall be quantified.

Under the conditions given in column E of Table 21, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 21 — Requirements for cutter properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Cutting capabilities				At worst-case temperatures	
a)	Dimensions	mm	TBPM	N/A	Associated with material properties	
b)	Ultimate strength	MPa	TBPM	TBPM		
c)	Tension load	kN	N/A	TBPM		
2	Mass of generated particles	mg	TBPM	N/A		Total mass associated with load and load carrier properties.
3	Dimensions of generated particles	mm	TBPM	TBPM		Range of size associated with load and load carrier properties.

4.12.6 Valves

Properties of valves shall be in accordance with Table 22 and shall be quantified.

a) After firing, the valve piston shall remain in its actuated position.

b) The type of valve, NO or NC, and the flow direction shall be marked on the device.

Under the conditions given in column E of Table 22, the properties given in column A, expressed in the units specified in column B, shall be between the values of column C (maximum) and those of column D (minimum).

Table 22 — Requirements for valve properties

	A	B	C	D	E	F
	Property	**Unit**	**Max. value**	**Min. value**	**Condition**	**Other**
1	Valve capabilities				Associated with fluid properties	
a)	MEOP	MPa	TBPM	TBPM	In fluid circuit	
b)	Pressure drop	MPa	TBPM	TBPM	In fluid circuit	
c)	Valve passage diameter	mm	TBPM		In fluid circuit, nominal	
d)	Fluid circuit leak rate	scc He/s	10^{-6}	TBPM	@ Δp= 0,1 MPa before and after firing	Before and after functioning.
e)	Internal leak rate (blow by)	scc He/s	TBPU	TBPM	TBPM	During functioning.
2	Mass of generated particles	mg	TBPM	N/A	In fluid circuit	
3	Dimensions of generated particles	mm	TBPM	TBPM	In fluid circuit	

4.13 Items external to the flight equipment

4.13.1 GSE

Ground support equipment is used to support assembly, integration, test, handling, transport and launch campaign activities.

a) GSE validation:

   1) The GSE shall be validated based on expected environmental conditions and operational constraints.

   2) Hazards to personnel, flight hardware, facilities and environments shall be processed.

b) Only approved equipment and procedures shall be used.

c) GSE shall provide support and protection within specified limits, including ESD and EMI.

d) Test equipment shall be energy-limited (e.g. electrical, optical) in accordance with 4.8.4.

e) The status indication of the explosive system shall be provided.

f) Changes in the status indications shall be provided.

g) Status and status changes shall be recorded.

4.13.2 Test equipment

a) Only approved equipment and procedures shall be used.

b) Uncontrolled modifications to equipment or procedures shall be prohibited.

4.13.3 Launch site

a) The launch site shall provide specified transport, handling and storage facilities for explosive components and systems.

b) The status of explosive safety barriers shall be monitored when the space vehicle (e.g. launcher, satellite, spacecraft) induces a catastrophic risk.

c) Provisions shall be made to make visible the status of explosive safety barriers.

d) Any indicators used to show the status of the explosive devices and the barriers shall be clear and unambiguous.

e) Periods of sensitivity to external environment (e.g. EMI) shall be notified to the authorities.

f) Provisions shall be made for access to safe and arm devices for manual disarming.

4.14 Verification

4.14.1 General

Following exposure to the conditions specified in 4.14.3, explosive devices and systems shall meet the performance requirements specified in the appropriate subclauses of 4.10 and 4.12 when measured according to 4.14.3.

4.14.2 Inspection

a) Inspection stages and procedures shall be compliant with the product assurance plan agreed with the customer.

b) Non-destructive inspection is required to demonstrate specified assembly and condition of every explosive component (e.g. X-Ray or N-Ray).

c) Resolution shall be better than the dimension of the smallest feature to be checked (e.g. micro-cracks).

d) It shall be demonstrated by inspection of all fired components that the internal dimensions, surfaces and material properties have not been degraded beyond specified limits.

NOTE Erosion, corrosion and burning due to the functioning can cause failure or leakage.

4.14.3 Tests

4.14.3.1 Test specification

The test specification describes in detail the test requirements applicable to any major test activity included in the AIV plan. In particular, it defines the purpose of the test, test approach, test article and set-up, the required GSE, test equipment and instrumentation, test conditions, test sequence, test facility, pass/fail criteria, required documentation, participants and test schedule.

The document is used as an input to the test procedures, as a requirements document for booking the environmental test facility and to provide evidence to the customer on certain details of the test activity in advance of the activity itself.

a) The test specification shall be detailed and agreed with the customer in advance.

b) The test conditions for explosive components and systems shall be derived from the operational conditions and constraints (e.g. ground, flight, in orbit).

c) Qualification and lot acceptance tests shall be in accordance with 4.14.4.

d) Acceptance tests shall be done at identical limit conditions and levels, whatever the application, to ensure valid reference to previous results and to reduce the numbers of tested items.

4.14.3.2 Test procedures

The test procedure gives directions for conducting a test activity in terms of description, resources, constraints and step-by-step procedure. The document is used and filled-in as appropriate during the execution and becomes the as-run procedure.

a) The test specification shall be detailed and agreed with the customer in advance.

b) The test procedure shall be written to comply with the test specification.

4.14.3.3 Test report

The test report describes the execution of a particular test and the results obtained. It contains the as-run procedure with supporting data, the anomalies and the evaluation of the test data in comparison with the requirements. Its principal use is to provide the customer with the evidence of the performed test activity in verification close-out of the relevant requirements.

Test results shall

— describe the execution and results of the test activity;

— be detailed according to the content and format agreed with the customer in advance.

4.14.3.4 Essential confirmation

For every test, connection to the correct initiator shall be checked and recorded.

4.14.3.5 Routing tests

a) It shall be demonstrated that the correct stimulus arrives at the correct initiator and no other.

b) Records shall be kept of the routing test.

4.14.3.6 End-to-end tests

a) End-to-end test shall be performed to ensure system capability within the reliability and safety limits agreed with the end user, during which

   1) a verification that the correct ignition energy levels are present at each pyrotechnic device shall be performed prior to final connection of the firing circuit to the device,

   2) a simulator of the pyrotechnic device characteristics shall be used during these tests,

   3) circuit continuity and stray energy checks shall be made prior to connection of any firing circuit to any pyrotechnic device, and

   4) circuit continuity checks shall be repeated whenever that connection is opened and prior to re-connection.

b) Only planned and approved activities shall be performed, according to approved procedures.

c) Firing tests shall not be performed until a successful rehearsal has been completed.

4.14.3.7 Safety tests

Safety tests shall be performed on unpacked articles in accordance with Table 23.

Table 23 — Safety tests

Reference test	Test method	Recommended sequence	
		L	S/C
Slow cook-off	*UNO Manual of tests and criteria*, test 7 (h)	R	N/A
External fire	*UNO Manual of tests and criteria*, test 7 (g)	R	N/A
Handling drop test (e.g. 2 m height)	TBPU	R	O
12 m drop test	*UNO Manual of tests and criteria*, test 4 (b)	R	N/A
Mechanical shock	TBPU	O	N/A
Radiated field	Mil-std 1576	R	R
Lightning	TBPU: pyro device level shall be calculated from launcher level (e.g. peak current 5 000 A, average rise time 4 µs, fall time 100 µs)	O	N/A
L: launcher S/C: spacecraft R: required O: optional N/A: not applicable			

4.14.3.8 Lifetime demonstration

a) Lifetime tests or analysis shall be done to establish changes over time in performance and susceptibility.

b) If accelerated ageing is used, it shall be justified.

4.14.3.9 Reliability tests

a) For any component, performances shall be declared in terms of reliability, confidence level, test and analysis methods.

b) The method or methods given for the corresponding component in Table 24 shall be used.

Table 24 — Reliability methods

Component	Method
Initiator	Bruceton or Neyer
Cutter/release nut/valve/pusher/puller	Severe method
TBI	Severe method
Shaped charge	Probit or severe method
Expanding tube	Probit or severe method
Transmission lines	Bruceton or Neyer or severe method

4.14.4 Qualification and lot acceptance

4.14.4.1 General

a) Qualification and acceptance of explosive components and systems shall be in accordance with quality assurance requirements TBPU.

b) For qualification, each device shall meet the requirements corresponding to that device specified in 4.11 or 4.12 after exposure to the complete sequence of conditions specified in Table 25.

c) For lot acceptance, each device shall meet the requirements corresponding to that device specified in 4.11 or 4.12 after exposure to the selected conditions specified in Table 26

d) For lifetime, each device shall the requirements corresponding to that device specified in 4.11 or 4.12 after exposure to the complete sequence of conditions specified in Table 25.

e) Dynamic leak measurement shall be made under vacuum.

4.14.4.2 Qualification tests

Qualification tests shall be performed in accordance with Table 25.

NOTE Typical values are given in Annex B.

Table 25 — Qualification tests

Qualification test	Spacecraft component	Launcher component
No-fire stimulus	R	R
Physical properties (measurement)	R	R
Secondary characteristics measurement	R	R
Functional and performance (measurement)	N/A	N/A

R: required

O: optional

N/A: not applicable

NOTE 1 Only possible at the end of the qualification sequence.

NOTE 2 See 4.14.4.1 e).

Table 25 *(continued)*

Qualification test	Spacecraft component	Launcher component
No-damage drop	O	R
Salt fog	N/A	R
Rain	N/A	R
Humidity	O	R
Leakage test	O	O
Generated shock	O	O
Pressure	N/A	N/A
Acceleration	O	R
Sinusoidal vibration	R	R
Random vibration	R	R
Acoustic	N/A	R
Shock	R	R
Corona and arcing	N/A	N/A
Thermal vacuum	O	O
Thermal cycling	R	R
EMC/ESD (for initiator only)	R	R
Life	O	
Microgravity	N/A	N/A
Audible noise	N/A	N/A
Radiation	O	N/A
Functional and performance (measurement)	R	R
Destructive physical analysis	R	R

R: required

O: optional

N/A: not applicable

NOTE 1 Only possible at the end of the qualification sequence.

NOTE 2 See 4.14.4.1 e).

4.14.4.3 Acceptance tests

a) Lot acceptance tests shall be performed.

b) Acceptance tests shall be in accordance with Table 26.

c) Lot acceptance tests results shall confirm that the hardware replicates the qualified product.

Table 26 — Acceptance tests

Acceptance test	Spacecraft component	Launcher component
Physical properties	R	R
Secondary characteristics	R	R
Functional and performance	N/A	N/A
Leak	R	R
Pressure	N/A	N/A
Random vibration	O	O
Acoustic	N/A	N/A
Generated shock	N/A	N/A
Thermal vacuum	O	N/A
Thermal cycling	O	N/A
Burn-in	N/A	N/A
Microgravity	N/A	N/A
Audible noise	N/A	N/A
Functional and performance	O	O
Destructive physical analysis	O	O
R: required O: optional N/A: not applicable NOTE 1 Only possible at the end of the acceptance sequence. NOTE 2 See 4.14.4.1 e).		

4.15 Transport, facilities, handling and storage

4.15.1 General

Specified transport, handling and facilities for explosive subsystems and devices shall be provided.

4.15.2 Transport

a) Devices and packaging containing explosives shall comply with ST/SG/AC.10/1. Containers shall comply with the applicable national and international transportation regulations.

b) At the beginning of the development programme the transport classification level requirement shall be agreed to by the customer and suppliers and justified by technical data.

c) The containers shall protect the component from the mission.

NOTE 1 It is good practice to pack explosive components individually to prevent changes in humidity and electrostatic charge.

d) Containers shall not be exposed to environments exceeding those specified.

NOTE 2 It is good practice to use thermal and shock sensors.

e) A permanent identification label shall be marked before delivery in a permanent way on each deliverable.

f) Containers shall be in accordance with the applicable national and international transportation regulations and shall be marked with the following information:

   1) equipment name and part number;

   2) contents and quantity;

   3) mass (gross and net explosive weight) in kilograms;

   4) contract number;

   5) supplier name and address;

   6) explosive label with Hazard and compatibility classifications;

   7) the following label: “Open only in clean-room area by qualified operators”, if necessary.

g) Containers shall indicate the required orientation.

4.15.3 Facilities

a) No explosive component shall be stored with incompatible equipment or materials.

b) The nature of, and precautions required for, all explosive components and systems shall be communicated to facility providers and authorities.

c) All explosive devices shall be stored in places with controlled temperature and humidity and in secure storage areas, except when required for controlled spacecraft activities.

d) Records of all environmental conditions (e.g. thermal, humidity) in locations where explosive components or systems are stored or handled shall be maintained and be available for review.

e) The location of every live or fired explosive component or subsystem shall be known and identifiable at any time.

4.15.4 Handling

a) All handling shall be done by qualified personnel according to specified procedures.

   NOTE Handling includes testing, measuring, and installing.

b) Personnel and equipment shall be grounded to a common ground.

c) Only approved tools, aids and test equipment shall be used for explosive devices.

d) Consistent, coherent and complete records shall be maintained of components or systems which have a direct effect upon the system, including test activities and measurements during any break-in activities.

e) Restoration of the original accepted condition shall be required.

f) The correctness of all connections shall be confirmed and a record of all connections maintained.

g) Site safety regulations, provisions and procedures shall be checked for adequacy for explosive activities.

4.16 In-service

4.16.1 Information feedback

a) Checks shall be made to ensure consistency of information between different equipment at different stages in the launch preparation.

b) Results shall be recorded.

c) Information shall be provided of hardware and software provisions for the monitoring and command of explosive functions, and shall show changes from one stage to the next.

d) RF links, wiring, connectors and pin functions shall be specified for checking of the source and destination.

e) Diagrams or photographs of consoles and installations shall be provided.

f) Confirmation shall be provided that no unwanted responses or drifts have occurred.

4.16.2 Launch site procedures

a) Only planned and approved activities which follow approved procedures shall be undertaken.

b) These shall include contingency actions.

c) Rehearsals shall be performed.

4.16.3 Monitoring

Confirmation of operation shall be made available immediately.

4.17 Product assurance

4.17.1 General

a) The explosive functions on a vehicle shall be treated together as a single subsystem.

b) All explosive devices shall be treated as critical items.

4.17.2 Dependability

a) The explosive system shall comply with all dependability requirements of Clauses 6, 7, 8 and 9 to meet the reliability and confidence requirements.

b) Age-sensitive parts and materials shall be identified.

4.17.3 Safety

a) Properties of the subsystem and all activities shall comply with the safety requirements to meet the reliability and confidence requirements.

b) Immediately before every electrical or optical connection and disconnection, it shall be confirmed that no conductor is live and that no power can flow or be interrupted across the interfaces.

c) Immediately before every connection and disconnection, it shall be confirmed that the operator and parts are grounded to a common ground.

4.18 Deliverables

Documentation in accordance with Table 27, coordinated and tailored with the customer contract agreement, shall be delivered.

NOTE Additional specific documents can be established at the customer's request.

Table 27 — Documentation to be delivered

Document	Response to RFP	KO	PDR & CDR	MRR & TRR	DRB	A/N	Reference standard
DRD for management							
Management and development plan	X		X				
Risk assessment report Risk management plan						X	
Progress reports						X	
Audit reports						X	
Inspection reports						X	
Non-conformance reports (minor)						X	
Non-conformance reports (major)					X		
DRD for product assurance							
Verification matrix	Xd	X	X				
Declared materials list Declared mechanical part list Declared processes list			Xd	X			
Qualification status list				X			
FMECA			X	X			
Request for deviation				X			
Request for waiver				X			
DRD for engineering and verification							
Functional and technical specifications	x	x	x	x	x		
Mechanical, thermal, electrical ICD's			X	X	X		
Design justification file	X	X	X	X	X		
Verification matrix	X	X	X	X	X		
Verification control document (design, reliability, qualification plan)	X	X	X	X	X		
Verification report (design, reliability, qualification justification reports)			X	X	X		
User manual			X	X	X		
Manufacturing and test documents							

RFP: to be included in the request for proposal documentation

KO: to be included in the kick-off meeting documentation

DKP: to be included in the design key point documentation

MRR: to be included in the manufacturing readiness review data package

TRR: to be included in the test readiness review data package

DRB: to be included in the delivery review board data package (including Qualification data package)

A/N: as necessary or as required

Xd: draft document.

Table 27 *(continued)*

Document	Response to RFP	KO	PDR & CDR	MRR & TRR	DRB	A/N	Reference standard
Test procedure			Xd	X			
Production documentation tree	Xd		X	X			
Acceptance test plan			Xd	X			
Configuration item data list				X	X		
As-built configuration list				X	X		
Test reports					X		
Logbook					X		
End item data package (EIDP)					X		
Certificate of conformance					X		

RFP: to be included in the request for proposal documentation

KO: to be included in the kick-off meeting documentation

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TRR: to be included in the test readiness review data package

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A/N: as necessary or as required

Xd: draft document.

Annex A
(normative)

Loads and factors of safety relationship

QL, AL, DLL, DYL and DUL, for the rest of the design of spacecraft, expendable launch vehicles, pressurized hardware, shall be calculated from the LL in accordance with Figure A.1 and Table A.1.

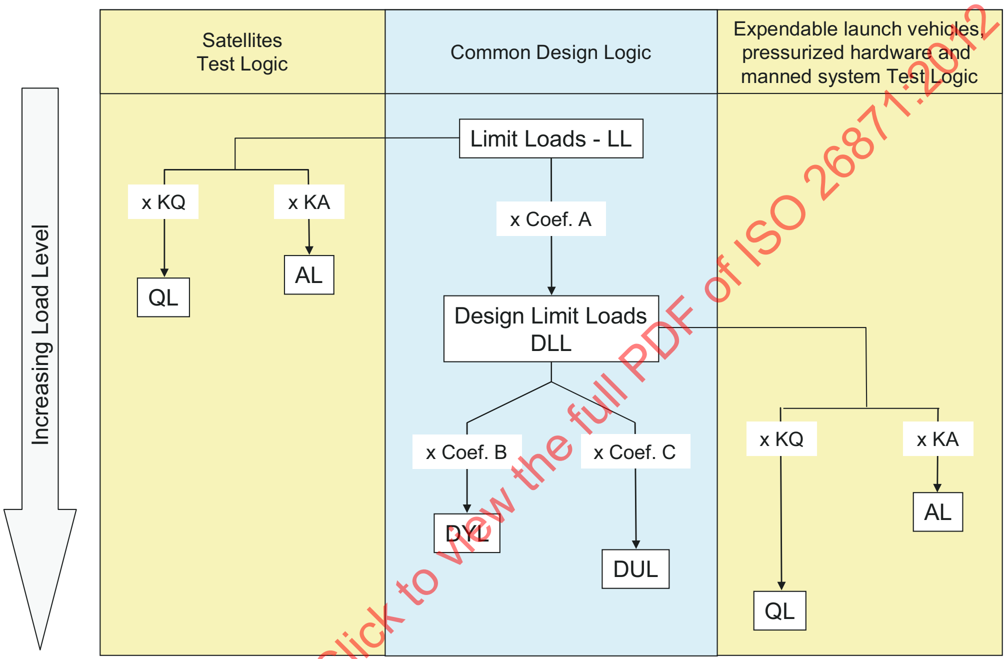

Figure A.1 — Logic for factors of safety applications

Table A.1 — Relationship among structural factors of safety, design factors and additional factors

Coefficient	Satellite	Launch vehicles and pressurized hardware
Coef. A or Design factor	KQ × KP × KM	KP × KM
Coef. B	FOSY × KLD	FOSY × KMP × KLD
Coef. C	FOSU × KLD	FOSU × KMP × KLD
NOTE The yield factor (FOSY) ensures a low probability of yielding during loading at DLL level.		

