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Space systems — Explosive systems and devices

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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.

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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.

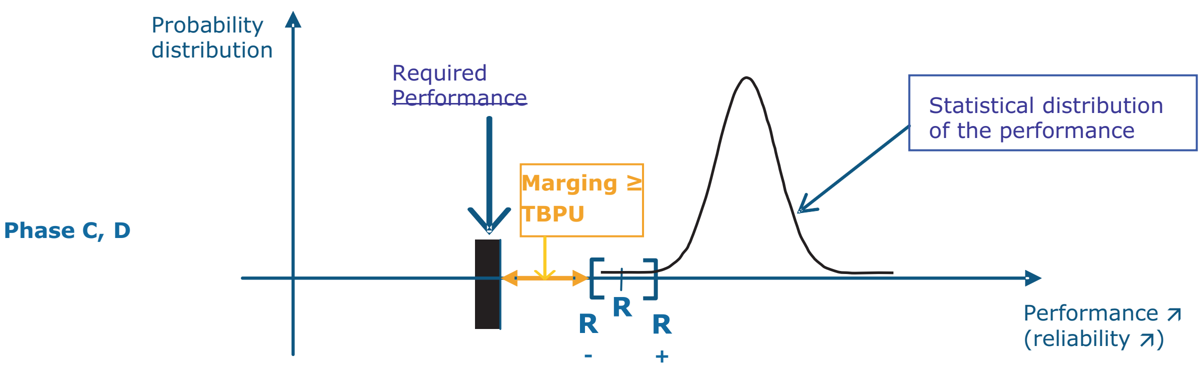

Figure 1 — Margin and reliability relationship