International Standard

ISO 17546

Second edition
2024-02

Space systems — Lithium ion battery for space vehicles — Design and verification requirements

Systèmes spatiaux — Batteries à ions lithium pour véhicules spatiaux — Exigences de vérification et de conception

Reference number
ISO 17546:2024(en)

Contents

Page

Foreword

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

This second edition cancels and replaces the first edition (ISO 17546:2016), which has been technically revised.

The main changes are as follows:

— updated 5.4 and Annex F.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document has been developed for the purpose of establishing the standard to obtain sustainable development and to prevent incidents of lithium-ion battery for space vehicles.

Lithium-ion batteries belong to the category of rechargeable batteries which are based on electrochemical systems. The batteries generally consist of lithium metal oxide for positive electrodes and carbon for negative electrodes. Lithium element exists in an ionic or quasi-atomic form within a lattice structure of each electrode material.

For battery developers and spacecraft system architects, this document leads the way to assessing the whole life cycle from electrolyte filling to the end of the mission in space and to clarify what is considered in the battery design phase and the processes to reach the appropriate verification.

It is important to prevent lithium-ion batteries (LIB) for space vehicles from having performance defects in orbit and incidents through the life cycle. The total life cycle of lithium-ion batteries consists of material manufacturing to deorbit after mission completion as shown in Figure 1.

Since lithium-ion batteries start to deteriorate just after cell activation during cell manufacturing of stage 1, the service life starts at that point. And it continues through cell testing, cell transportation of stage 2, battery manufacturing/testing of stage 3, battery transportation of stage 4. Eventually, the service life is regarded defined as the duration until deorbit which corresponds to the end of life of stage 9.

Clauses in this document address “performance”, “safety” and “logistics” according to each stage of the life cycle, and each requirement belongs to the shelf life of lithium-ion batteries. The shelf life means from cell activation to launch and does not exceed the shelf life limit. A battery whose shelf life exceeds the shelf life limit is judged to be non-conforming even if it is not used because the battery capacity is insufficient for the mission completion. In other words, the shell life is the period until launch while maintaining the battery capacity to complete required missions.

— Performance

Since LIB starts to degrade from activation, it is necessary to consider meeting the power requirement through the mission life; that is, to be unaffected from handling conditions (temperature) and usage conditions in orbit (temperature, cycle, current or power and depth of discharge). Also, the risk in orbit can be mitigated based on the life estimation; and with care unexpected degradation can be avoided throughout the whole life cycle.

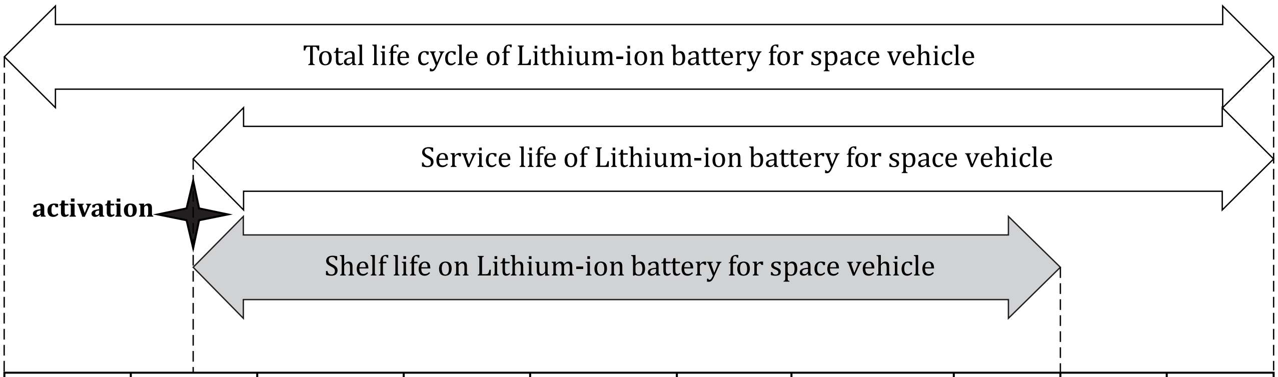
— Safety

A complex risk assessment process that is easy to understand is established. The method was agreed internationally at ISO/IEC and is a traditional method for space use. LIB keeps some amount of the SOC to avoid significant capacity degradation, so that the specific consideration and care for handling are required because of potential hazard source. It is well known that LIB has specific risks with higher voltage when compared to other power sources and no saturation characteristic for over-charge. The important thing is that the process, which can result in a hazardous situation, does not always immediately result in an incident. Because of these risks, LIB is considered hazardous at all times. The risk assessment becomes very important to cover a variety of environments during the handling or use and history of stress.

— Logistics

The most important aspect of assuring battery safety and space quality in transportation is to perform a life cycle assessment of performance and safety from a broad perspective.

Critical damage includes, for example, the temperature history (especially high uncontrolled temperature outdoors), shock/vibration, and electrical shorts. Also, to reflect the results of handling or usage, the measurement should be done. All the personnel with responsibilities for the development, design, and handling should survey and estimate the influence of their assessment spontaneously to improve the sustainable development of the space component.



Stage 0	Stage 1 Clause 5	Stage 2 Clause 5	Stage 3 Clause 6	Stage 4 Clause 6	Stage 5 Clause 7	Stage 6 Clause 7	Stage 7 Clause 8	Stage 8	Stage 9
Material Manufacture / Inspection	Cell Manufacture / Testing	Cell Transportation	Battery Manufacture / Testing	Battery Transportation	Space vehicle Integration / Testing	Space vehicle Transportation equipped battery	Launch site - Launch	Mission in orbit	End of life - Deorbit

Figure 1 — Definition of life cycle stages of lithium-ion battery for space vehicle

Space systems — Lithium ion battery for space vehicles — Design and verification requirements

1 Scope

This document specifies design and minimum verification requirements for lithium-ion batteries from the perspectives of performance, safety and logistics.

This document is applicable to battery assemblies for space vehicles and component cells of batteries, which are critical devices to be harmonized with standards and regulations for other industries. In addition, this document is applicable to component cells which are not designed for space vehicles but can be used in space.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 24113, *Space systems — Space debris mitigation requirements*

MIL-STD-1686, *ELECTROSTATIC DISCHARGE CONTROL PROGRAM FOR PROTECTION OF ELECTRICAL AND ELECTRONIC PARTS, ASSEMBLIES AND EQUIPMENT (EXCLUDING ELECTRICALLY INITIATED EXPLOSIVE DEVICES)*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
activation
process of making an assembled *cell* (3.4) functional, by introducing an electrolyte at the manufacturing facility during cell production, which is used to define the start of *battery* (3.3) shelf *life* (3.19)

Note 1 to entry: See References [4], [5], [6] and [11].

3.2
aging
permanent loss of capacity due to repeated cycling or passage of time from *activation* (3.1)

Note 1 to entry: See Reference [6].

3.3
battery
two or more *cells* (3.4) which are electrically connected together, fitted with devices necessary for use, for example, case, terminals, marking and *protective devices* (3.26)

Note 1 to entry: A single cell battery is considered a "cell"[9].

Note 2 to entry: A battery may also include some or more attachments, such as electrical bypass devices, charge control electronics, heaters, temperature sensors, thermal switches, and thermal control elements[4][5].

Note 3 to entry: Units that are commonly referred to as “battery packs”, “modules”, or “battery assemblies” having the primary function of providing a source of power to another piece of equipment are, for the purposes of this document, treated as batteries[9].

3.4
cell
single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across its two terminals

Note 1 to entry: See Reference [9].

3.5
COTS cell
cell (3.4) mass-produced for terrestrial use by third parties such as distributors

Note 1 to entry: COTS cells have various kinds of types, 26650, 21700,18650, 17670, 18500, 18350, 17500, 16340, 14500, 10440 of cylindrical shape identified by external dimensions, and rectangular shape in metallic container, and thin pouch type.

3.6
dangerous phenomenon
phenomenon where a *lithium-ion battery* (3.20) is damaged

EXAMPLE *fire* (3.10), bust/*explosion* (3.8), *leakage* (3.18) of *cell* (3.4) electrolyte, *venting* (3.34), burns from excessively high external temperatures, *rupture* (3.28) of battery case with exposure of internal components, and smokes

3.7
disassembly
vent (3.34) or *rupture* (3.28) where solid matter from any part of a *cell* (3.4) or *battery* (3.3) penetrates a wire mesh screen (annealed aluminium wire with a diameter of 0,25 mm and grid density of 6 wires per centimetre to 7 wires per centimetre) placed 25 cm away from the cell or battery

Note 1 to entry: See Reference [9].

3.8
explosion
condition that occurs when a *cell* (3.4) container or *battery* (3.3) case violently opens and major components are forcibly expelled and the cell or battery casing is torn or split

Note 1 to entry: See References [12] and [14].

3.9
external short circuit
direct connection between positive and negative terminals of a *cell* (3.4) or *battery* (3.3) that provides less than 0,1 Ω resistance path for current flow

Note 1 to entry: An external short circuit occurs when a direct connection between the positive and negative terminals is made where the connection resistance is sufficiently low enough to higher than rated current flow through the cell.

Note 2 to entry: See Reference [9].

3.10
fire
flames emitted from the test *cell* (3.4) or *battery* (3.3)

Note 1 to entry: See References [9] and [12].

3.11
out-gassing
evolution of gas from one or more of the electrodes in a *cell* (3.4)

Note 1 to entry: See Reference [6].

3.12
harm
physical injury or damage to the health of people or damage to property or the environment

3.13
hazard
potential source of *harm* (3.12)

Note 1 to entry: The term hazard is qualified in order to define its origin or the nature of the expected *harm* (3.12) (e.g. electric shock hazard, crushing hazard, cutting hazard, toxic hazard, *fire* (3.10) hazard, drowning hazard).

3.14
hermetic seal
permanent air-tight seal

Note 1 to entry: See Reference [10].

3.15
intercalation
process where lithium-ions are reversibly removed or inserted into a host material without causing significant structural change to that host

Note 1 to entry: See Reference [11].

3.16
intended use
use of a product, process or service in accordance with specifications, instructions and information provided by the supplier

Note 1 to entry: See Reference [12].

3.17
internal resistance
opposition to the flow of current within a *cell* (3.4) or a *battery* (3.3), that is, sum of electronic resistance and ionic resistance with the contribution to total effective resistance including inductive/capacitive properties

3.18
leakage
visible escape of electrolyte or other material from a *cell* (3.4) or *battery* (3.3) or the loss of material (except battery casing, handling devices or labels) from a cell or battery such that the loss of mass exceeds specific values

Note 1 to entry: Mass loss means a loss of mass that exceeds the values in Table 1.

Table 1 — Mass loss limit

mass M of cell	mass loss limit
$M < 1$ g	0,5 %
1 g $\leq M \leq$ 75 g	0,2 %
$M > 75$ g	0,1 %

Note 2 to entry: In order to quantify the mass loss, the following procedure is provided:

$$L_{mass} = \frac{M_1 - M_2}{M_1} \times 100$$

where M_1 is the mass before test; M_2 is the mass after test; and L_{mass} is lost mass (%).

When mass loss does not exceed the values in Table 1, it is considered as “no mass loss”[9].

3.19
life
duration of maintaining a required performance [e.g. 50 % of beginning of life (BOL) capacity], estimated in years (calendar life) or in the number of charge/discharge cycle

Note 1 to entry: See Reference [6].

3.20
lithium-ion battery
rechargeable electrochemical *cell* (3.4) or *battery* (3.3) in which the positive and negative electrodes are both *intercalation* (3.15) compounds (intercalated lithium exists in an ionic or quasi-atomic form with the lattice of the electrode material) constructed with no metallic lithium in either electrode

Note 1 to entry: See Reference [9].

3.21
load profile
illustration of the power needed from a *battery* (3.3) to support a given system, which is usually expressed by graphing required current versus time

Note 1 to entry: See Reference [11].

3.22
lot
group of components produced in continuous and uninterrupted production run with no change in processes or drawings

Note 1 to entry: See Reference [5].

[SOURCE: ISO 26871:2020, 3.1.40, modified — The preferred term "batch" has been removed; the definition has been editorially improved; note 1 to entry has been added.]

3.23
open circuit voltage
voltage across a lithium-ion *cell* (3.4) or *battery* (3.3) with no-load and no current in external circuit

Note 1 to entry: See References [6] and [9].

3.24
over-charge
charge past the manufacture’s recommended limit of voltage

3.25
over-discharge
discharging a *cell* (3.4) or *battery* (3.3) past the point determined by the cell supplier where the full capacity has been obtained

3.26
protective device
device which interrupts the current flow, blocks the current flow in one direction or limits the current flow in an electrical circuit

EXAMPLE Fuses, by-pass, diodes and current limiters.

Note 1 to entry: See Reference [9].

3.27
reasonably foreseeable misuse
use of a product, process or service in the way which is not intended by the supplier but which results from a readily predictable human behaviour

Note 1 to entry: See Reference [12].

3.28
rupture
mechanical failure of a *cell* (3.4) container or *battery* (3.3) case induced by an internal or external cause, resulting in exposure or spillage but not ejection of solid materials

Note 1 to entry: See Reference [9].

3.29
self-discharge
phenomenon due to *leakage* (3.18) current in open circuit at *cell* (3.4) and/or *battery* (3.3) level

3.30
shelf life limit
maximum allowed *life* (3.19) time from *cell* (3.4) *activation* (3.1) to launch when the *battery* (3.3) capacity before launch, which is deteriorated due to both preliminary charge and discharge and storage damage depending on temperature, can certainly complete all of subsequent missions on orbit

Note 1 to entry: See References [4] and [5].

3.31
space quality
high reliability required for vehicles and equipment built for space use

3.32
tailoring
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

Note 1 to entry: See ISO 27025.

[SOURCE: ISO 10795:2019, 3.237, modified — Note 1 to entry has been added.]

3.33
thermal runaway
uncontrollable condition whereby a *cell* (3.4) or a *battery* (3.3) overheats and reaches very high temperatures in very short periods (seconds) through internal heat generation caused due to an internal short or due to an abusive condition

Note 1 to entry: See Reference [6].

3.34
vent
release of excessive internal pressure from a *cell* (3.4) or *battery* (3.3) in a manner intended by design to preclude *rupture* (3.28) or *disassembly* (3.7)

Note 1 to entry: See References [9], [11] and [12].

4 Symbols and abbreviated terms

BOL	beginning of life
C	capacity, expressed in ampere hours (Ah)
CC/CV	constant current/constant voltage
CID	current interrupt device
COTS	commercial off the shelf
DOD	depth of discharge [6]
EOCV	end of charge voltage [7]
EODV	end of discharge voltage [7]
EOL	end of life [7]
FMEA	failure modes, effective analysis [7]
FTA	fault tree analysis
GEO	geosynchronous earth orbit
GTO	geosynchronous transfer orbit [6]
GSE	ground support equipment
IPA	iso-propyl alcohol
LAT	lot acceptance test
LEO	low earth orbit
LIB	lithium-ion battery
V_{oc}	open circuit voltage [6]
PTC	positive temperature coefficient
SOC	state of charge
UN38.3	United Nations UN Manual of Tests and Criteria, Part III, 38.3

5 Cell

5.1 Performance

5.1.1 General

This subclause describes the electro-chemical performance as a single cell in harmony with other standards.

Each article specifies the items that are necessary to verify when specific cells are to be assembled into the battery for space vehicle.

The cell contained in a battery is described as a component cell and a cell whose contents are enclosed within a sealed flexible pouch rather than a rigid casing is expressed as “pouch cell”.

The definitions of the size of cell, such as a small or large format, may be tailored from UN38.3 and IEC 62281.