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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*

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Contents

Page

Foreword	vi
Introduction	vii
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols and abbreviated terms	6
5 Cell	6
5.1 Performance.....	6
5.1.1 General.....	6
5.1.2 Test requirements.....	7
5.1.3 Test data trending [4].....	7
5.1.4 Cell qualification test.....	8
5.1.5 Leakage (hermetic) test.....	8
5.1.6 Safety tests.....	8
5.1.7 Thermal/thermal vacuum test [5].....	8
5.1.8 Mechanical environmental test.....	8
5.1.9 Radiation test.....	9
5.1.10 Life cycle test.....	9
5.1.11 Models for analysis.....	10
5.2 Safety.....	10
5.2.1 General.....	10
5.2.2 Hazard description.....	10
5.2.3 Protective devices as a hazard control.....	10
5.2.4 Safety testing.....	11
5.2.5 Important test considerations.....	12
5.2.6 Optional test.....	13
5.3 Logistics.....	13
5.3.1 General.....	13
5.3.2 Cell manufacturing, storage and testing.....	14
5.3.3 Safety measure for handling.....	15
5.3.4 Cell transportation.....	15
5.4 COTS cells for space use.....	15
5.4.1 General.....	15
5.4.2 Safety requirements.....	15
5.4.3 Lot integrity assessment.....	15
5.4.4 Mission conformance test.....	16
5.4.5 Charge and discharge test.....	16
5.4.6 Thermal vacuum test.....	16
5.4.7 Mechanical environment test.....	16
5.4.8 Cycle life test.....	16
5.4.9 Storage life test.....	16
6 Battery	17
6.1 Performance.....	17
6.1.1 General.....	17
6.1.2 C/n charge or discharge current (c-rate) [4][5][6].....	17
6.1.3 Cut-off voltage.....	17
6.1.4 Cycle.....	17
6.1.5 Depth of discharge (DOD) [4][5][6][13].....	17
6.1.6 End of charge voltage.....	17
6.1.7 Energy.....	18
6.1.8 Energy density.....	18
6.1.9 Energy reserve [4][5].....	18

6.1.10	Fully charged [9][13]	18
6.1.11	Nameplate capacity	18
6.1.12	Nominal capacity	18
6.1.13	Nameplate energy [5][12]	18
6.1.14	Nominal voltage [9]	19
6.1.15	State of charge	19
6.1.16	Standard method for capacity measurement	19
6.1.17	Battery internal resistance (ohmic)	19
6.1.18	Battery impedance	20
6.1.19	Life test demonstration	20
6.1.20	For GEO simulated	20
6.1.21	For LEO simulated	21
6.1.22	For launch vehicle: simulate ground storage and usage at launch phase	21
6.1.23	Battery general requirements [5][11]	21
6.1.24	Electrical design	21
6.1.25	Thermal design	21
6.1.26	Mechanical design	21
6.1.27	Cell-to-cell balancing mechanisms	21
6.1.28	Marking	22
6.1.29	Cell matching	22
6.1.30	Polarization testing (optional)	22
6.1.31	Self-discharge rate test	22
6.1.32	Tailoring screening tests	22
6.1.33	Cell matching criteria	23
6.1.34	Contamination control	23
6.1.35	Test data trending [4]	23
6.1.36	Flight verification acceptance testing [5]	23
6.1.37	Assurance of the life estimation [8]	24
6.1.38	Parameter measurement tolerances	24
6.1.39	Battery testing [5][15]	24
6.1.40	Development testing [4][15]	24
6.1.41	Charge control testing	25
6.1.42	Thermal control testing	25
6.1.43	Mechanical test	25
6.1.44	Qualification test [4]	25
6.1.45	Qualification test levels and duration	26
6.1.46	In-process inspections and tests	26
6.1.47	Data collection and acquisition rates	26
6.2	Safety	26
6.2.1	General	26
6.2.2	Definitions of dangerous phenomenon	27
6.2.3	Technical requirement	28
6.2.4	Fault tolerance	28
6.2.5	Hazard controls [5]	28
6.2.6	Over-current prevention	28
6.2.7	Over-voltage protection	29
6.2.8	Temperature/current management	29
6.2.9	Insulation and wiring	29
6.2.10	Positive protection against accidental shorting	29
6.2.11	Venting	29
6.2.12	Crew touch temperature requirements	30
6.2.13	Terminal contacts	30
6.2.14	Safety testing	30
6.2.15	Important test considerations	30
6.2.16	Thermal runaway propagation	32
6.2.17	Special provision	32
6.2.18	Description for necessary information for system safety review	32
6.3	Logistics	32

6.3.1	General	32
6.3.2	Manufacture/assembly storage and testing	33
6.3.3	Safety measure for handling	34
6.3.4	Transportation	34
7	Battery onboard space vehicle	34
7.1	Performance	34
7.1.1	General	34
7.1.2	Basic design	34
7.1.3	Electrical ground bonding	35
7.1.4	Temperature reference point of battery module	35
7.1.5	Preparation for handling, transportation	35
7.2	Safety	35
7.2.1	General	35
7.2.2	Definitions of dangerous phenomenon	36
7.2.3	Technical requirement	36
7.3	Logistics	36
7.3.1	General	36
7.3.2	Safety measure for handling	36
7.3.3	Integration to the space vehicle	36
7.3.4	Battery maintenance on the space vehicle	37
7.3.5	Battery transportation equipped in space vehicle	37
8	Launch site	37
8.1	General	37
8.2	Performance	38
8.3	Safety	38
8.4	Logistics	38
8.4.1	General	38
8.4.2	Safety measure for handling	39
8.4.3	Preparation for transportation	39
8.4.4	SOC level for transportation	39
8.4.5	Container for transportation	39
8.4.6	Battery testing (health checking after transportation)	39
8.4.7	Inspection	39
8.4.8	State of health verification	40
8.4.9	Battery storage at launch site	40
8.4.10	Self-discharge rate	40
8.4.11	Protection under integration	40
8.4.12	Handling plate	40
8.4.13	Electrical connection	41
8.4.14	Electrical checkout	41
8.4.15	Battery monitoring	41
8.4.16	Battery monitoring preceding launch	41
9	Mission in orbit and end of life	41
	Annex A (informative) Parameter measurement tolerances	42
	Annex B (informative) Example of cell qualification test	43
	Annex C (informative) Hazard identification method	45
	Annex D (normative) Safety measure for handling	47
	Annex E (informative) Transportation	49
	Annex F (informative) Lot assessment of COTS cells	53
	Bibliography	55

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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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 shelf 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.

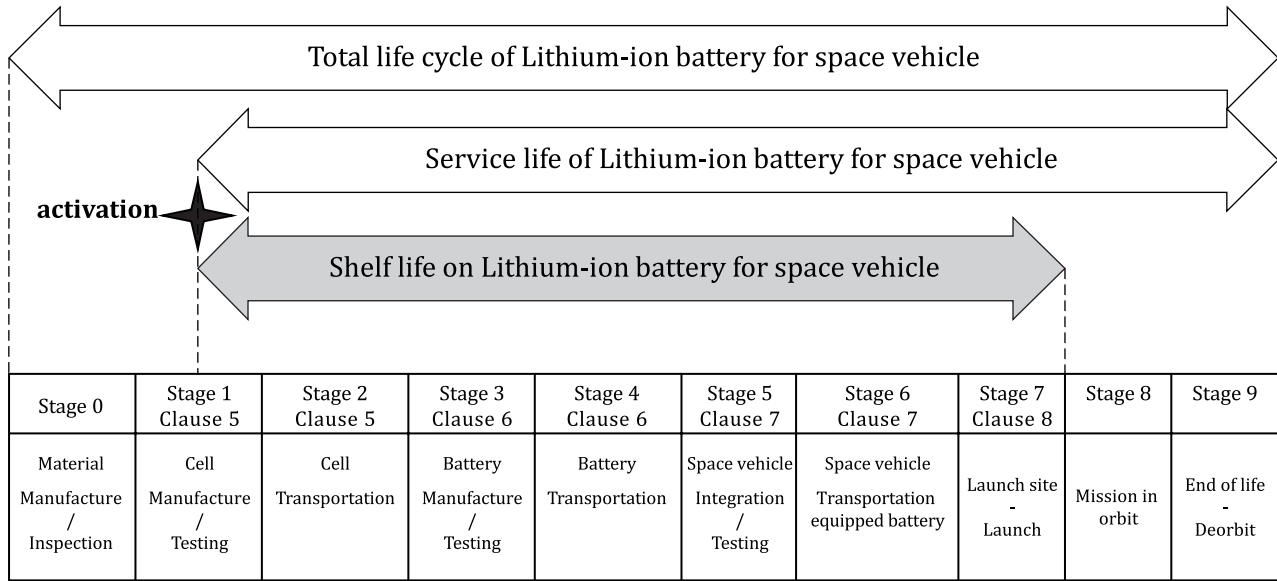


Figure 1 — Definition of life cycle stages of lithium-ion battery for space vehicle

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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 [\[5\]](#).

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.

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”.