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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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Foreword

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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

This International Standard has been developed for the purpose of addressing the standard to obtain sustainable development and to prevent incident of lithium ion battery for space vehicle.

For battery developer and spacecraft system architects, this International Standard leads the way to assess 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 for lithium ion battery (LIB) for space vehicle to prevent performance defect in orbit and incident through the life cycle.

The three objectives in the life cycle, which are “performance”, “safety”, and comfortable “logistics”, aim to realize more reliable, more safe, and high efficient means at the same time for development of space vehicle batteries.

We address each objective as follows.

Performance

“How to estimate the life degradation at end of life”

Since LIB starts to degrade from activation, the consideration to meet the power requirement through the mission life is needed, that is, unaffected from handling conditions (temperature) and usage conditions in orbit (temperature, cycle, current or power and depth of discharge). Also, the risk in orbit could be mitigated based on the life estimation and unexpected degradation could be carefully avoided throughout the whole life cycle.

Safety

Here, we establish a complex risk assessment process that is easy to understand. The method was agreed internationally at ISO/IEC and is a traditional method for space use.

LIB needs to keep 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 overcharge.

The important thing is that the process, which can result to a hazardous situation, does not always immediately result to an incident. Because of these risks, LIB is considered hazardous at all times. The risk assessment needs to become very important to cover a variety of environment during the handling or use and history of stress.

Logistics

“How to bring the demand close to the general requirements to guarantee the safety and space quality”

From a wide-ranging point of view, the most important thing is to conduct life cycle assessment against performance and safety. For example, temperature history (especially high temperature history when cell is kept outdoors, where temperature is not controlled) and shocks/vibrations that cell receives during transport and electrical short when handling. Also, to reflect the results of handling or usage, measurement is needed.

All the personnel who owed responsibility of development, design, and handling are desired to survey and estimate the influence of their assessment spontaneously to improve for sustainable development of space component. As a result, a third party can evaluate the validity of the design and verification.

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

1 Scope

This International Standard specifies design and minimum verification requirements for lithium ion rechargeable (including lithium ion polymer) batteries for space vehicles.

Lithium ion secondary electrochemical systems use intercalation compounds (intercalated lithium exists in an ionic or quasi-atomic form within the lattice of the electrode material) in the positive and in the negative electrodes.

The focus of this International Standard is on “battery assembly” and cell is described as “component cells” to be harmonized with other industrial standards and regulations.

“Performance”,” safety”, and “logistics” are the main points of view to specify.

This International Standard does not address “disposal” or “recycle”; however, some recommendations regarding disposal are suggested.

1.1 Life cycle

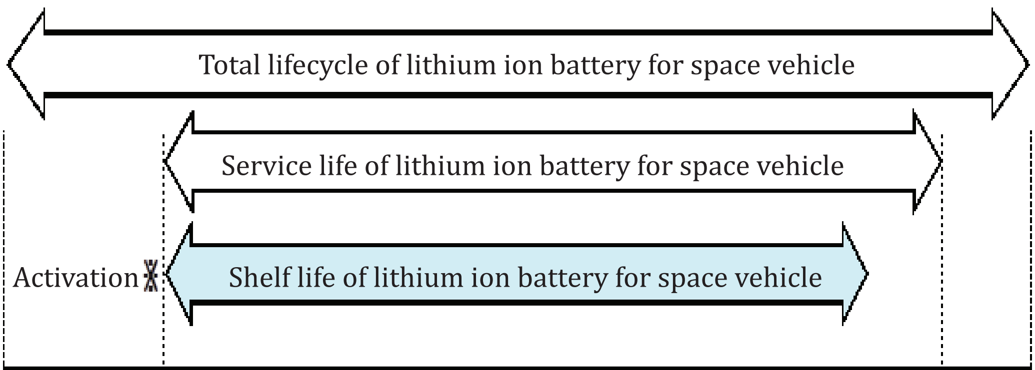
The service life of a battery starts at cell activation and continues through all subsequent fabrication, acceptance testing, handling, storage, transportation, testing preceding launch, launch and mission operation.

The scope of this International Standard addresses the shelf life, from cell activation to launch, although the life design and evaluations of the battery on the ground need to accommodate to the whole mission life in space.

Each article in this International Standard addresses “performance”, “safety”, and “logistics”, according to the each stage of lifecycle.

NOTE Stages 3 and 5 include storage period which induce some performances verifications.

Table 1 — Life cycle of lithium ion battery for space vehicle



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

1.2 Performance

Evaluation items and methods of application for battery used for space vehicle is explained. The focus of the applicability is on the performance characteristics at the end of life (EOL).

The scope of the performance addresses terminology for the basic performance, typical usage (charge and discharge profile), quality assurance, testing method.

1.3 Safety

This International Standard follows the principle of ISO/IEC Guide 51.

Classify the hazards while normal usage through the lifecycle and provide rationale for the dangerous phenomenon, such as fire, burst/explosion, leakage of cell electrolyte, venting, burns from excessively high external temperatures, rupture of battery case with exposure of internal components, and smokes. Typical risk analysis, hazard analysis and fault tree analysis (FTA) through the battery life cycle is suggested in this International Standard. Hazard control method is distributed and tailored into each stage of life cycle, to harmonize with other industrial standards.

The safety test involves the items of “United Nations UN Manual of Tests and Criteria, Part III, sub-section 38.3, (UN38.3)” or UL1642. Necessary minimum safety precaution is described as Lithium Ion Battery for Space Vehicle.

Technical requirements are intended to reduce the risk of fire or explosion when lithium batteries are used in space vehicle. The final acceptability of these batteries is dependent on their use in a space vehicle that complies with the requirements applicable for range safety or payload safety.

These requirements are also intended to reduce the risk of injury to persons due to fire or explosion when prior to the launch site, transportation, battery testing and manufacturing.[11]

1.4 Logistics

In this International Standard, “logistics” means not only physical distribution or transportation but also descriptions on how to handle and care for and configuration (status or conditions of hardware and desirable environment) by each stage of lifecycle.

Descriptions of logistics contain the precautions for “manufacture”, “assembling”, “handling”, “testing”, “storage”, “packing” and “transportation”.

The scope of the logistics addresses the miscellaneous important precaution and rationale to maintain the performance and safety as a space vehicle battery, to harmonize with other industrial standards and regulations. Although, each item of relevant compliances is referred to the original document because each document or regulation is revised independently.

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 24113, *Space systems — Space debris mitigation requirements*

IEC 61960, *Secondary cells and batteries containing alkaline or other non-acid electrolytes — Secondary lithium cells and batteries for portable applications*

3 Terms and definitions

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

3.1
accelerated test
test designed to shorten the controlled environmental test time with respect to the service use time by increasing the frequency of occurrence, amplitude, duration, or any combination of these of environmental stresses during service use[7]

3.2
activation
process of making an assembled cell functional, by introducing an electrolyte at the manufacturing facility during cell production, which is used to define the start of battery shelf life[1][2][3][8]

3.3
aging
permanent loss of capacity due to repeated cycling or passage of time from activation[3]

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

Note 1 to entry: A single cell battery is considered a “cell”.[6]

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.[1][2]

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 International Standard, treated as batteries.[6]

3.5
calendar loss
degradation of electrical performances due to passage of time after activation

3.6
cell
single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across its two terminals[6]

3.7
dangerous phenomenon
fire, burst/explosion, leakage of cell electrolyte, venting, burns from excessively high external temperatures, rupture of battery case with exposure of internal components, and smokes

3.8
disassembly
vent or rupture where solid matter from any part of a cell or battery penetrates a wire mesh screen (annealed aluminum wire with a diameter of 0,25 mm and grid density of 6 wires per cm to 7 wires per cm) placed 25 cm away from the cell or battery[6]

3.9
effluent
liquid or gas released when a cell vents or leaks[6]

3.10
explosion
condition that occurs when a cell container or battery case violently opens and major components are forcibly expelled and the cell or battery casing is torn or split[9][11]

3.11
external short circuit
direct connection between positive and negative terminals of a cell or battery that provides less than 0,1 ohm resistance path for current flow[6]

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.

3.12
fading
degradation of electrical performances due to cycling

Note 1 to entry: It is evaluated through life test and wear out test.

3.13
fire
flames are emitted from the test cell or battery[6][9]

3.14
gassing
evolution of gas from one or more of the electrodes in a cell[3]

3.15
harm
physical injury or damage to the health of people or damage to property or the environment

3.16
hazard
potential source of harm

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

3.17
hermetic seal
permanent air-tight seal[7]

3.18
intercalation
process where lithium ions are reversibly removed or inserted into a host material without causing significant structural change to that host[8]

3.19
intended use
use of a product, process or service in accordance with specifications, instructions and information provided by the supplier[9]

3.20
internal resistance
opposition to the flow of current within a cell or a battery, that is, sum of electronic resistance and ionic resistance with the contribution to total effective resistance including inductive/capacitive properties

3.21
leakage
visible escape of electrolyte or other material from a cell or battery or the loss of material (except battery casing, handling devices or labels) from a cell or battery such that the loss of mass exceeds the values in Table 2

Note 1 to entry: Mass loss means a loss of mass that exceeds the values in Table 2.

Table 2 — Table of mass loss limit

Mass M of cell	Mass loss limit
M < 1 g	0,5 %
l g ≤ M ≤ 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:

$$\text{Mass loss (\%)} = \frac{(M1 - M2)}{M1} \times 100$$

where

M1 is the mass before the test and M2 is the mass after the test.

When mass loss does not exceed the values in Table 2, it shall be considered as “no mass loss”.[6]

3.22
life
duration of maintaining a required performance (e.g. 50 % of BOL capacity), estimated in years (calendar life) or in the number of charge/discharge cycle[3]

3.23
lithium ion battery
rechargeable electrochemical cell or battery in which the positive and negative electrodes are both intercalation 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[6]

3.24
load profile
illustration of the power needed from a battery to support a given system, which is usually expressed by graphing required current versus time[8]

3.25
lot
continuous, uninterrupted production run with no change in processes or drawings[2]

3.26
open circuit voltage
difference in electrical potential voltage between the terminals of a cell or battery measured when the circuit is open (no-load condition) and no external current is flowing[3][6]

3.27
overcharge
charge past the manufacturer's recommended limit of voltage

3.28
over discharge
to discharge a cell or battery past the point determined by cell supplier where the full capacity has been obtained

Note 1 to entry: Continuous discharging of a cell or battery below zero volts causing voltage reversal is defined as forced discharge.[3]

3.29
probability of occurrence
theoretical distribution that measures of how likely it is that some event shall occur[7]

3.30
protective devices
devices such as fuses, by-pass, diodes and current limiters which interrupt the current flow, block the current flow in one direction or limit the current flow in an electrical circuit[6]

3.31
reasonable foreseeable misuse
use of a product, process or service in the way which is not intended by the supplier but which results from readily predictable human behaviour[9]

3.32
rupture
mechanical failure of a cell container or battery case induced by an internal or external cause, resulting in exposure or spillage but not ejection of solid materials[6]

3.33
self-discharge
phenomenon due to leakage current in open circuit at cell and/or battery level

3.34
shelf life limit
maximum allowed time from cell activation to launch, which includes any time in storage, whatever the temperature storage conditions[1][2]

3.35
space quality
high reliability required for vehicles and equipments built for space use

3.36
tailoring
process of choosing design characteristics/tolerances and test environments, methods, procedures, sequences and conditions, and altering critical design and test values, conditions of failure, etc., to take into account the effects of the particular environmental forcing functions to which material normally is subjected during its life cycle[7]

3.37
thermal runaway
uncontrollable condition whereby a cell or battery shall overheat and reach very high temperatures in very short periods (seconds) through internal heat generation caused due to an internal short or due to an abusive condition[3]

3.38
vent
release of excessive internal pressure from a cell or battery in a manner intended by design to preclude rupture or disassembly[6][8][9]

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
DOD	depth of discharge[3]
EOCV	end of charge voltage[4]
EODV	end of discharge voltage[4]
EOL	end of life [4]
FMEA	failure modes, effective analysis[4]
FTA	fault tree analysis
GEO	geosynchronous earth orbit
GTO	geosynchronous transfer orbit[3]
GSE	ground support equipment
IPA	iso propylic alcohol
LAT	lot acceptance test
LEO	low earth orbit
LIB	lithium ion battery
MSDS	material safety data sheet[8]
OCV	open circuit voltage[3]
PTC	positive temperature coefficient

QA quality assurance[4]

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 Purpose

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

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

The cell contained in a battery shall be 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, shall be tailored from UN38.3 and IEC 62281.

Recommended cell qualification test items are specified and the requirement for quality assurance of flight cells shall be addressed.

5.1.2 Terminology

For the purposes of understanding requirement of cell performance, the following terms and definitions apply.

Cell operating region

The conditions during charging and discharging in which the cell operates within its voltage and current and temperature range as specified by the cell manufacturer. See Figure 1 for a graphic representation of the cell operating region.[11]

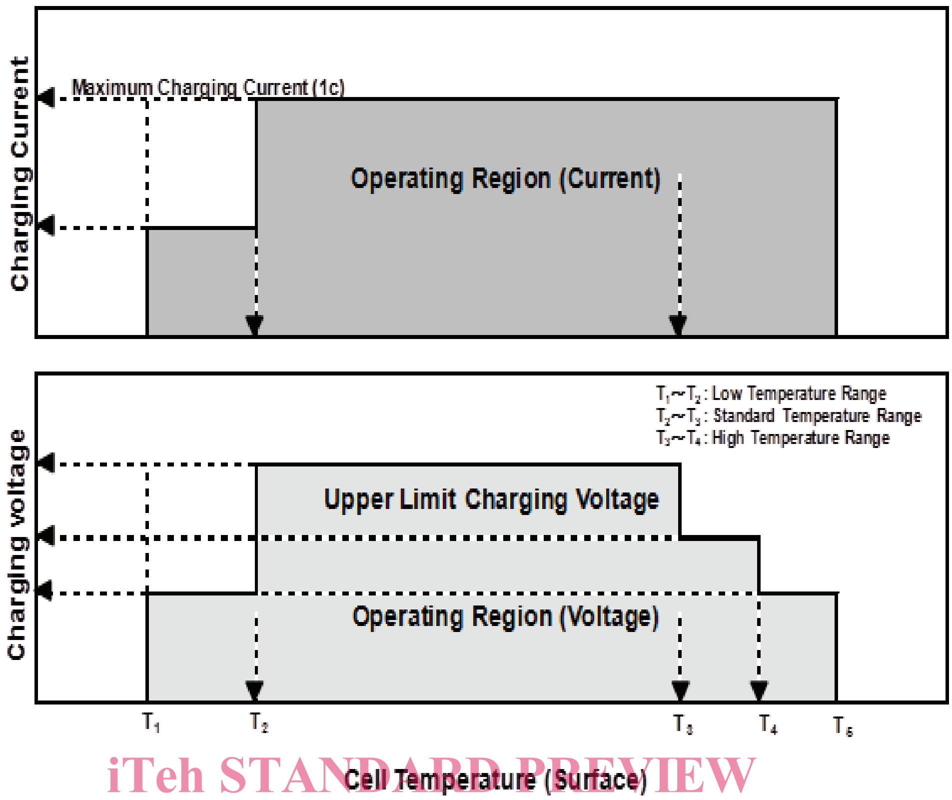


Figure 1 — Diagram representing an example of a cell operating region (e.g. from the Battery Association of Japan)

Maximum charging current for safety aspect

The maximum charging current in the cell operating region, which is specified by the cell manufacturer for the safety reason.[11]

Charging current limits for performances

The charging current limits in the cell operating region, which is specified by the cell manufacturer for the performances reason, shall not exceed the maximum charging current.

5.1.3 Requirement for quality assurance

Cells shall be manufactured under a quality management programme specified in United Nation Recommendation (see Annex E).

Acceptance tests shall be performed on cell level before the cells are installed in the battery-powered flight hardware.

Acceptance testing for Li-ion cells shall include as a minimum: a) visual inspection; b) leak check; c) dimensions and weight measurement; d) open circuit voltage; e) self-discharge, capacity or energy tests; e) internal resistance. Some environmental and safety device testing such as vibration, extreme thermal cycling, CID/PTC testing, etc. include acceptance test. In each testing, criteria shall be specified by the battery manufacturer.

Test data trending[1]

Key cell performance parameters, such as charge retention, capacity or energy, voltage under maximum load, and resistance, shall be monitored across successive manufacturing lots (trend analysis) to