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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 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 CD-17546 was prepared by Technical Committee ISO/TC 020, Aircraft and Space Vehicle, Subcommittee SC 14, *Space systems and operations*.

Introduction

This document 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 standard lead to the way to assess the whole life cycle "from electrolyte filling to the end of the mission in space", and to clarify what shall be 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 trinity measure to specify the "performance", "safety", and comfortable "logistics" through the lifecycle, realize more reliable, more safety, high efficient means for development of Space Vehicle batteries.

We shall address each objective as follows,

Performance;

"How to estimate the life degradation at End of Life."

Since LIB starts to degrade from activation; 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 shall be mitigated based on the life estimation and unexpected degradation shall be carefully avoided throughout the whole life cycle.

Safety;

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

Since LIB shall keep some amount of the SOC to avoid significant capacity degradation, so that the specific consideration and care for handling shall be required because of potential hazard source.
It is well known that LIB has specific risks of the higher voltage when compared to other power sources, and no saturation characteristic for overcharge.
Important thing is the process what generate the hazardous situation, does not always leads incident immediately. Because of these risks, LIB shall be considered hazardous at all times. Then, the risk assessment shall be very important to care 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, most important things are 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 transportations, and electrical short when handling. Also, to reflect the result to the handling or usage measurement is needed.

All the personnel who owed responsibility of development, design, and handling shall be 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 Vehicle — Design and Verification Requirements

1 Scope

This document specifies design and minimum verification requirements for Lithium Ion rechargeable (include Lithium Ion Polymer) battery for Space Vehicle.

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 the document is on “Battery assembly” and cell shall be described as “component cells” to be harmonized with other industrial standards and regulations.

“Performance”,” Safety”, and “Logistics” are the main point of view to specify.

This document does not address “disposal” or “recycle”, however, some recommendation regarding disposal is suggested

1.1 Life cycle

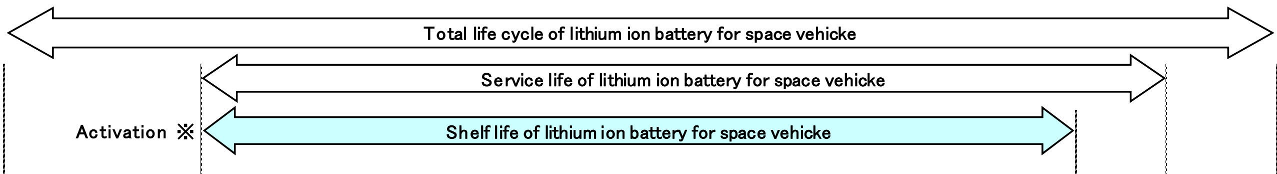
The service life of a battery starts at cell activation and continues through all subsequent fabrication, acceptance testing, handling, storage, transportation, testing preceding launch, launch and mission operation.

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

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

Note: Stage 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 shall be explained. The focus of the applicability shall be 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 standard follows the principal of ISO/IEC Guide51:1999, Safety aspects – guidelines for their inclusion in standards.

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 document. Hazard control method shall be distribute 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 document, "Logistics" means not only physical distribution or transportation, but also descriptions that how to handle and care for, and configuration (status or conditions of hardware and desirable environment) by each stage of lifecycle.

Descriptions of logistics contains 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, the each item of relevant compliances shall be referred to the original document, because each document or regulation shall be revised independently.

2 Normative references

The following referenced documents are indispensable for the application 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 10795: Space systems – Programme management – Vocabulary

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.
Note; Each captioned reference document shall be deleted after completion for DIS phase.

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. single cell battery is considered a “cell” [6]

battery may also includes one or more attachments, such as electrical bypass devices, charge control electronics, heaters, temperature sensors, thermal switches, and thermal control elements. [1], [2]

NOTE 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. [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 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 occur 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]. 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. 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 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 electric current within a cell or battery expressed as the sum of the ionic and electronic resistances of the cell components. [3]

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 below

Mass loss means a loss of mass that exceeds the values in below.

Table 2. Table of Mass loss limit

Mass M of cell	Mass loss limit
M < 1 g	0.5%
I g ≤ M ≤ 75 g	0.2%
M > 75 g	0.1%

NOTE: 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 the Table of Mass loss limit, it shall be considered as "no mass loss". [6]

3.22
life
duration of satisfactory performance, measured in years (float life) or in the number of charge/discharge cycles[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 form 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: continuous discharging a cell or battery below zero volts causing voltage reversal is defined as forced discharge. [3]

3.29
probability of occurrence
theoretical distribution that measure 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 form 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 materiel 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
COTS	Commercial-off-the-shelf
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
MEO	Medium Earth Orbit
MSDS	Material Safety Data Sheet [8]
OCV	Open Circuit Voltage [3]
PTC	Positive Temperature Coefficient
QA	Quality Assurance [4]
RH	Relative Humidity
RT	Room Temperature
SOC	State Of Charge
UN38.3	United Nations UN Manual of Tests and Criteria, Part Ⅲ, sub-section 38.3
WCA	Worst Case Analysis