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

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National foreword

This British Standard is the UK implementation of ISO 17546:2024. It supersedes BS ISO 17546:2016, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

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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

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.

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.

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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.

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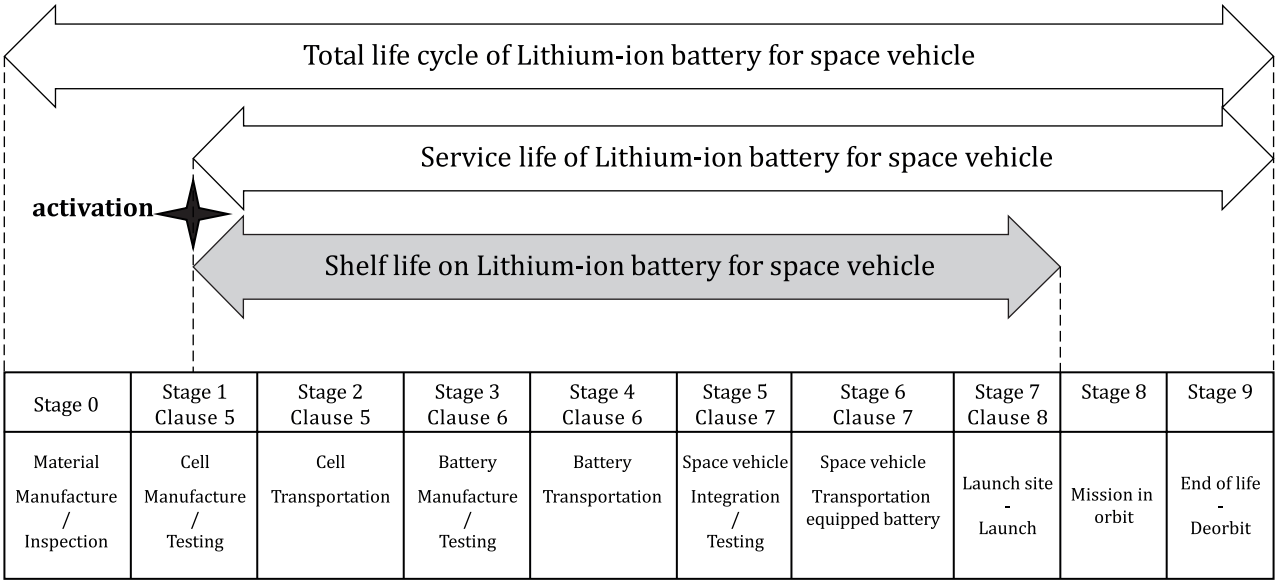

Figure 1 — Definition of life cycle stages of lithium-ion battery for space vehicle

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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].

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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].

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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:

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

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].

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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].

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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.

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

5.1.2 Test requirements

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

The design and manufacturing procedure shall be verified through the qualification test and be guaranteed with its test report.

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

Acceptance testing for lithium-ion cells 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;

f) internal resistance.

Some environmental and safety device testing, such as vibration, extreme thermal cycling, CID/PTC testing, includes acceptance tests. In each testing, the criteria are specified by the battery or cell manufacturer.

5.1.3 Test data trending [4]

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 identify possible performance degradation due to unanticipated material or manufacturing variation during acceptance testing.

Additional tests are carried out as for example:

a) closed circuit voltage check

b) cycle testing, vibration

c) thermal cycling

d) X-ray

e) impedance

f) LAT

g) electrical wear-out cycling.

Off-gassing/out-gassing tests are available for materials compatibility. Any cell displaying any evidence of electrolyte leakage fails these tests.

Users verify that all cells intended for flight use are within the designated shelf life based on the cell manufacture date as specified in the limited life items data.

The overall accuracies of controlled or measured values are commonly specified in Annex A.

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5.1.4 Cell qualification test

Standard cell qualification test includes functional checkout (operational, cycle), environmental (i.e. vibration, thermal, thermal vacuum, radiation) and safety as stated in 5.2 or others as deemed appropriate for the specific hardware and application[5][15][16].

Recommended test items of the component cell qualification for the space vehicle are specified. Examples are in Annex B.

For the space use, critical items for evaluations are hermetic test, safety testing, mechanical environment test, radiation, life cycling data and thermal/thermal vacuum test. The typical test method and criteria include, but are not limited to, those specified in 5.1.5 to 5.1.10.

5.1.5 Leakage (hermetic) test

Each cell is tested for leakage in cell/battery acceptance test.

Criteria: The maximum leakage rate shall be low enough so that at the end of life, the remaining amount of electrolyte inside the cells is still compatible with the required performances of the cell. For example, the maximum helium gas leakage equivalent rate should not exceed, for example, $1{,}0 \times 10^{-6}$ Pa·m^3/s for a cell.

5.1.6 Safety tests

Each cell type shall be subjected to over-charge, over-discharge, and over-current (short circuit testing) to ensure the cell does not result in a scenario where flame or fire exists.

5.1.7 Thermal/thermal vacuum test [5]

Cells shall be tested in an environment that encompasses the intended application as possible. The thermal environment, in particular, is a factor that significantly affects how a battery performs. Qualification temperature ranges encompass the mission temperature ranges and have a range sufficient to stress the hermeticity of the cell. The cells also experience a vacuum environment to determine the integrity of the cell hermetic seal.

5.1.8 Mechanical environmental test

Mechanical environment tests including sine and random vibrations and shock tests values shall encompass all possible space mission profiles.

Examples of mechanical environment level for cells are described in Tables 2 to 4.

Table 2 — Sine vibration (sweep rate: 2 octave/min)

	Qualification	
Axis	Frequency Hz	Amplitude Acceleration
All axis	5 to 22 22 to 100	20 mm (double) 20 (9,8 m/s^2)

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Table 3 — Random vibration (duration: 180 s per each axis)

Axis	Frequency Hz	Level
cell Z axis along the length of cell	20 to 50 50 to 300 300 to 450 450 to 700 700 to 1 000 1 000 to 2 000	+6 dB / oct 0,2 (9,8 m/s^2)^2 / Hz +12 dB / oct 1,0 (9,8 m/s^2)^2 / Hz -19,43 dB / oct -3 dB / oct
	overall	23,68 (9,8 m/s^2) rms
cell X and Y axes for rectangular shape cell R axis for cylindrical shape in the plane of cell cross section	20 to 50 50 to 100 100 to 150 150 to 250 250 to 284 284 to 500 500 to 783 783 to 1 000 1 000 to 2 000	+6 dB / oct 0,1 (9,8 m/s^2)^2 / Hz +17,1 dB / oct 1,0 (9,8 m/s^2)^2 / Hz -12 dB / oct 0,6 (9,8 m/s^2)^2 / Hz -12,43 dB / oct 0,1 (9,8 m/s^2)^2 / Hz -3 dB / oct
	overall	21,19 (9,8 m/s^2) rms

Table 4 — Shock (three times per axis)

Axis	Frequency Hz	Acceleration (× 9,8 m/s^2)
All axis	200 1 400 4 000	24 4 200 4 200

5.1.9 Radiation test

Cells shall be exposed to the cumulative radiation dose, as a minimum, as specified for the mission environment.

5.1.10 Life cycle test

Life tests shall be performed for lot performance verification and for mission lifetime demonstration.

The life test for lot performance evaluation purpose is also included in a lot trend analysis. The supplier proposes a representative wear out life test using accelerated conditions for current and cycle duration. The total energy (or capacity) degradation is checked after a defined number of cycles. An example of test procedure is given hereafter.

For lot acceptance: DOD 100 %

a) Temperature T_{bat} (°C) (T_{amb}/T_{bat}): defined by battery supplier typically at ambient temperature).

b) CC/CV; Charge current 0,5 C (A)/EOCV: V_{ch} (V): defined by battery supplier.

c) CC; Discharge current 0,5 C (A) to EODV: V_{disch} (V): defined by battery supplier.

Standard capacity measurements are performed before the life test and every 100 cycles.

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5.1.11 Models for analysis

The following information shall be clearly defined by the battery supplier based on the cell suppliers' information for the battery design evaluation, if available; and their information is provided to the battery assembler.

Models are correlated with on-ground and on-orbit experimental data, where available.

a) Heat generation and thermal model

   To evaluate worthiness of thermal design of the battery.

b) Structural model

   To evaluate worthiness of structural design of strength and stiffness of the battery.

c) Life (aging) model

   To evaluate worthiness of electrical power storage performance with appropriate margin through the life cycle.

5.2 Safety

5.2.1 General

The purpose of this subclause is to clarify the dangerous phenomenon of independent cell and equipped safety features. Necessary test items for safety are provided.

The safety tests that prove two-fault tolerance to catastrophic hazard are performed as part of a qualification test program and repeated for each newly purchased lot of the same battery[5].

5.2.2 Hazard description

This subclause identifies the potential hazard when a cell is treated independently. See Annex C.

Potential hazards which are the subject of this document are as follows[12][17]:

a) fire;

b) burst/explosion;

c) leakage of cell electrolyte;

d) venting;

e) burns form excessively high external temperatures;

f) rupture of battery case with exposure of internal components;

g) smoke.

5.2.3 Protective devices as a hazard control

For the purpose of hazard control, some protective devices shall be equipped within a cell. Although these protective devices are reliable in single cell use, it is necessary to evaluate their ability within a multi- cell

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