Battery Safety and Passivation

ESA CleanSpace Industrial Days

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ESTEC – 23rd October
Why are we talking today about Battery Passivation?

Main objective: avoid space debris generation

Goals:

- Assessing various passivation strategies
- Understanding battery behaviour at End-of-Life under extreme conditions through testing

Causes of known satellite breakups until 2008.
Source: US Space Surveillance Network (SSN)

- Deliberate 29%
- Unknown 20%
- Accidental collision 2%
- Propulsion 45%
- Battery 4%

2008: French law LOS (Loi d’Opérations Spatiales) applicable to satellites launched after 2020 from CNES Passivation/Fin de vie du sous-système de puissance


ESA GSTP Spacecraft Power System Passivation

ESA TRP Battery Passivation

CNES Battery Passivation regarding LOS constraints

CNES ABSL End-of-Life
GSTP Spacecraft Power System Passivation
Battery thermal analysis

• Three different cases have been studied:

A LEO spacecraft with external battery
AstroBus-S platform

A LEO spacecraft with internal battery
Astrobus-M or AS250 platform

A GEO satellite
E3000 platform
GSTP Spacecraft Power System Passivation

Battery thermal analysis

- Three different cases have been studied:

1. A LEO spacecraft with external battery
   AstroBus-S platform

2. A LEO spacecraft with internal battery
   Astrobus-M or AS250 platform

3. A GEO satellite
   E3000 platform
GSTP Spacecraft Power System Passivation

Battery thermal analysis

- Three different cases have been studied

Assumptions:
- Orbit: Geo-synchronous orbit
- Duration: 100 years (or forever)
- Season: Solstice (no eclipse) – certain worst case
- Attitude: Radiator pointing the Sun – possible scenario

Battery covers
- MLI completely torn off – Unlikely?
- Absorptivity degraded to 1 - Possible
- Heatpipes failure - Unlikely
- Internal MLI remains intact - Likely

Unlikely accumulation of Worst Cases
Objective of the study:
To test Li-Ion battery cells and modules under extreme conditions encountered after spacecraft disposal in order to assess their safety

→ Abusive tests on 200+ SAFT and ABSL space cells

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<th>ABSL cells</th>
<th>Modules</th>
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<td>o 18650HC</td>
<td>8P VES140</td>
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<tr>
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<td>o 18650HCM</td>
<td>6S2P NL</td>
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<tr>
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In order to optimize the overall test campaign, it was decided to:
1. Perform a first test campaign on VES140 model only
2. Perform a second test campaign with the remaining cell models.

First assessment of the impact of ageing and radiations
Identification of useless tests (if any)
Possibility to add new tests
# TRP Battery Passivation - Cells and Battery abusive testing

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TRP Battery Passivation - Cells and Battery abusive testing

- **External short-circuit**
- **Internal short-circuit**
- **Overcharge**
  - Cell opening – high speed camera
- **Overdischarge**
- **High temperature**
- **Micrometeoroids debris**
External short-circuit - Assessment

Short circuits are a direct connection between the positive and negative terminals of a cell and/or battery.

- Can be caused by:
  - Faulty connections between the positive and negative terminals.
  - Conductive electrolyte leakage paths within a battery.
  - Structural failures.

- Can result in:
  - Very high current spikes that cause high pressure inside the cell resulting in venting and explosions.
  - Any hot spot may induce a fire and ejection of parts.

- Can be prevented:
  - With the use of internal protections at cell level
  - Fuses, circuit breakers, thermal switches at battery level.

3 mΩ short-circuit on VES140 Test setup

ABSL cells test setup
**External short-circuit - Results**

**General conclusions:**
Cells internal protections help limiting the maximum temperature reached as well as avoiding the generation of debris.

**SAFT cells:**
- **VES140 & VES180:** no internal protections
  - High current spikes (>1000 A)
  - High temperatures (up to 160°C)
  - Ejection of electrolyte and even the jelly roll (debris generation).
- **VES16:**
  - Circuit Breaker activation
  - Electrolyte leakage and smoke but no debris generation

**ABSL cells:**
- PTC (internal protection) is activated for all cells, limiting the temperature rise (85°C)
- No ejection of electrolyte or smoke. No debris generation.
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Internal short-circuit - Assessment

- Internal short circuits are a **direct contact** between the positive and negative materials **inside a battery cell**.
- It is a **punctual perforation of the separator** which generates a local hot spot.

**Can be caused by:**
- **Manufacturing defect.**
- **Induced internal shorts in the field:**
  - usage in **extreme thermal environments**;
  - **crash** or a failure of the fixture system

**Can result in:**
- Venting, smoke, fire and go into thermal runaway.

**Can be prevented:**
- No prevention
- Use of venting disk to mitigate the impact.

Impact of nail location and penetration depth was assessed
General Conclusions:

- No impact of the nail location on tests outcome and temperature results.
  - Fast exothermic reaction in any case

- No clear impact of ageing or depth of penetration (full or partial)
  - However, with higher nail velocity, it is suspected that the maximum temperature would be reduced as the surface for energy release would be higher.

Nail test on a VES180 cell

Nail test on a HC cell

Release of smoke
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Overcharge - Assessment

On the anode:
• **Overcharge can cause plating** that can ultimately **result in a short circuit**.

On the cathode:
• **Overcharge can cause excess removal of lithium.** The crystalline structure becomes unstable, resulting in an **exothermic reaction**.

• **Can be caused by:**
  • Charging a cell to **too high of a voltage** (over voltage overcharge).
  • Charging at **excessive currents**, but not excessive voltages.

• **Can result in:**
  • Immediate cell thermal runaway.

• **Can be prevented:**
  • With the **use of internal protections** at cell level.
  • **Fuses, circuit breakers**, thermal switches at battery level.
  • **Voltage control** at battery level.
TRP Battery Passivation - Cells and Battery abusive testing

### Overcharge - Results

**General conclusions:**

Cells *internal protections* help limiting the maximum temperature reached as well as *avoiding the generation of debris.* The worst case might not be with high currents

**SAFT cells:**
- **VES140 & VES180:** no internal protections
  - Exothermic reaction (up to 990°C), opening of the cell
  - Flames, jelly roll ejection sometimes *(debris generation)*
- **VES16:**
  - Circuit Breaker activation and *no debris generation* with overcharge at 2C and 5C
  - At higher current (10C), rapid heating, smoke and electrolyte ejection *(debris generation)*

**ABSL cells:**
- *No debris generation at any current* (2C, 5C & 10C), only a slight electrolyte leakage for some cells
- Internal protections (CID, PTC) activated
TRP Battery Passivation - Cells and Battery abusive testing

**Overcharge on Modules - Results**

**ABSL NL Modules**:  
- Overcharge at 1.5C (7.2A) - 124°C  
  Activation of the CID, limiting temperature rise
- Overcharge at C/3 (1.6A) - 1333°C  
  Activation of the CID on 1 string only

**SAFT Modules**:  
- Video
- Overcharge at C/8 (40A) - 950°C

**Battery Safety and Passivation - Clean Space Industrial Days**
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Over-discharge can cause **internal damage to electrodes and current collectors** (copper dissolution), can lead to **Cu dendrite generation** and can ultimately lead to **short-circuit**.

**Can be caused by:**
- Discharging a cell to **too low of a voltage**.

**Can result in:**
- **Exothermic reaction** linked to the copper reduction-oxidation reaction, no thermal runaway since there is almost no electric charge.

**Can be prevented:**
- No prevention at cell level
- Voltage control at battery level.
**TRP Battery Passivation - Cells and Battery abusive testing**

**General conclusions:**
- No safety issues identified during over-discharge.
- Discharging to positive voltage or 0V damage the cell but it is still possible to recharge the cell even after one month at 0V.
- Discharging to negative voltage reverse the cell (not possible to recharge the cell).

**VES16 cells**
- VES16 BOL
- VES16 Cycled and Irradiated

**HCM 6S2P module**
- Cycling (10 cycles)
- 3h rest - relaxation
- Charge and Over-discharge
- Over-discharge through a resistance during one month

**Min Voltage at End Of Discharge - String 2 cells**
- Some cells are damaged
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TRP Battery Passivation - Cells and Battery abusive testing

High Temperature - Assessment

- Operating at high temperatures helps increasing the reaction rate, leading to higher I²R heat dissipation and thus even higher temperatures.

- Can result in:
  - Cell thermal runaway.
  - Separator melting and decomposition,
  - Hot surface ignition of flammable mixtures, there must be sufficient oxygen in the surrounding environment to sustain combustion
  - Cell contents may be ejected.

- Can be prevented:
  - With the use of Internal Protective Devices.
  - Low SOC, the ambient environmental temperature, the electrochemical design of the cell and the mechanical design of the cell.
  - Ageing reduces carbon reactivity leading to more thermally stable cell

VES140 & VES180 cells test setup
High Temperature - Assessment

- **ARC testing (Accelerating Rate Calorimetry)**

  Objective: analyse the **thermal behaviour** of the cells under adiabatic conditions in order to identify the **non-self-heating, self-heating and thermal runaway regions** for each cell model as a function of the **state of charge** and the **state of health**.

  - **N2 flow**: 0.1L/min
  - **Cells is charged up to desired SoC**
    - 100% - 50% - 0% SoC and 0V
  - **Temperature is increase gradually until a thermal runaway appears. Stop heating.**
    - **Temperature step**: 5°C
    - **Temperature rate sensitivity**: >0.02°C/min. = onset point of exothermic reaction
    - **End temperature**: 180°C
    - **Safety temperature rate**: 3°C/min. (test stop)
• The onset point decreases when SOC increases.

• Contrary to what one might think, ageing and radiation impact is not clear.

• VES140 and VES180 cells have lower onset point temperature than VES16 and ABSL cells.

• VES16 and ABSL cells could go up to 100°C at 100% SoC without going into thermal runaway.

• VES16 cells at 0% SoC or 0V do not go into thermal runaway (safe at every temperature up to 210°C).
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Micrometeoroids - Assessment

- Micrometeoroids impact can be associated to a mechanical damage (crush or penetration).
- Can be caused by:
  - Micrometeoroid and/or debris impact.
- Can result in:
  - Internal short circuit (low impedance shorting between the current collectors) likely to cause cell thermal runaway.
- Can be prevented:
  - With the mechanical design of the cell, battery and/or spacecraft.

An aluminum ball of 8mm diameter is projected three different location of the cell. Its mass is 0.72 – 0.73 g and its speed is above 1000 m.s-1
Micrometeoroids - Conclusion

• Aluminum ball enters into the cell but **does not cross the cell**.

• Consequence: **internal short-circuit** involving an important **increase of temperature** (360°C - 660°C), **sparks, smokes** and **emissions of particles**.

• VES140 debris tests ended with the ball located inside (no pass through the cell) and reached **similar temperatures than the internal short-circuit tests**.

• Equivalent debris for small cells would destroy the cells due to their size.
Battery Safety and Passivation
Conclusions

Assessment of passivation strategies in order to ensure battery safety at end-of-life.

At battery level

- **Discharge** the battery as much as possible at the EoM.
- Connect it to a **bleed resistance** and **disconnect it from the bus**.
- Cell **internal protections** are an asset.
- Develop **safer** batteries: solid electrolyte, casings, inter-cells material...

At satellite level

- Assess the most probable attitude once the satellite is uncontrolled.
- Determine the best possible way to reduce the satellite temperature: spin it!