DEFENCE AND SPACE

Battery Safety and Passivation

ESA CleanSpace Industrial Days

Mathilde Aouizerate – Airbus Defence & Space
ESTEC – 23rd October

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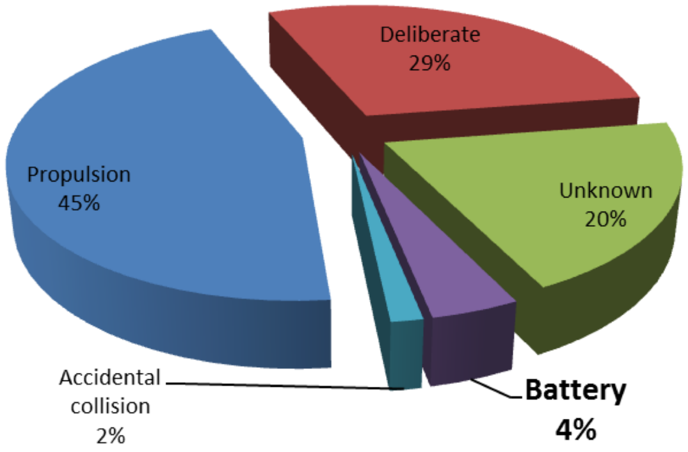
Why are we talking today about Battery Passivation?

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



Main objective: avoid **space debris** generation

Goals:

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

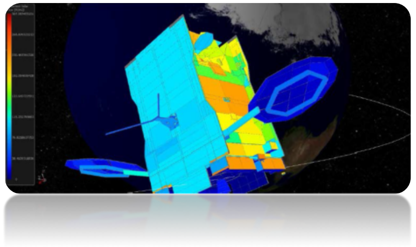
CNES Passivation/Fin de vie du sous-système de puissance

ESA GSTP Spacecraft Power System Passivation

CNES Battery Passivation regarding LOS constraints

2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

2008: French law LOS (Loi d'Opérations Spatiales) applicable to satellites launched after 2020 from



ESA TRP Battery Passivation

CNES ABSL End-of-Life

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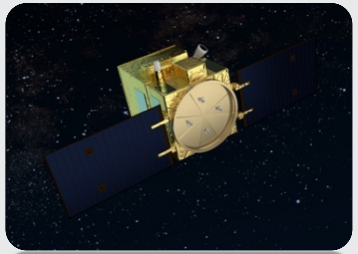
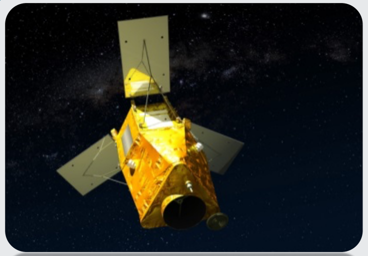
GSTP Spacecraft Power System Passivation

Battery thermal analysis

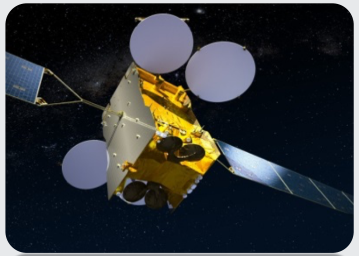
- Three different cases have been studied:



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

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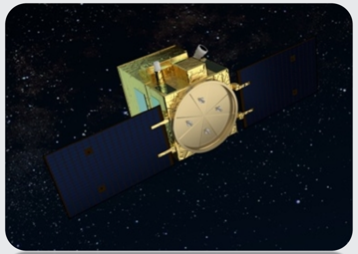
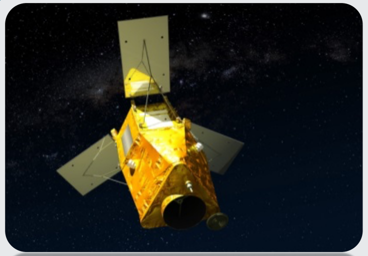
GSTP Spacecraft Power System Passivation

Battery thermal analysis

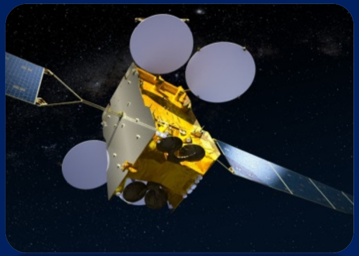
- Three different cases have been studied:



A **LEO** spacecraft with <u>external</u> battery
AstroBus-S platform



A **LEO** spacecraft with <u>internal</u> battery
Astrobus-M or AS250 platform



A **GEO** satellite
E3000 platform

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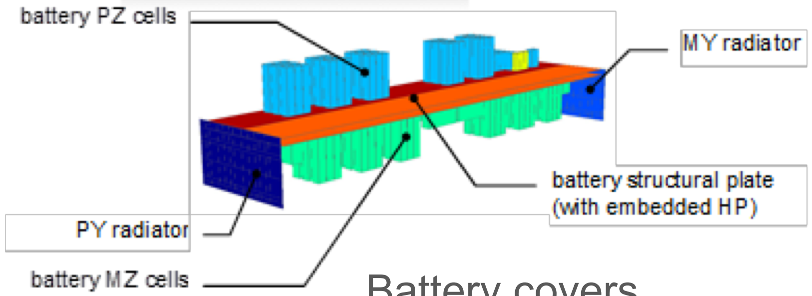
GSTP Spacecraft Power System Passivation

Battery thermal analysis

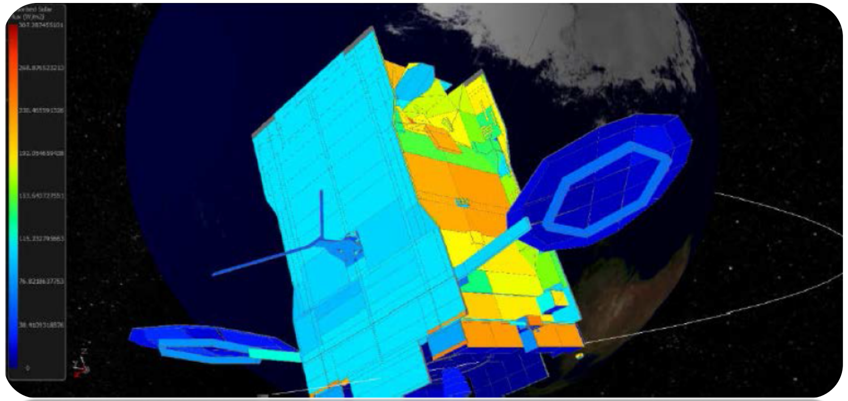
- Three different cases have been studied

A **GEO** satellite
E3000 platform



<u>Battery covers</u>

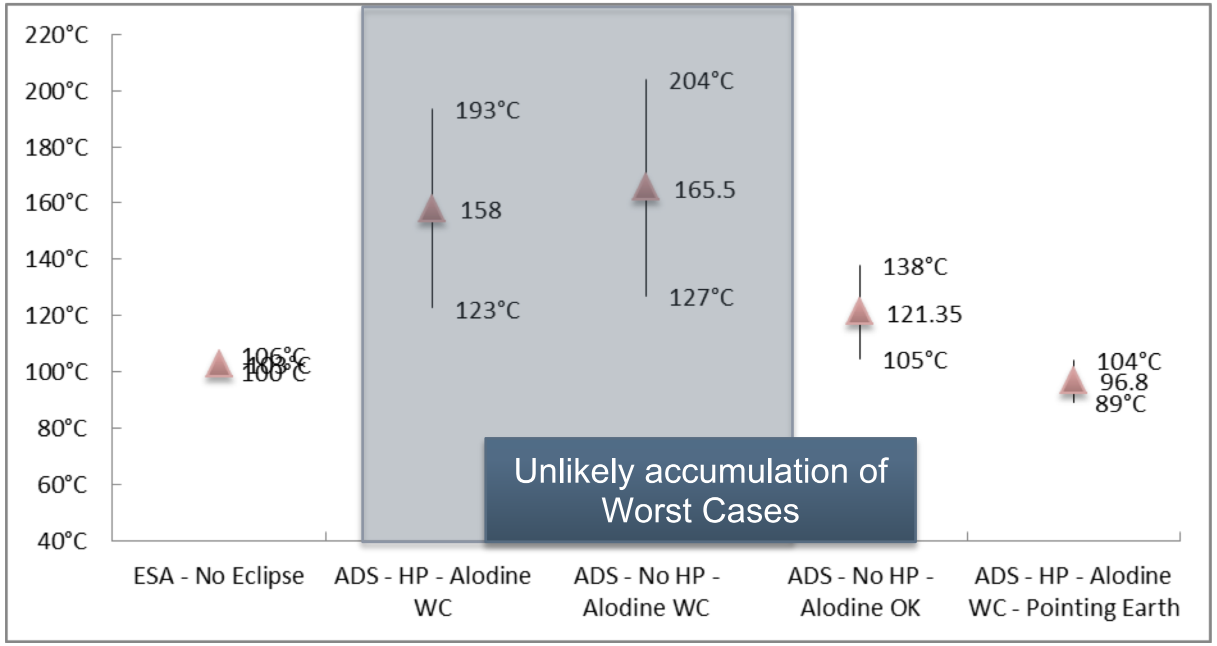
- MLI completely torn off – Unlikely?
- Absorptivity degraded to 1 - Possible
- Heatpipes failure - Unlikely
- Internal MLI remains intact - Likely



*Thermal Analysis with Systema/ **Airbus DS***

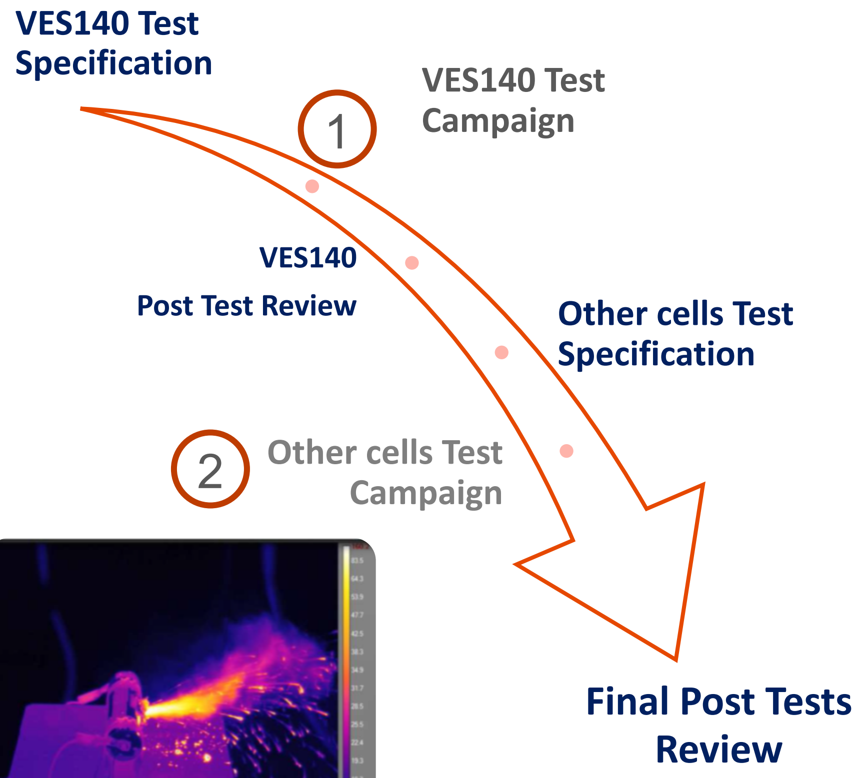
Assumptions :

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



TRP Battery Passivation

Space cells and Battery abusive testing



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

SAFT cells	ABSL cells	Modules
○ VES140	○18650HC	8P VES140
○ VES180	○18650HCM	6S2P NL
○ VES16	○18650NL	6S2P HCM

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**

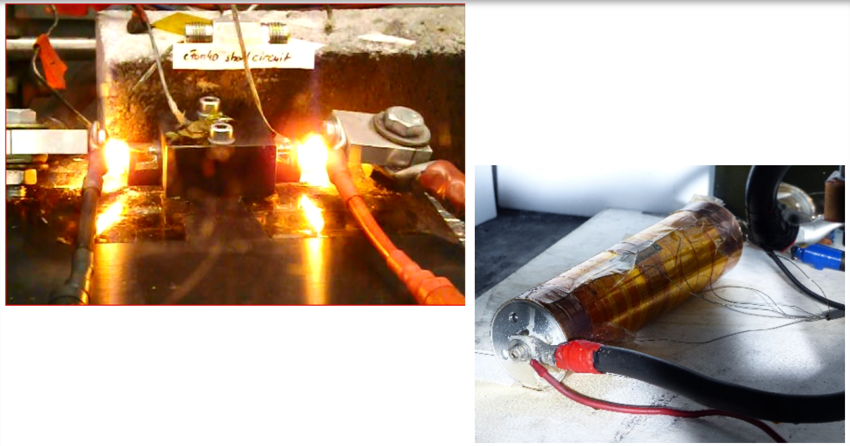
✓ Identification of **useless tests** (if any)

✓ Possibility to **add new tests**

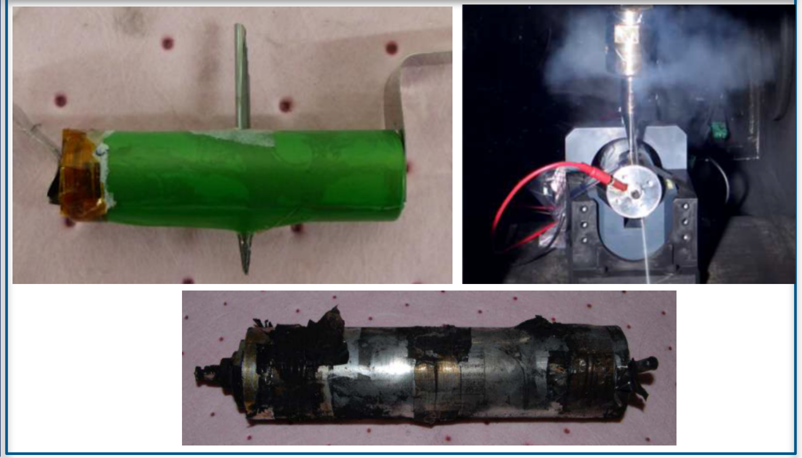
saft ABSL cea AIRBUS

TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit

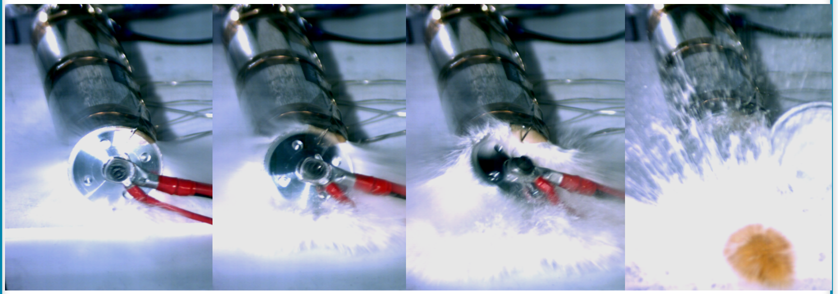


Internal short-circuit



Overcharge

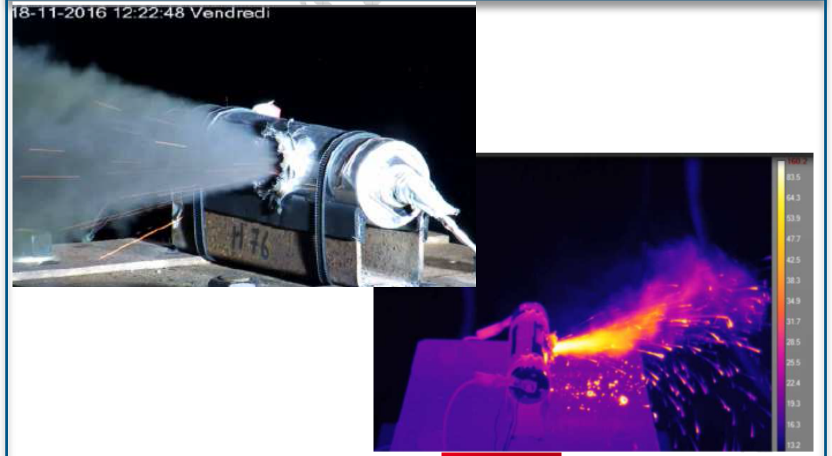
Cell opening – high speed camera



Overdischarge

High temperature

Micrometeorids debris



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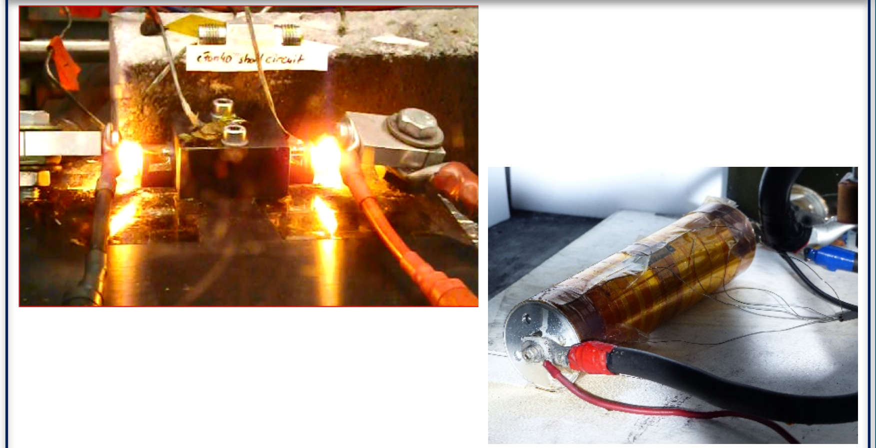
TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit



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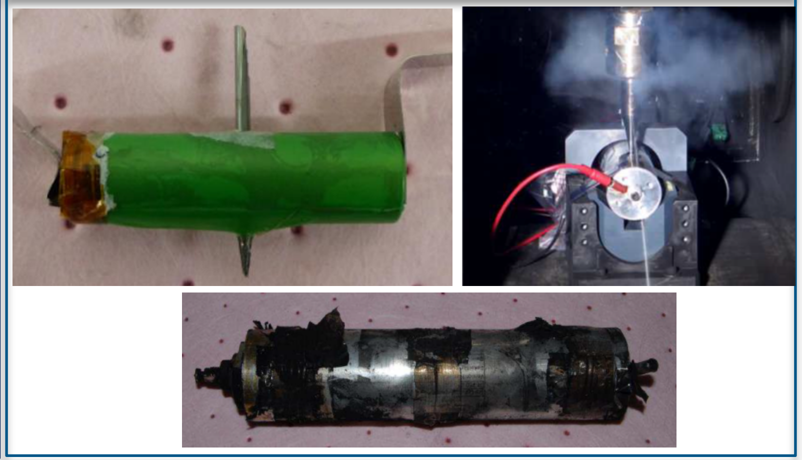
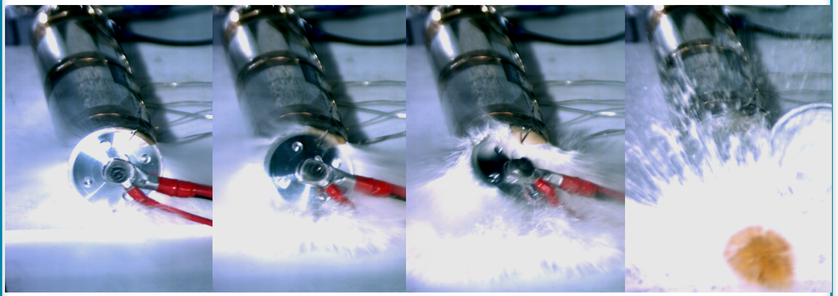


Overcharge

Cell opening – high speed camera



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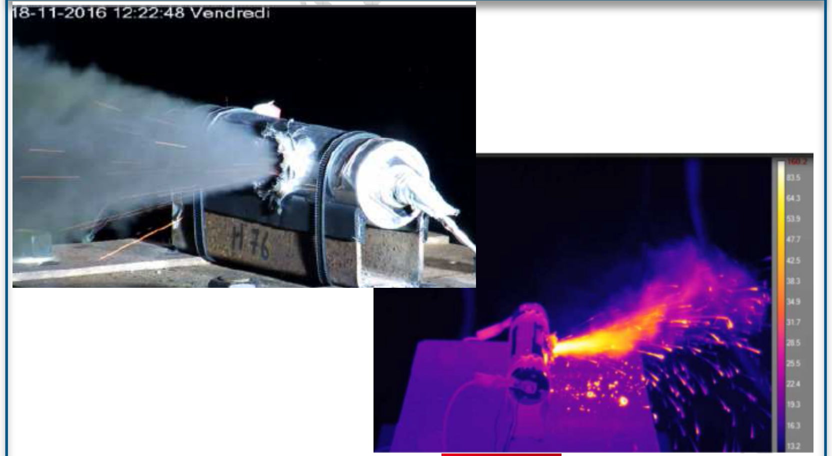
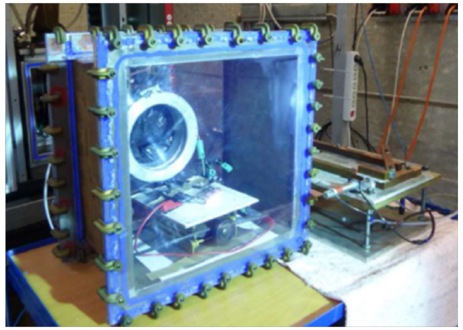


TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit - Assessment

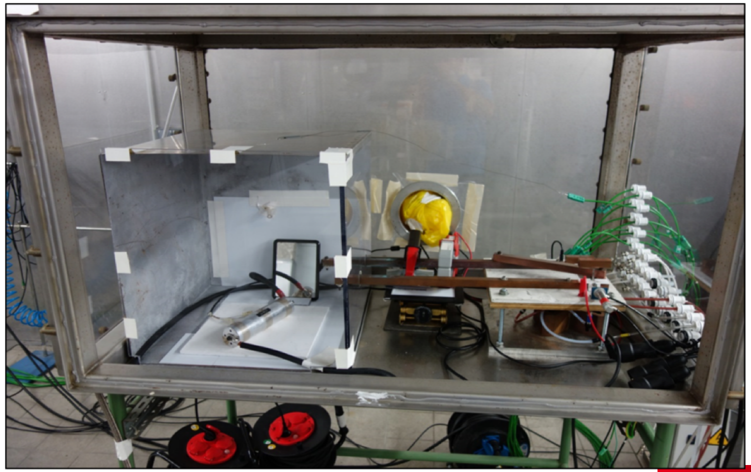
Short circuits are a **direct connection between the positive and negative terminals** of a cell and/or battery.

- <u>Can be caused by:</u>
    - **Faulty connections** between the positive and negative terminals.
    - **Conductive electrolyte leakage** paths within a battery.
    - **Structural failures**.
- <u>Can result in:</u>
    - **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.
- <u>Can be prevented:</u>
    - With the **use of internal protections** at cell level
    - **Fuses**, **circuit breakers**, thermal switches at battery level.



ABSL cells test setup

3 mΩ short-circuit on VES140 Test setup



TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit - Results

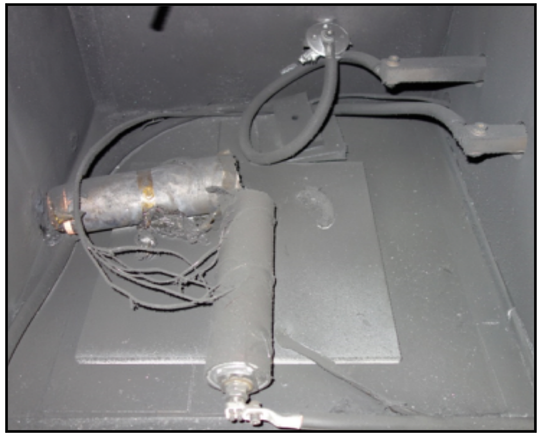
<u>**General conclusions**</u>:
Cells **internal protections** help **limiting the maximum temperature** reached as well as **avoiding the generation of debris**.

SAFT cells:

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

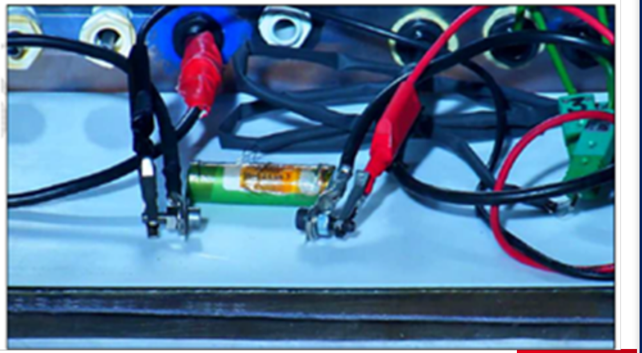
ABSL cells:

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



3 mΩ short-circuit on VES140

100 mΩ short-circuit on HCM cell



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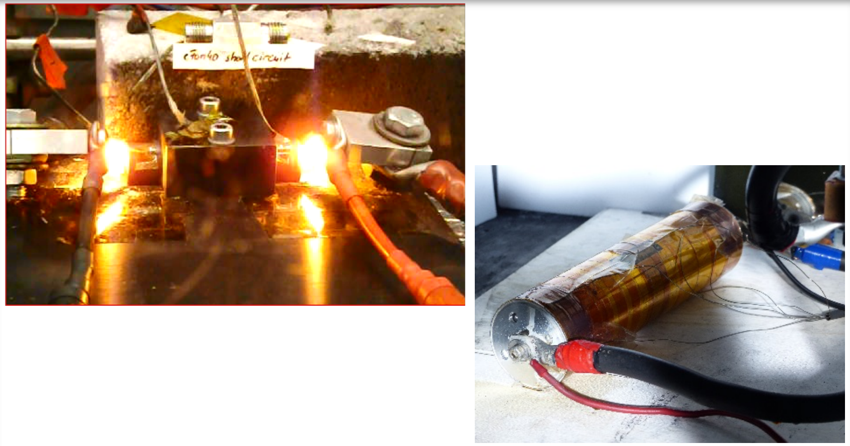
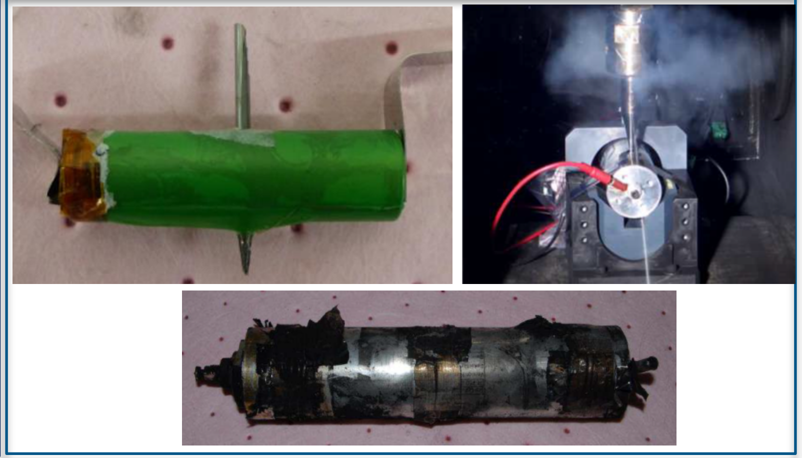
TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit

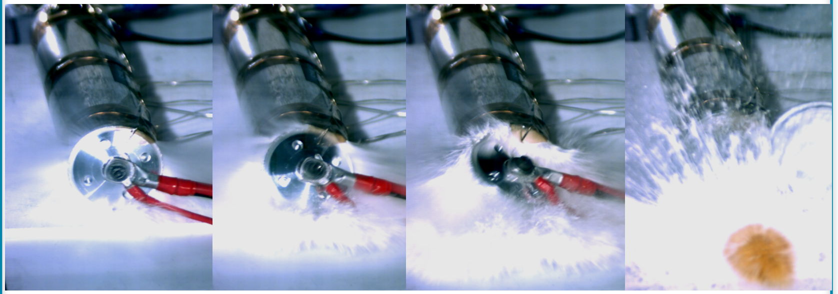


Internal short-circuit



Overcharge

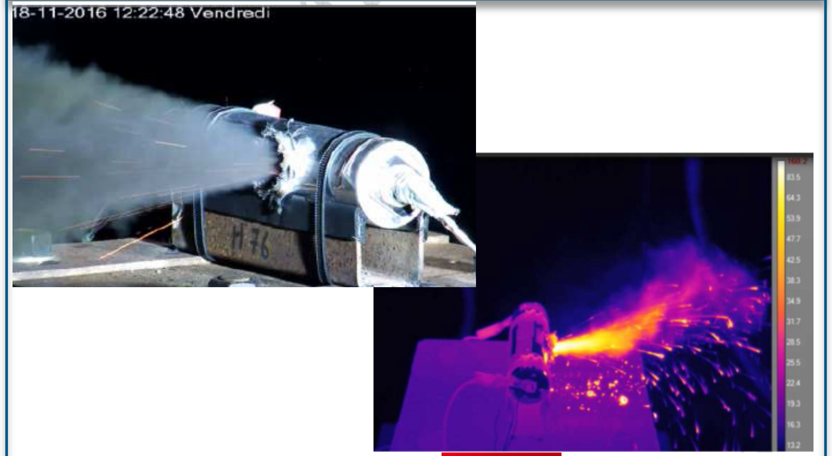
Cell opening – high speed camera



Overdischarge

High temperature

Micrometeorids debris



TRP Battery Passivation - Cells and Battery abusive testing

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

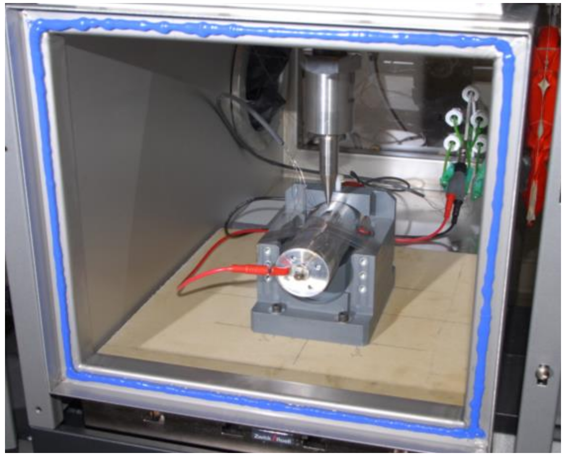
•Can result in:

- Venting, smoke, fire and go into thermal runaway.

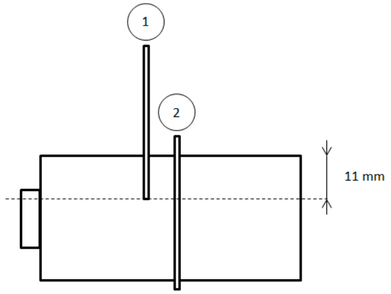
•Can be prevented:

- No prevention
- Use of venting disk to mitigate the impact.

VES140 Test setup



ABSL cells test setup



Impact of nail location and penetration depth was assessed

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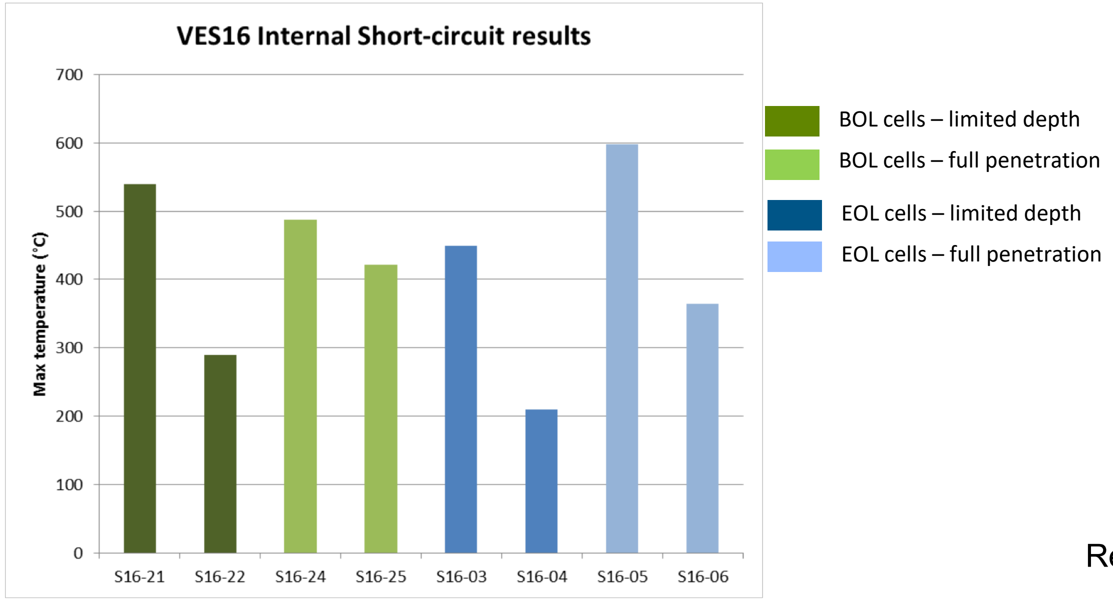
TRP Battery Passivation - Cells and Battery abusive testing

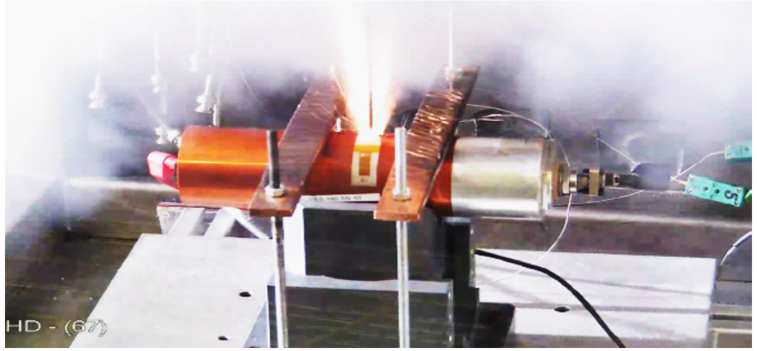
Internal short-circuit - Assessment

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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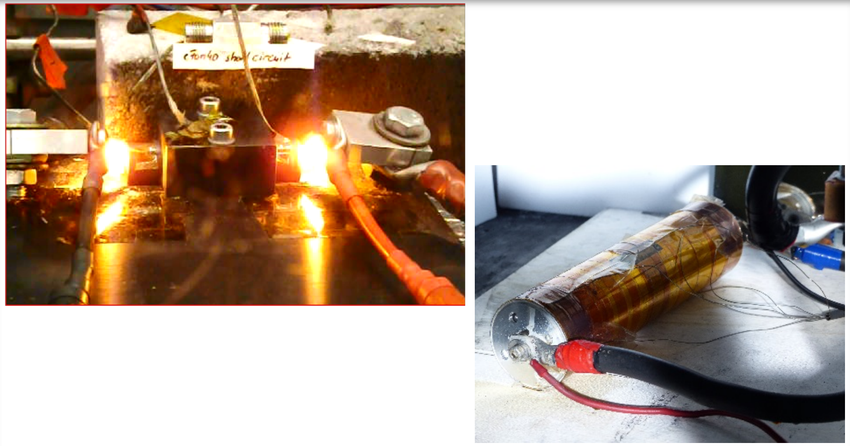
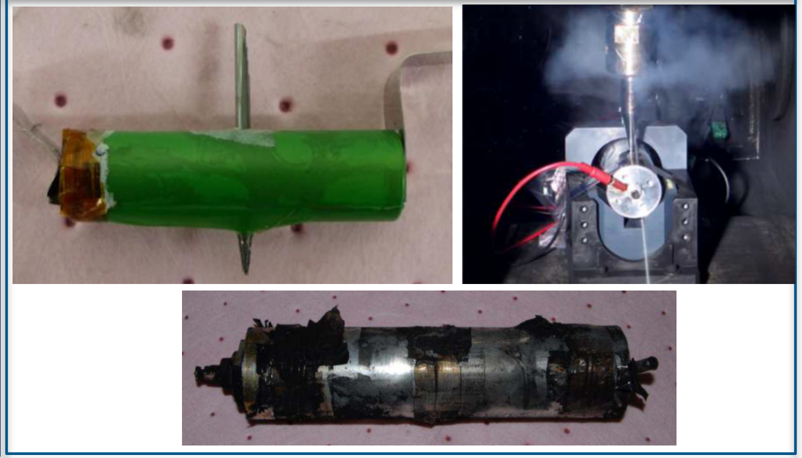
TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit

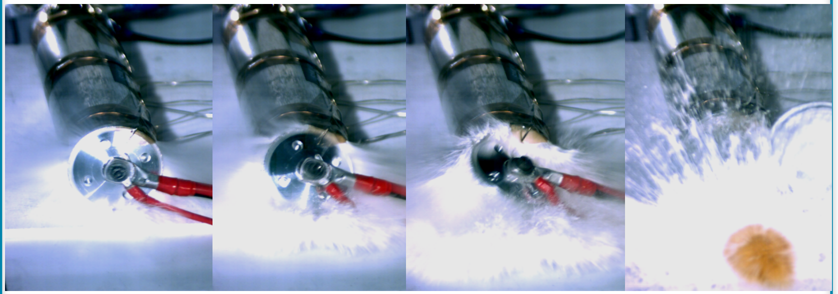


Internal short-circuit



Overcharge

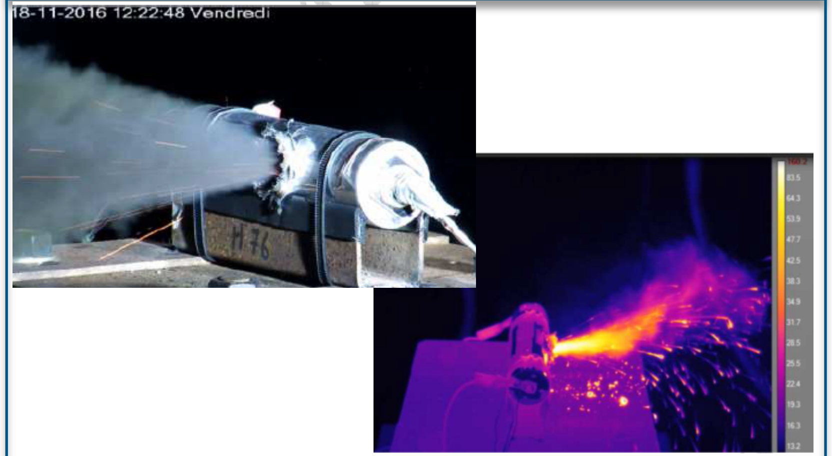
Cell opening – high speed camera



Overdischarge

High temperature

Micrometeorids debris



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TRP Battery Passivation - Cells and Battery abusive testing

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:

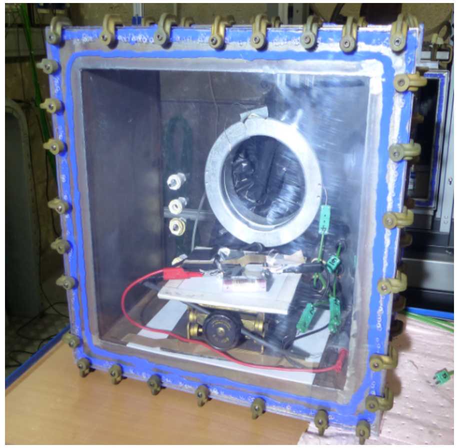
- Charging a cell to **too high of a voltage** (over voltage overcharge).
- Charging at **excessive currents**, but not excessive voltages.

•Can result in:

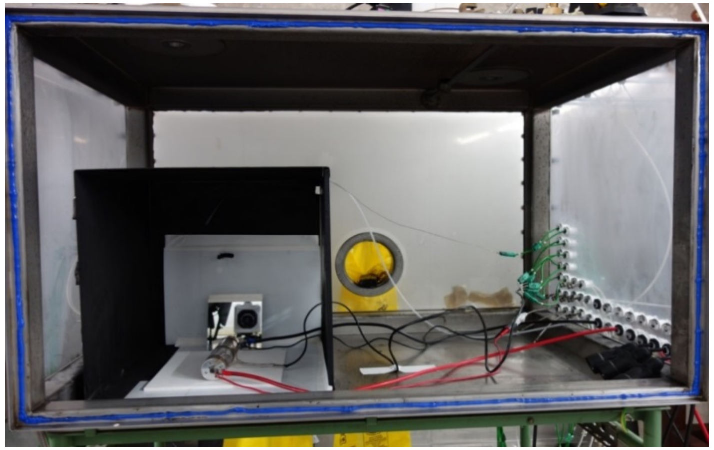
- **Immediate cell thermal runaway**.

•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.



VES16 & ABSL cells - Test setup



VES140 & VES180 cells test setup

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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

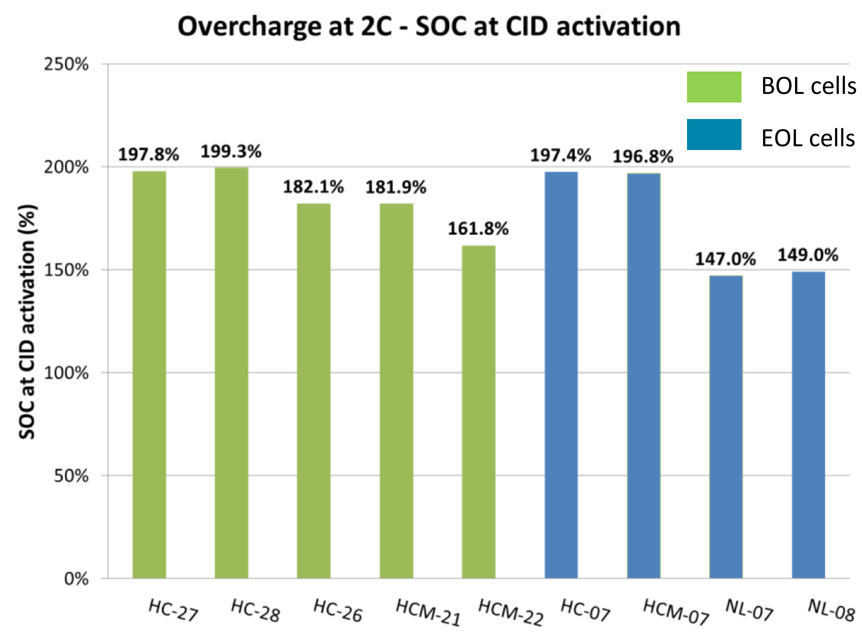
VES140 cell after overcharge at 1C

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



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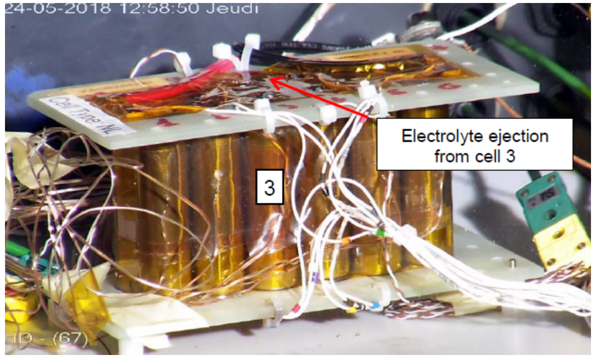
TRP Battery Passivation - Cells and Battery abusive testing

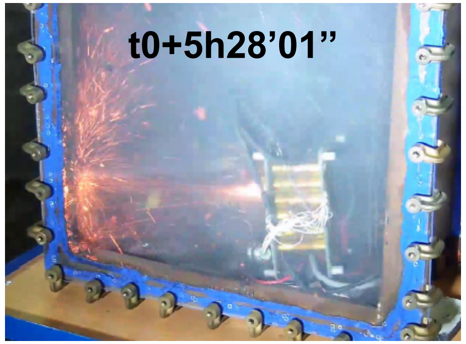
Overcharge on Modules - Results

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

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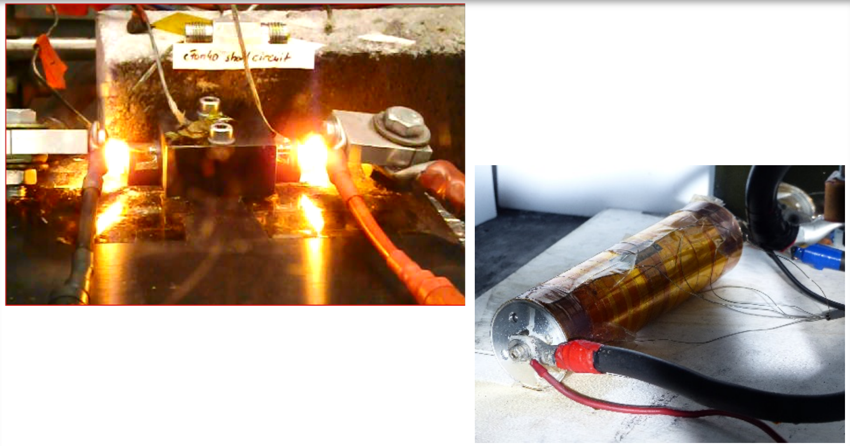
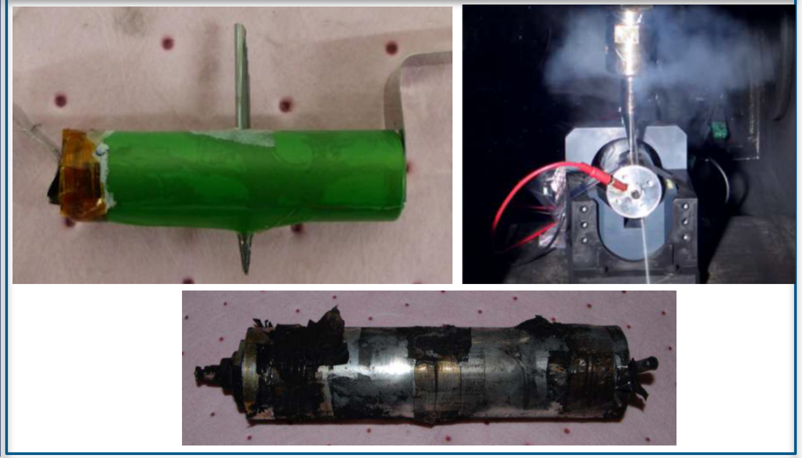
TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit

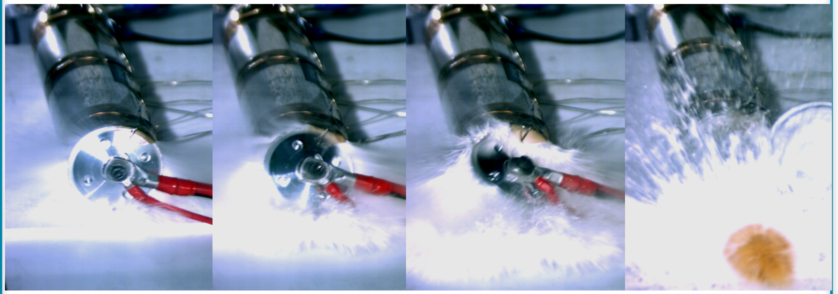


Internal short-circuit



Overcharge

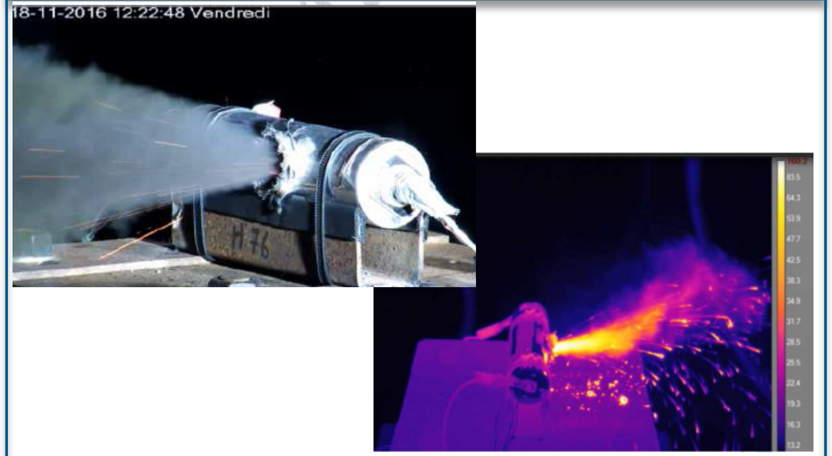
Cell opening – high speed camera



Overdischarge

High temperature

Micrometeorids debris



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TRP Battery Passivation - Cells and Battery abusive testing

Over-discharge - Assessment

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:

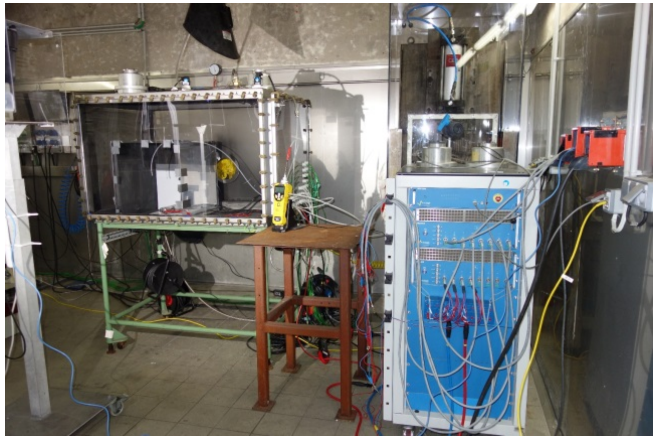
- •Discharging a cell to **too low of a voltage**.

•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.



VES140 cells - Test setup

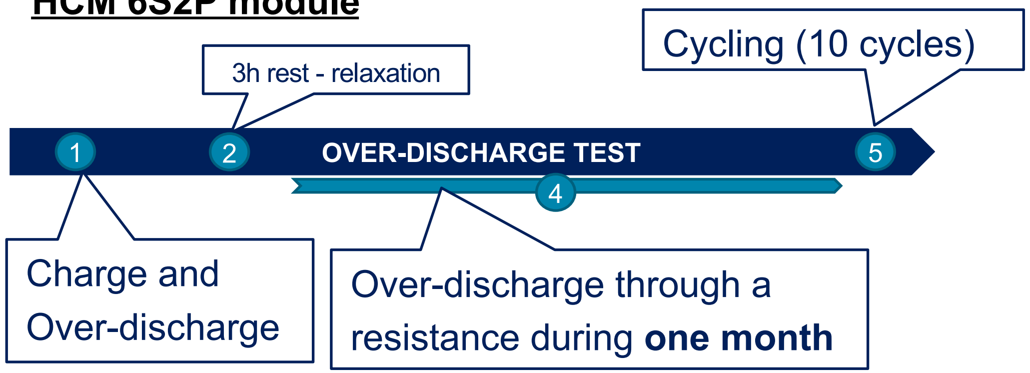
Other cells Test setup

TRP Battery Passivation - Cells and Battery abusive testing

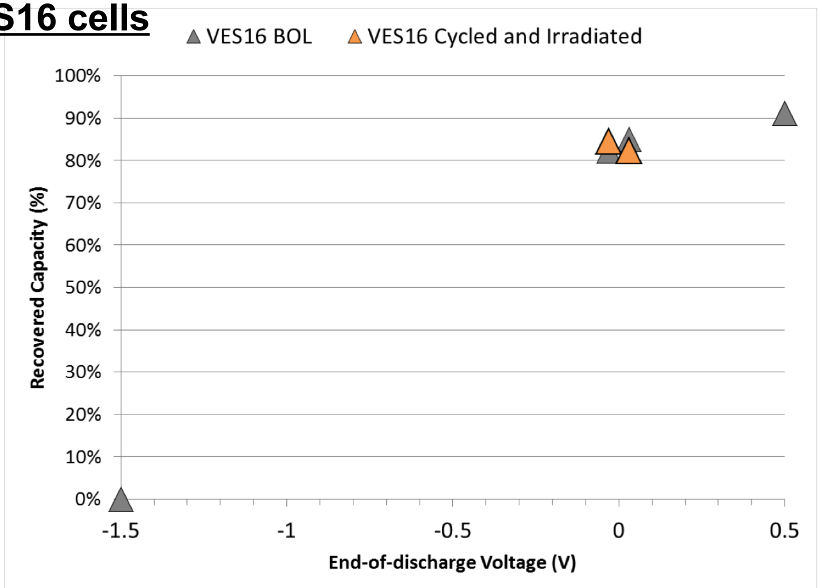
Over-discharge - Results

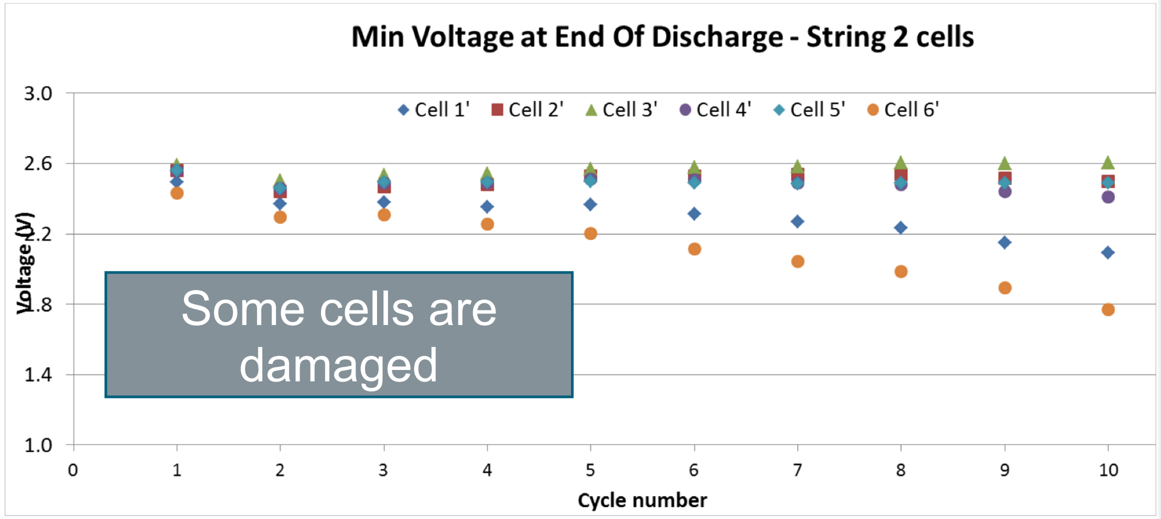
General conclusions:
- No safety issues identified during over-discharge.
- Discharging to positive voltage or 0V damage the cell but it is still possible to recharge the cell even after one month at 0V
- Discharging to negative voltage reverse the cell (not possible to recharge the cell)

HCM 6S2P module



VES16 cells





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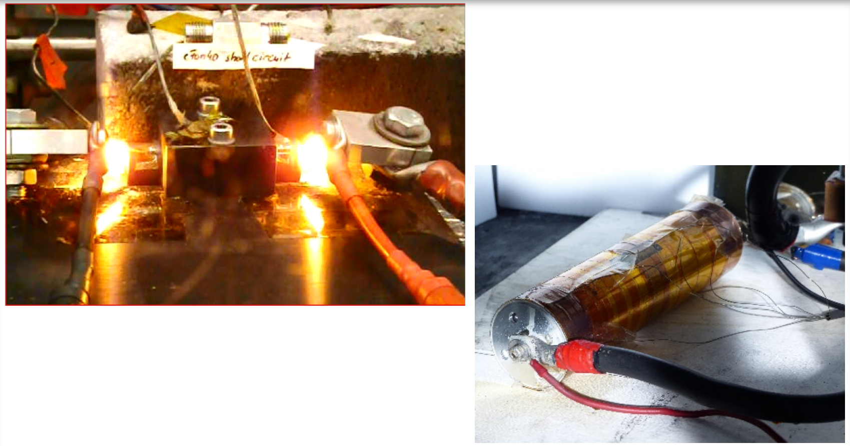
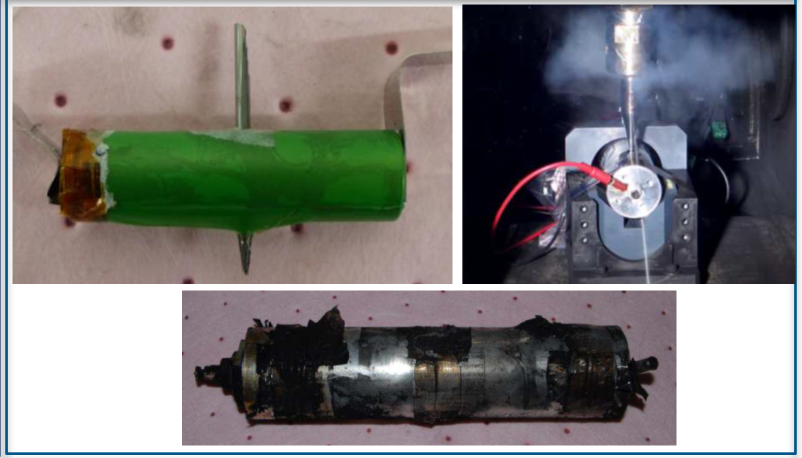
TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit

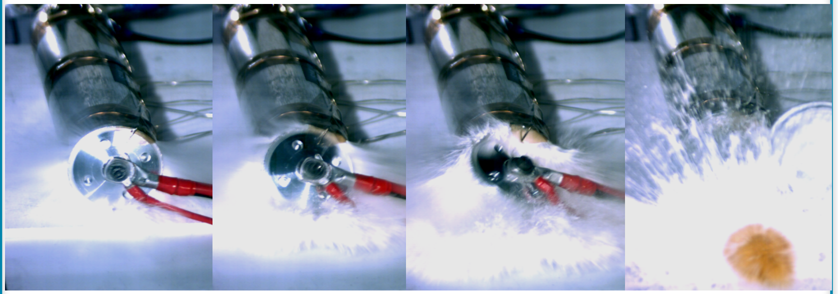


Internal short-circuit



Overcharge

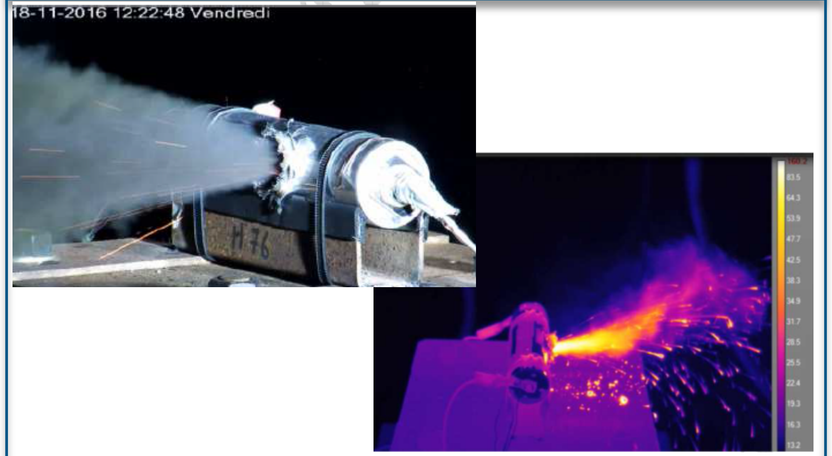
Cell opening – high speed camera



Overdischarge

High temperature

Micrometeorids debris



TRP Battery Passivation - Cells and Battery abusive testing

High Temperature - Assessment

- Operating at high temperatures helps **increasing the reaction rate**, leading to **higher I^2R 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

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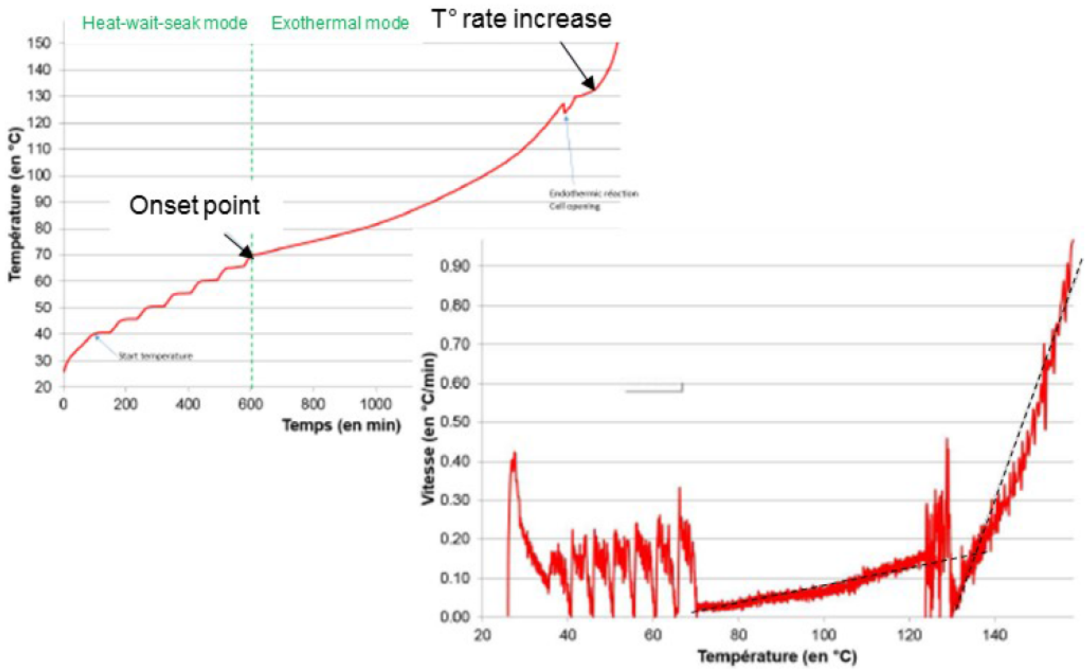
TRP Battery Passivation - Cells and Battery abusive testing

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)

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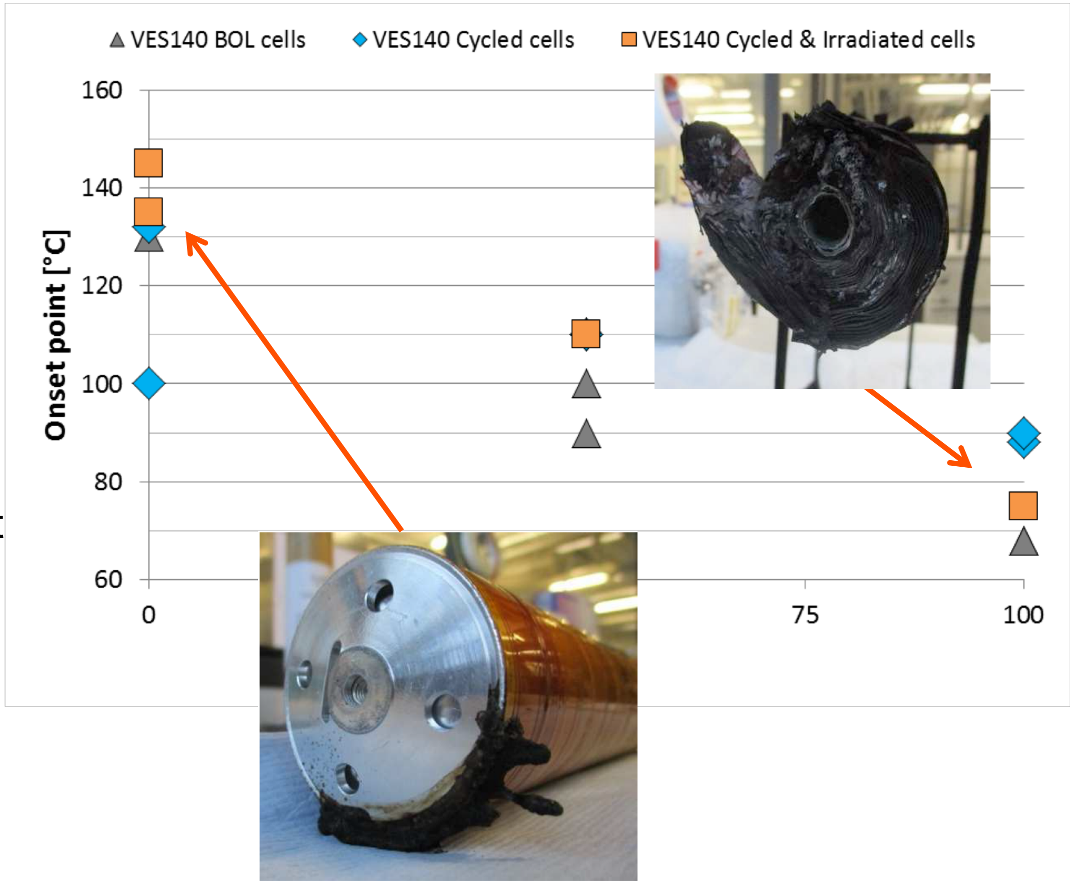
TRP Battery Passivation - Cells and Battery abusive testing

High Temperature - Conclusions

- **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)

VES140 cells – Onset point



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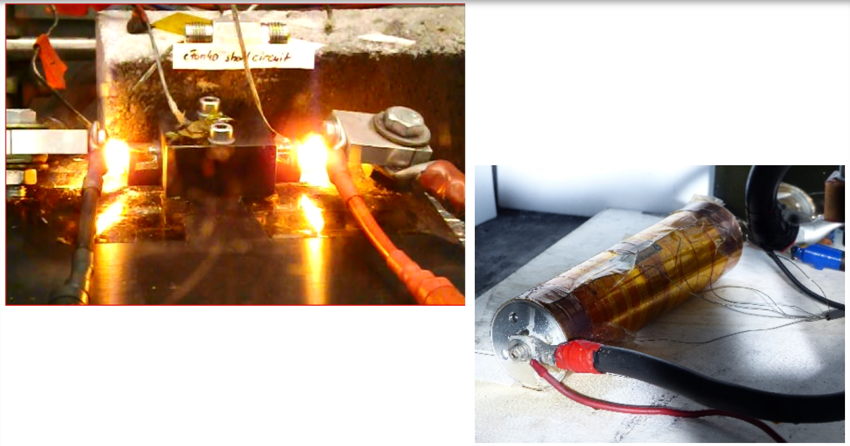
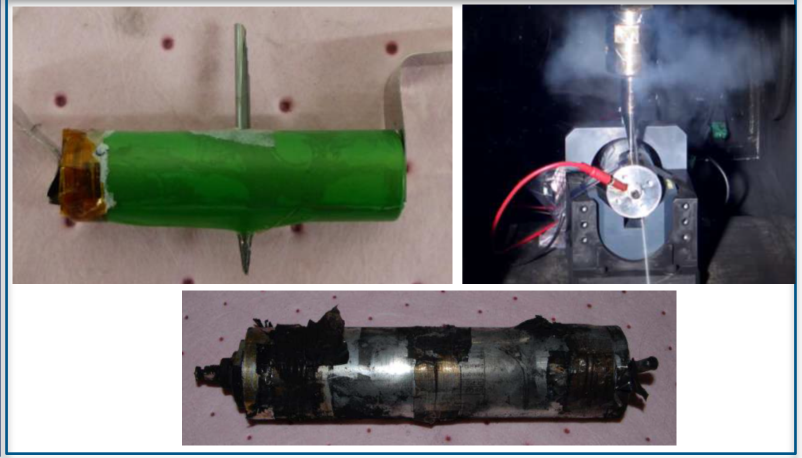
TRP Battery Passivation - Cells and Battery abusive testing

External short-circuit

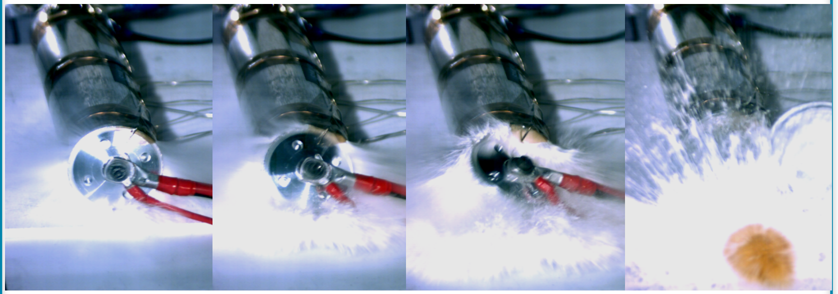


Internal short-circuit



Overcharge

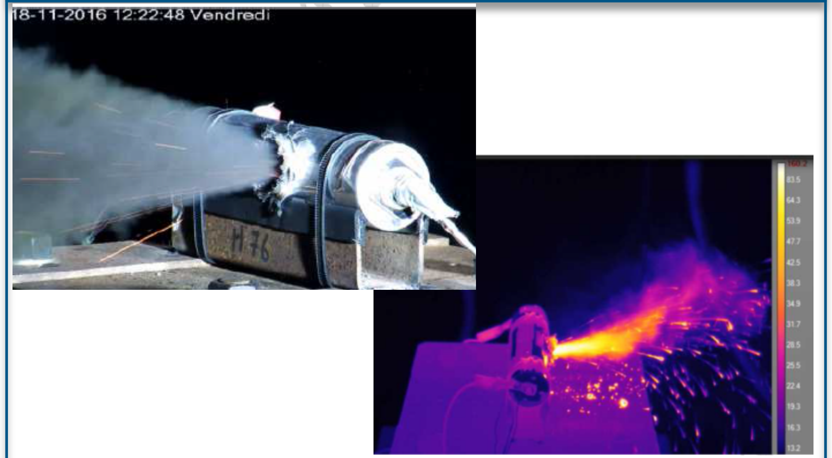
Cell opening – high speed camera



Overdischarge

High temperature

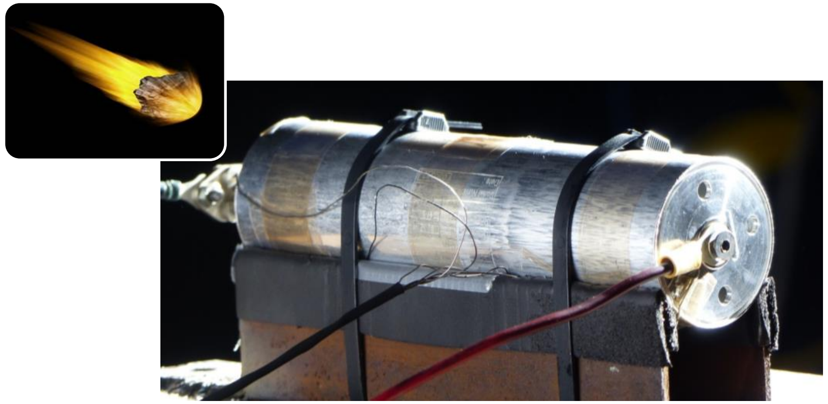
Micrometeorids debris



TRP Battery Passivation - Cells and Battery abusive testing

Micrometeorids - 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

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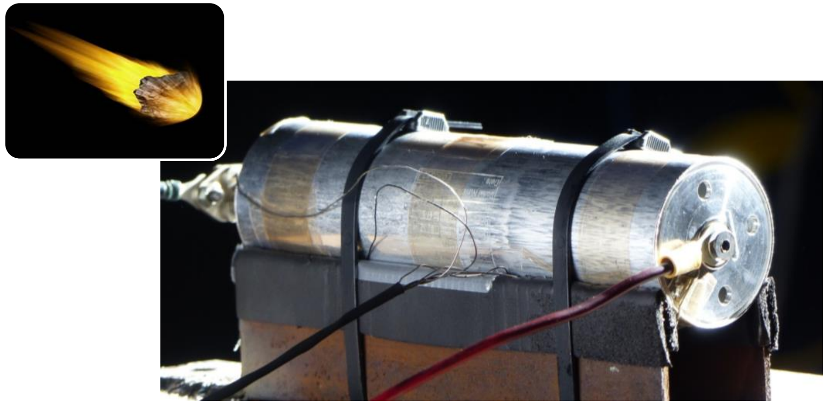
TRP Battery Passivation - Cells and Battery abusive testing

Micrometeorids - 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.



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

Video

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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!