DEFENCE AND SPACE

# D6 - Final Presentation

## Battery Passivation

ELEC.ENG.PRS.2018.1000070464.ADS

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

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# Battery Safety and Passivation

## ESA CleanSpace Industrial Days

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

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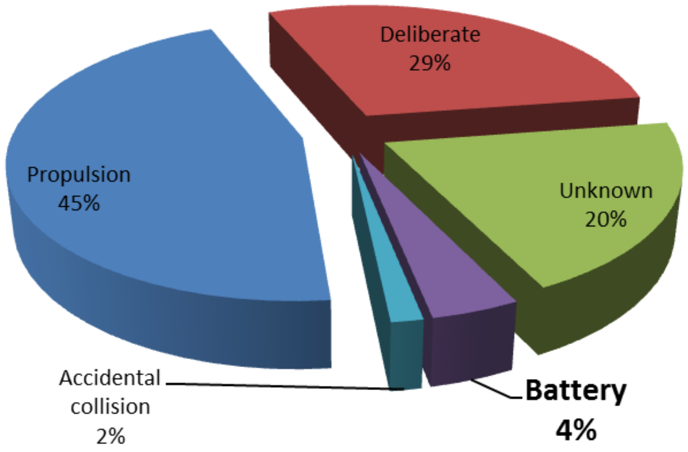
# Why are we talking today about Battery Passivation?

*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**

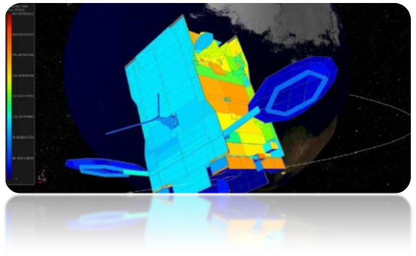
**CNES** Passivation/Fin de vie du sous-système de puissance

**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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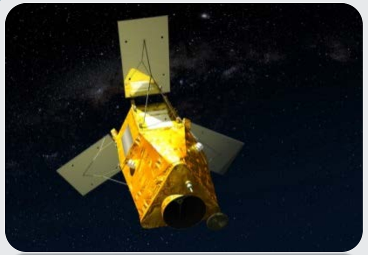
# GSTP Spacecraft Power System Passivation

## 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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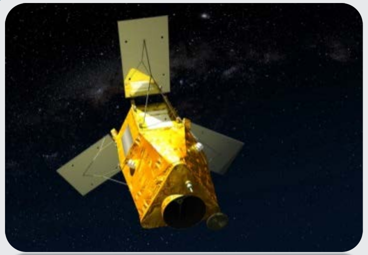
# GSTP Spacecraft Power System Passivation

## 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**

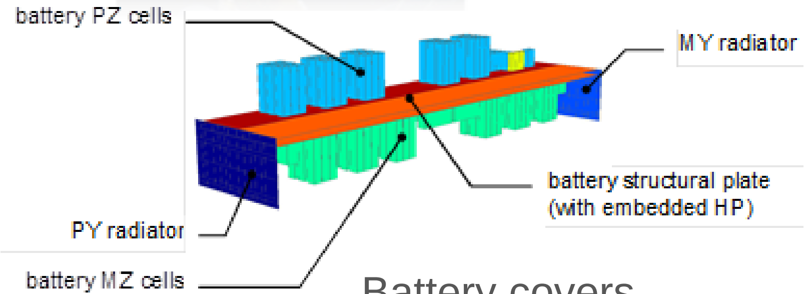
A **GEO** satellite
**E3000 platform**

# GSTP Spacecraft Power System Passivation

## Battery thermal analysis

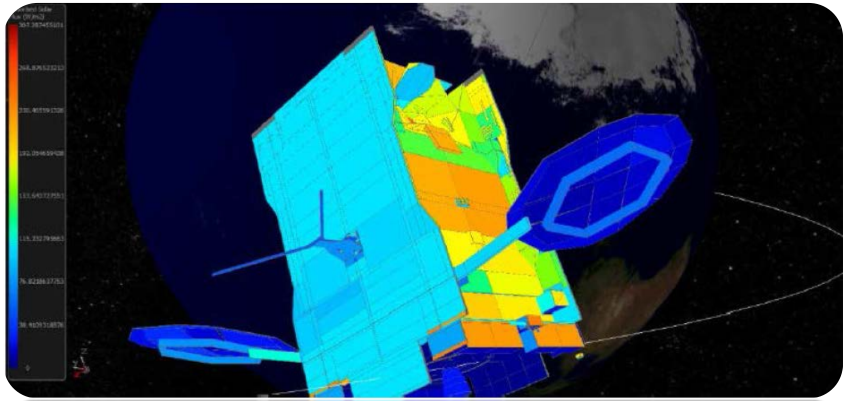
- Three different cases have been studied

A **GEO** satellite
**E3000 platform**




Battery covers

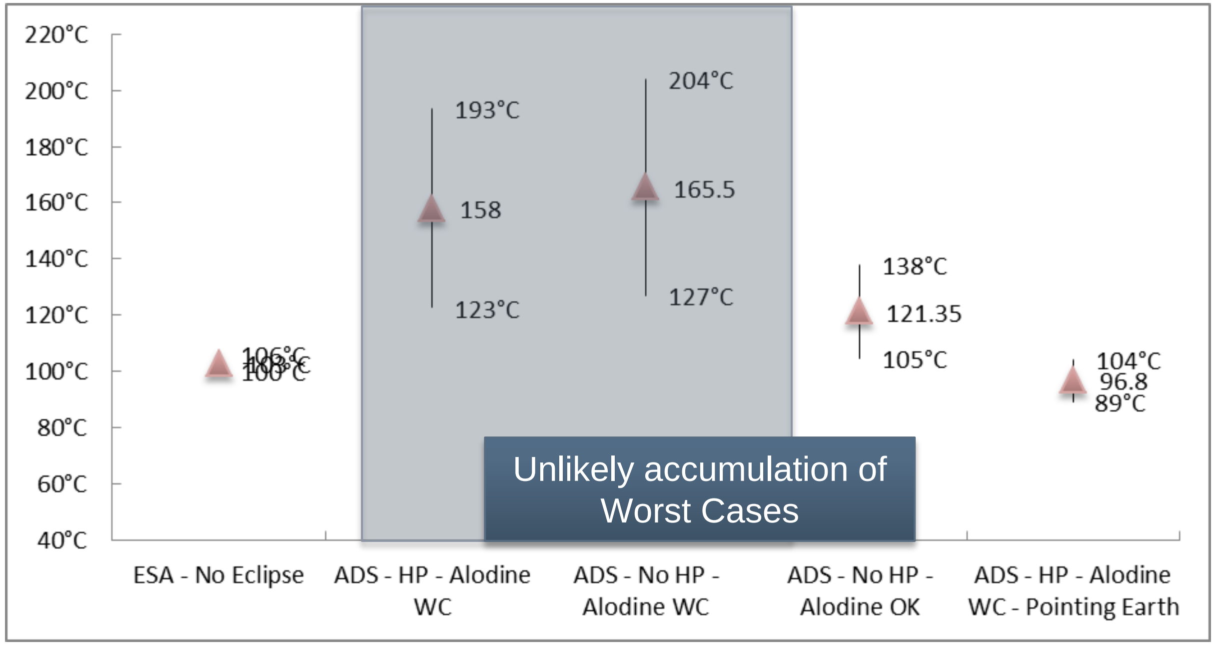
- MLI completely torn off – Unlikely?
- Absorptivity degraded to 1 - Possible
- Heatpipes failure - Unlikely
- Internal MLI remains intact - Likely



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

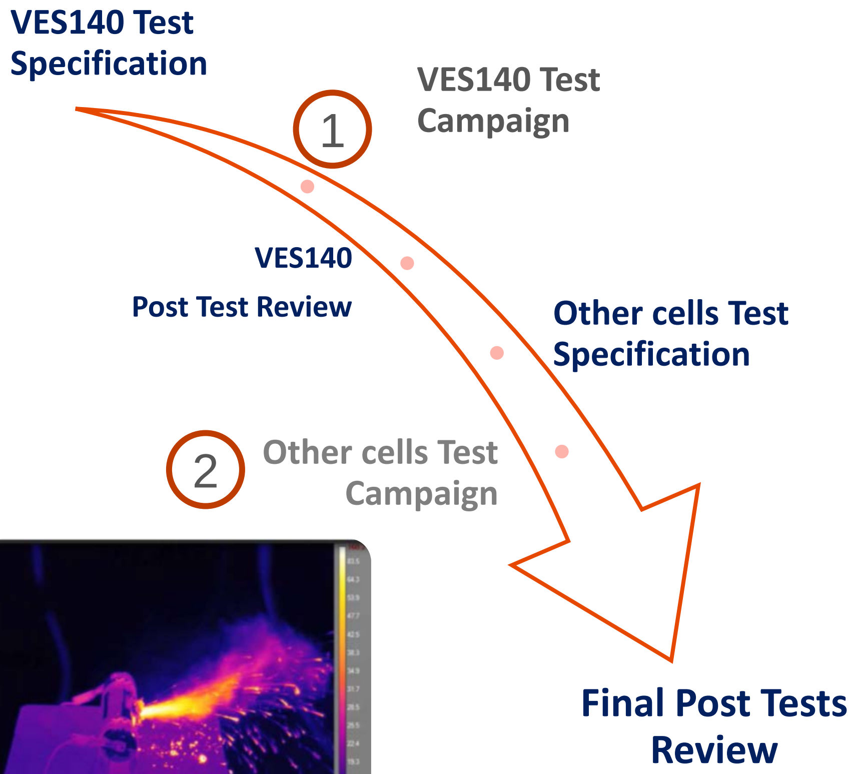
**Assumptions :**

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



# TRP Battery Passivation

## Space cells and Battery abusive testing




<u>Objective of the study:</u>

To test Li-Ion battery cells and modules under extreme conditions encountered after spacecraft disposal in order to assess their safety

→ <u>Abusive tests</u> on 200+ SAFT and ABSL space cells

| SAFT cells | ABSL cells | Modules |
| --- | --- | --- |
| o VES140 | o18650HC | 8P VES140 |
| o VES180 | o18650HCM | 6S2P NL |
| o VES16 | o18650NL | 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**



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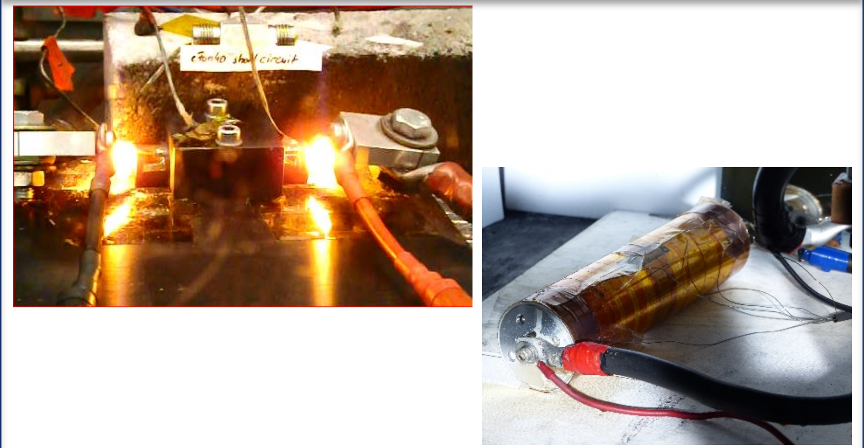
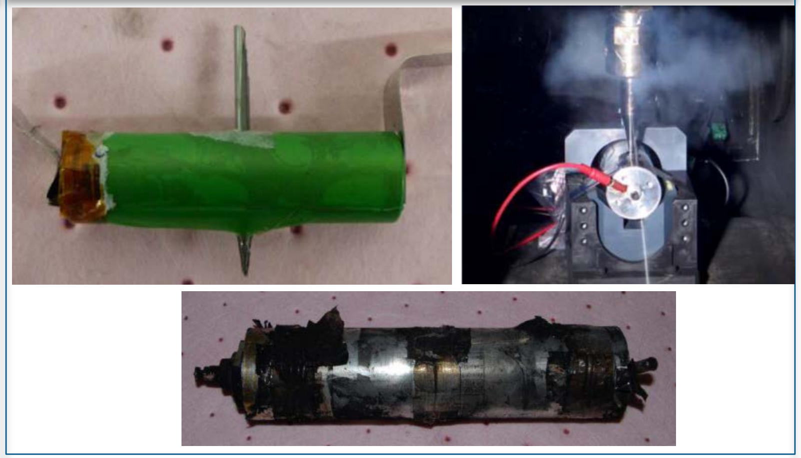
# TRP Battery Passivation - Cells and Battery abusive testing

## External short-circuit

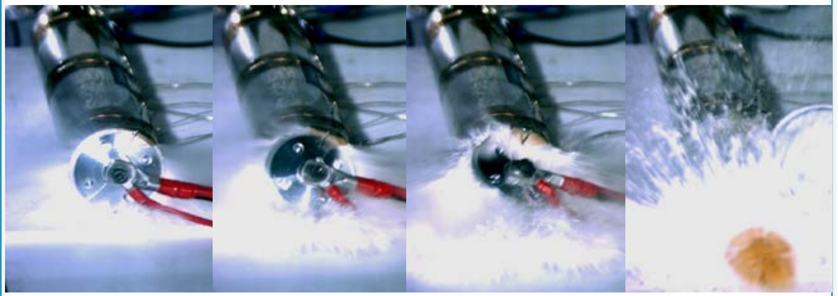


## Internal short-circuit



## Overcharge

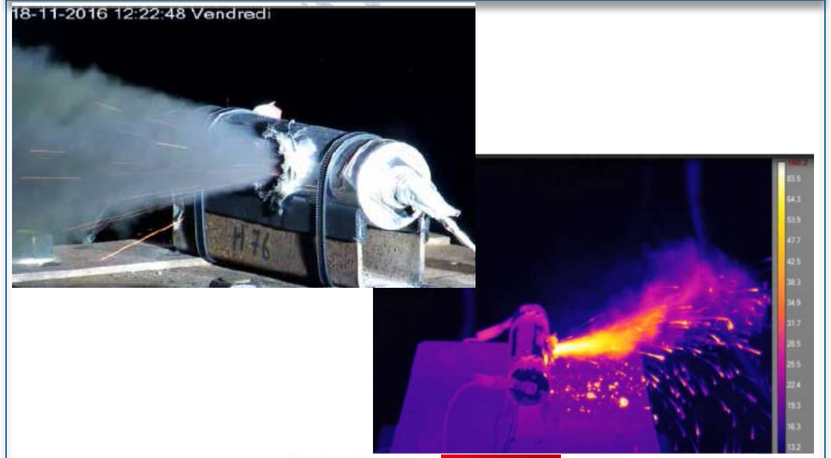
Cell opening – high speed camera



## Overdischarge

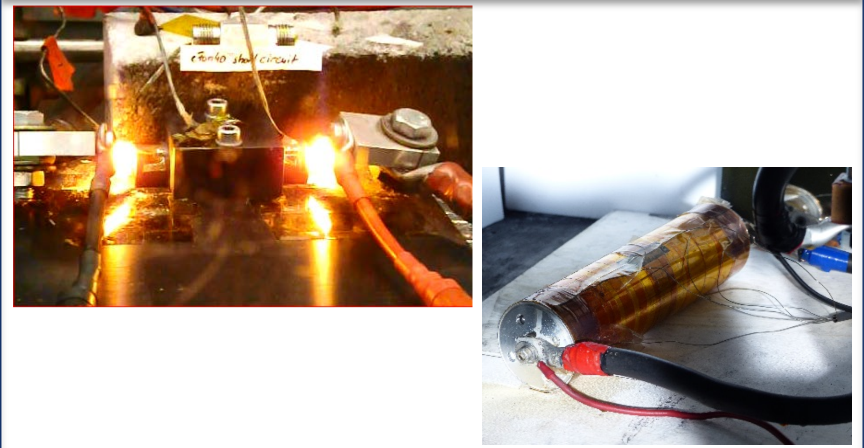
## High temperature

## Micrometeorids debris



# TRP Battery Passivation - Cells and Battery abusive testing

## External short-circuit



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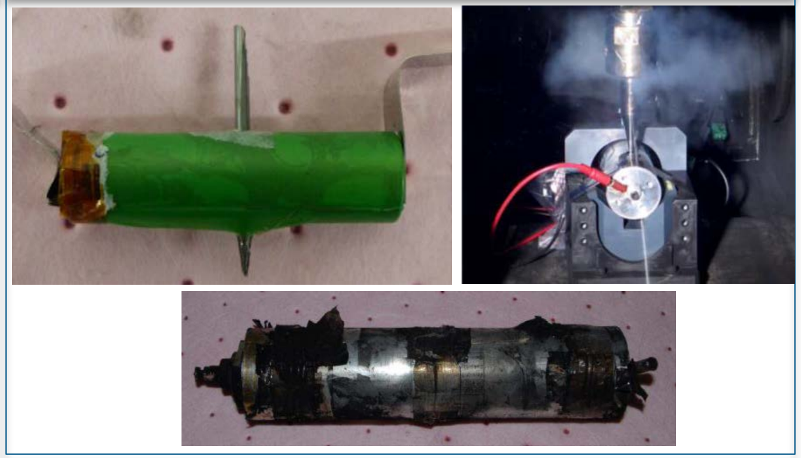

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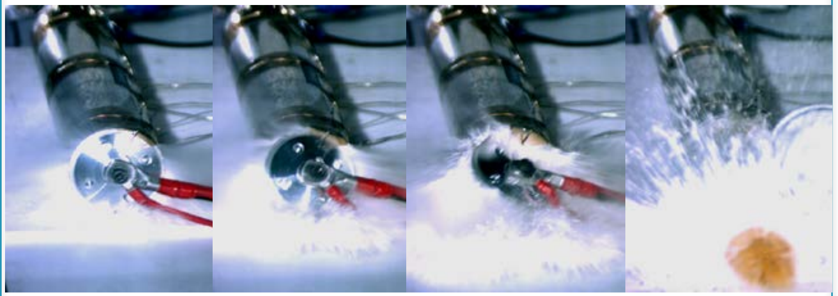

## Overdischarge

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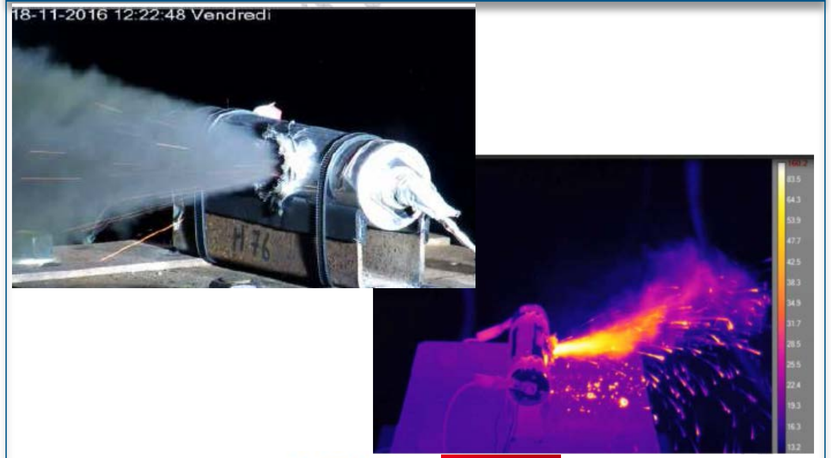
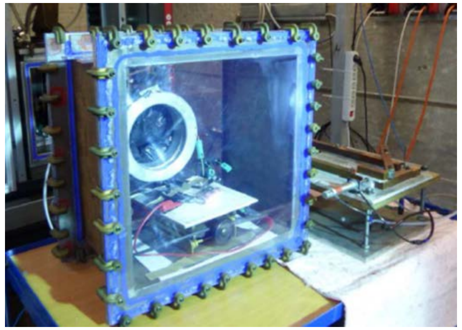


# TRP Battery Passivation - Cells and Battery abusive testing

## 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**



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# TRP Battery Passivation - Cells and Battery abusive testing

## 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**:

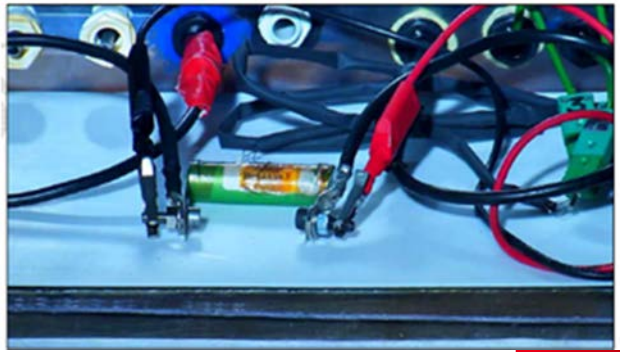
- VES140 & VES180: no internal protections
  - → High current spikes (>1000 A)
  - → High temperatures (up to 160°C)
  - → Ejection of electrolyte and even the jelly roll (**debris generation**).
- VES16:
  - → Circuit Breaker activation
  - → Electrolyte leakage and smoke but **no debris generation**

**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.**

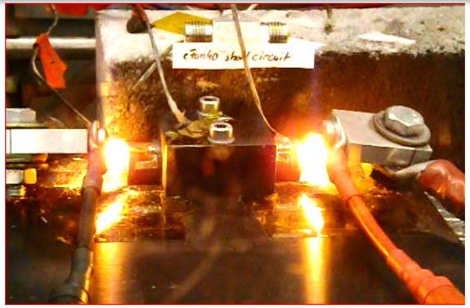
**3 mΩ short-circuit on VES140**

**100 mΩ short-circuit on HCM cell**

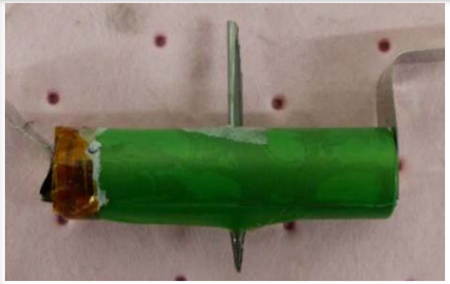


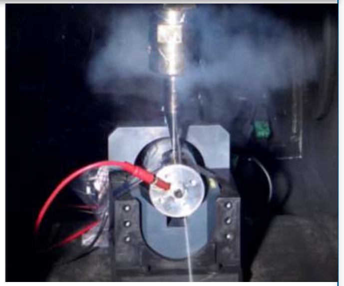
# TRP Battery Passivation - Cells and Battery abusive testing

## External short-circuit



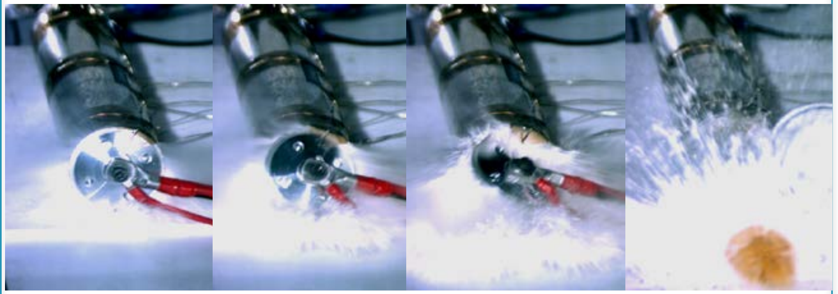
## Internal short-circuit



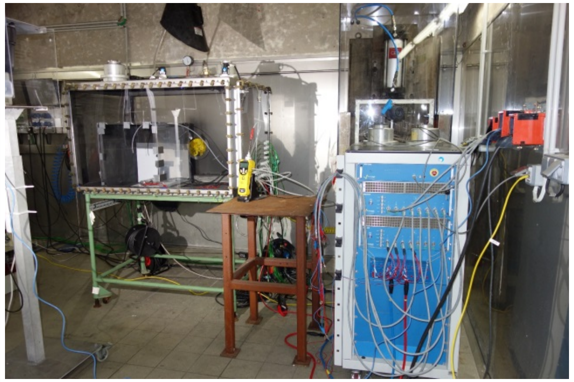


## Overcharge

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

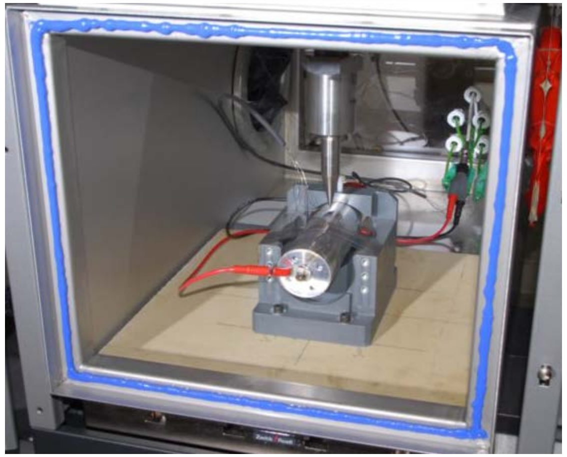
•Can result in:

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

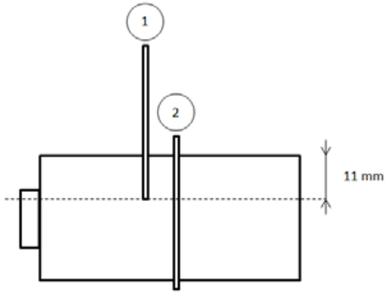
•Can be prevented:

- 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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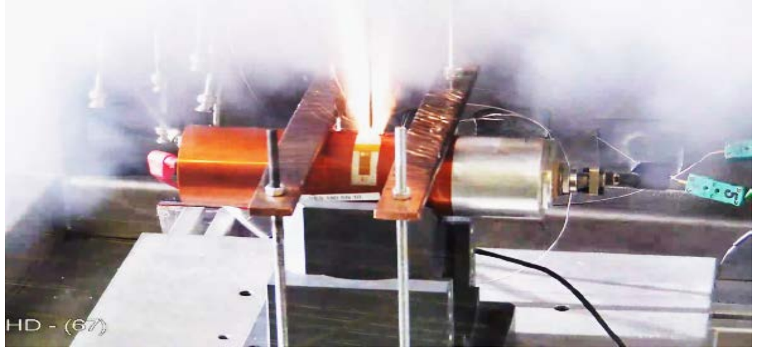
# TRP Battery Passivation - Cells and Battery abusive testing

## Internal short-circuit - Assessment

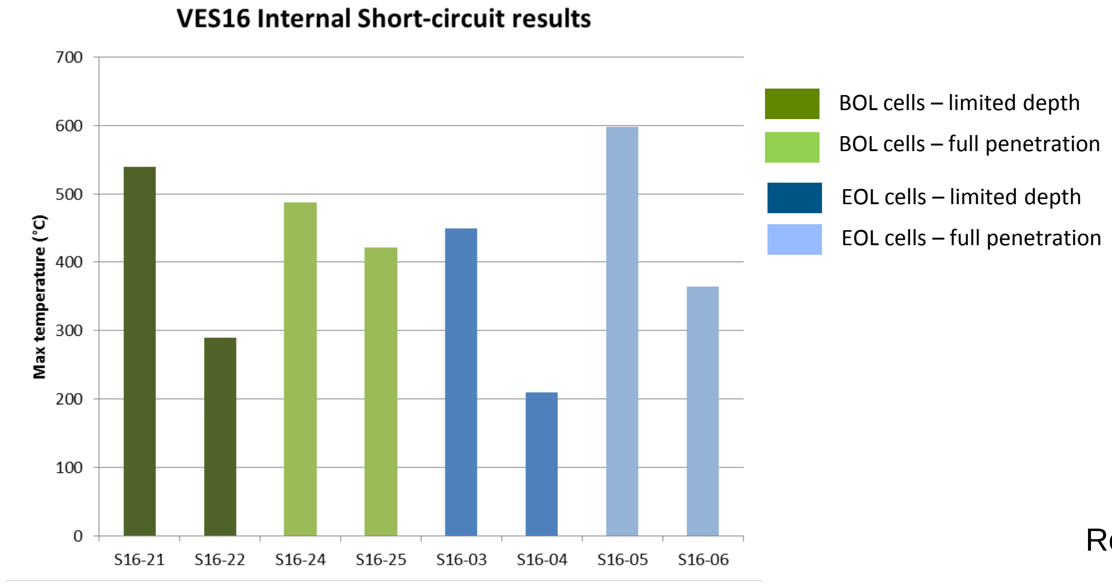
**General Conclusions:**

- 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**

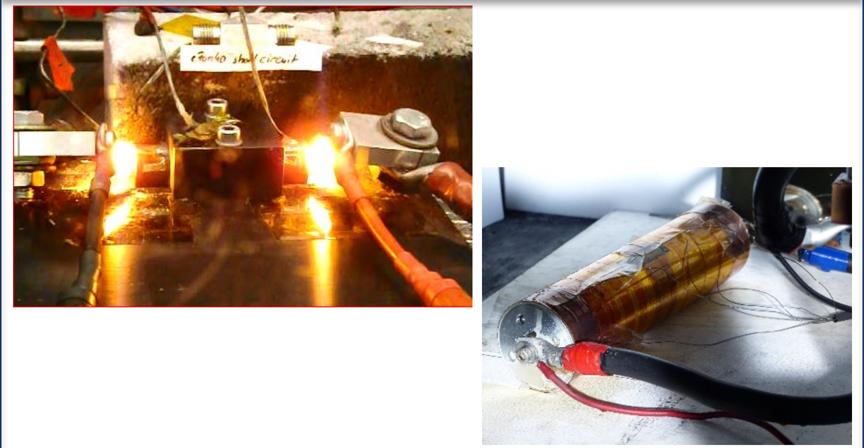




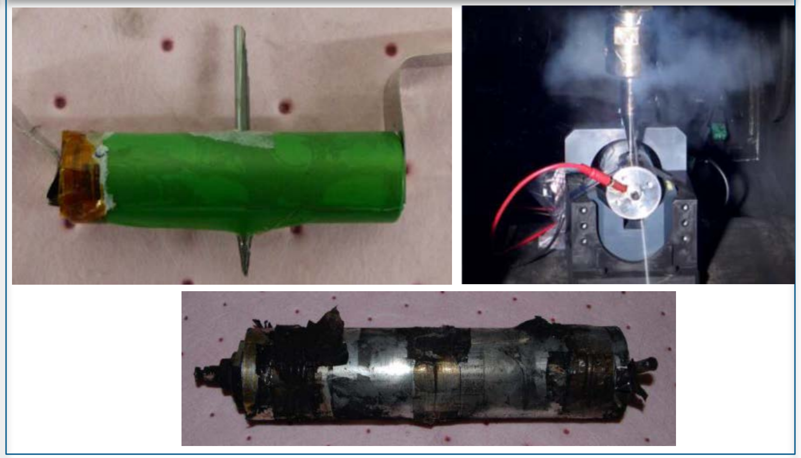
**Nail test on a HC cell**
Release of smoke

# TRP Battery Passivation - Cells and Battery abusive testing

## External short-circuit

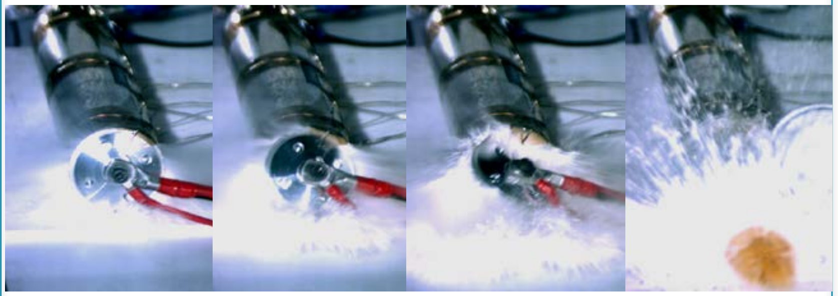


## Internal short-circuit



## Overcharge

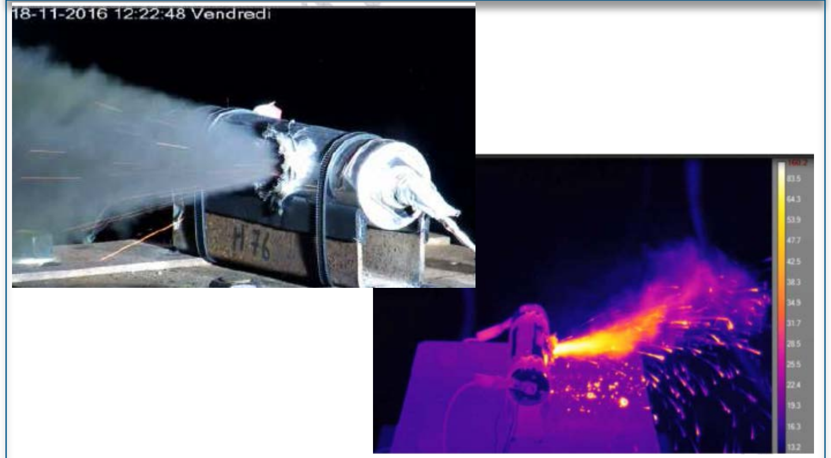
Cell opening – high speed camera



## 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:

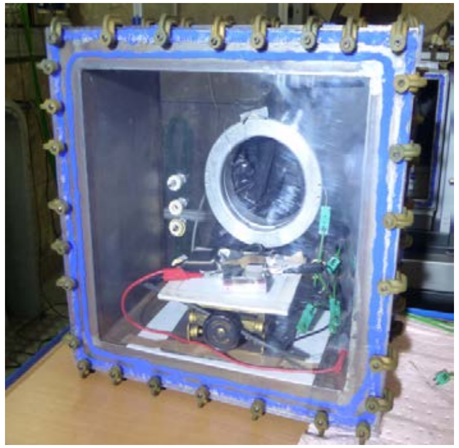
- Charging a cell to **too high of a voltage** (over voltage overcharge).
- Charging at **excessive currents**, but not excessive voltages.

•Can result in:

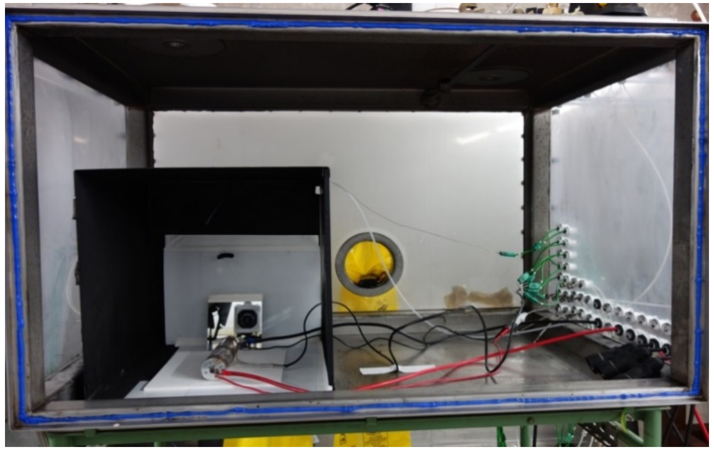
- **Immediate cell thermal runaway**.

•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

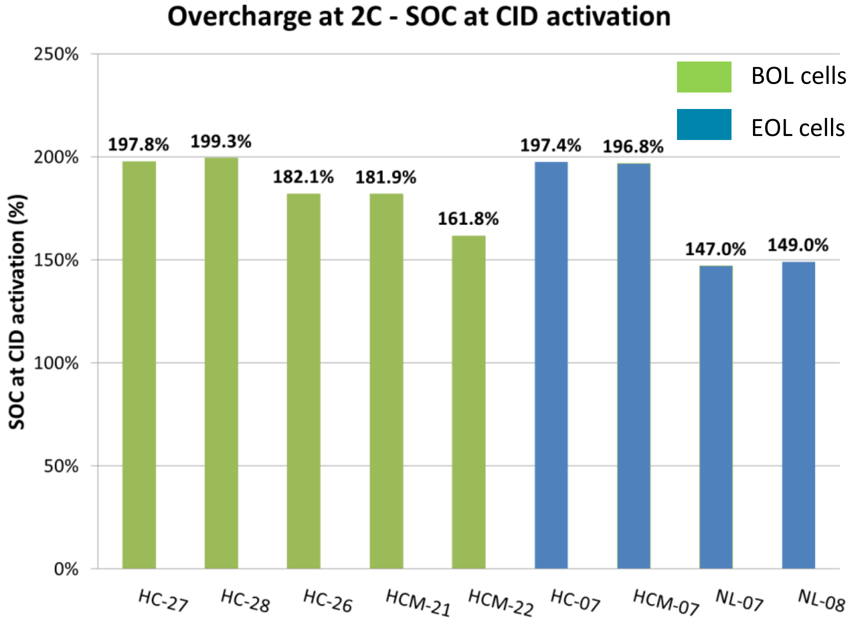
**SAFT cells**:

- 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

**VES140 cell after overcharge at 1C**



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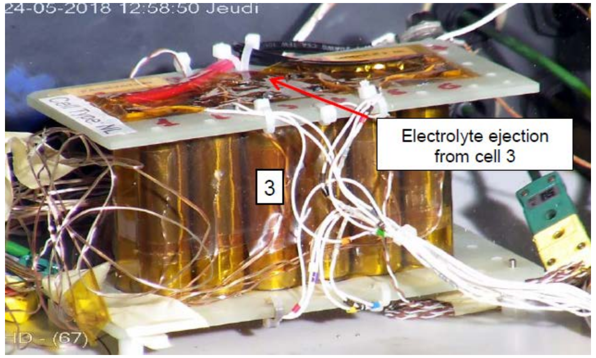
# TRP Battery Passivation - Cells and Battery abusive testing

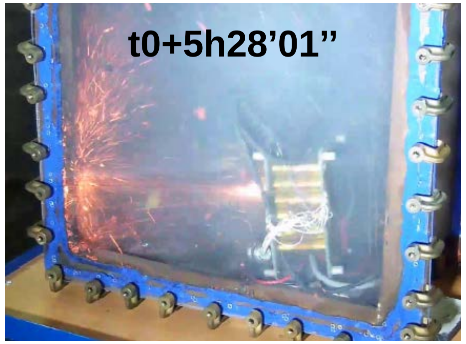
## Overcharge on Modules - Results

### 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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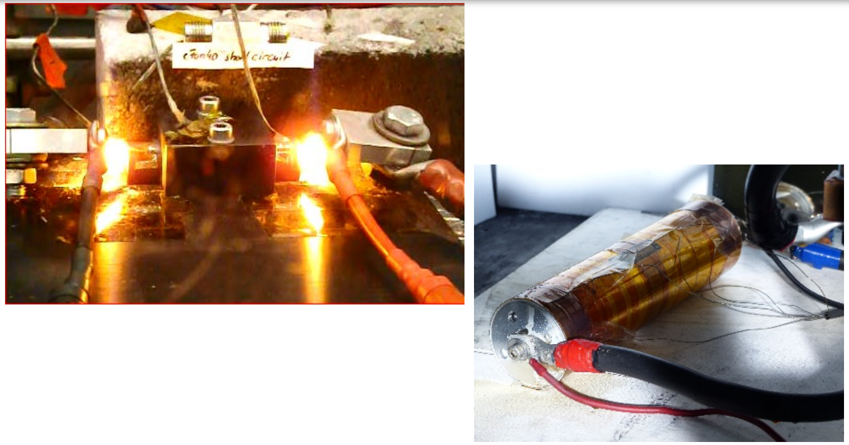
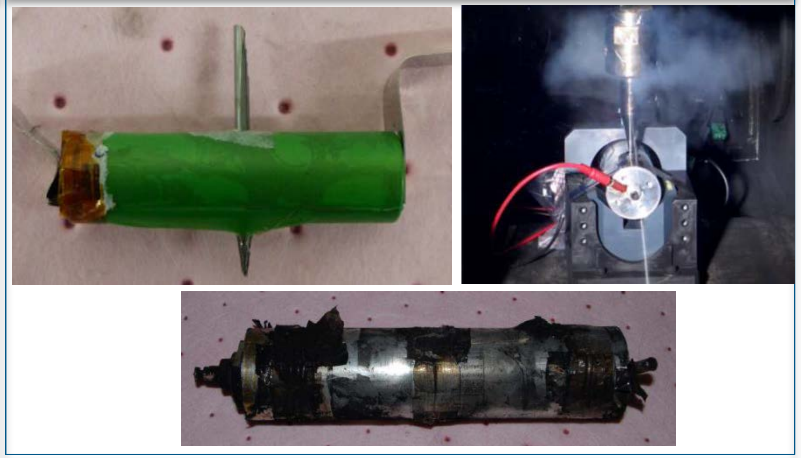
# TRP Battery Passivation - Cells and Battery abusive testing

## External short-circuit

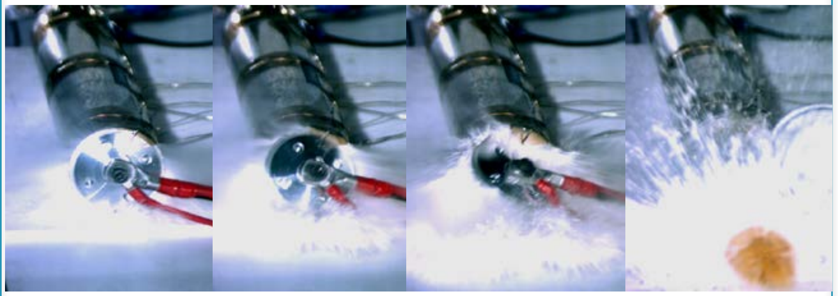


## Internal short-circuit



## Overcharge

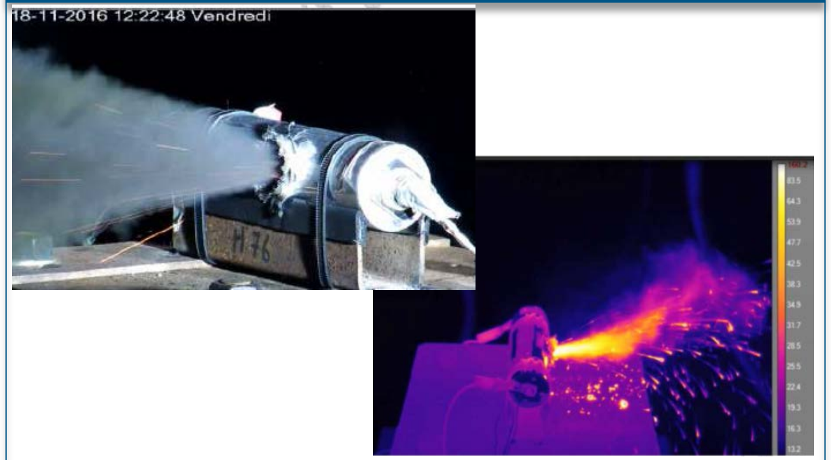
Cell opening – high speed camera



## Overdischarge

## High temperature

## Micrometeorids debris



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# TRP Battery Passivation - Cells and Battery abusive testing

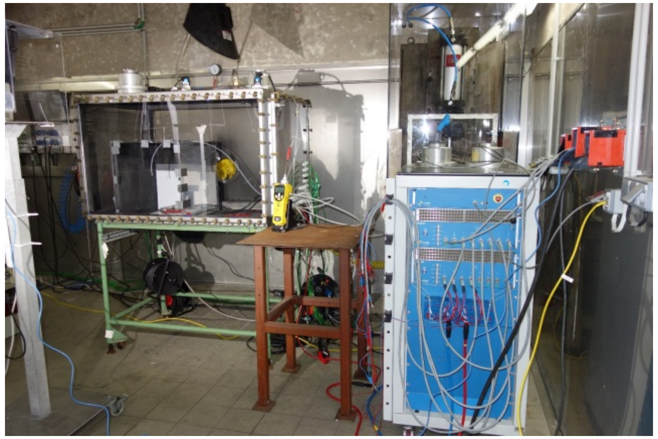
## Over-discharge - Assessment

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**



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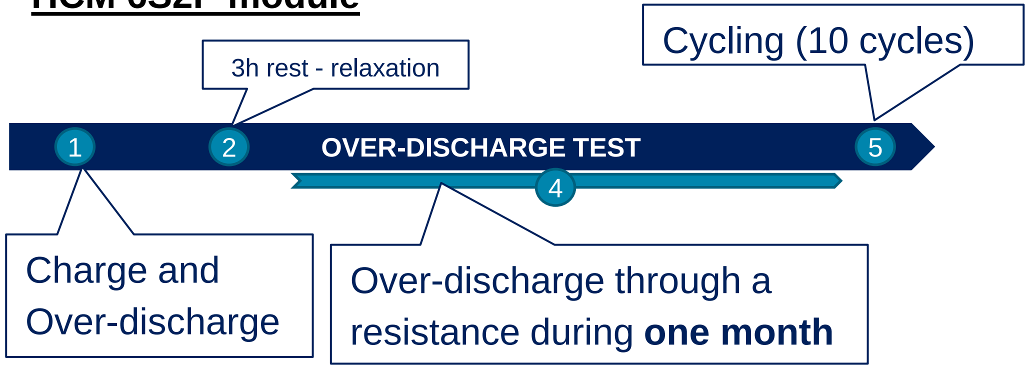
# TRP Battery Passivation - Cells and Battery abusive testing

## Over-discharge - Results

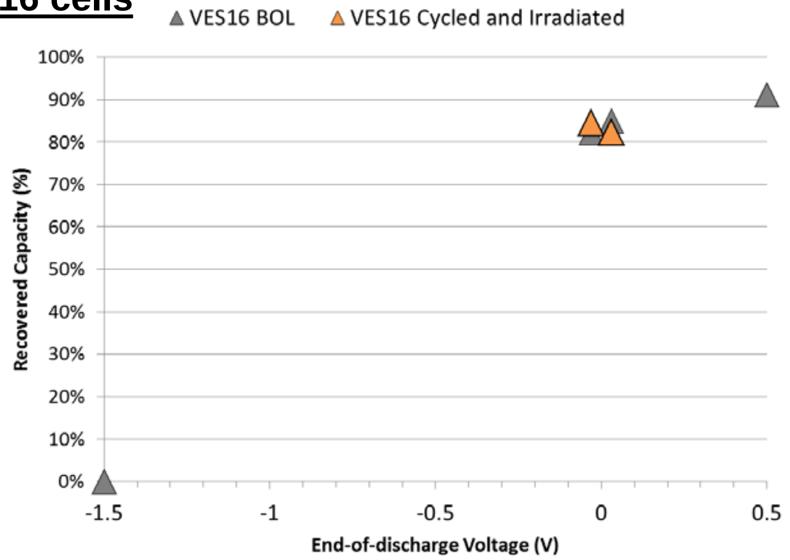
**General conclusions:**

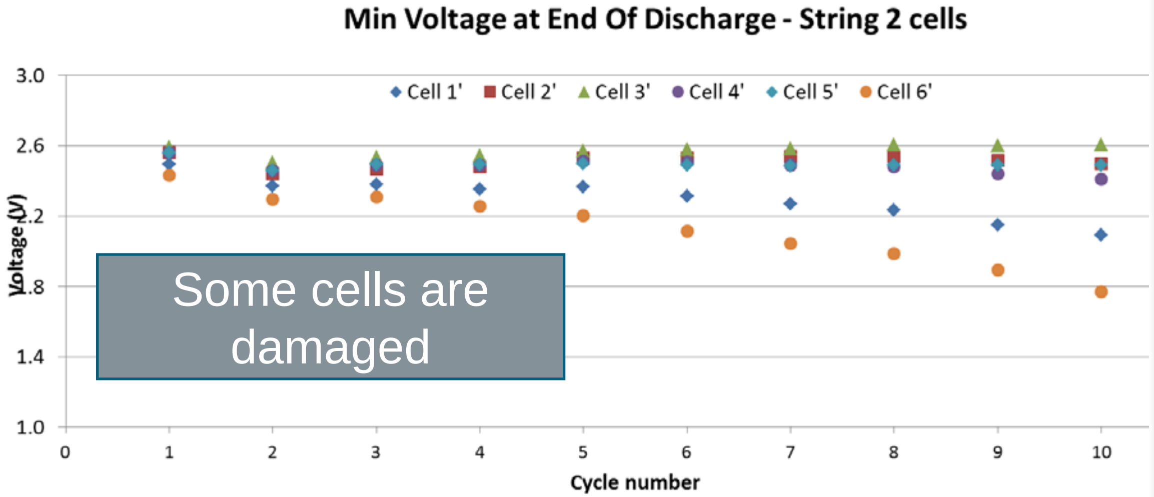
- No safety issues identified during over-discharge.
- Discharging to positive voltage or 0V damage the cell but it is still possible to recharge the cell even after one month at 0V
- Discharging to negative voltage reverse the cell (not possible to recharge the cell)

**HCM 6S2P module**




**VES16 cells**



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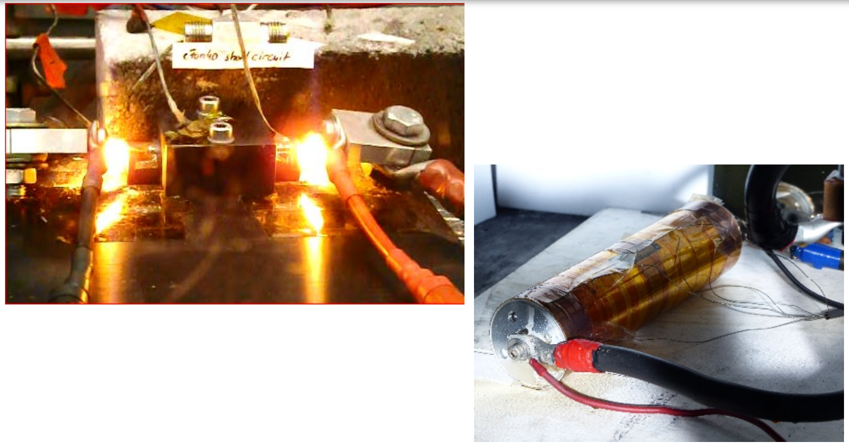
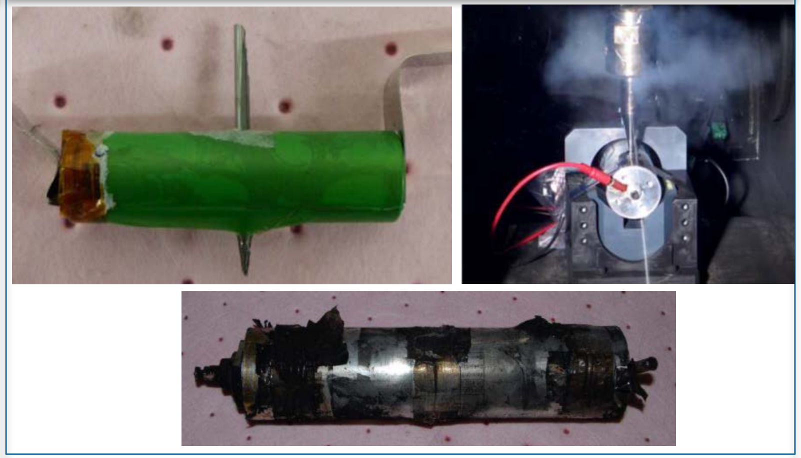
# TRP Battery Passivation - Cells and Battery abusive testing

## External short-circuit

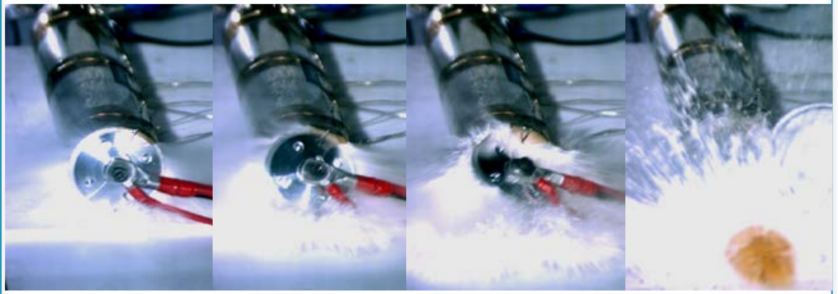


## Internal short-circuit



## Overcharge

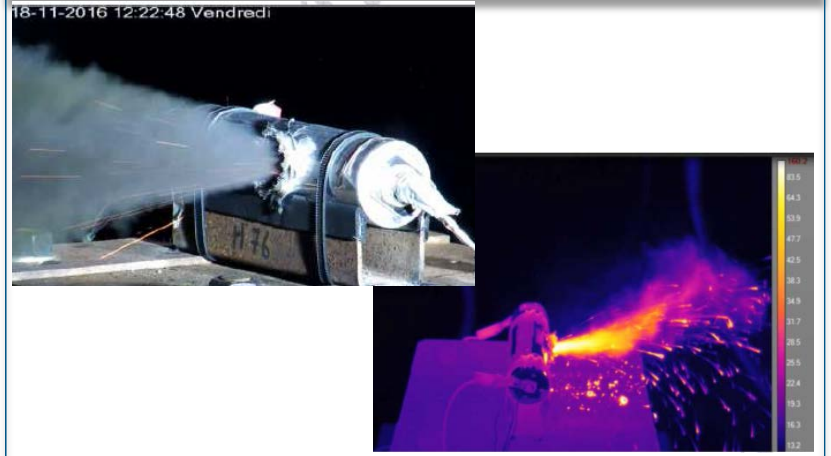
Cell opening – high speed camera



## Overdischarge

## High temperature

## Micrometeorids debris



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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 $I^2R$ 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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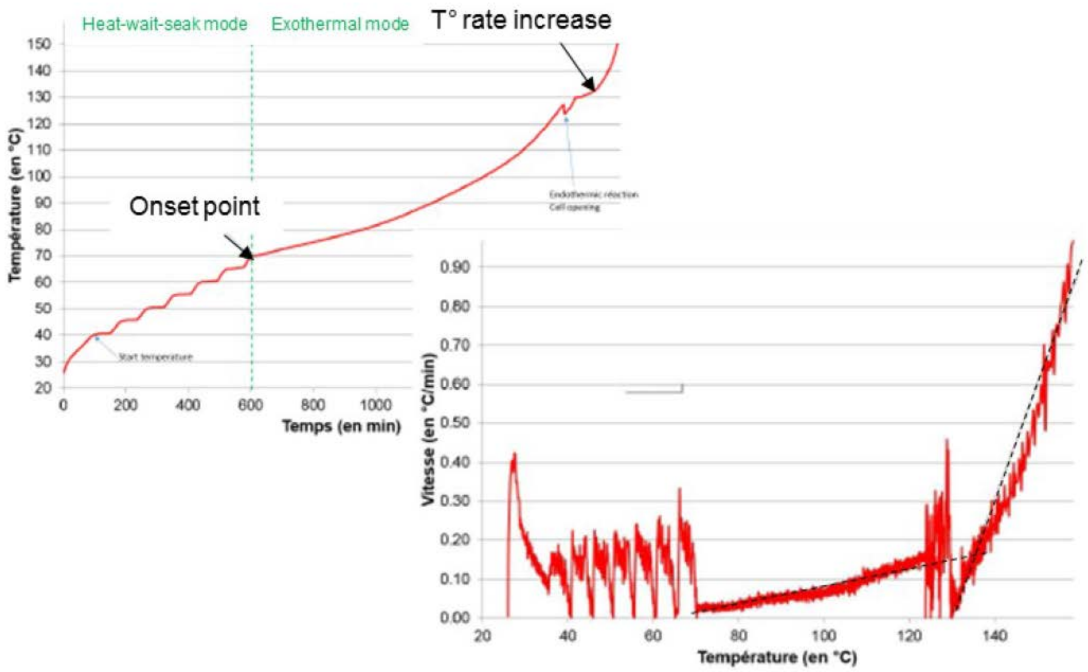
# TRP Battery Passivation - Cells and Battery abusive testing

## 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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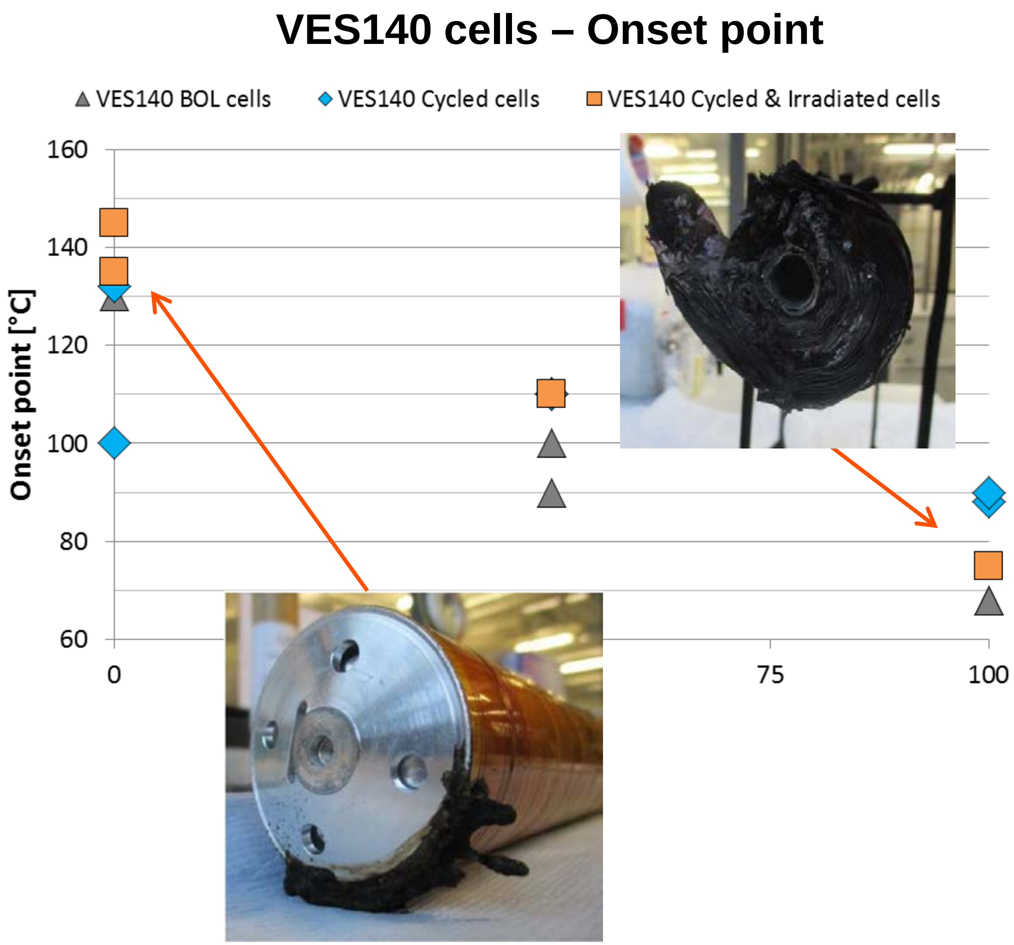
# TRP Battery Passivation - Cells and Battery abusive testing

## 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)



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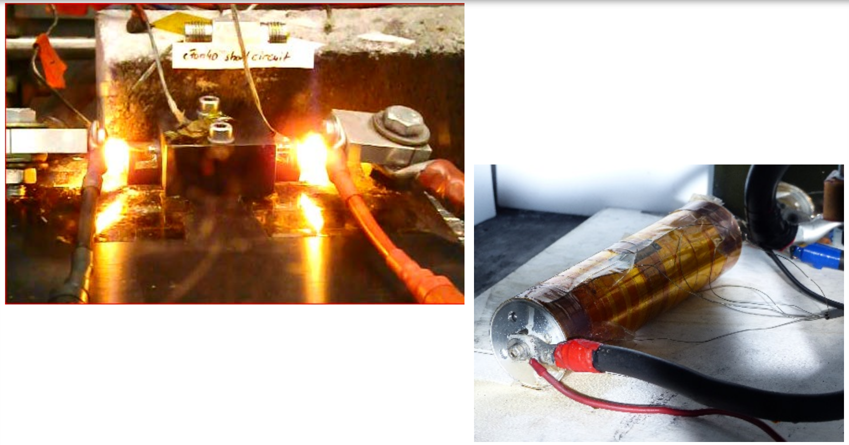
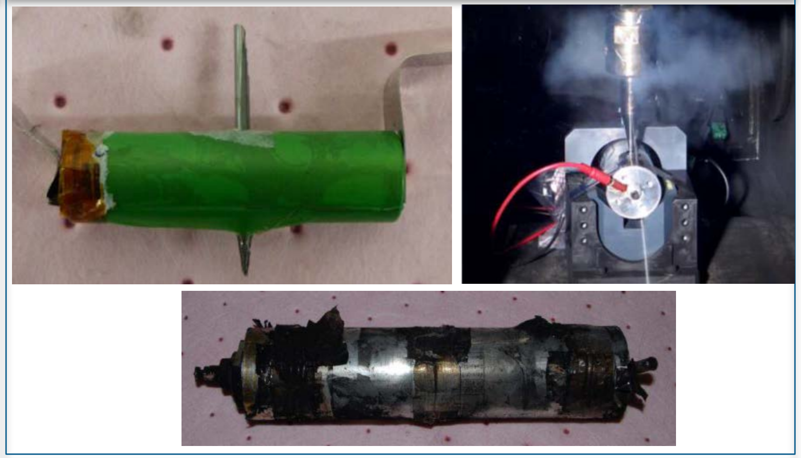
# TRP Battery Passivation - Cells and Battery abusive testing

## External short-circuit

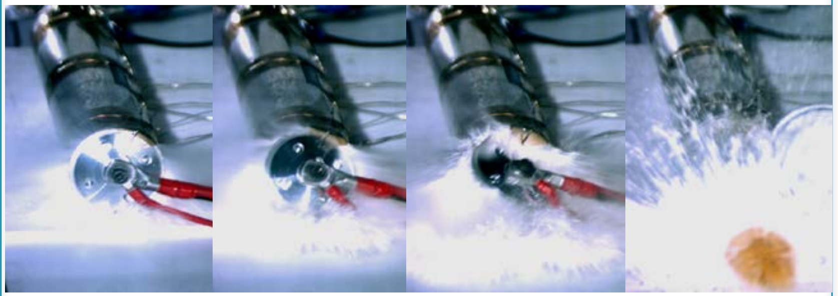


## Internal short-circuit



## Overcharge

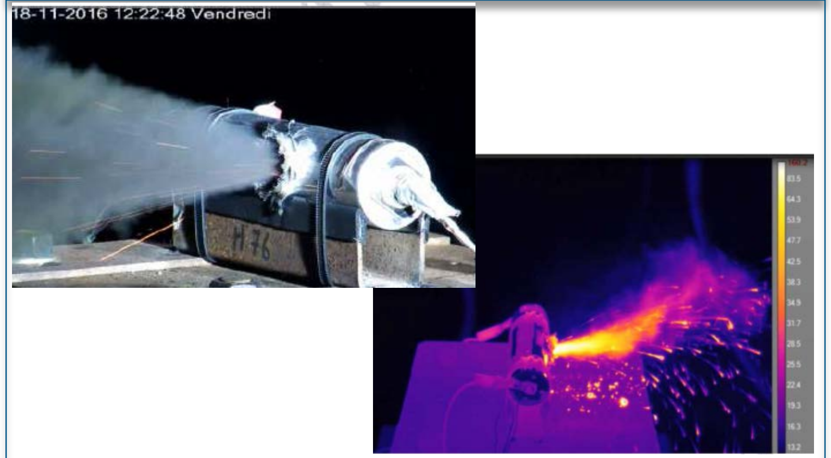
Cell opening – high speed camera



## Overdischarge

## High temperature

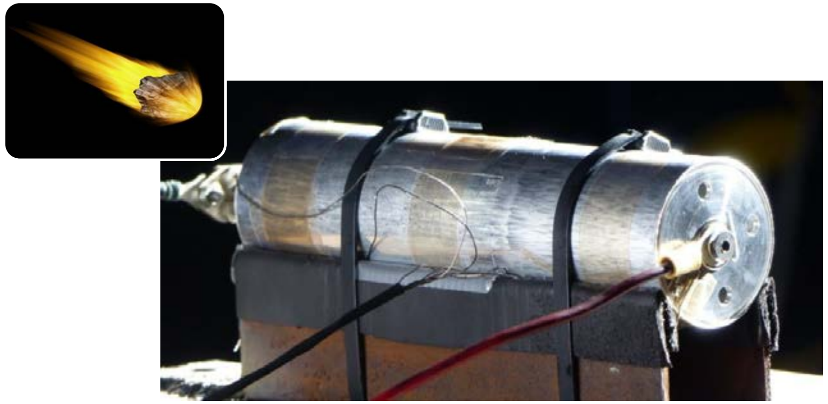
## Micrometeorids debris



# 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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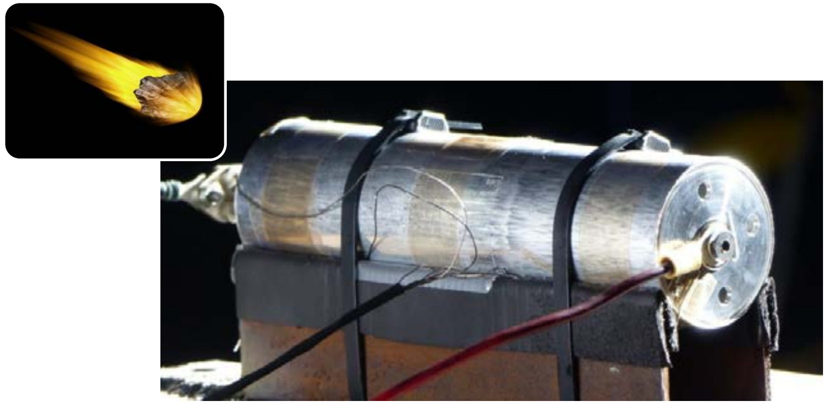
# TRP Battery Passivation - Cells and Battery abusive testing

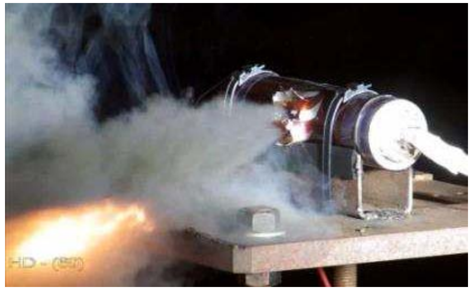
## Micrometeorids - Conclusion

- 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!