Battery Safety Assessment and Testing

ESA CleanSpace Industrial Days

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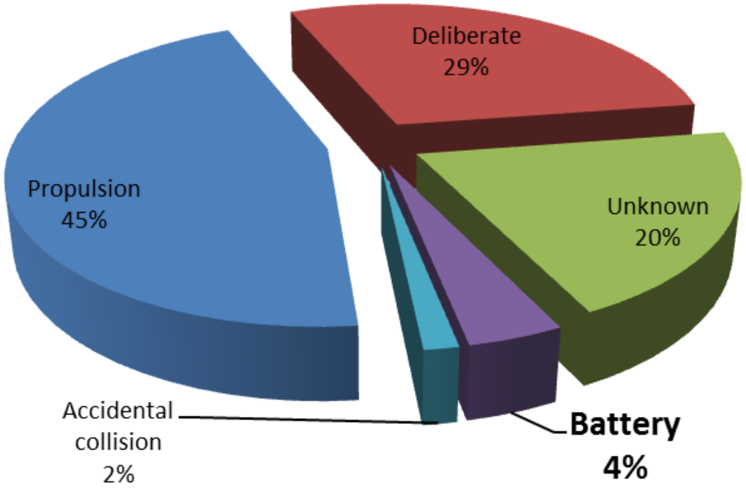
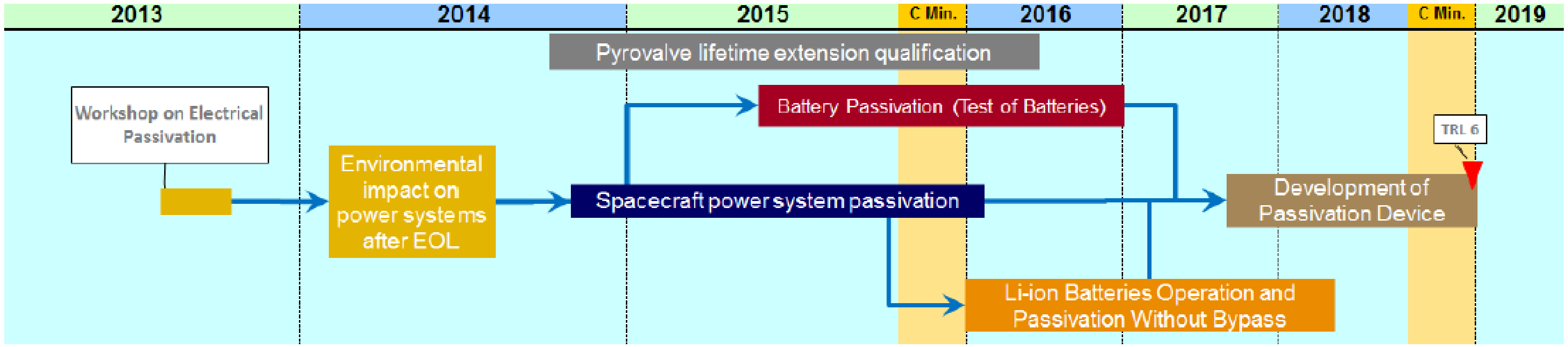
Why are we talking today about Battery Passivation?

- Video presentation.

- **2008 - Loi d'Opérations Spatiales (LOS)**
- **2012 - Passivation Electrique En Fin De Vie Du Sous-Système De Puissance** (CNES n°116287/00) :
- **2014 - Spacecraft Power System Passivation** (ESA n°: AO/1-7840/14/NL/LvH).
- **2015 - Battery Passivation** (ESA n° AO/1-8325/15/NL/LvH).



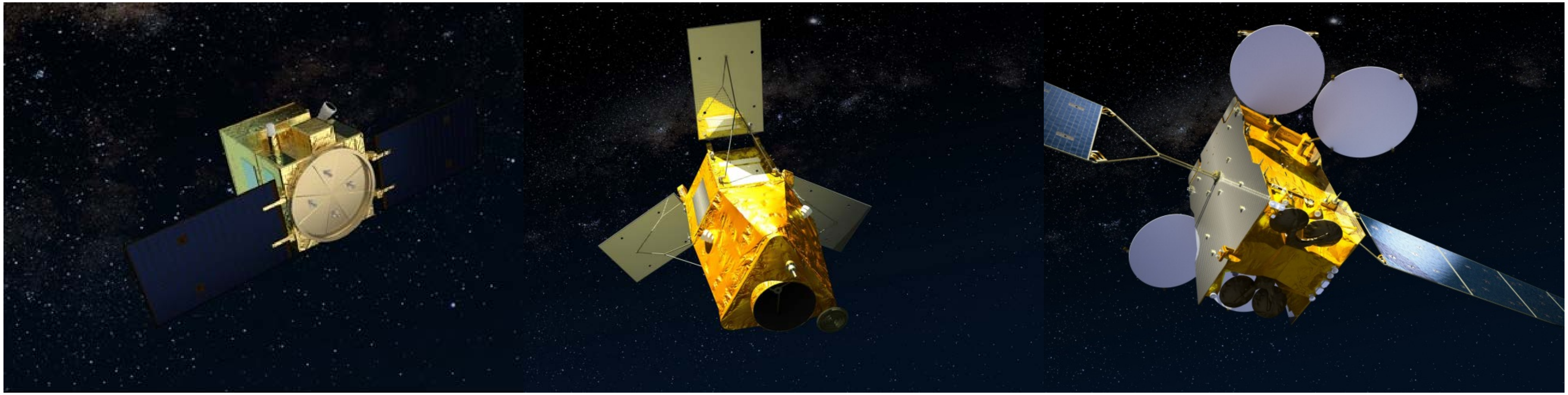
Causes of known satellite breakups until 2008.
Source: US Space Surveillance Network (SSN)



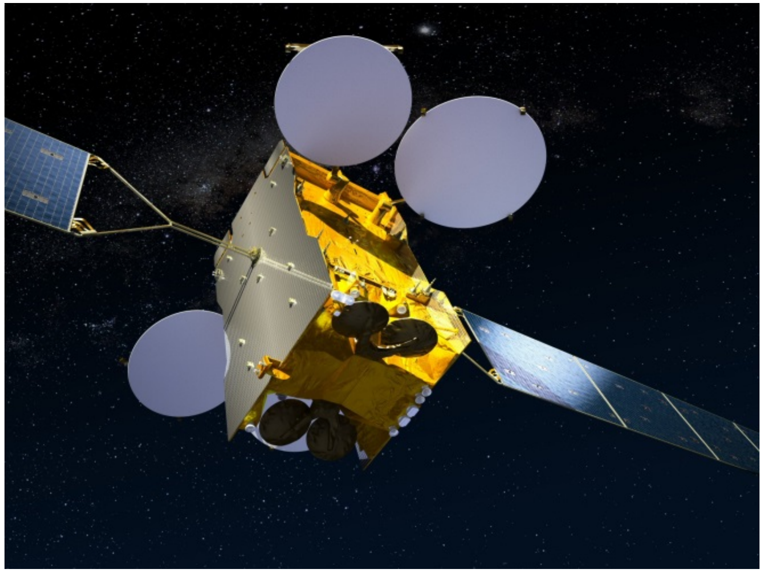
Spacecraft Power System Passivation - Thermal analysis

Three different cases have been studied:

- a LEO spacecraft with a battery located outside the satellite (**AstroBus-S platform**)
- a LEO spacecraft with batteries located inside the satellite (**AstroBus-M or AS250 platform**)
- a GEO satellite (**E3000 platform**)

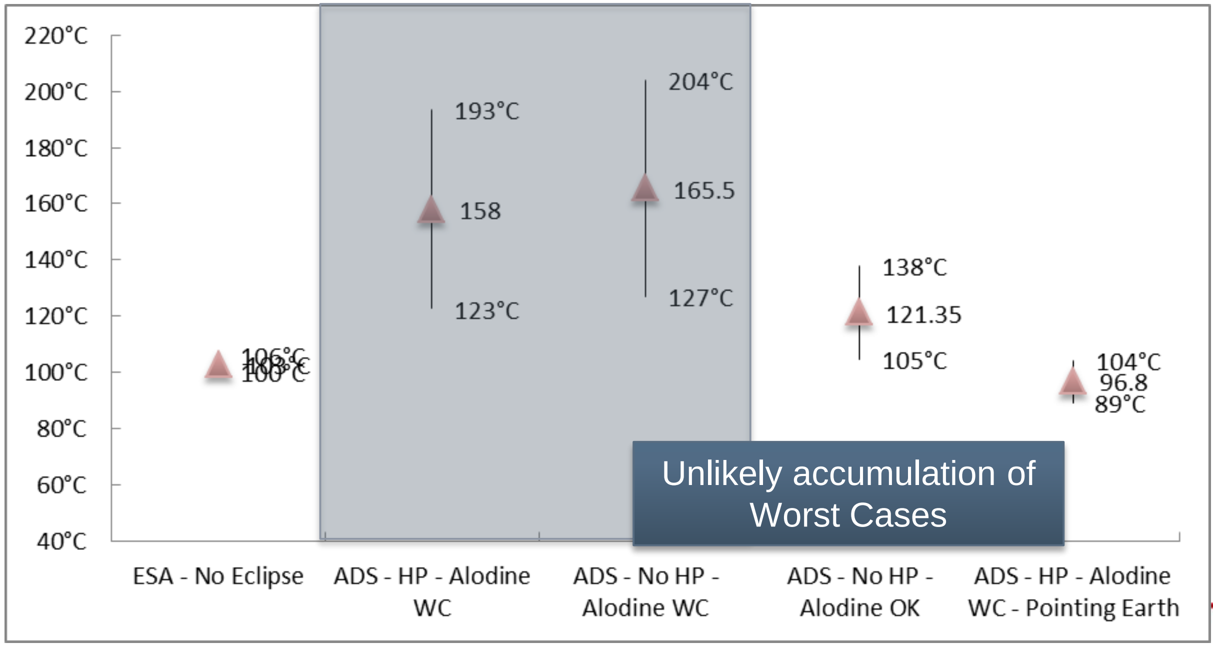


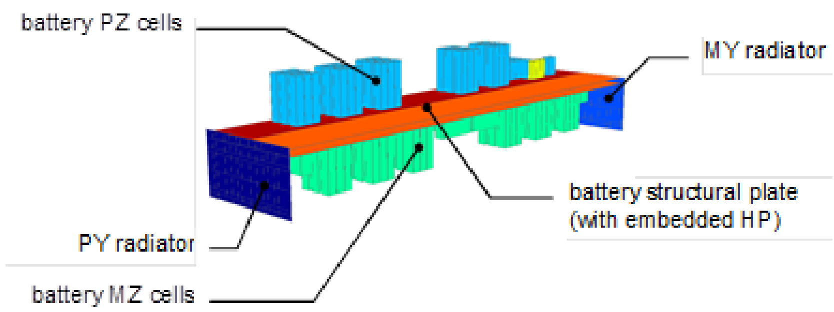
Thermal analysis: GEO case



For this case, the assumptions that could be taken:

- Duration: 100 years (or forever)
- Orbit: Geo-synchronous orbit.
- Season: Solstice: No Eclipse (Certain worst case)
- Attitude: Disturbance torques (Solar pressure? Gravity?). Radiator pointing to the Sun is a Possible scenario.
- Battery covers:
  - MLI completely torn off — Unlikely? Likely? (micro-meteoroids during 100 years…)
  - Absorptivity degraded to 1: — Possible (MLI protects until it is torn off)
  - Heatpipes failure: — Unlikely (passive device)
  - Internal MLI remains intact — Likely





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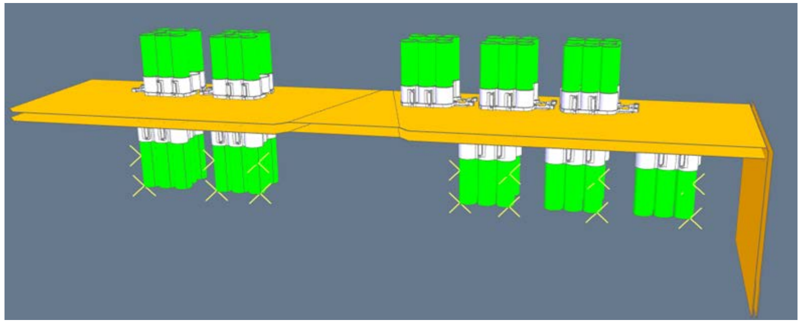
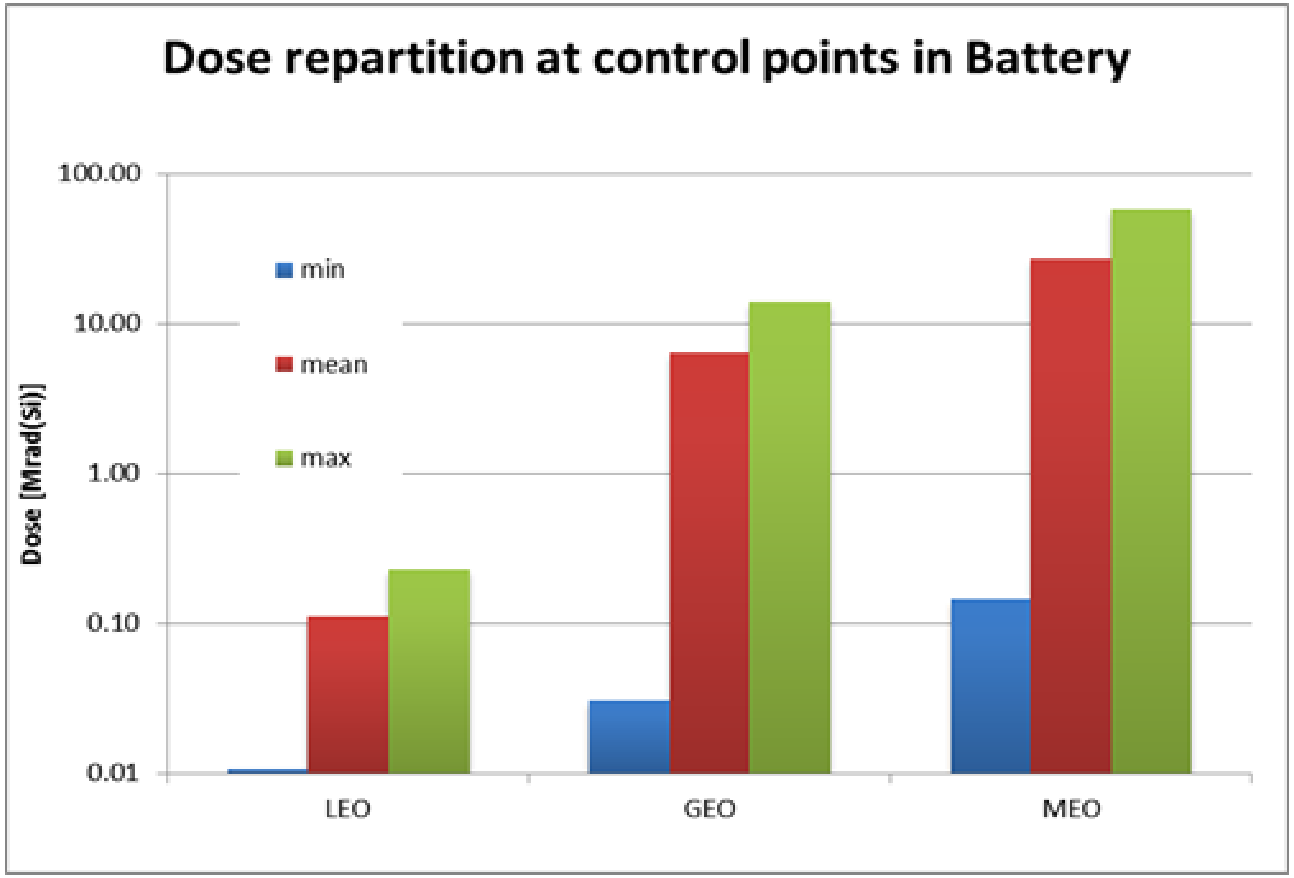


Spacecraft Power System Passivation
Radiation analysis

Dose partition on battery/ Airbus DS



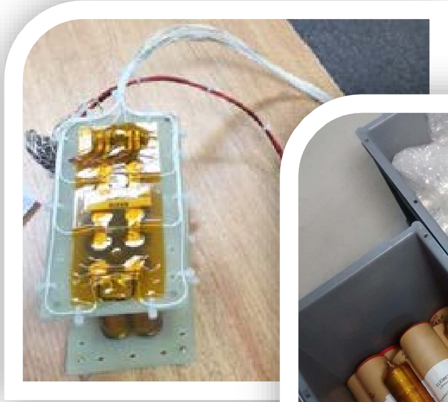
Approach of the Study

<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>Approach:</u>

1. Iteration on the test specifications and test plans
2. Test samples supply
3. Upgrade of test samples conditions
4. Tests execution
5. Tests results analysis

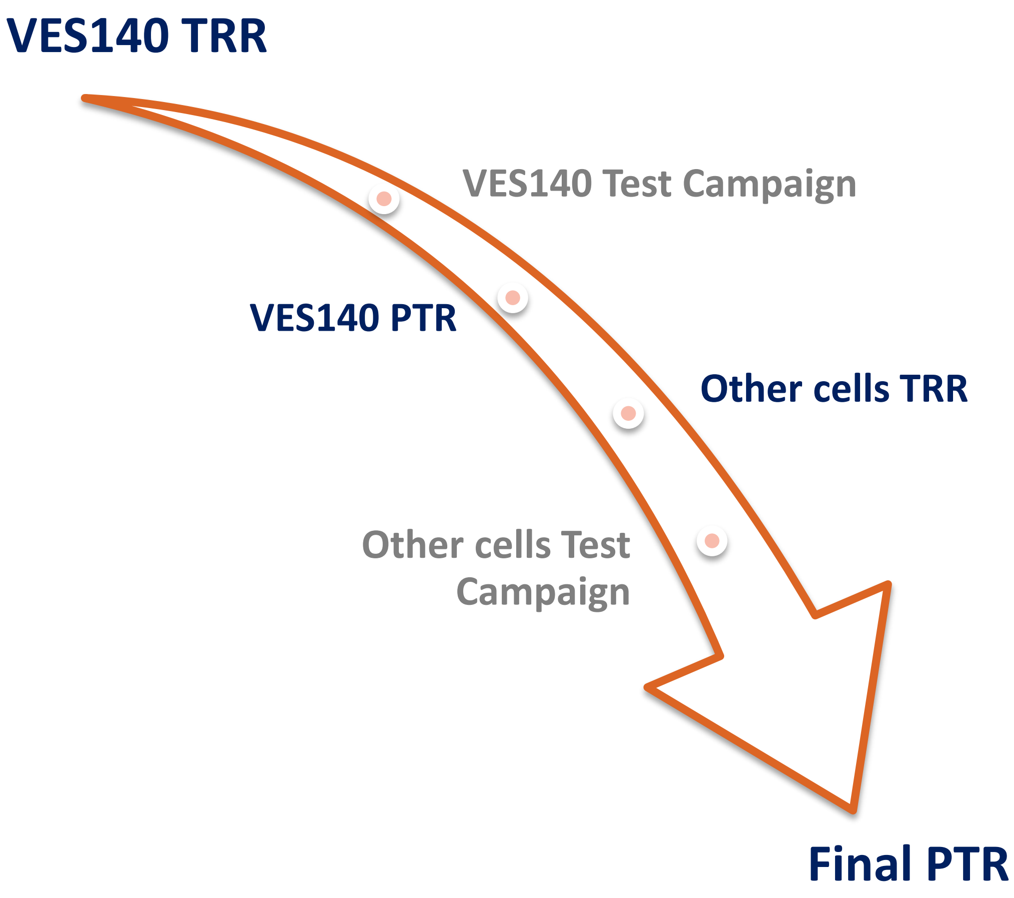


Test Campaign

- **The goal of this Test campaign Proposal** is to optimize the quality of the test results at the end of the study by:
  - Avoiding to perform a too late identified useless test on all the samples.
  - Giving the possibility to add new tests after a first set of results is available.

- **How?**
  - By performing a first test campaign just on VES140 model.
  - Assessing the impact of aging, radiation and SOC.

- **Why VES140?**
  - Because of the availability of aged and representative cells.
  - Because new cells VES180 are more valuable for current and future missions.



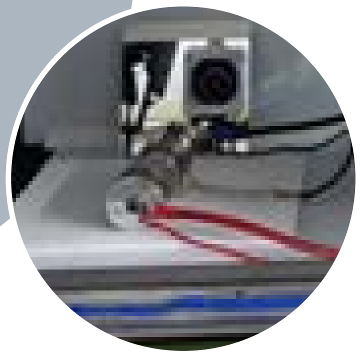
Battery Passivation Tests

External Short-circuit

Internal Short-circuit

ARC
Overtemperature

Micrometeoroids
Debris



Overcharge

Overdischarge

Assessment on Li-Ion Battery Safety
External Short-circuit

- **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 pressures inside the cell resulting in **venting and explosions**.
  - The organic solvent leaves the cell **via the vent**.
  - Any **hot spot may induce a fire** and ejection of parts.

- Can be prevented:
  - With the **use of CIDs/CBs and/or PTCs**
  - Fuses, circuit breakers, thermal switches at battery level.

RESULTS

- Cell opening: positive terminal (To +1’44’’)
- Ejection of electrolyte

Max current: 1200A

Max temperature: 160°C

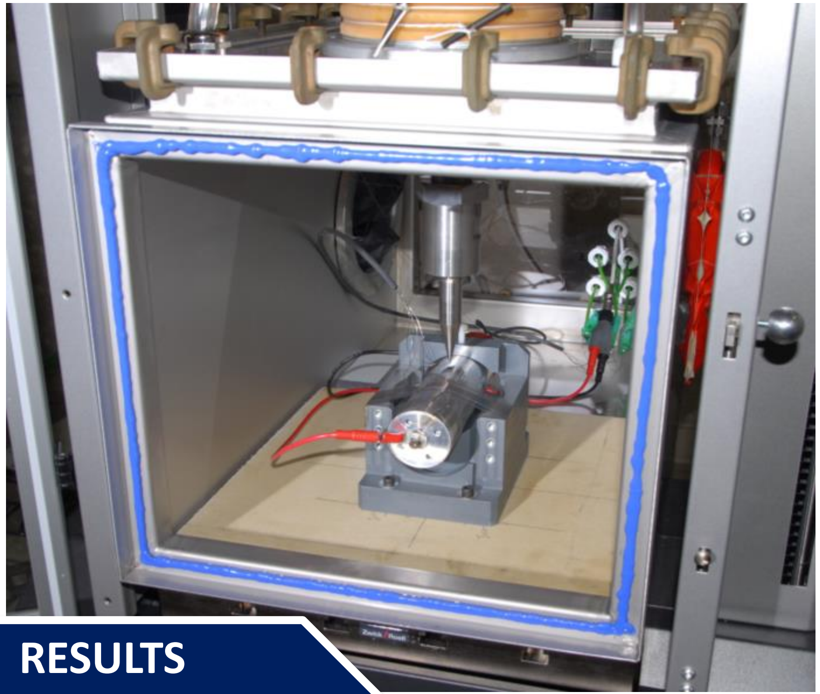
Assessment on Li-Ion Battery Safety
Internal Short-circuit

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

- Can be caused by:
  - **Manufacturing defect**.
  - **Induced internal shorts in the field**: due to usage and/or storage in **extreme thermal environments**; to usage **outside** manufacturer's voltage and current **specifications**; to **high thermal gradients** or to a crash or a failure of the fixture system

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

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



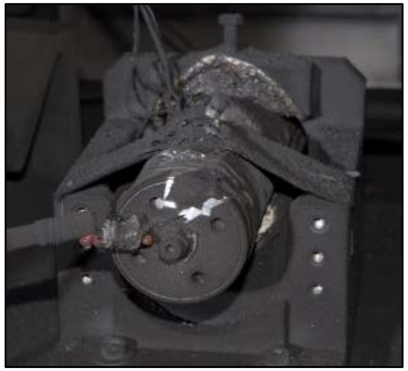
RESULTS

Voltage at 0.5V 25s after the beginning of the short-circuit

Fast exothermic reaction

Release of black smoked

Max temperature: 460°C



Assessment on Li-Ion Battery Safety
Over-charge

- On the anode:
  - **Overcharge can cause plating** rather than intercalation of lithium.
  - **The plating is not necessarily homogeneous**, but dendritic in form, it 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 also cause an overcharge failure
- Can result in:
  - **Immediate cell thermal runaway**,
- Can be prevented:
  - With the **use of CIDs/CBs** at cell level.
  - Fuses, circuit breakers, thermal switches at battery level.
  - Voltage control at battery level.

RESULTS 1.5C

Cell opening: positive terminal (To +56’10’’)
+ Ejection of electrolyte
Ejection of jelly roll
+ Release of smoked

Max temperature: 800°C

Assessment on Li-Ion Battery Safety
Over-discharge

- Over-discharge can cause **internal damage to electrodes and current collectors** (i.e., dissolution of copper), can lead **to Cu dendrite generation** and **can ultimately lead to short-circuit.**

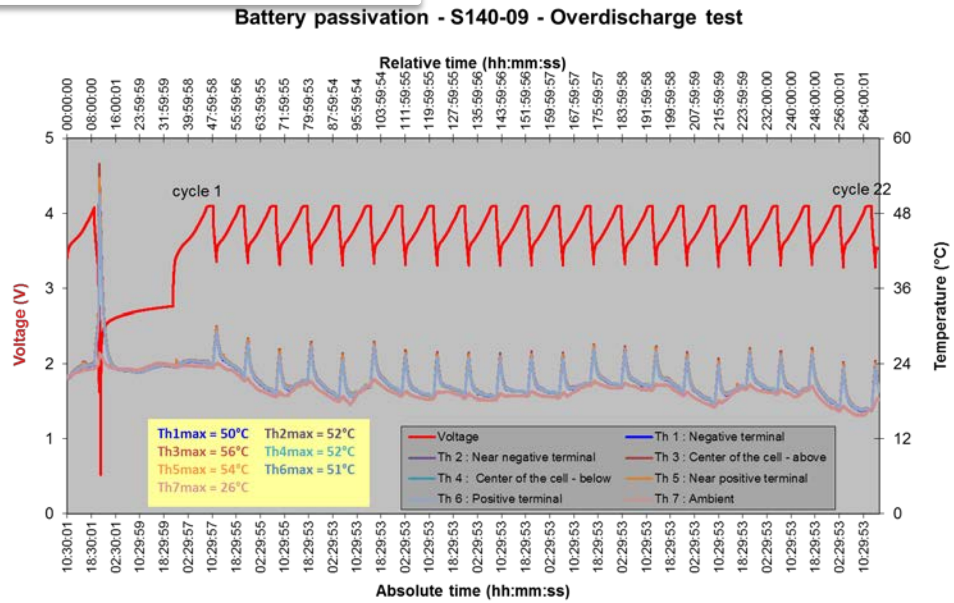
- <u>Can be caused by:</u>
  - Discharging a cell to **too low of a voltage**.

- <u>Can result in:</u>
  - Copper ions which are dispersed throughout the electrolyte are precipitated as metallic copper wherever they happen to be, not necessarily back on the current collector foil. This is a dangerous situation which can ultimately **cause a short circuit between the electrodes**.
  - **Exothermic reaction** linked to the copper reduction-oxidation reaction, no thermal runaway since there is almost no electric charge.

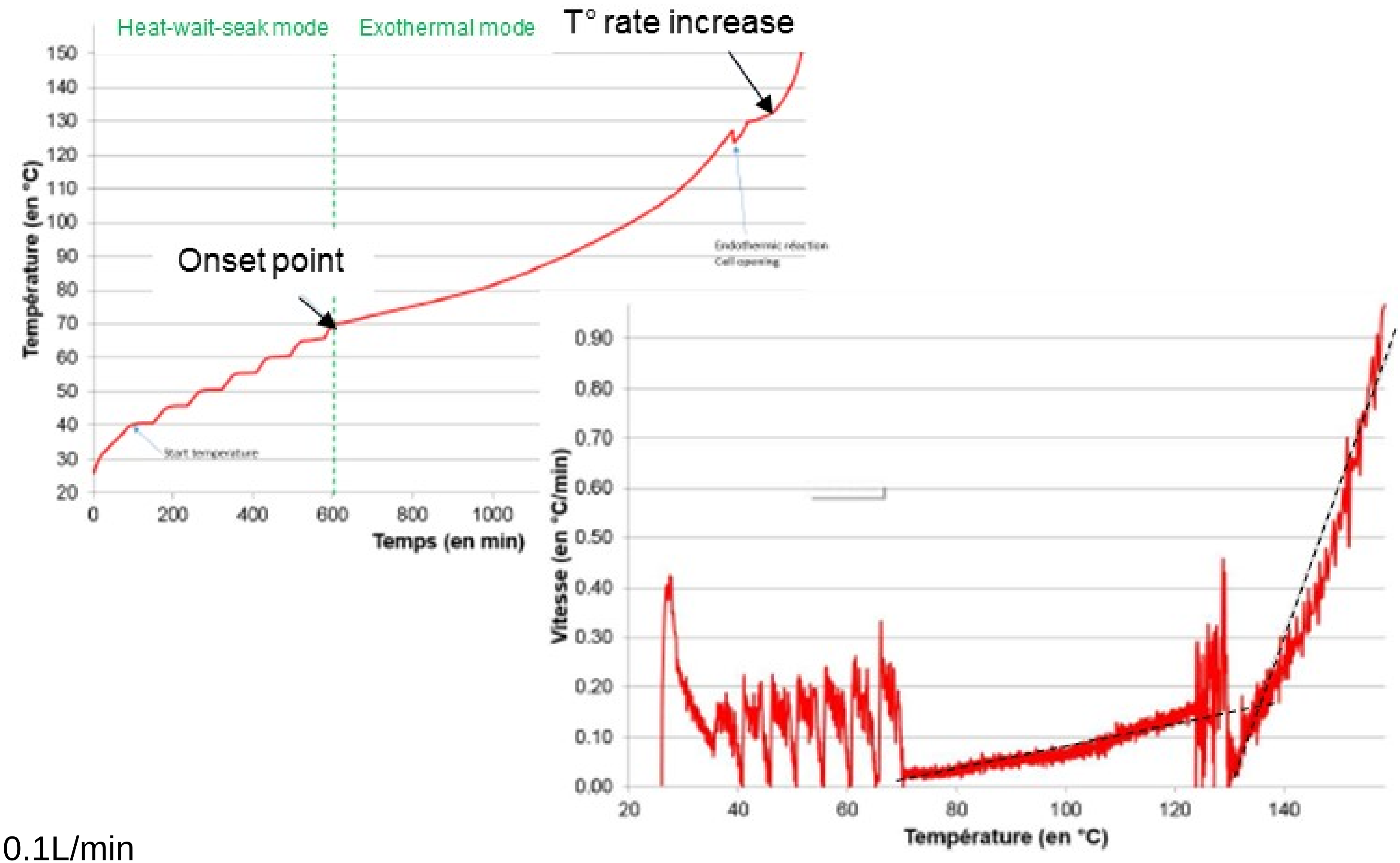
- <u>Can be prevented:</u>
  - With the **use of CIDs/CBs** at cell level.
  - Voltage control at battery level.

RESULTS

Max temperature: 56°C



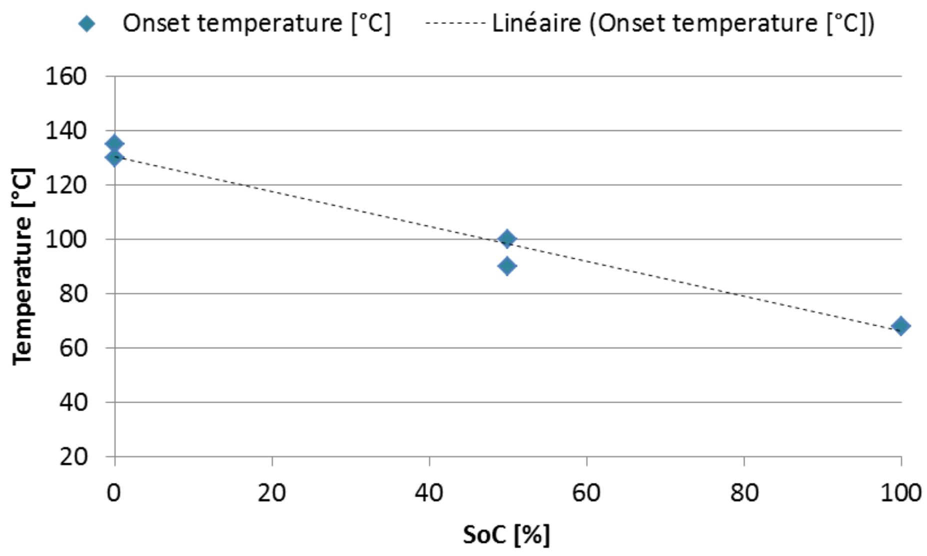
Assessment on Li-Ion Battery Safety
High temperature



- N2 flow : 0.1L/min
- Charge the cell at C/10 up to defined SoC (100% SoC; 50% SoC; 0% SoC)
- Increase gradually the temperature until a thermal runaway appears. Stop heating.
    - Temperature step: 5°C
    - Temperature rate sensitivity': >0.02°C/min. = thermal runaway
    - End temperature': 180°C (test stop)
    - Safety temperature rate': 1°C/min. (test stop)

Assessment on Li-Ion Battery Safety
High temperature

- Operating at high temperatures helps to get higher power out of the cell by **increasing the reaction rate**, but higher currents give rise to **higher I²R heat dissipation** and thus **even higher temperatures**.
- Can be caused by:
  - Exotherms begin at anode due to SEI (Solid Electrolyte Interphase) reactions and decomposition **at temperatures as low as 50°C.**
- 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 o
  - **Cell contents may be ejected** and can travel significant distances (many meters), spreading heated material.
- 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.**
  - **Aging reduces carbon reactivity** (more stable, well developed SEI layer) leading to more thermally stable cell



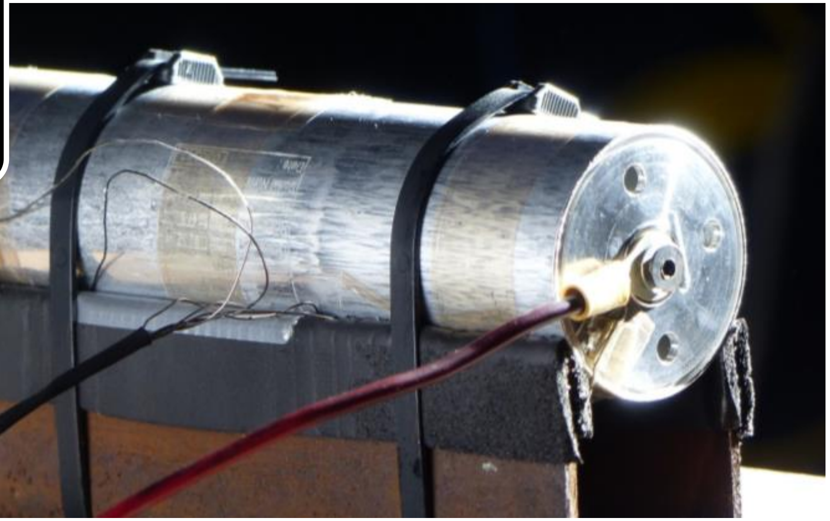
Assessment on Li-Ion Battery Safety
Micrometeoroids and Debris

- Micrometeoroids impact can be associated to a mechanical damage (crush or penetration).

- <u>Can be caused by:</u>
  - Micrometeoroid and/or debris impact.

- <u>Can result in:</u>
  - Damage that occurs at electrode edges is significantly more likely to cause **cell thermal runaway** than damage perpendicular to electrode surfaces.
  - Perpendicular to electrode surfaces: **low impedance** shorting will occur between current collectors, and cell heating may be too low to result in cell thermal runaway.
  - Perpendicular to electrode edges: that deformation is likely to result in **high impedance** shorting between electrode layers and initiate cell thermal runaway

- <u>Can be prevented:</u>
  - 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

RESULTS

Max temperature: 400°C

Max temperature: 680°C

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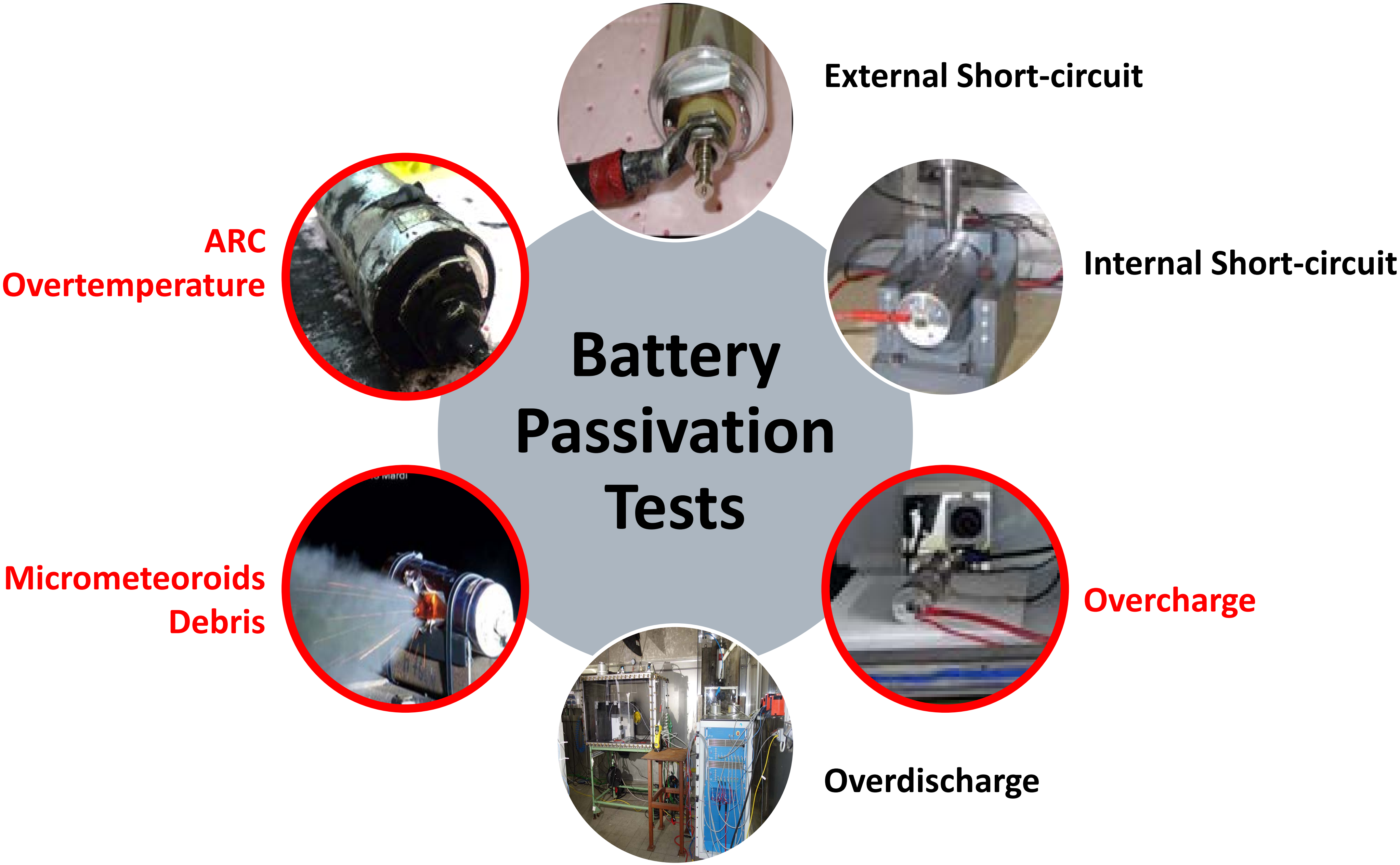
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ARC Overtemperature

This looks awful… so what can we do?

At Battery level

- Discharge your 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 worst thermal scenario and design the S/C to be avoided.
- Determine the best possible way to reduce the satellite temperature: spin it!