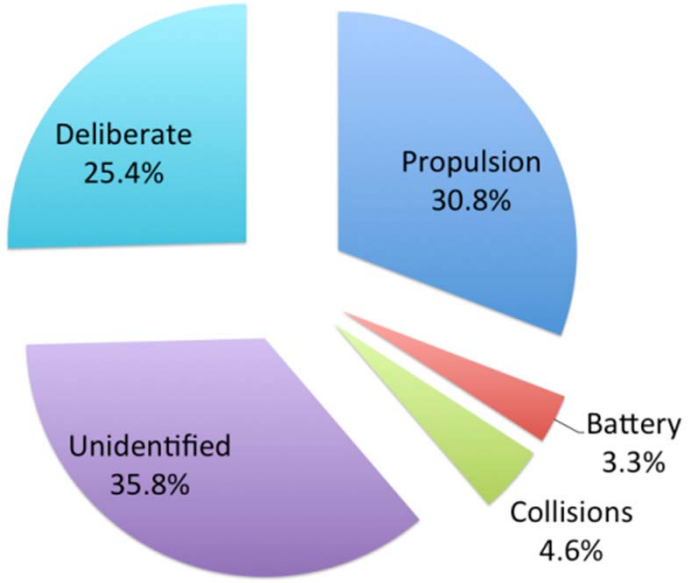
Spacecraft electrical passivation Overview

Clean Space Industrial Days, 24 October 2017

François Bausier, ESA

Background

Among 240 accidental in-orbit break-ups of spacecraft and launch vehicle orbital stages recorded from 1957 to May 2014 (ESA DISCOS), about 3% are due to battery



At least 9 spacecraft broke-up due to battery:

1. Cosmos 839 (USSR), 29/09/1977
2. Ekran-2 (USSR), 25/06/1978 (first known fragmentation in GEO)
3. Cosmos 880 (USSR), 27/11/1978
4. Cosmos 1275 (USSR), 24/07/1981
5. Cosmos 1375 (USSR), 21/10/1985
6. Cosmos 1691 (USSR), 22/11/1985 (NiH_2)
7. NOAA 8 (USA), 30/12/1985 (caused by battery overcharge)
8. Cosmos 1823 (USSR), 17/12/1987 (NiH_2)
9. DMSP-F13 (USA), 03/02/2015 (Ni-Cd)

Specifications and guidelines

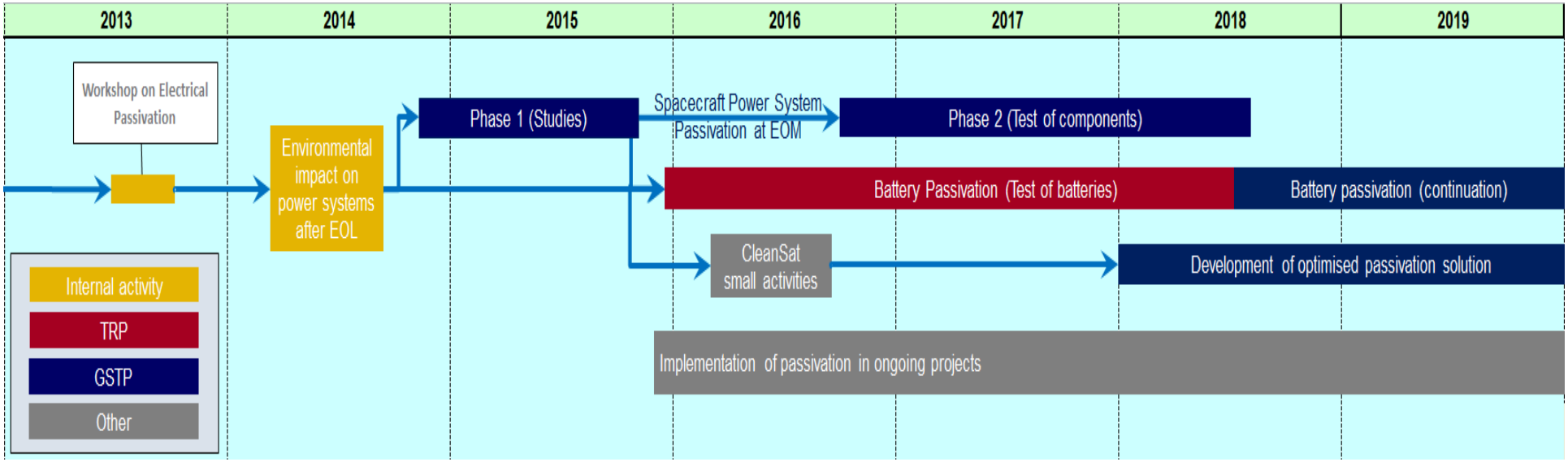
For European spacecraft:

- **ECSS**-U-AS-10C, 10/02/2012 “Space Sustainability, Space debris mitigation requirements”
  - → **ISO** 24113, Second Edition, 15/05/2011 “Space Systems, Space Debris Mitigation Requirements”
- **ESA**/ADMIN/IPOL(2014)2, 28/03/2014 “Space Debris Mitigation for Agency Projects” → ECSS → ISO
- “**ESA** space debris mitigation compliance verification **guidelines**”, ESSB-HB-U-002-Issue1, 19/02/2015

- **French space operations law (LOS)**, law 3/6/2008, decree 9/6/2009, bylaw 31/3/2011
- **CNES guidelines**, RNC-LOS-GR-CNF-8-CNES, version 2, 24/03/2014, « Guide des bonnes pratiques maîtrise d’un object spatial »

Roadmap

CleanSpace Electrical Passivation Roadmap



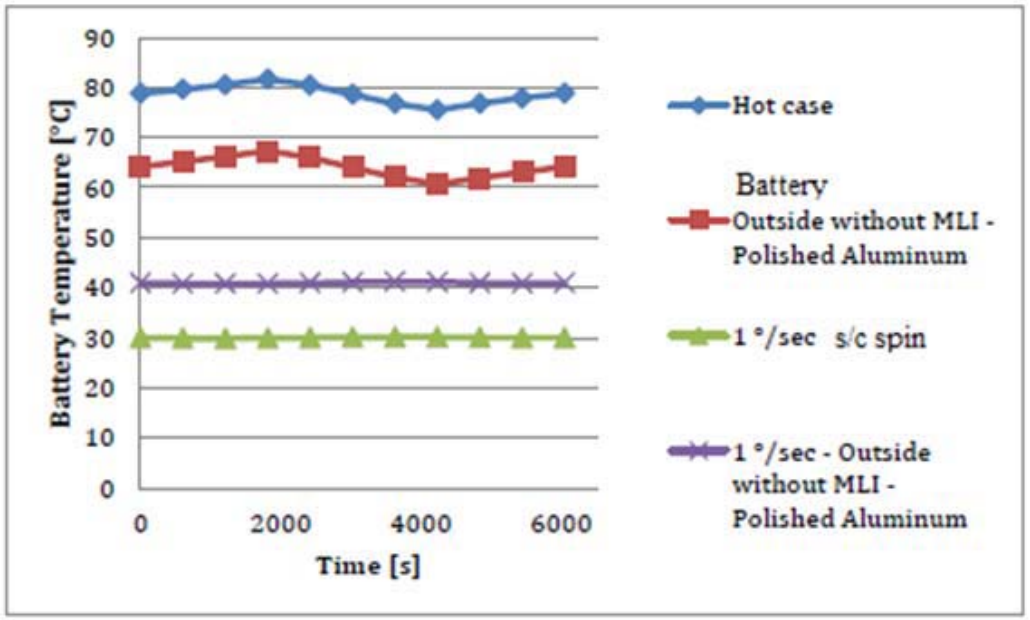
R&D activities
Environmental Impact on Power Systems after EoL

ESA internal activity completed in 2014

Analysis after 15y operational + 25y disposal = 40y, considering loss of spacecraft control in LEO, MEO or GEO

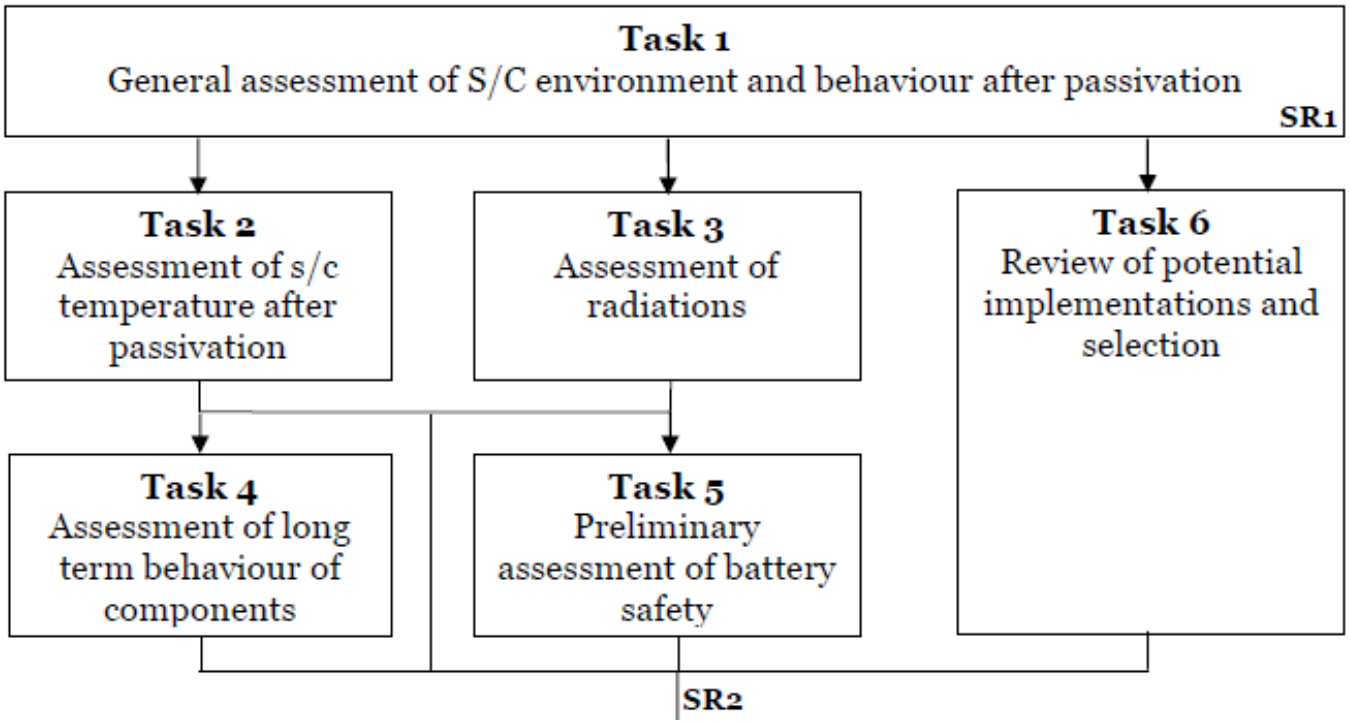
Focus on:

- Thermal analysis
- Radiation analysis
- Micrometeoroid / Debris analysis



R&D activities
GSTP – Spacecraft power system passivation at EoM

- Activity lead by RUAG Finland with Airbus DS
- Objective: study, implement and evaluate most adequate means to ensure proper and reliable spacecraft power system passivation at end of mission
- **Phase 1** (completed):



R&D activities
GSTP – Spacecraft power system passivation at EoM

Battery safety analysis after EoM

- Despite various cell protections, the **speed of the thermal runaway** reaction may be too high for the protections to react in time in some cases and **the risk of breakup cannot be completely excluded**
- **Recommendations** to keep battery in safe conditions:
  - **Discharge** battery as low as possible (50% SoC or lower)
  - **Avoid high temperature** (< 100° C)
  - Prevent recharging of the battery and in particular **avoid overcharging**
  - **Passivation device shall sustain the harsh environment** after passivation

Potential implementations

- Most promising solutions according to ranking:
  - Battery disconnection by relay or by-pass switch and discharge by resistor
  - Solar array disconnection by relays
  - Solar array short-circuit by relays via diodes
- In addition following options promising when combined or in particular cases:
  - Adapting s/c configuration or attitude (e.g. spinning)
  - Decrease of battery charge voltage/current
  - Over-discharge the battery to 0V
  - Battery containment for cubesat
  - Use battery bypass switches to disconnect battery

Main recommendations

- System: perform thermal and radiation analyses after disposal to check impact on battery and passivation device (PCDU)
- Battery: keep discharged as low as possible and avoid high temperature
- Components used for passivation: privilege (electro-) mechanical devices such as relays or by-pass switches

R&D activities
GSTP – Spacecraft power system passivation at EoM

Phase 2 (ongoing):

1. Toolbox document describing in detail most interesting solutions
2. Evaluate and test components to be used for passivation:
   - **Relays**
   - **Semiconductors (Mosfet, diode)**
   - **By-pass switch**

   Thermal cycling, life test, functional tests

R&D activities
TRP Battery Passivation

- Activity lead by **Airbus DS with Saft, ABSL and CEA**
- Objective: **test** Li-Ion battery cells and modules under extreme conditions encountered after spacecraft disposal
- Both **fresh** and **aged** (cycled and irradiated) cells: ABSL18650-HC,-HCM, -NL & Saft VES16, VES140, VES180
- Tests:
  - External short-circuit
  - Internal short-circuit (nail test)
  - Over-charge
  - Over-discharge (to 0.5V/cell, 0V, -0.8V, followed by cycling)
  - Accelerating Rate Calorimetry (ARC) test (at various SoC)
  - Over-temperature test
  - Micrometeoroid/debris impact test

R&D activities
CleanSat activities

Jointly managed by 3 main European primes (Airbus, TAS, OHB)

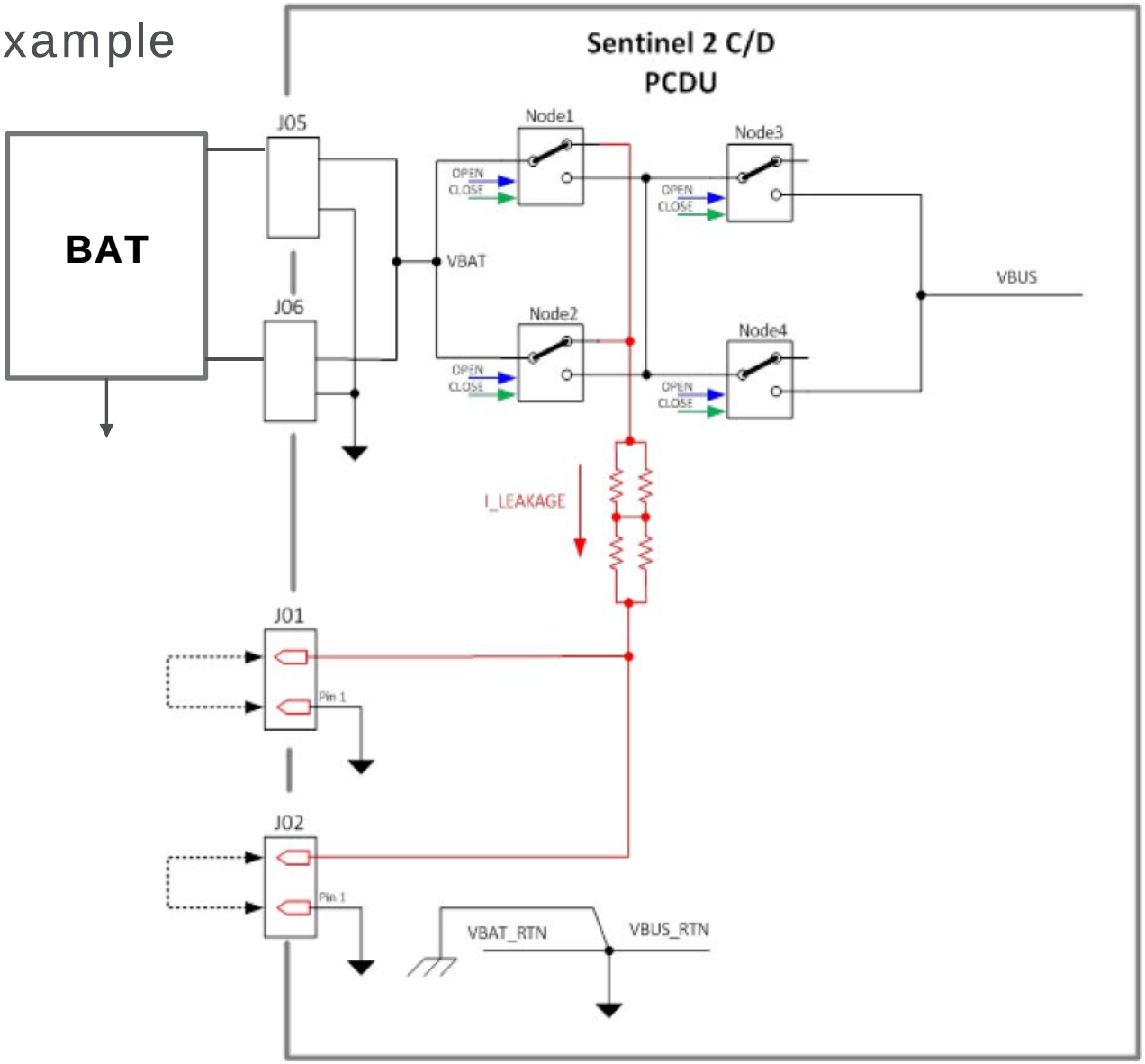
1. **Battery safety** (ABSL)
   - Analysis of battery safety after EoM
   - Recommendations provided for battery conditions after EoM
   - List of qualification tests related to safety after EoM
2. **Solar array disconnection** (Leonardo):
   - Trade-off of various solar array disconnection solutions
   - Selected concept: short-circuit each SA section by relay(s) in dedicated modules to be included in PCDU
3. **Passivation of solar array in PCDU** (TAS Belgium):
   - Trade-off of various solar array disconnection solutions
   - Selected concept: SAR with isolated DC/DC converter and use of galvanic isolation of transformer to achieve passivation

R&D activities
Upcoming GSTP activities

1. **Electrical Passivation – PCDU upgrade for power passivation (700k€, 24 months)**
   - Follow-up previous CleanSat activities
   - Technological tests and elegant breadboard
2. **Battery Passivation – Safety Testing (250k€, 18 months)**
   - Follow-up previous CleanSat activity
   - Complement of TRP

Implementation on real missions

Example



+ environmental analysis during disposal phase

+ detailed EoM operations procedure

Implementation on real missions

Example

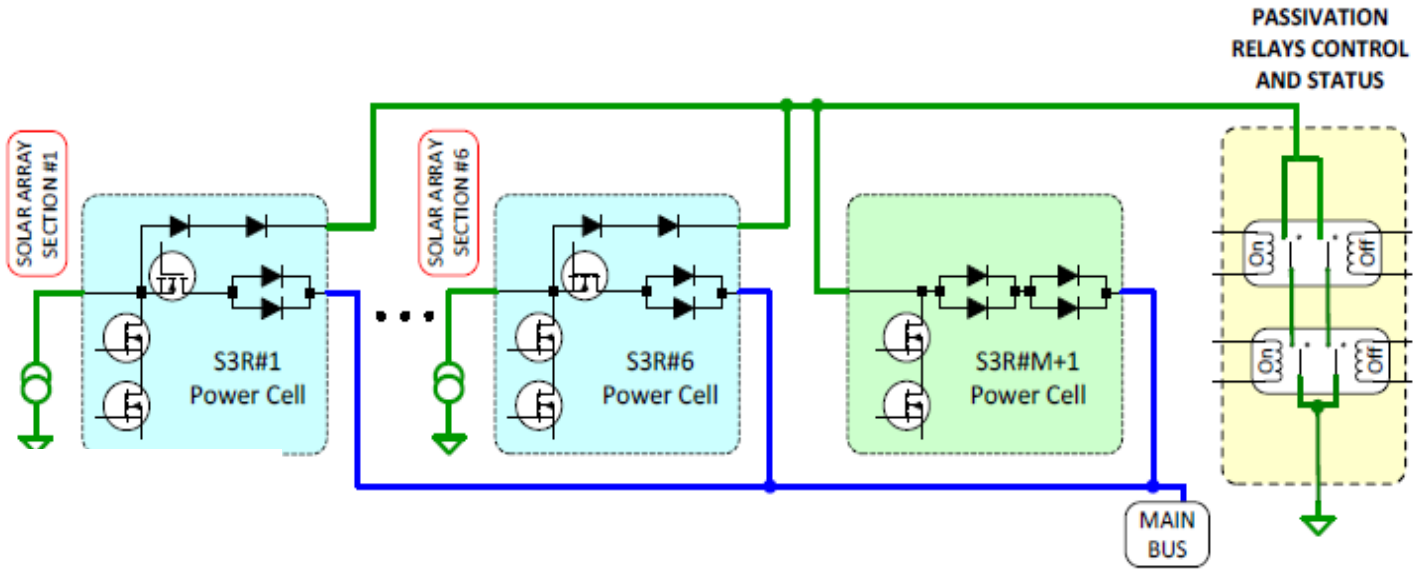


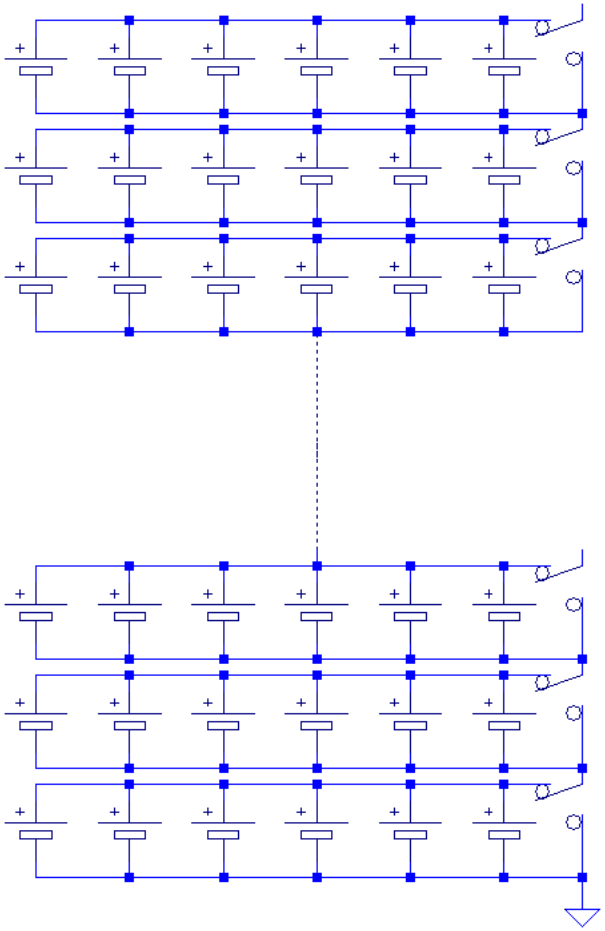
Figure 1. LEO PCDU EVO Solar Array Passivation

Credit: Airbus DS,
ESPC 2016

Implementation on real missions

Example GEO telecom satellite

Battery ps configuration with bypass switch

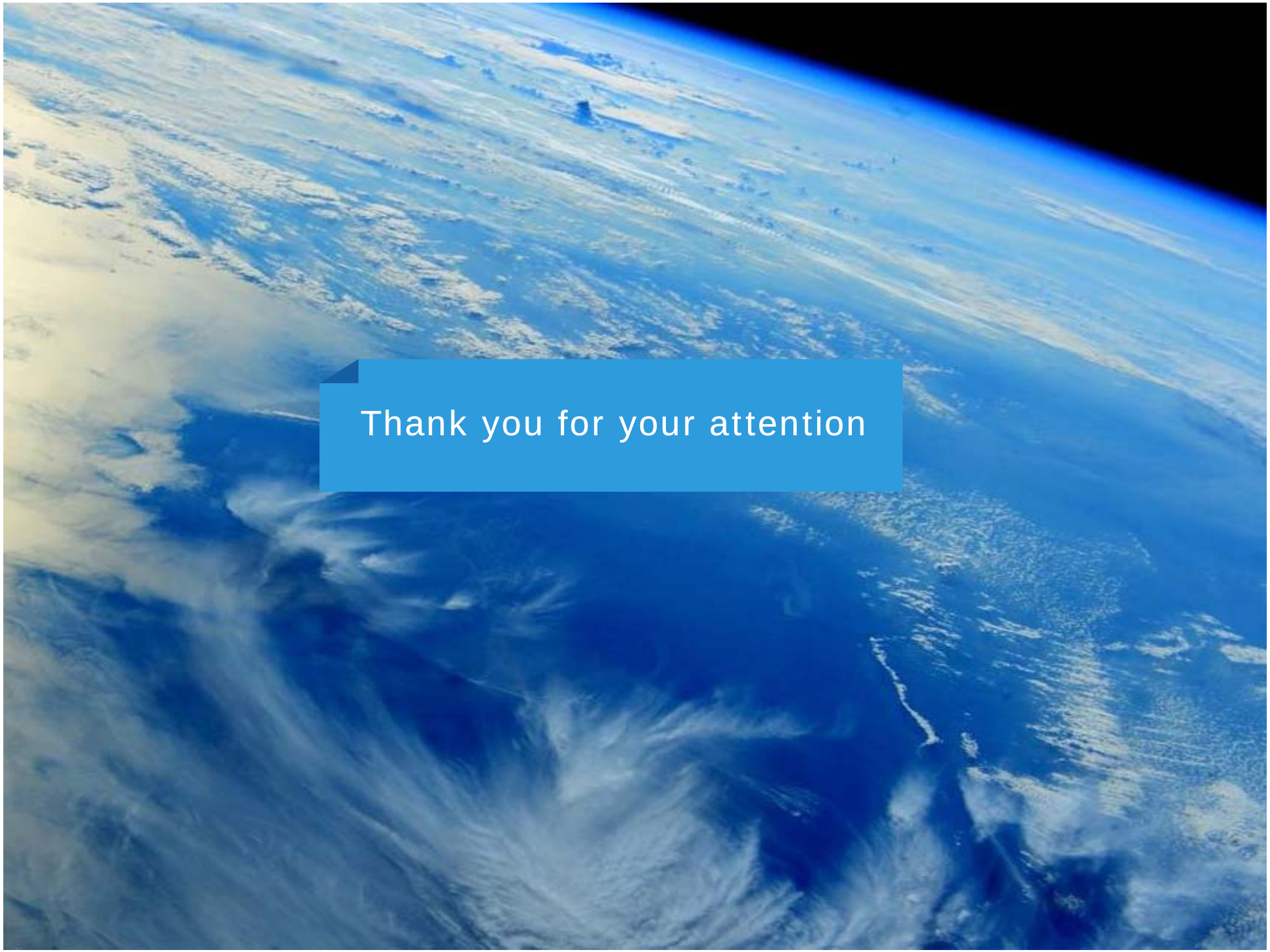


Perspectives for the future

It is expected that **more and more spacecraft will implement electrical passivation** from now on

Main planned activities:

- **Tests on batteries** (cells and modules) to assess their safety during disposal phase
  → via ongoing TRP activity and/or upcoming GSTP activity
- **Tests on components** used for passivation to assess their robustness under extreme conditions and/or extended lifetime → via ongoing GSTP phase 2
- **Development of optimal integrated designs** and operations to achieve passivation
  → via new upcoming GSTP activity and implementation on ongoing/future projects


Thank you for your attention