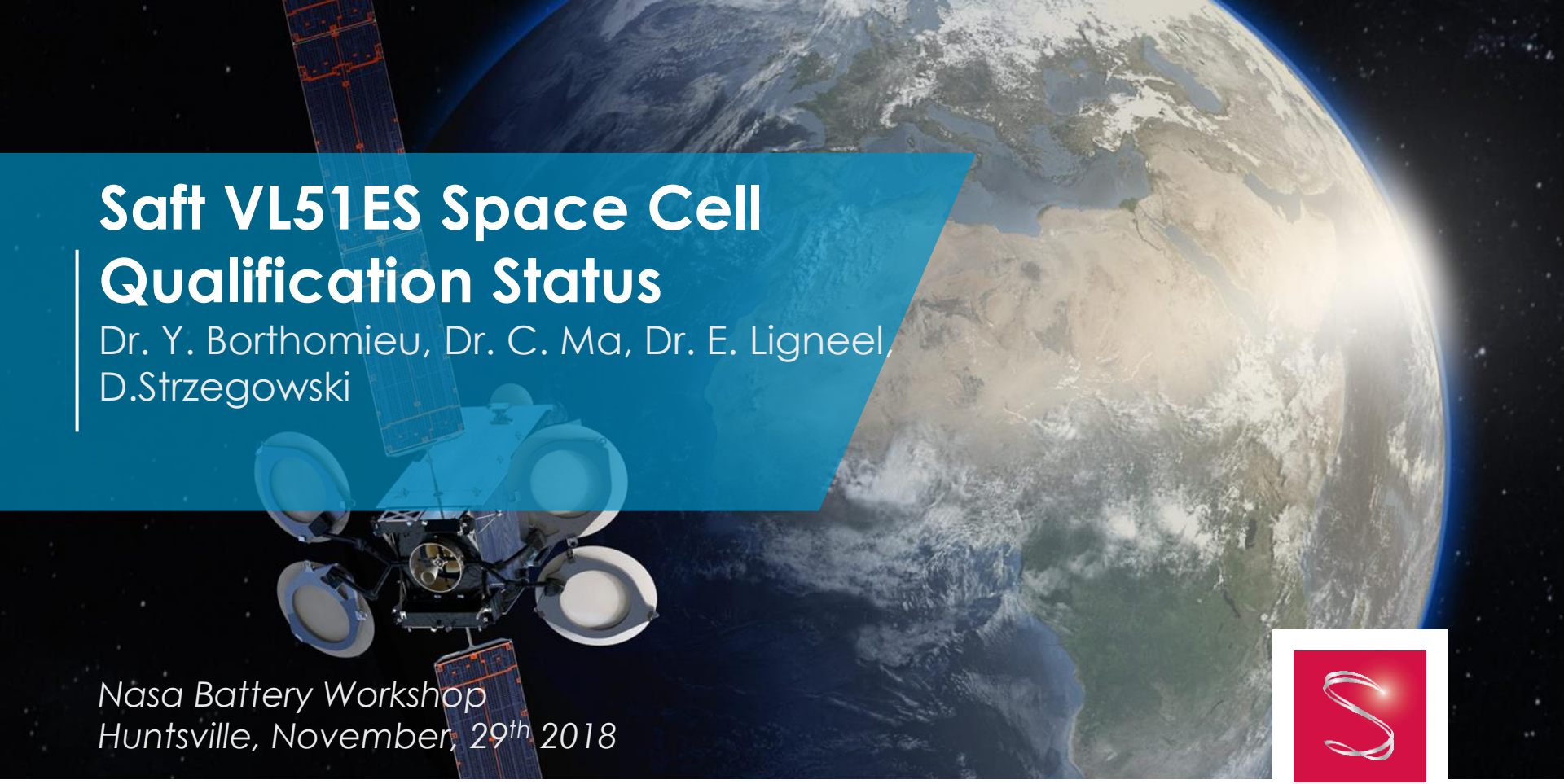


# Saft VL51ES Space Cell Qualification Status

Dr. Y. Borthomieu, Dr. C. Ma, Dr. E. Ligneel, D.Strzegowski

*Nasa Battery Workshop*
*Huntsville, November, 29th 2018*

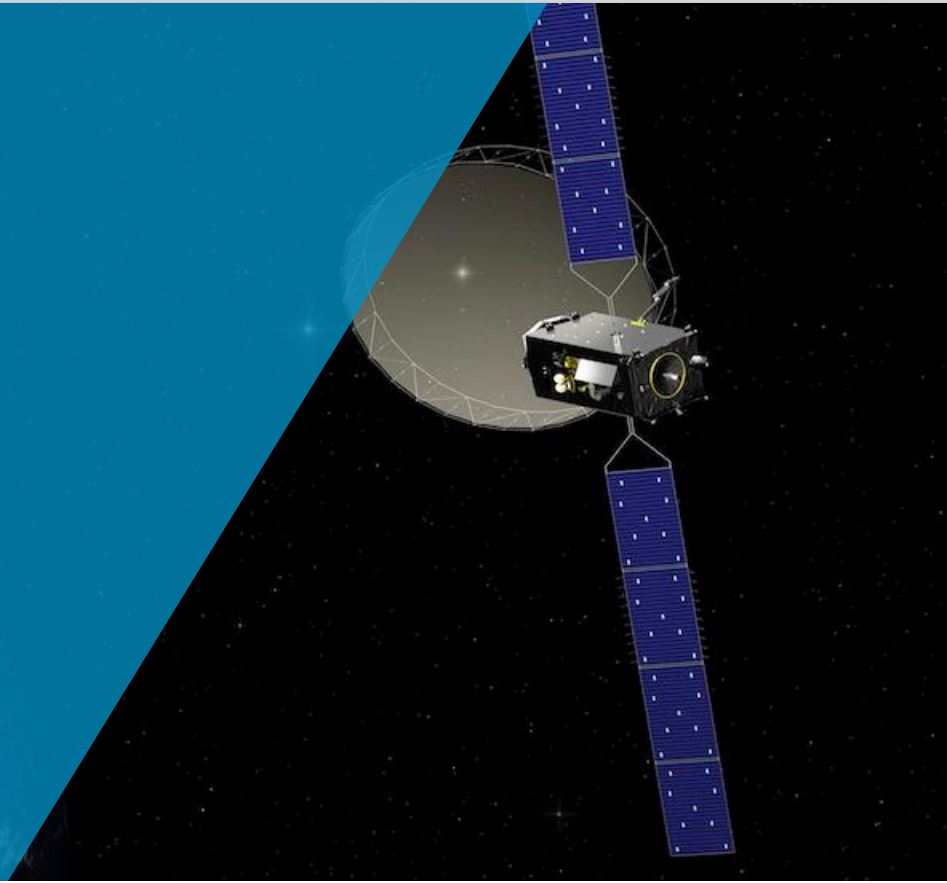
# Agenda

1 DESIGN

2 QUALIFICATION RESULTS

3 LIFE TEST

4 CONCLUSION



# Development Objectives

- Maintain and improve Saft leadership in the field of space batteries on both sides of the Atlantic with 2 manufacturing facilities : Cockeysville US and Nersac (France)
- Address mid-term and long-term **material obsolescence**
- Account for lessons learned that improve process & product robustness, and upgrade **to more industrial and cost-effective solutions**
- **Increase specific (and volumetric) energy by 10%** compared to VES180SA/VL48E
- Match or exceed performance of the VES180SA/VL48E for extended life mission with full electric missions (18 years) with **less than 8% energy degradation**

– Status:

- Mechanical & Electrochemical PDRs closed resp. in Feb13 & July13
- CDR held successfully in June 2015
- **Successful QR held Sept, 28th, 2018**

# Manufacturing Plants

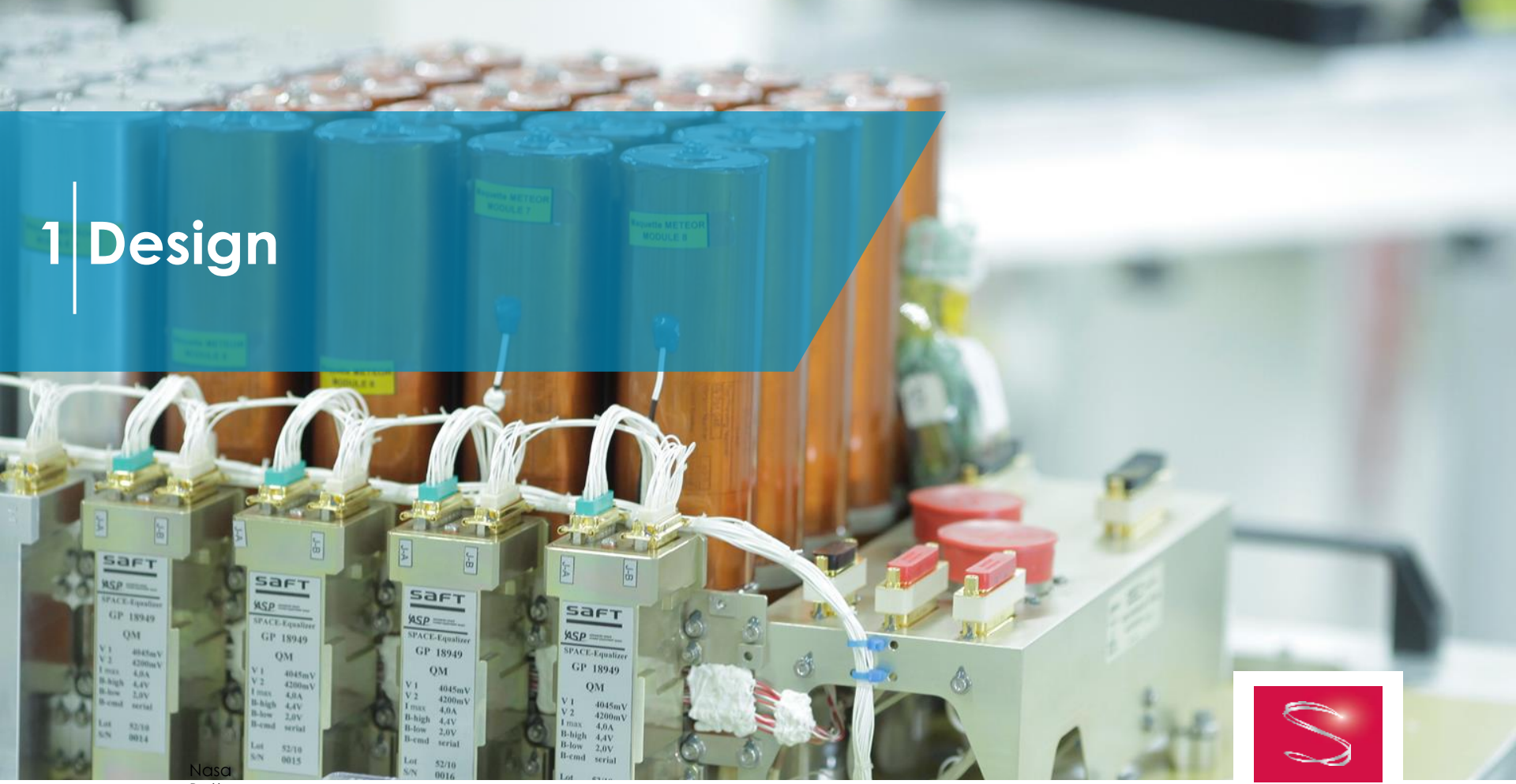
## Nersac (France)

- World's 1st production facility for Li-ion automotive batteries
- Opened since January 2008 - Automotive ISO/TS 16949
- Capacity installed : 900k power cells or 400k energy cells
- Industrial Processes to reduce costs

## Cockeysville (MD, USA)

- Multi technology cells and systems manufacturing
- High power and energy batteries
- Research & Development Center for North America

# 1 Design

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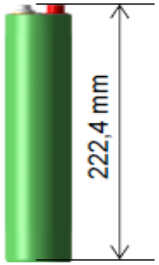
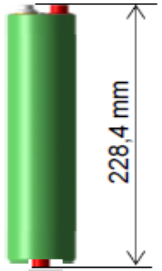
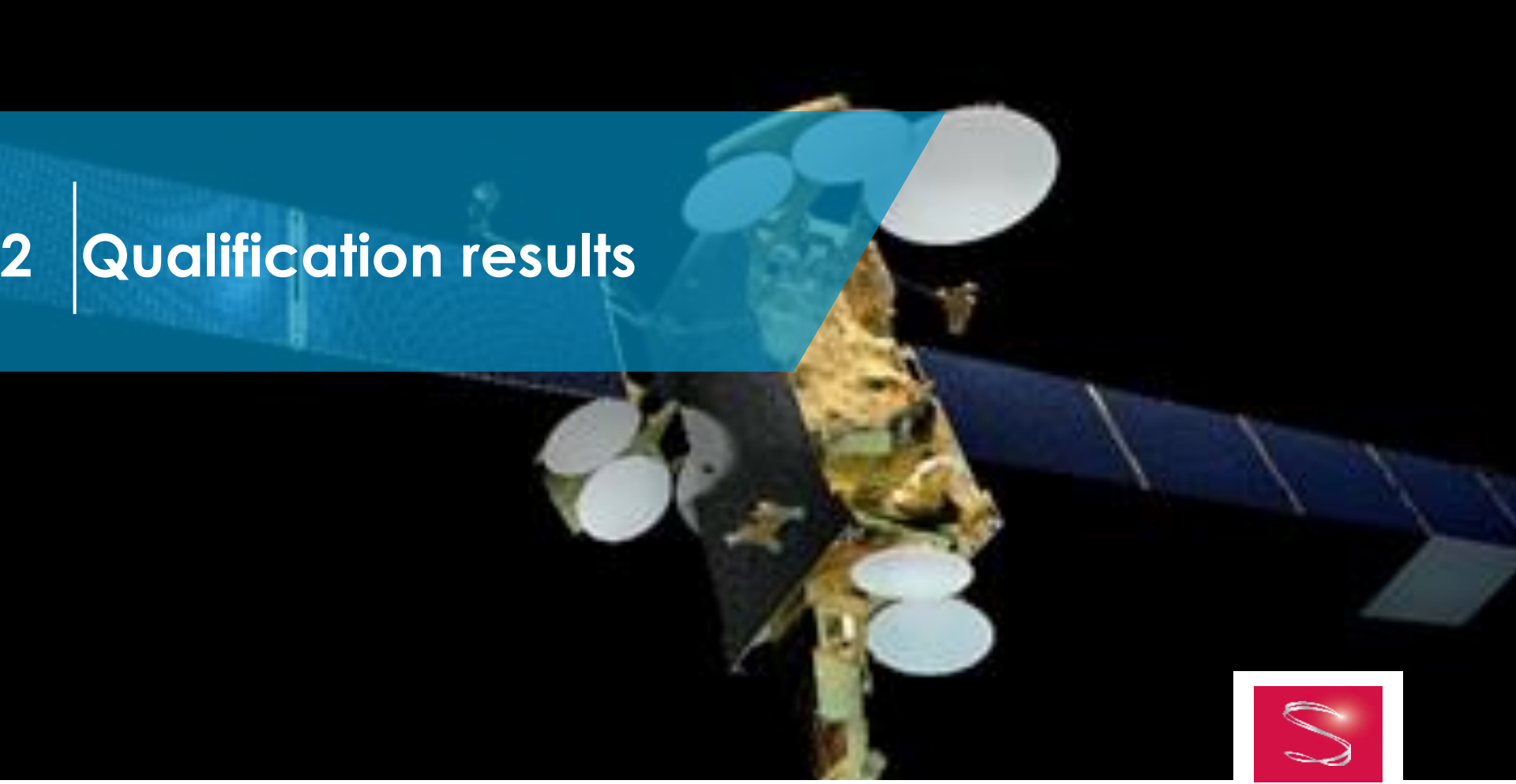
# Design overview vs VES180

- **Same diameter** but shorter compared to VES180SA/VL48E (same cell pack design)
- **Tabless design**
- Same side terminals with easier connection versus VES180/VL48E

| Configuration | 2 same side terminals as baseline | 2 same side terminals with optional bottom terminal | VES180 SA |
|---|---|---|---|
| Interface |   |   |   |

# Main characteristics

| | VES180SA/VL48E | VL51ES |
|---|---|---|
| Average capacity (Ah) @ 4.1V | 48 Ah | **51 Ah** |
| Average energy (Wh) @ 4.1V | 175 Wh | **186 Wh** |
| Average Weight (g) | 1128 g | **1079 g** |
| Voltage range (V) | 2.7-4.1 V | **2.7-4.1 V** |
| Average Specific Energy (Wh/kg) | 158 | **175** |
| Internal resistance (mΩ) | 2.5 mΩ | **1.5 mΩ** |
| Operating temperature (°C) | +10 to +40 °C | **+10 to +45 °C** |

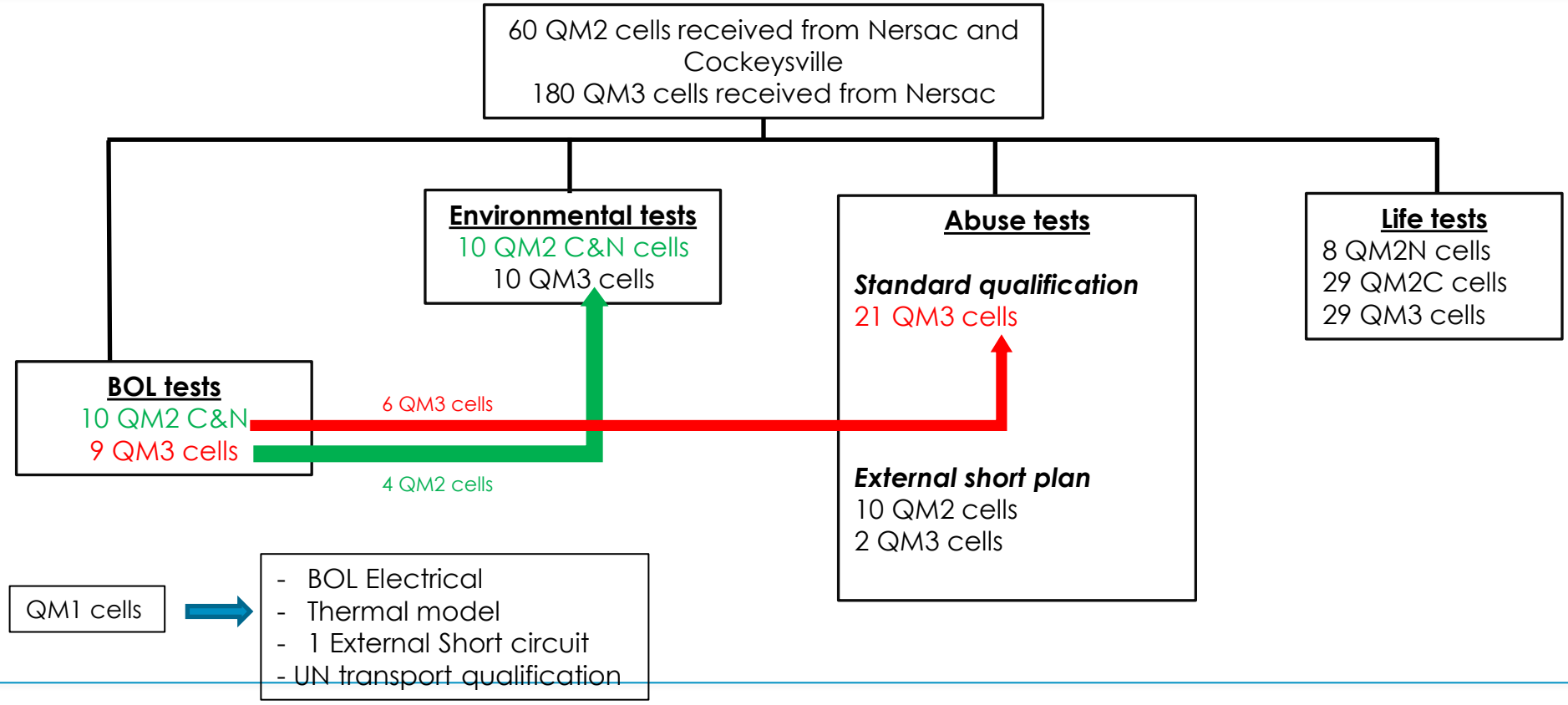


# 2 Qualification results

# VL51ES Space Cell - Qualification Plan

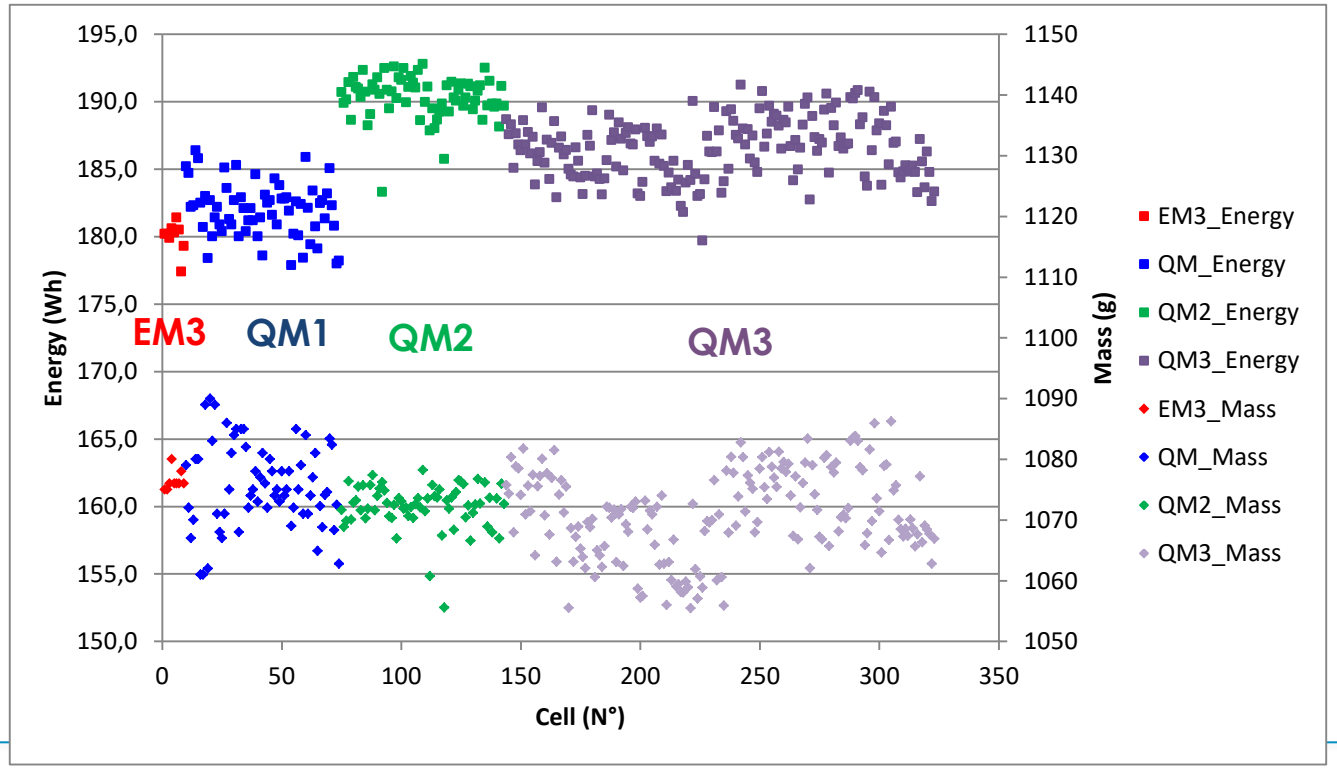
- Similar to the one applied on VES140 and VES180SA (ESA standards)
- **Same qualification plan** for both Nersac and Cockeysville batches (>100 cells each)
- Electrical characterization (Temperature, current, power, charge rate..)
- Environments tests : sine and random vibrations, accelerations and shocks on head down modules 4P and heat up 6P (on going)
- Thermal vacuum tests
- Radiations up to 8 Mrads with no degradation
- Abuse tests : Overcharge, overdischarge, high temperatures, short circuit, drop test, crush tests
- Air transport qualification
- Calendar test : different SOC (State of Charge) and Temperatures (10 to 40°C)
- Life cycles :
  - Total of **14 different life test conditions**
  - Life tests specific to customers/agencies needs (Full electric/PPS (Plasmic Propulsion System),…) started but to be extended depending customers requirements.

# QM1, QM2 & QM3 qualification organization

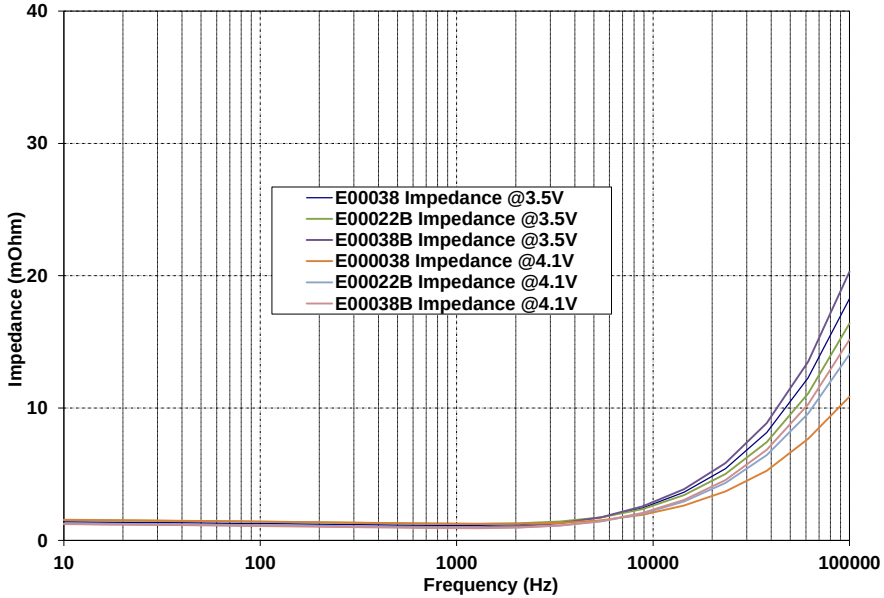


# QM Acceptance test results (including life tests cells)

## Energy and mass trend

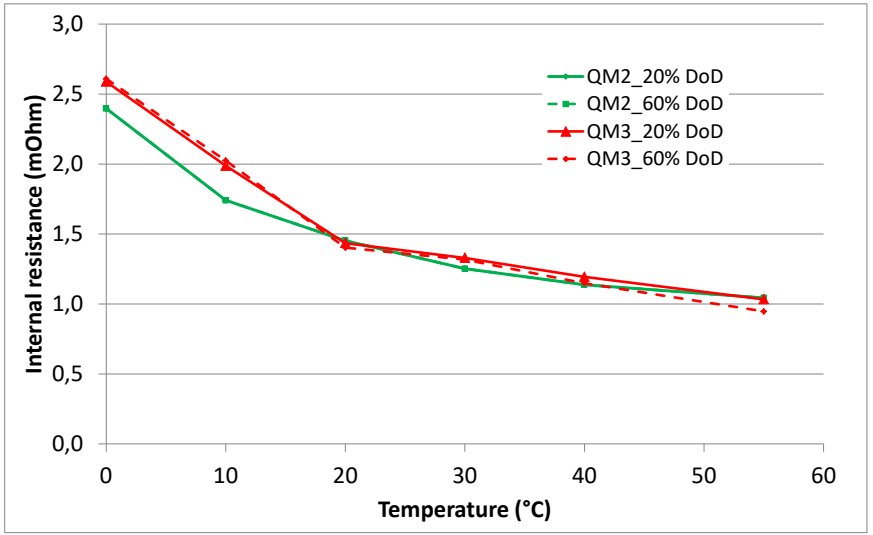


# QM BOL Electrical test : Characterization

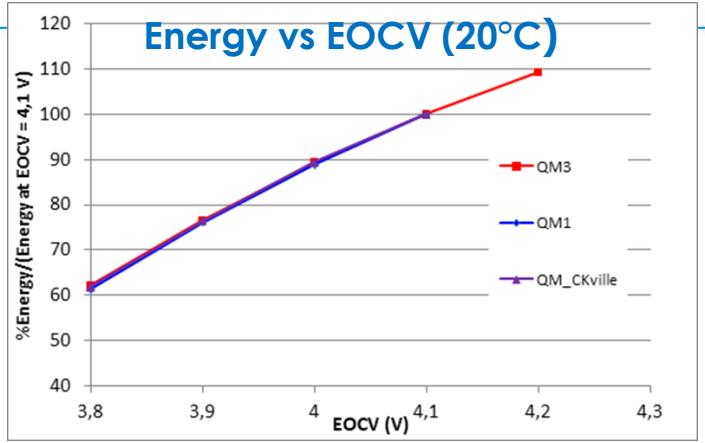


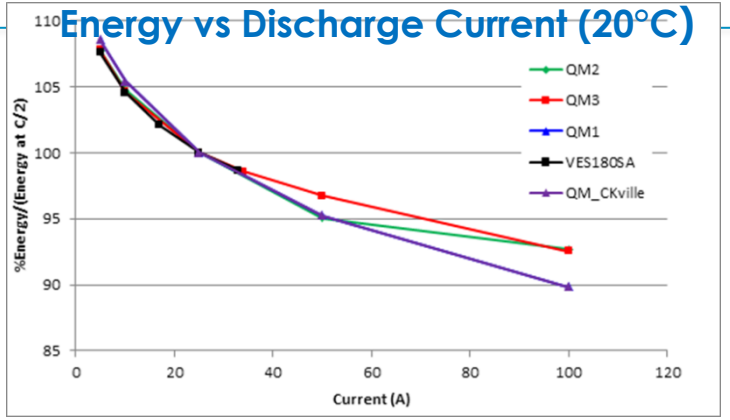

## Impedance vs DOD (@20°C)

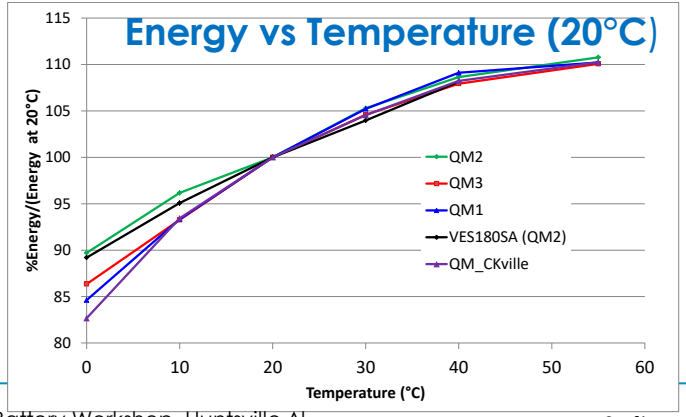
## Internal resistance vs Température

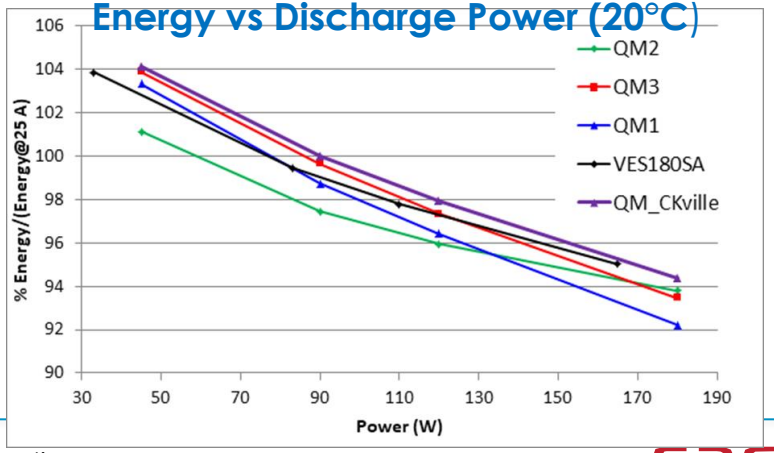


# QM BOL Electrical tests vs EOCV, Temperature, Discharge Current and Power



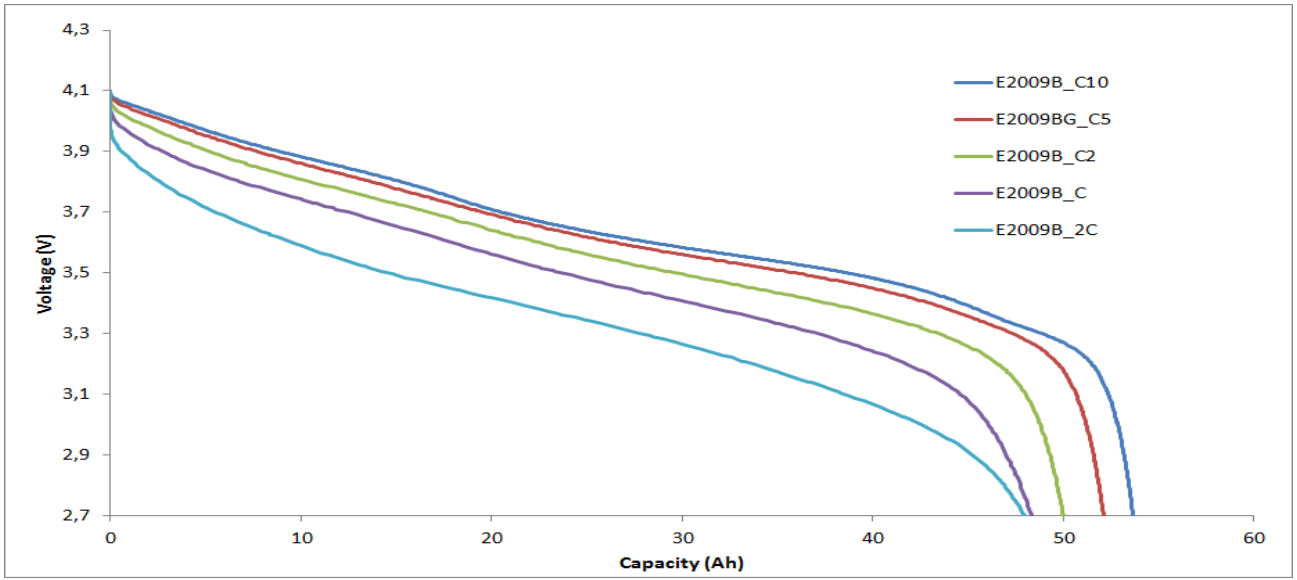



# QM BOL Electrical tests vs Discharge Current

## Capacity vs Discharge Current (20°C)



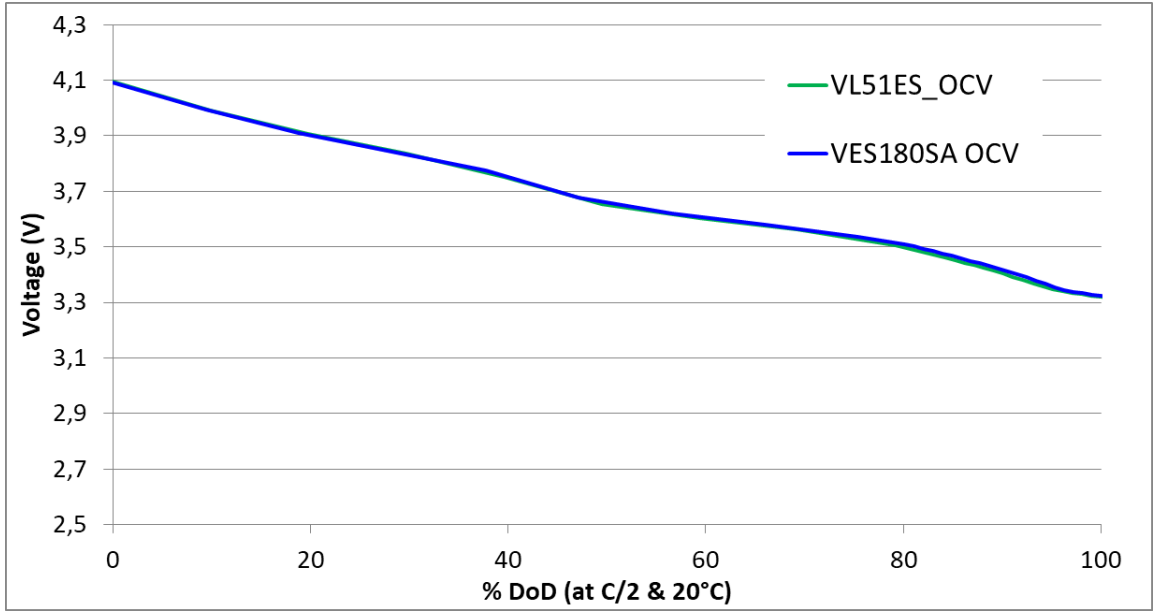
# BOL test (QM3) : Pulse

## End of pulses cell voltages

| | E00022B | E00038 | E00038B |
|---|---|---|---|
| 500 A pulse (0,9 s) at 20% DoD | 3,26 V | 3,26 V | 3,28 V |
| 153 A pulse (0,25 s) at 80% DoD | 3,37 V | 3,37 V | 3,38 V |

- **10 C discharge current pulse capability**

# BOL test (QM2) : EMF vs DoD measurements




- Typical NCA material EMF Li-ion cell
- VES180SA/VL48E and VL51ES OCV curves are identical

# 6.1.1 VL51ES QM3 4P1S and 6P1S Cell-Pack Configurations

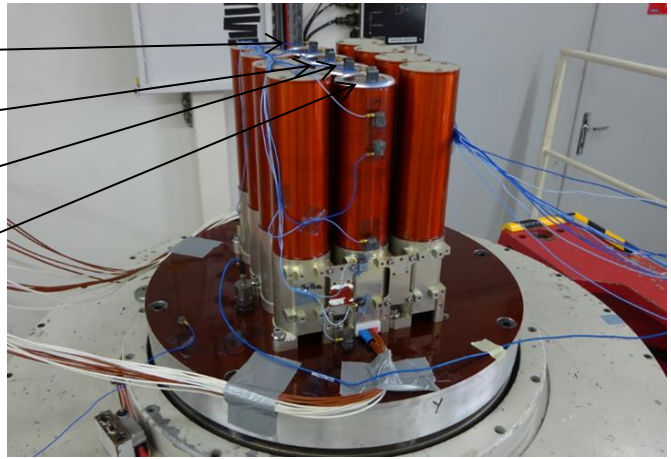
- Tests performed on three 4P3S and 6P1S VL51ES Cell-Packages

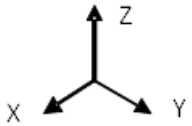
**A1 : E00116**

**A2 : E00018**

**A3 : E00042**

**A4 : E00147**






2 cell packs with four cells encapsulated head-down and six cells encapsulated head-up are interconnected in series for voltage noise measurement during all mechanical tests

# VL51ES QM3 4P1S Cell-Pack qualification tests conditions

## Mechanical & thermal qualification tests conditions:

1. **Vibration Test sequence** per axis (Resonance Frequency, Sine under discharge between 3.9V & 3.85V, Resonance Frequency, Random under discharge between 3.9V & 3.85V, Resonance Frequency)

| Sine vibrations ( 2 octaves per min.) on X, Y & Z axis | |
|---|---|
| Frequency | Amplitude |
| 5 –22.3Hz | ±10mm |
| 22.3 – 55Hz | 20g |
| 55 - 70Hz | 25g |
| 70 - 100Hz | 20g |

| Random vibrations (3 minutes per axis) | | |
|---|---|---|
| Axis | Frequency (Hz) | Amplitude |
| OX-OY 12.85g RMS 3min | 20-80 | 0.025g²/Hz |
| | 80-1000 | 0.1g²/Hz |
| | 2000 | 0.05g²/Hz |
| OZ 17.39g RMS 3min | 20 | 0.092g²/Hz |
| | 65-400 | 0.3g²/Hz |
| | 2000 | 0.06g²/Hz |

| | |
|---|---|
| Resonance research | Sine sweep 10-2000Hz – 2oct/min – 0.5g |

# VL51ES QM3 4P1S Cell-Pack qualification tests conditions

2. **Shock Test** per axis (3.5V < EOCV < 3.6V, 3 shocks per axis under discharge)

| Axis | Frequency | Shock spectrum response |
|---|---|---|
| OX-OY | 100 Hz | 60g |
| | 1000 Hz | 1000g |
| | 2000 Hz | 2000g |
| | 10000 Hz | 2000g |
| OZ | 100 Hz | 60g |
| | 1000 Hz | 1000g |
| | 2700 Hz | 2150g |
| | 10000 Hz | 2150g |

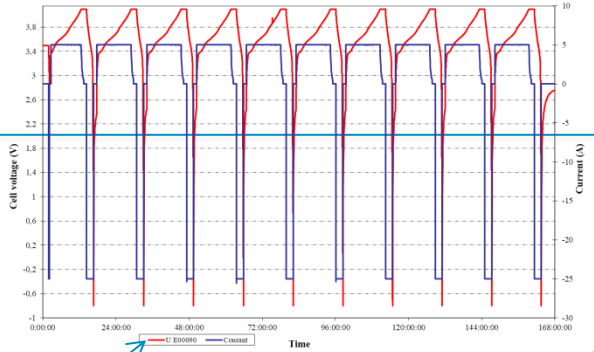
3. **Constant Acceleration** per axis (3.9V< EOCV < 4.0V, 7.5g-3min. under discharge)
4. **Thermal Vacuum Cycling** (7days at +40°C, 10 cycles from -20°C to +55°C)
5. DPA

*After each sequence : reference capacity test, charge retention and leak test*

- All vibrations criteria verified during mechanical environment qualification tests.
- All electrical performances and cell hermeticity checked after mechanical and thermal qualification environmental tests.
- No damage observed during DPA.

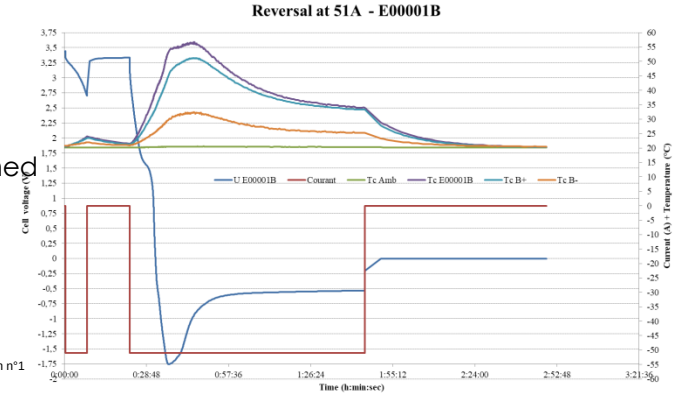
# Transport UN and Safety tests

- UN Transportation tests **done successfully**

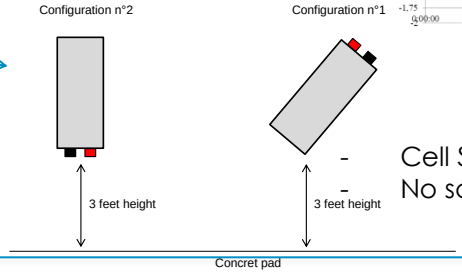



- No cell degradation
- No safety issue

- Safety test **performed sucessfully**
  - Overcharge to 4.5 V done 10 times
  - Overdischarge down to -0.8 V done 10 times
  - Cold charge 0°C C/5
  - Full reversal
  - Drop test
  - Crush test passed successfully
  - Short circuit tests 4 to 10 mOhms

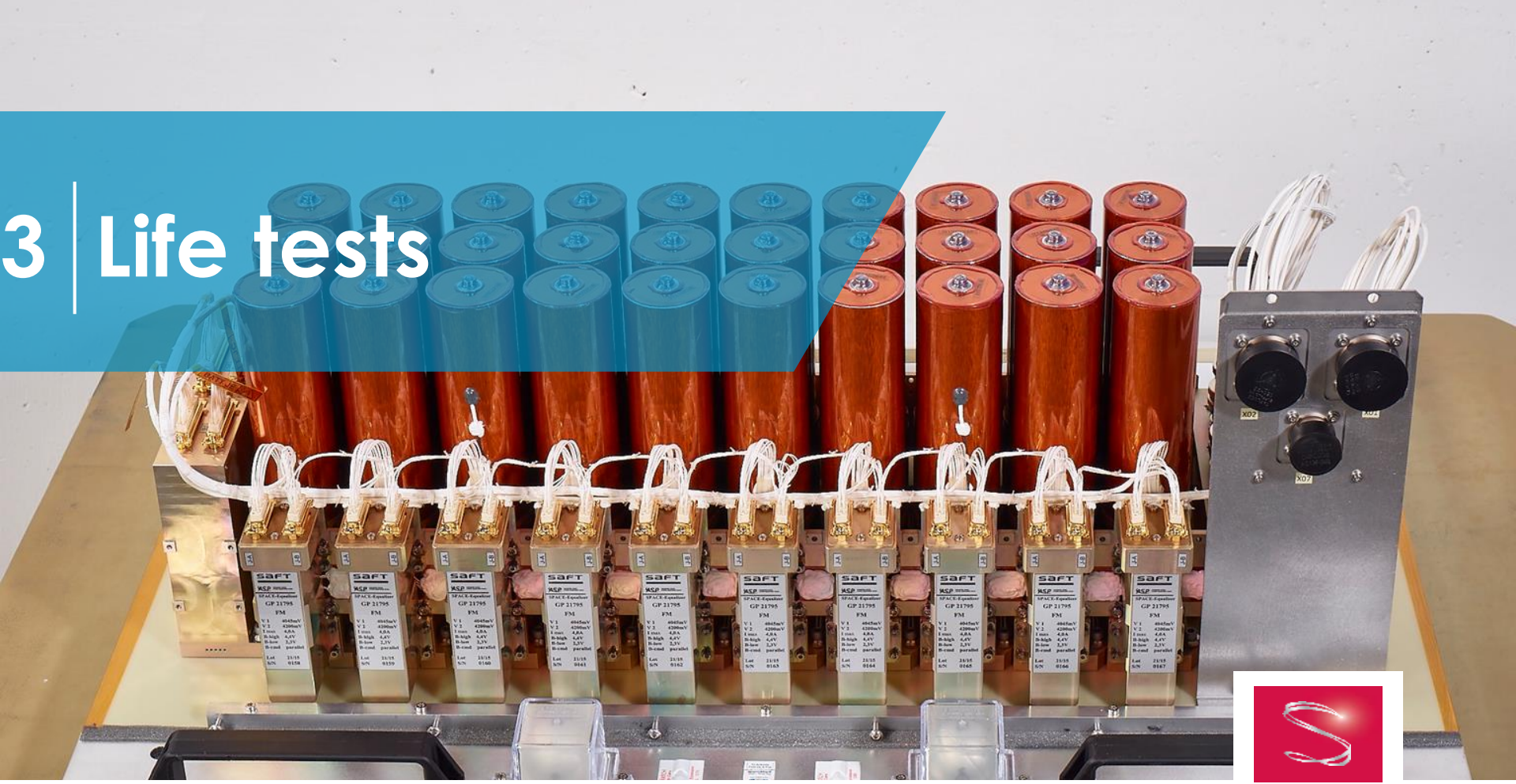



- Cell Self-short formed
- No safety issue




- Cell SOC = **100%** (storage and handling SOC)
- No safety issue for the 3 tested cells

# 3 | Life tests



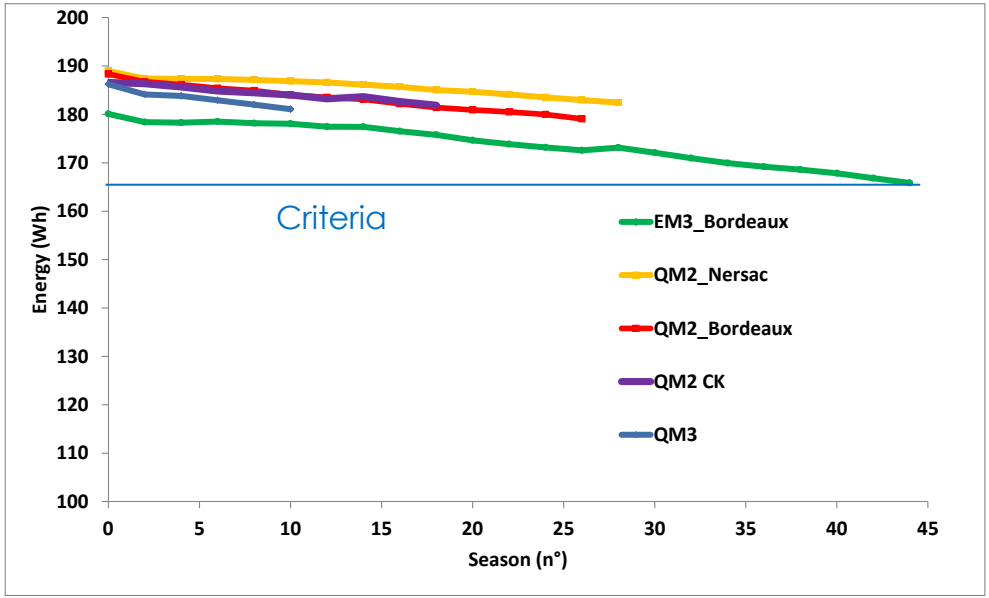
# QM3 GEO Life tests

| Life test | Key Parameter | QM1 | QM2N | QM2C and QM3 |
|---|---|---|---|---|
| LT1 | Ref : Accelerated 80 % DOD, 20°C, + radiation | 3 cells | 3 cells | 3 cells |
| LT2 | DOD 70 % | 2 cells | | 2 cells |
| LT3 | DOD 60 % | 2 cells | | 2 cells |
| LT4 | PPS | 4 cells | 4 cells | 8 cells |
| LT9 | EOCV =4,1V + vibration | 3 cells | | 3 cells |
| LT10 | Real Time | 2 cells | | 4 cells |
| LT11 | EOCV=4,075V 30°C temperature | 2 cells | | 4 cells |
| LT12 | EOCV=4,075V, Temperature, + Vibration | 2 cells | | 2 cells |

**LT5, 6 , 7 and 8 are LEO life tests**

# QM Life tests status

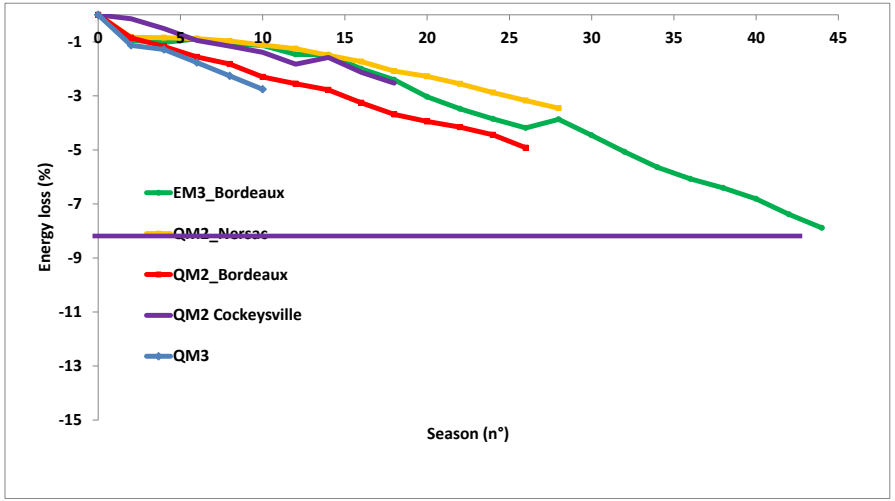
- **EM3 reached 45 seasons** corresponding to 1.5 times 30 seasons (22.5 years) with less than 6 % energy degradation
- **QM2 achieved 30 seasons** : 15 years demonstration

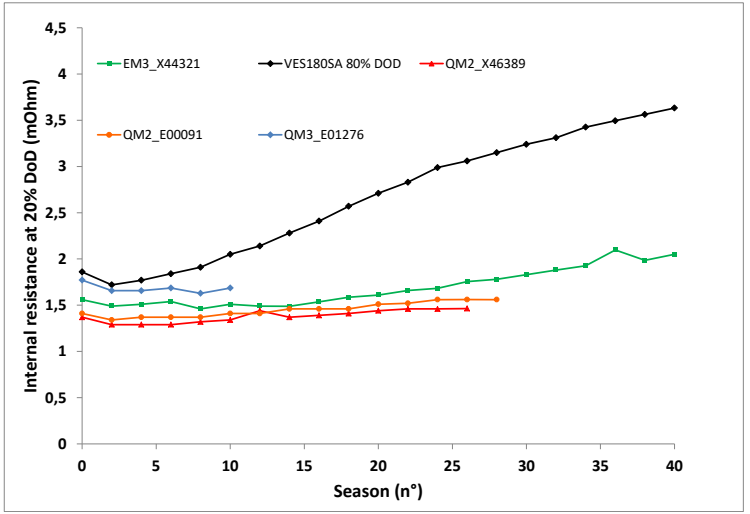



- **Accelerated LT 80 % DOD** without solstice period, charge C/10 @ 4.05 V

# Life tests status

## Accelerated GEO cycling without solstice (80% DoD ; EOCV = 4,05 V)

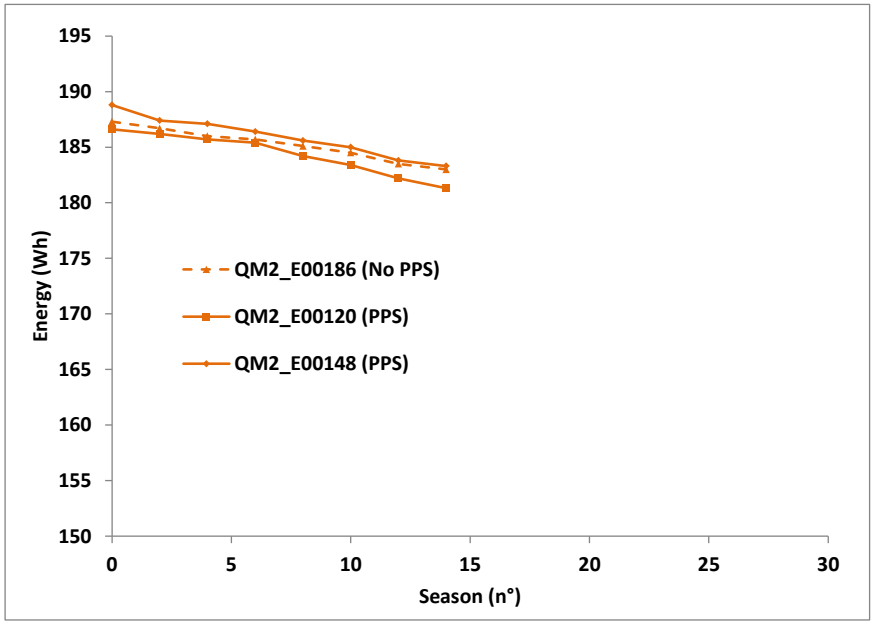


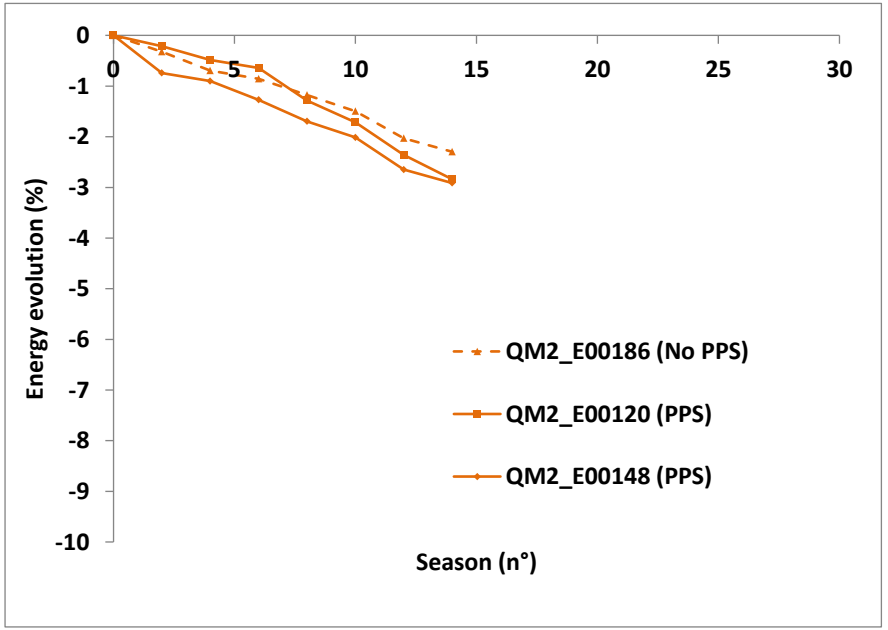




- QM2 & QM3 cell degradation are **less than 8 % at 30 seasons**
- Internal resistance is stable during the cycling

# Life tests status

## Accelerated GEO cycling with solstice & EPS (80% DoD ; EOCV = 4.075 V)




- **Full electric mission with plasmic propulsion** (2 cycles per day 20 % DOD) shows no additive degradation after 14 seasons

# 5 | Conclusion

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# Conclusion

- ✓ **VL51ES qualification review has been held successfully 28th Sept 2018**
  - BOL VL51ES cell electrical characterization completed on **3 QM batches**
  - Cell design passed mechanical/radiations & thermal vacuum tests.
  - Correlated Cell thermal Model.
  - **Abuse tests**
  - Transport qualification is successful
  - Life tests : **80 % DOD** cycle life demonstrated 1.5 factor (**45 seasons**) on EM3 and the full GEO mission **30 seasons** done on QM2

- ✓ **2 flight programs already ongoing with VL51ES batteries**