

Performances of SAFT VES16 Lithium-Ion Cells in LEO/GEO Cycling

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50 Years In Space

**Diapason 1A launched
the 17th February 1966**

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VES16 CELL MAIN ELECTRICAL CHARACTERISTICS

- VES16 is a 16Wh (4.5 Ah) **space designed** Li-ion cell
- Re-use Saft heritage in VES100/140/180 GEO series
- **Long life & low fading** NCA Li-ion technology
- **Qualification** held **in 2011** under CNES contract
- Designed for **LEO satellite** batteries
 - **>60000 cycles** with less than **20%** losses
 - **20% to 40%** DoD



- On orbit since 12/2015 on **TELEOS-1**





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VES16 CELL PERFORMANCES IN LEO LIFETIME TESTS

LEO Lifetime Tests Program

- The objective is to evaluate the effects of temperature, DOD/charge current, End Of Charge Voltage, Radar pulses on VES16 cell degradations in Low Earth Orbit cycling conditions.
- EOCV effect within the voltage range from 3.9 to 4.1 Volts during LEO cycling in real time at 20%DOD - @20°C.
- Temperature & DOD effect during LEO cycling in real time with EOCV=4.05Volts.

| LEO cycling EOCV = 4.05V | | Temperature (°C) | | | | |
|--------------------------------|----|------------------|---|----|----|----|
| | | 0 | 5 | 10 | 20 | 30 |
| DOD (%) | 10 | x | | x | x | |
| | 15 | x | | X | | |
| | 20 | x | x | x | x | x |
| | 30 | | | | x | x |
| | 40 | | | | x | |
| | 50 | | | | x | |

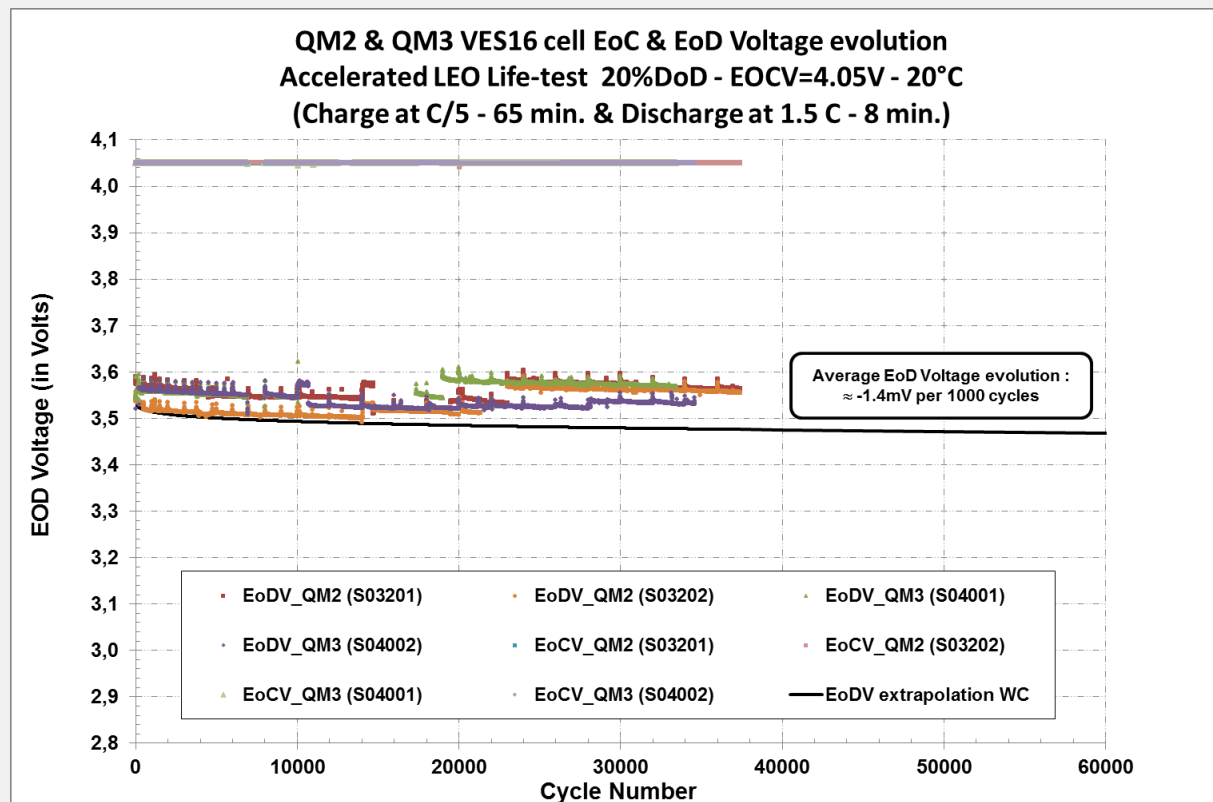
Temperature range from 0° to +30°C (700 cycles performed at 0°C in case of survival mode)

DOD range from 10% to 50%
Charge current from C/10 to C/2

- Impact of Radar Pulses at 1.5C, 2C, 2.5C & 3C during accelerated LEO cycling with EOCV=4.05V - @20°C.

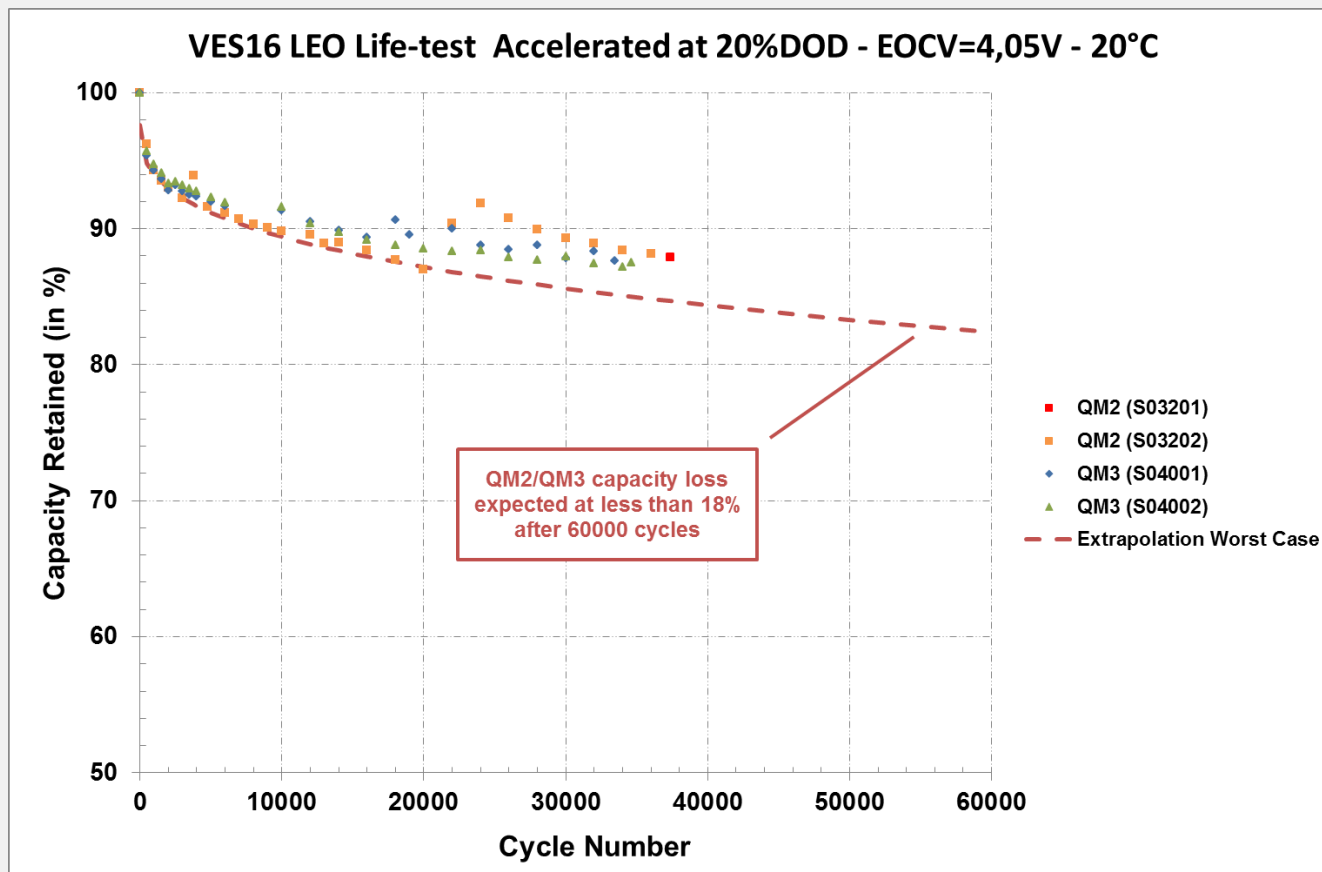
Accelerated LEO Cycling at 20%DoD results

- The objective is to evaluate quickly VES16 Li-ion cell behavior in LEO cycling conditions, even if more severe cell ageing is expected due to the acceleration of the discharge (**1.5C - 8 min.**) , **65 min Charge C/5.**



- EOD Voltage slope is stabilized at **≈ -1.4mV per 1000 cycles.**

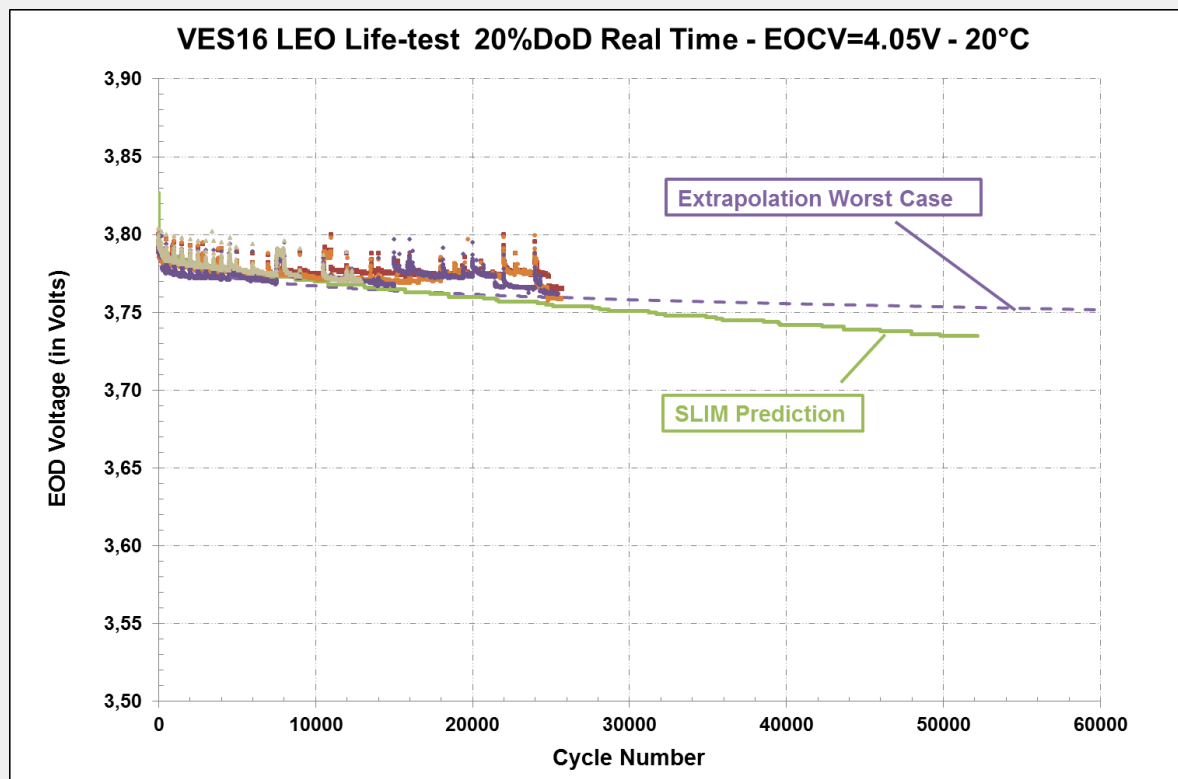
Accelerated LEO Cycling at 20%DoD results



- 13% capacity loss after respectively 38000 cycles on QM2 & 34000 cycles on QM3.
- **Less than 18% capacity loss expected after 60000 cycles.**

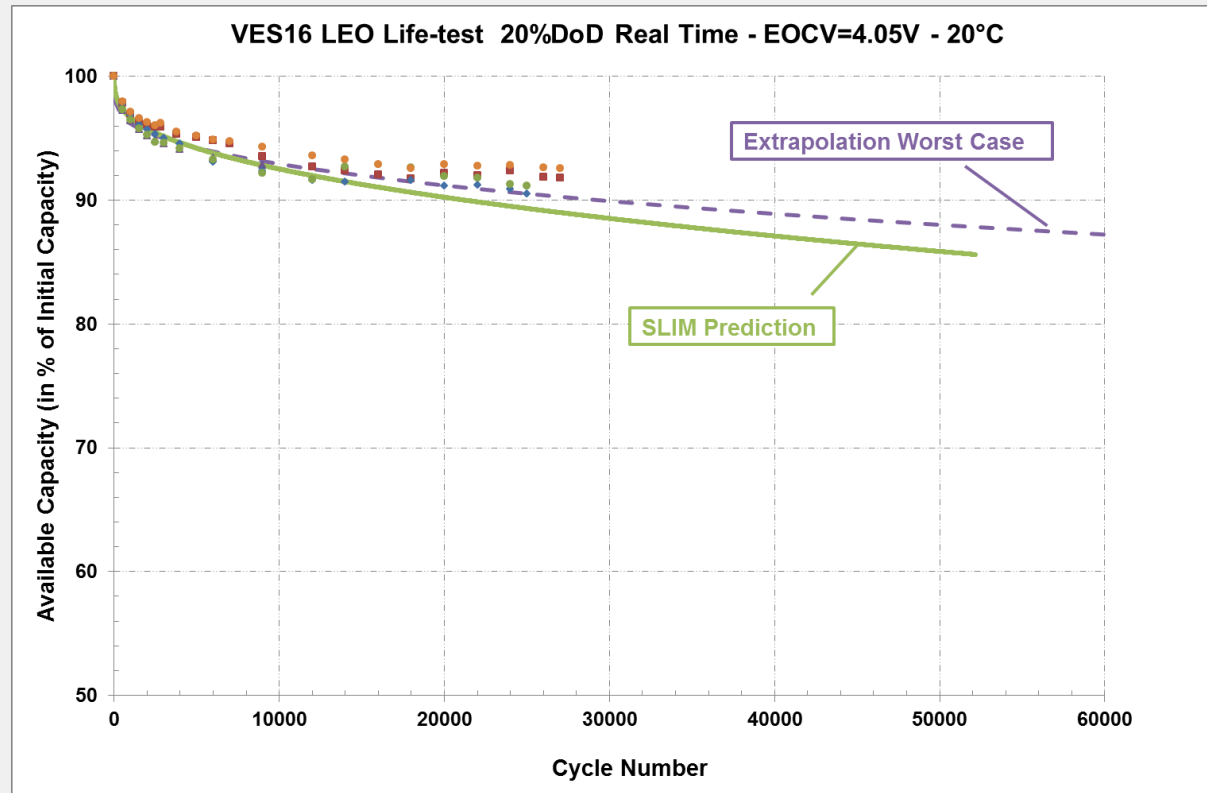
Real Time LEO Cycling at 20%DoD results

- Real LEO cycling conditions at 20%DOD (Charge at C/5 + taper at EOCV=4.05V - 65 minutes & discharge at 1.54 Amps - 35 minutes).



- EOD Voltages measured or extrapolated at 60000 cycles remain above **3.75 V**.

Real Time LEO Cycling at 20%DoD results



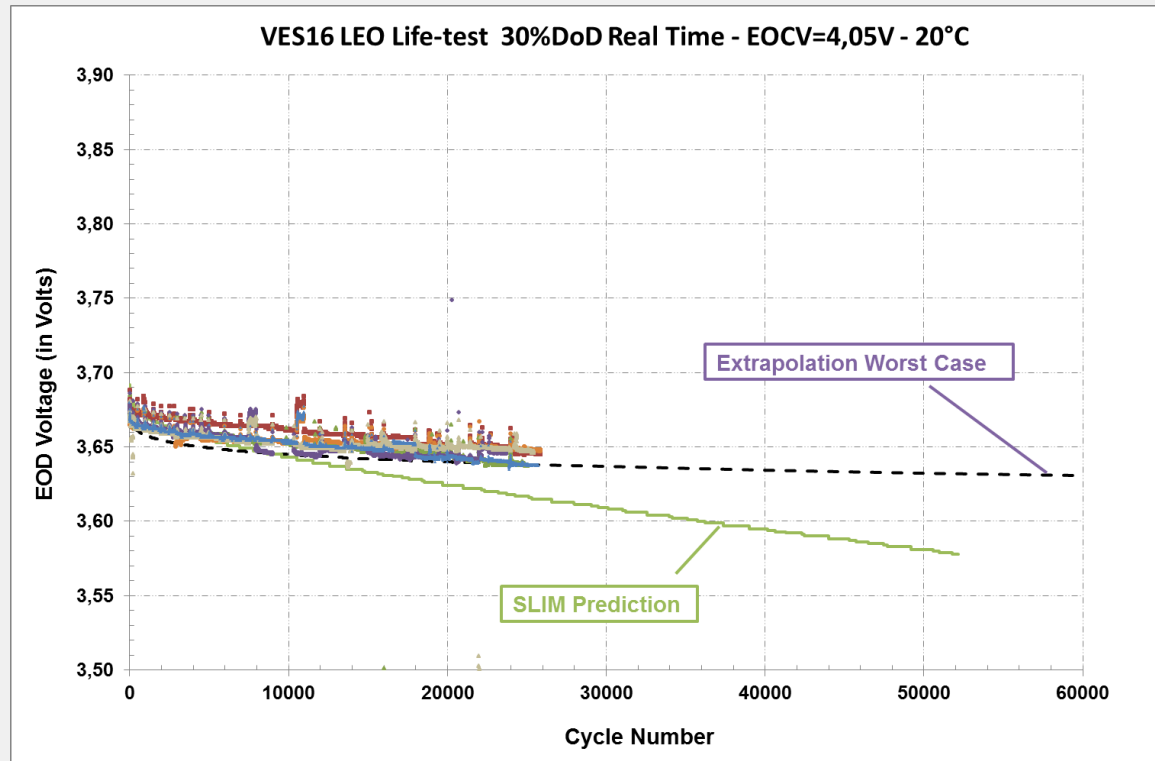
- 27000 cycles performed with less than 10% capacity loss.
- **Less than 13% capacity loss expected after 60000 cycles.**
- SLIM output fits with Worst Case extrapolation.

2. VES16 Cell Performances in LEO Lifetime Tests



Real Time LEO Cycling at 30%DoD results

- Real LEO cycling conditions at 30%DOD (Charge at C/3 + taper at EOCV=4.05V - 65 minutes & discharge at 2.31 Amps - 35 minutes).

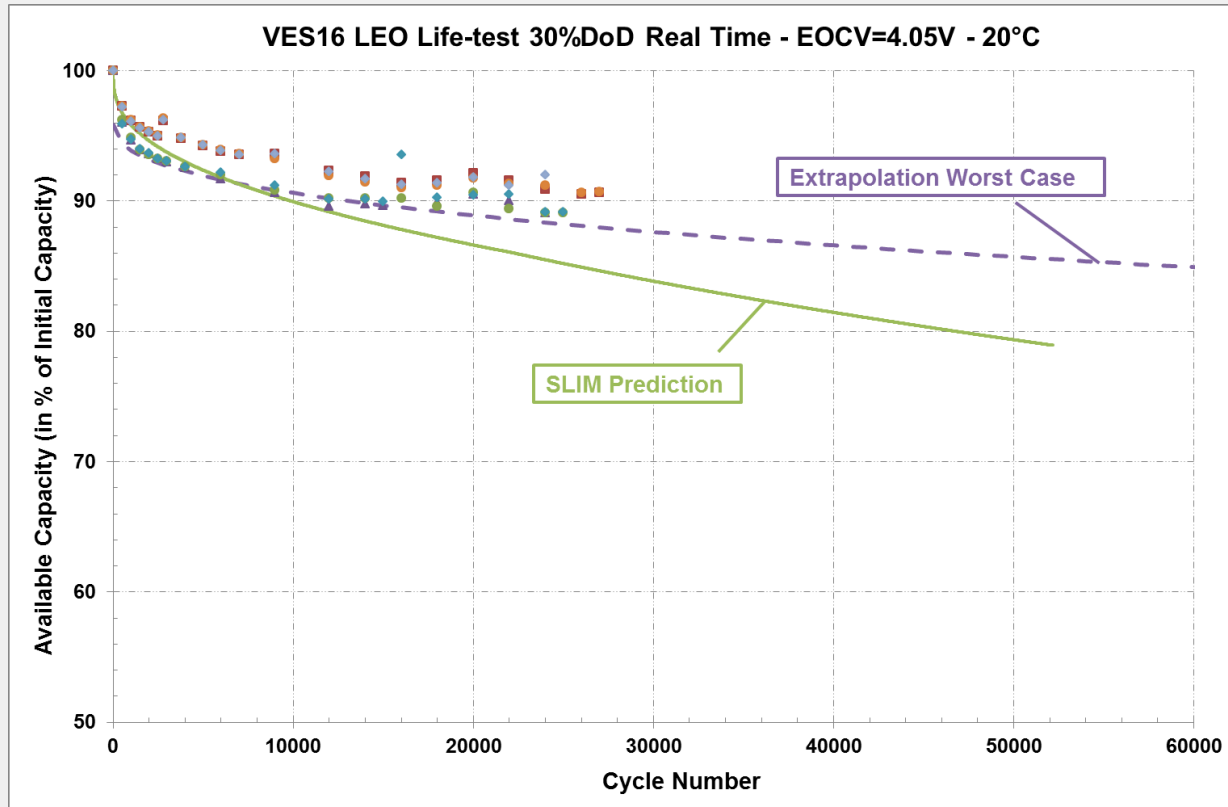


- EOD Voltages measured or extrapolated at 60000 cycles remain **above 3.63 V**.

2. VES16 Cell Performances in LEO Lifetime Tests



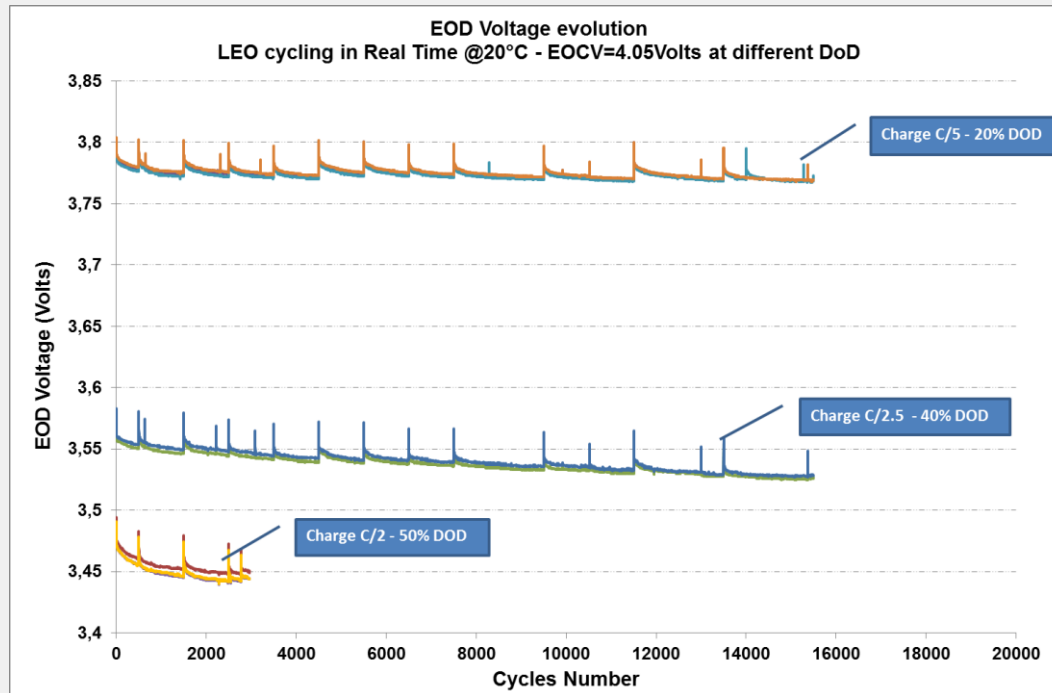
Real Time LEO Cycling at 30%DoD results



- 27000 cycles performed with less than 12% capacity loss.
- **Less than 15% capacity loss expected after 60000 cycles.**
- SLIM output fits with Worst Case extrapolation.

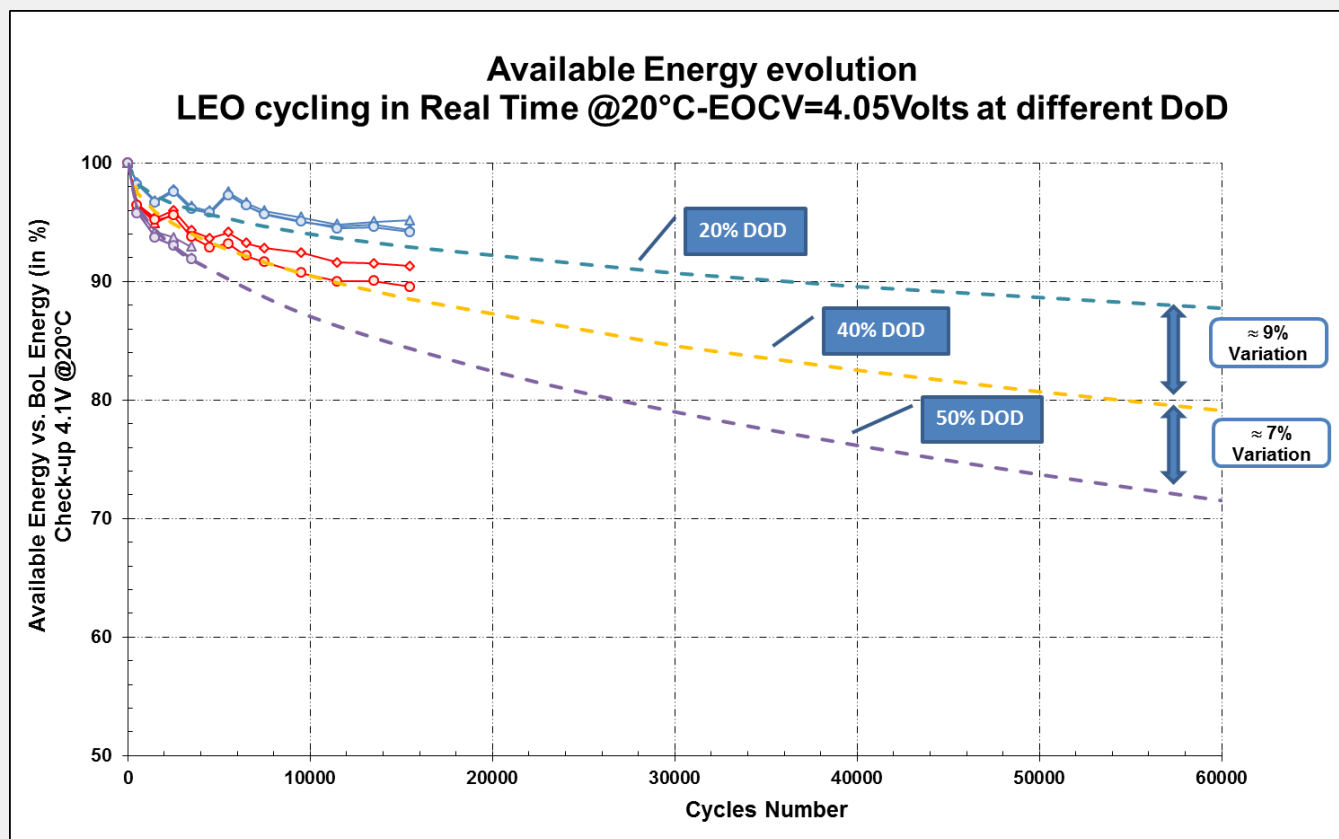
DOD/charge current effect on VES16 electrical performances in LEO cycling conditions

- The objective is to evaluate the effects of DOD/charge current on VES16 cell performances in LEO cycling conditions (EOCV=4.05 Volts - @+20°C).



- After 15500 cycles, EOD Voltage evolution slope increases **from -2,2 to -3,5 mV per 1000 cycles between 20% & 40% DOD.**
- Promising results in cycling at 50%oD presenting stabilization of EOD Voltage evolution slope from 1500 cycles.

DOD/charge current effect on VES16 electrical performances in LEO cycling conditions



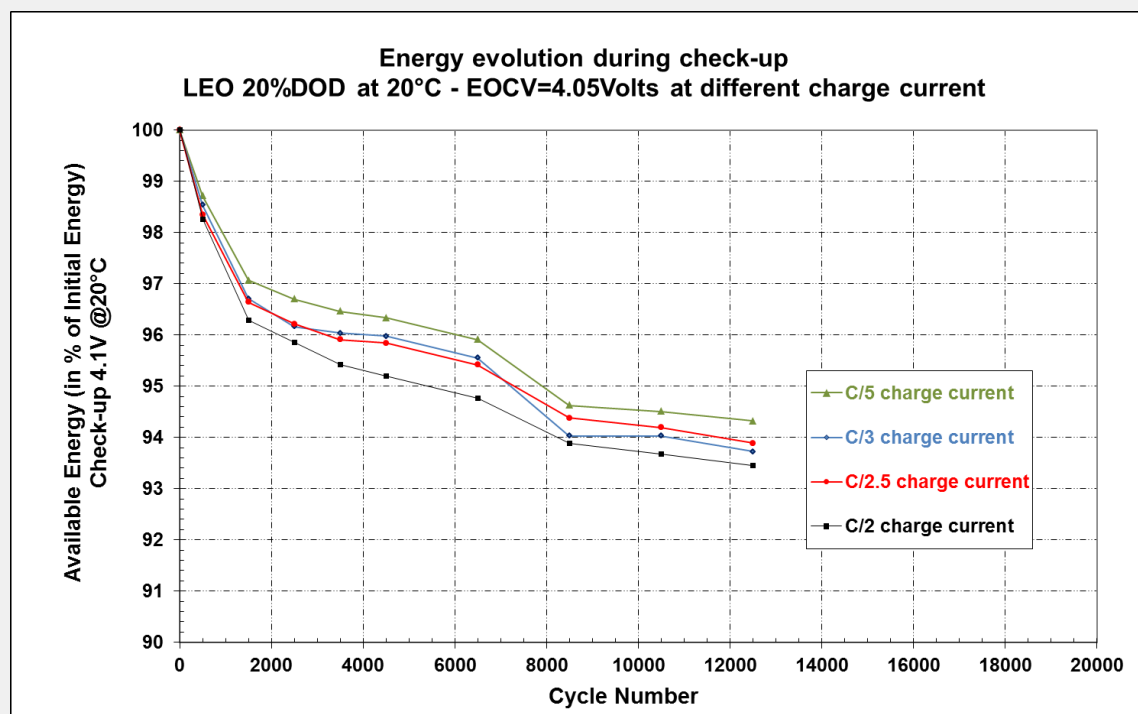
- Energy loss increase expected at 60000 cycles,
 - less than **≈9% between 20 & 40%DoD**
 - and less than **≈7% between 40% & 50%DoD**. (16 % from 20 to 50 %)

VES16 Cell Performances in LEO Lifetime Tests



DOD/charge current effect on VES16 electrical performances in LEO cycling conditions

- The objective is to evaluate the effect of the charge current from C/5 to C/2 without changing DoD on VES16 cell performances in LEO cycling at 20%DoD - EOCV=4.05 Volts @+20°C.

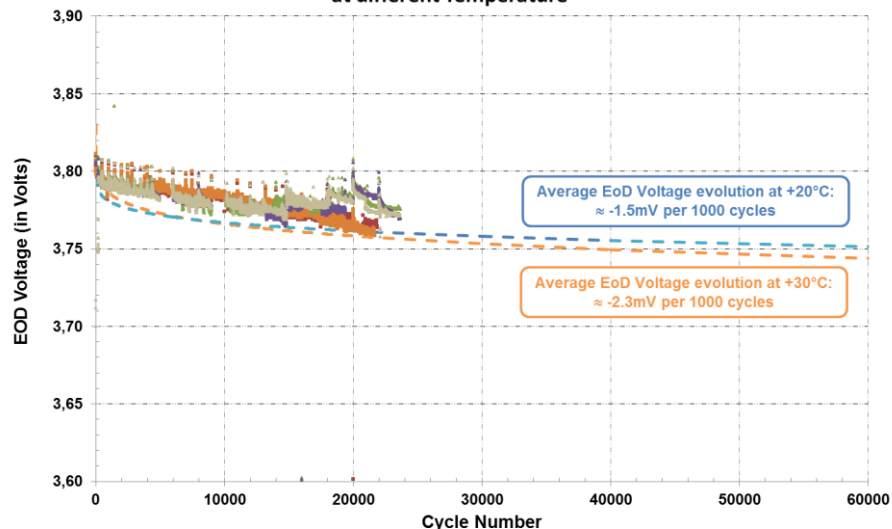


- The cell performance degradation when DoD/charge current increase , is mainly due to DoD, as no significant effect (less than 1%) on ageing is measured within the **charge current range from C/5 to C/2**.

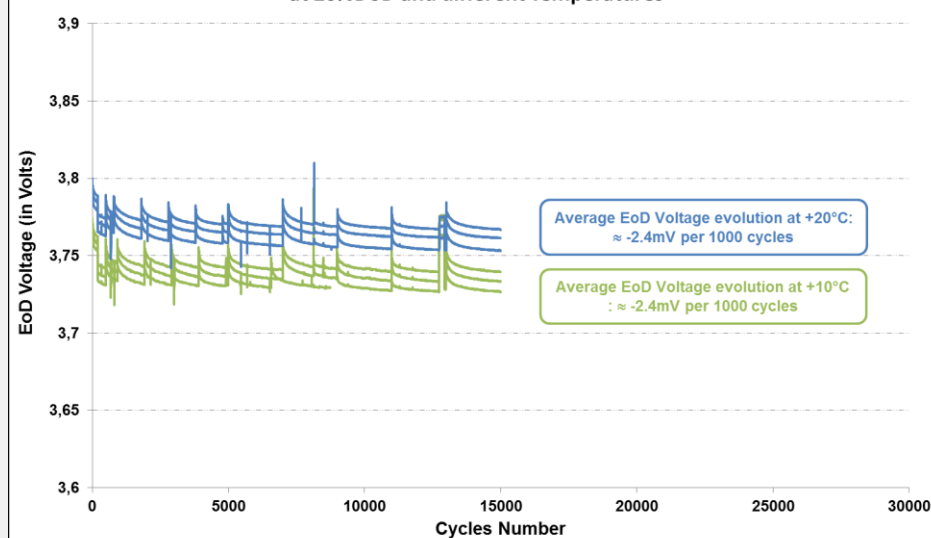
Temperature effect on VES 16 electrical performances in LEO cycling conditions

- Real time at 20%DoD - EOCV=4.05 Volts.

VES16 LEO Life-test 20%DoD Real Time - EOCV=4,05V
at different Temperature



EoD Voltage evolution during LEO Life-Tests
at 20%DoD and different Temperatures

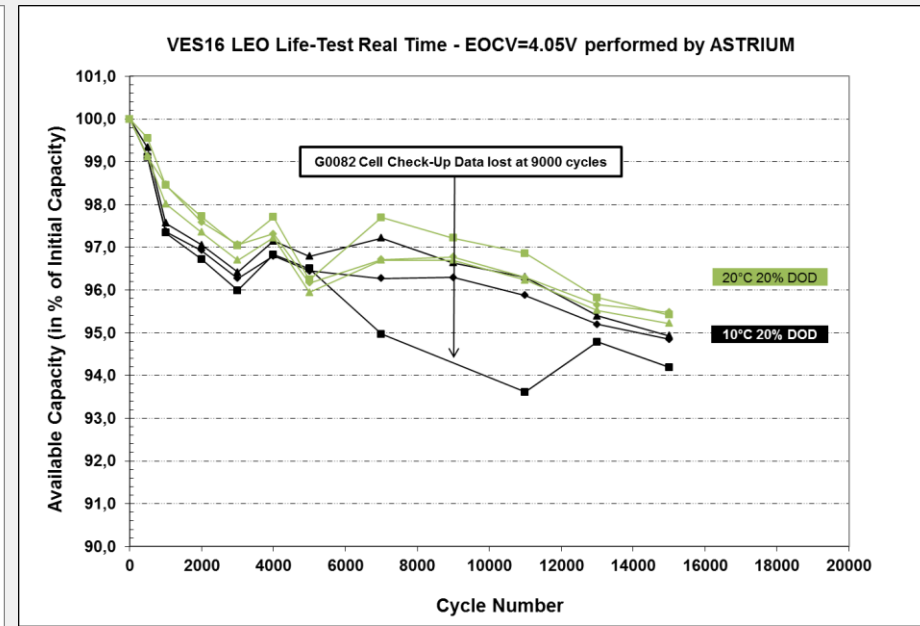
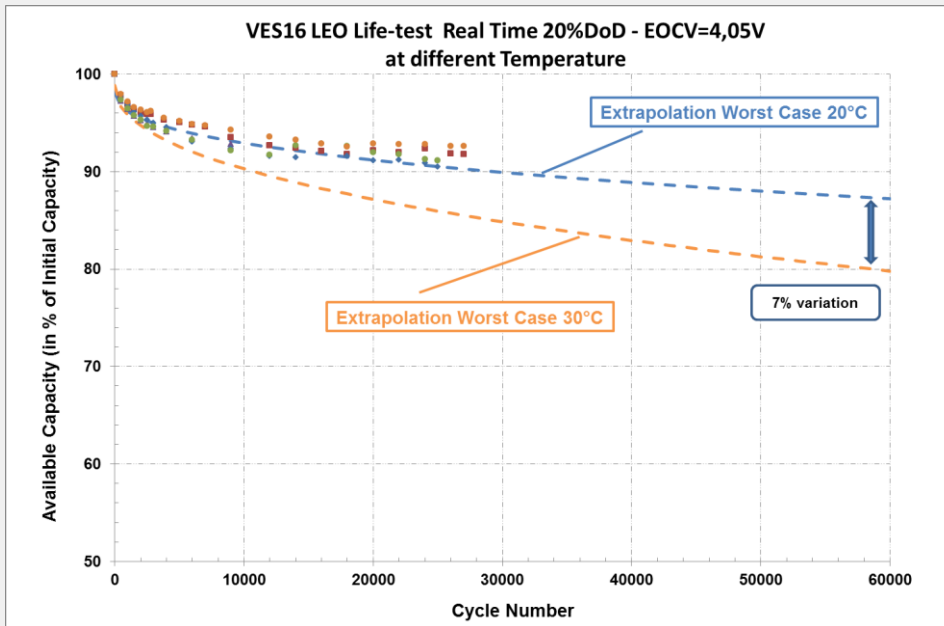


- EOD Voltage evolution slope increases with temperature, **from -1.5 to -2.3mV per 1000 cycles from 20 to 30°C** after 25000 cycles, while no significant variation is measured between 10°C & 20°C after 15000 cycles.

2. VES16 Cell Performances in LEO Lifetime Tests



Temperature effect on VES 16 electrical performances in LEO cycling conditions



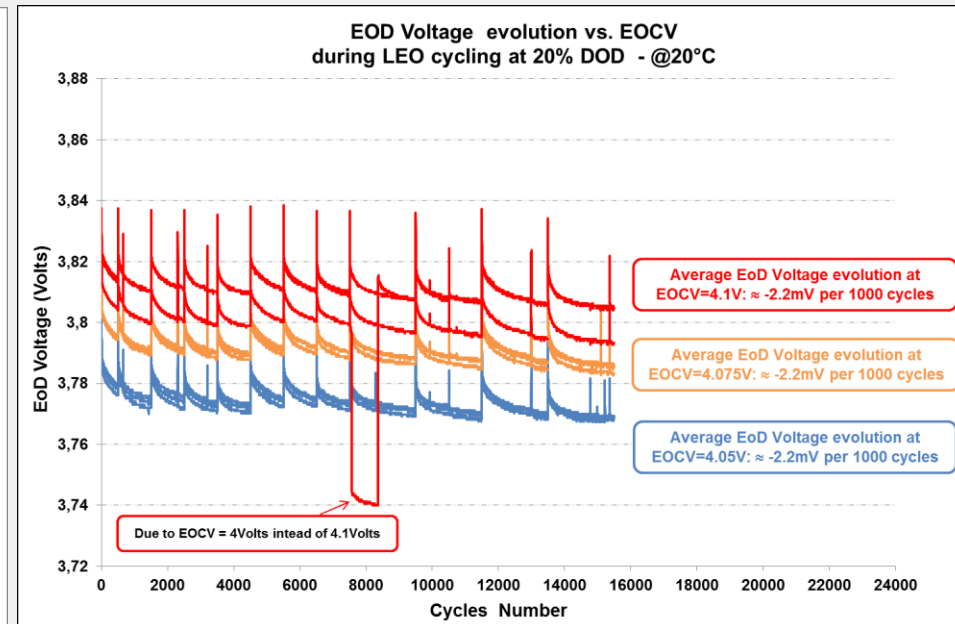
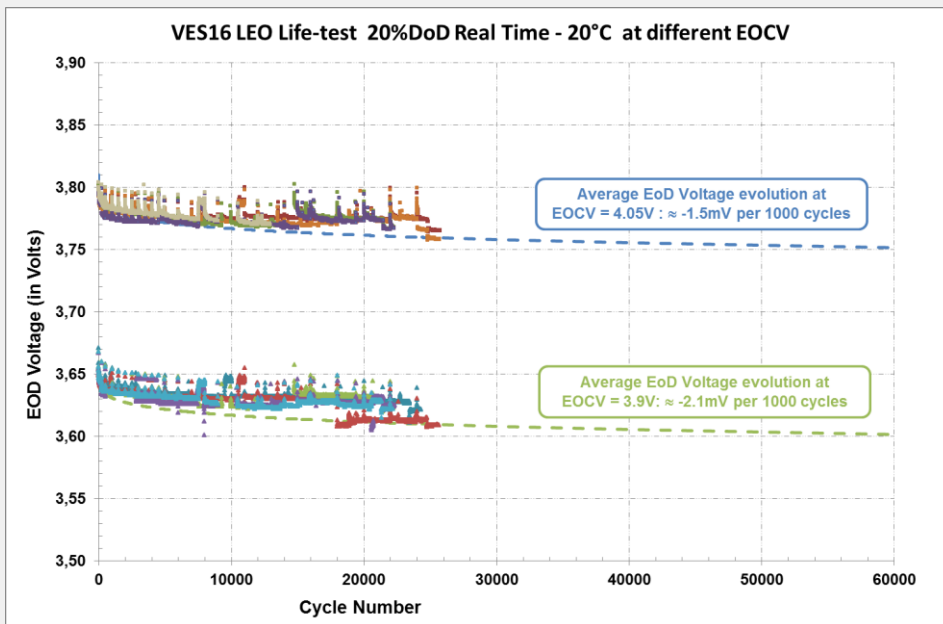
- Capacity loss increases with temperature, $\approx 4\%$ from 20 to 30°C after 25000 cycles, while no significant variation is measured between 10°C & 20°C after 15000 cycles.
- After **60000 cycles**, $\approx 7\%$ capacity loss increase is expected between 20°C & 30°C.

2. VES16 Cell Performances in LEO Lifetime Tests



EOCV effect on VES16 electrical performances in LEO cycling conditions

- EOC Voltage from 3.9 to 4.05, then from 4,05 to 4,1 Volts during LEO cycling in real time at 20%DoD - @20°C.

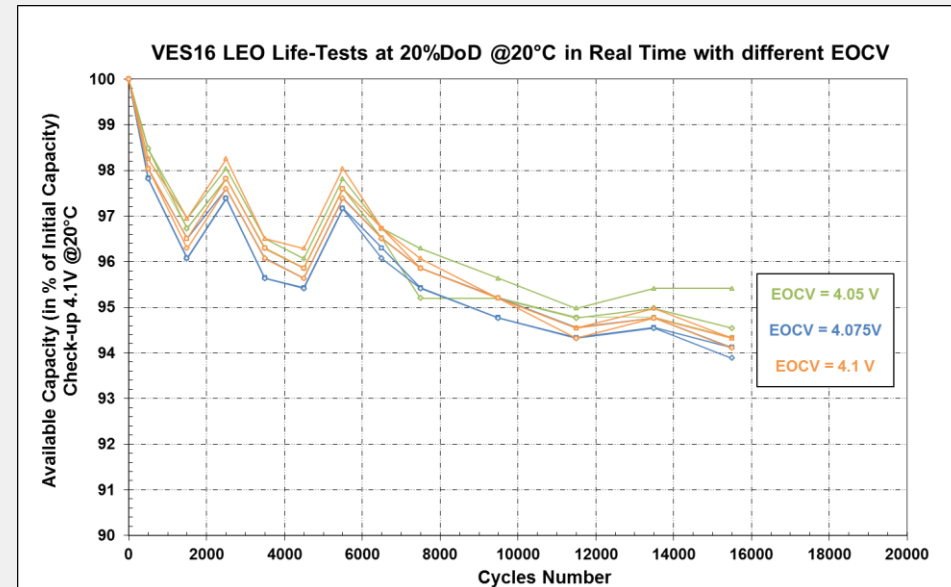
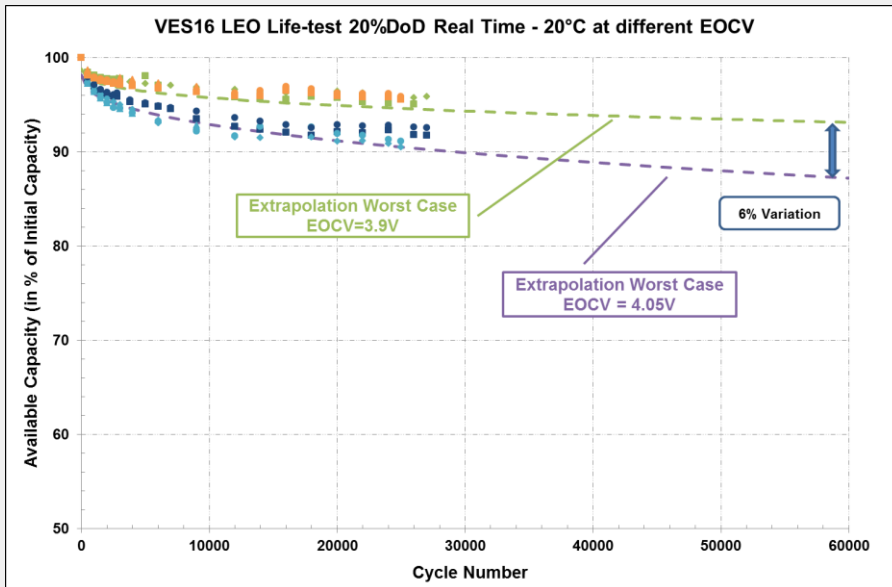


- **No significant effect of EOCV on EOD Voltage** evolution slope, from -2.1 to -1.5mV per 1000 cycles between 3.9 & 4.05 Volts after 27000 cycles, while no variation is measured between 4.05 & 4.1 Volts after 15000 cycles.

2. VES16 Cell Performances in LEO Lifetime Tests



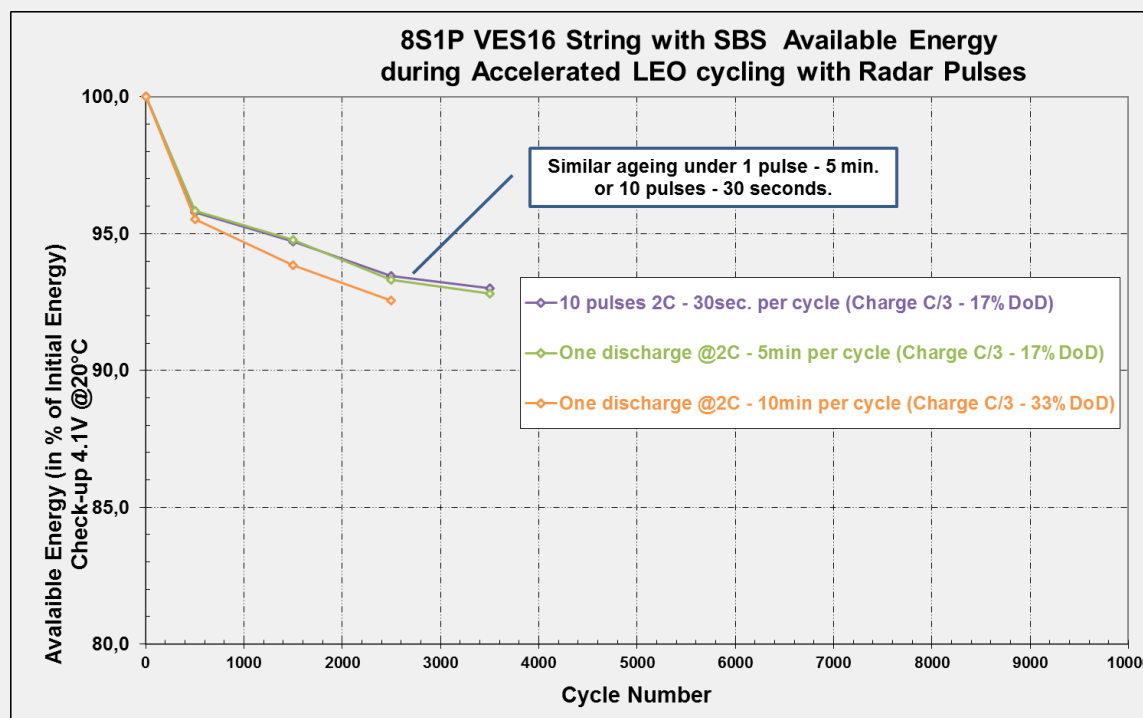
EOCV effect on VES16 electrical performances in LEO cycling conditions



- Capacity loss is reduced by $\approx 4\%$ (i.e. $\approx 6\%$ after extrapolation at 60000 cycles) when EOCV drops from 4.05 to 3.9 Volts.
- **No significant capacity variation is measured between 4.05 & 4.1 Volts after 15000 cycles.**

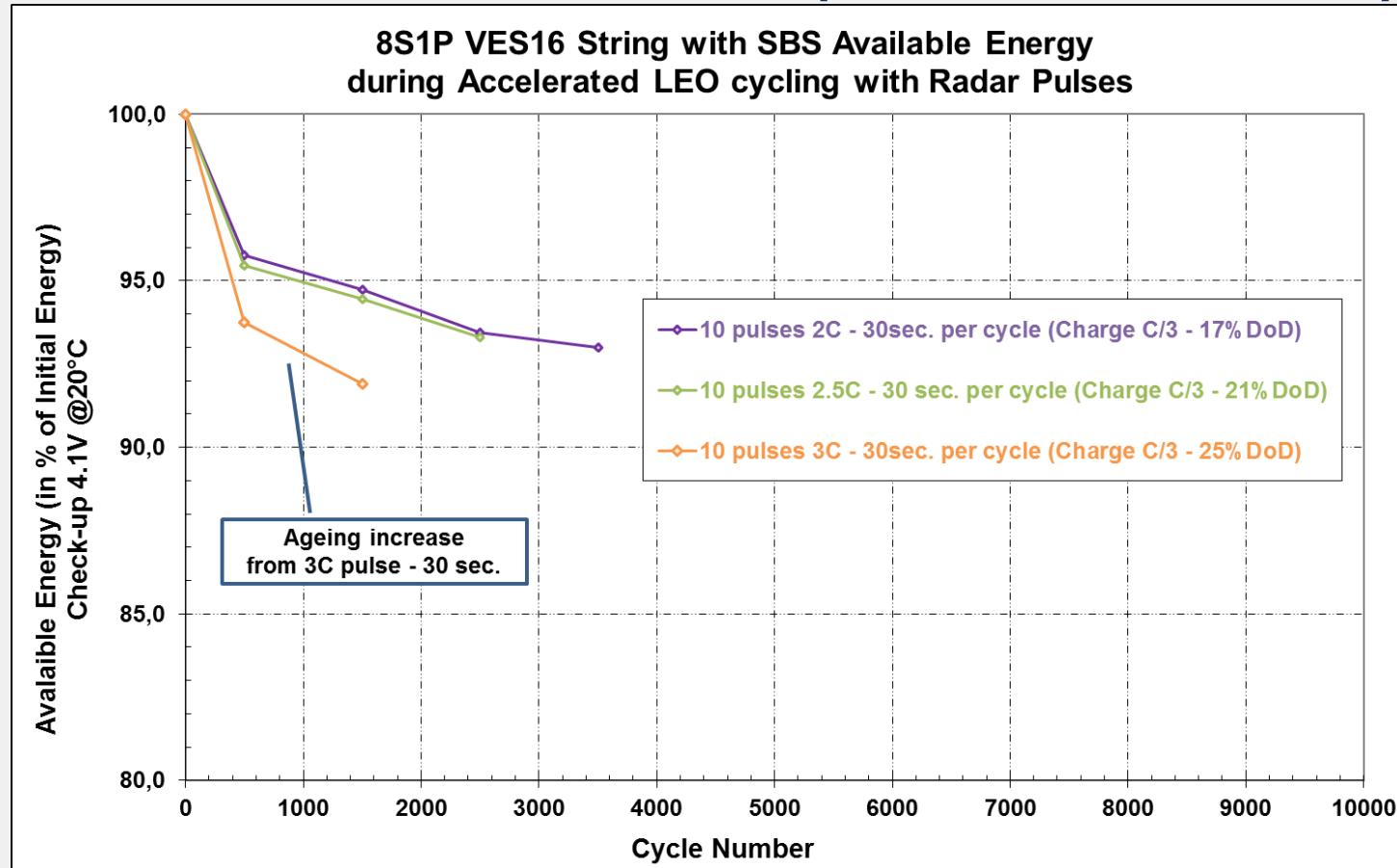
Radar Pulse effect on VES16 electrical performances in LEO cycling

- The objective is to evaluate **the effects of the depth from 2C to 3C and the duration from 30 seconds to 10 minutes of a radar pulse** during accelerated LEO cycling @20°C.



- Main ageing driver is the cumulated duration of the radar pulses per cycle (i.e. DoD), **similar energy degradation under one 2C pulse -5 min. & 10 pulses - 30 sec.**

Radar Pulse effect on VES16 electrical performances in LEO cycling



- From 2C & 2.5C 30 seconds peak : no effect
- . Ageing increase starting 3C peak

SUMMARY

- 38000 accelerated cycles at 20%DoD done, less than 13% capacity loss.
- 27000 real time cycles at 20%DoD done, with less than 10 % capacity loss.
- Energy loss remain low at 60000 cycles with DOD up to 40% DoD .
- No significant effect of the charge current increase on cell ageing (less than 1%) within the range from **C/5 to C/2**.
- No significant effect of EOCV on VES16 electrical performances within the range from **3.9 & 4.1 Volts**.
- SLIM V3 predictions fit with the worst case capacity losses, and EOD voltages.
- Peak capability to answer radar satellite requirements

A satellite with large solar panels is shown in orbit above the Earth. The Earth's blue and white clouds are visible on the left, and a portion of a brown, rocky planet is visible on the right. A semi-transparent blue banner is overlaid across the center of the image.

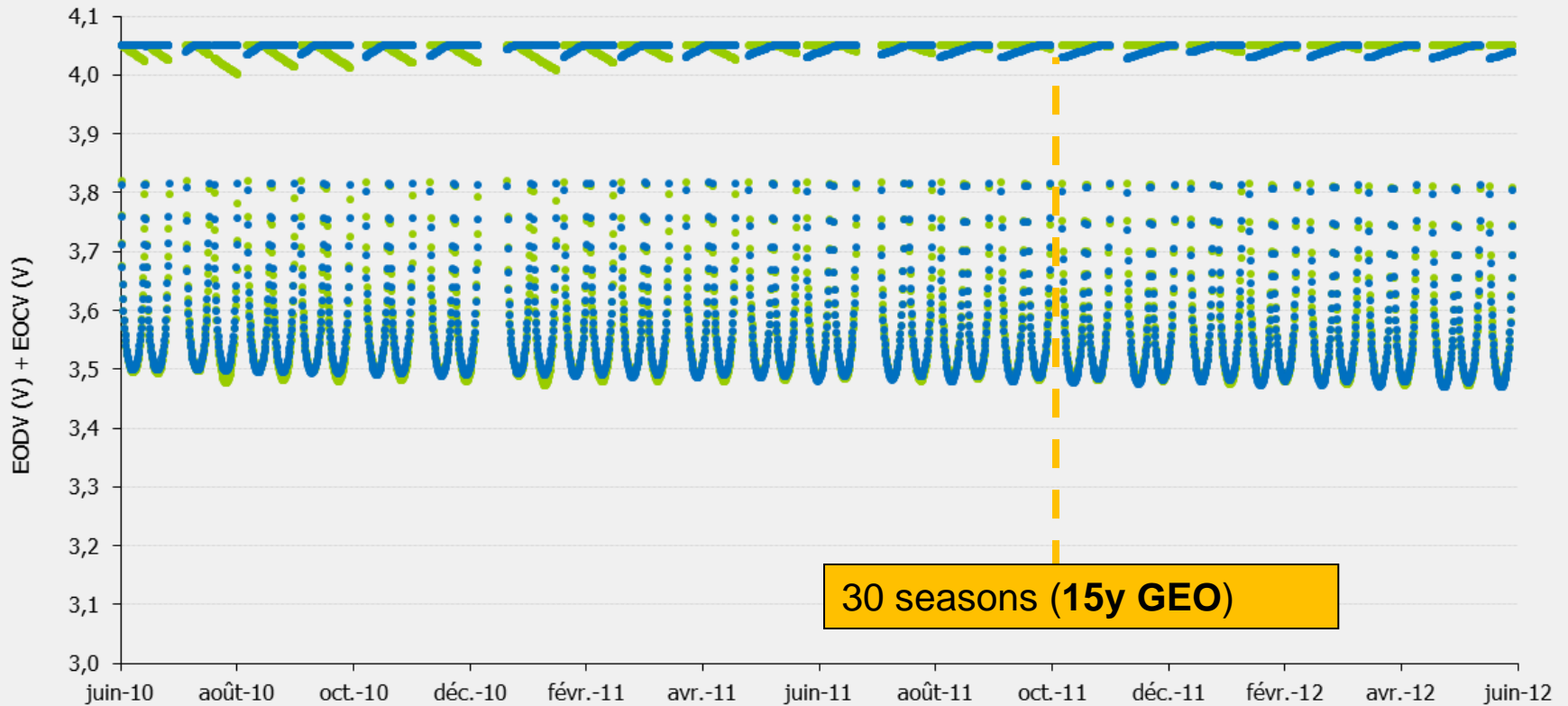
3

VES16 CELL PERFORMANCES IN GEO LIFETIME TESTS

VES16 cell cycling



VES16 cell life tests in semi-accelerated **GEO**, **60% DoD**,
EoCV=4,05V (real discharge profile 2 cycles/day, no solstice)



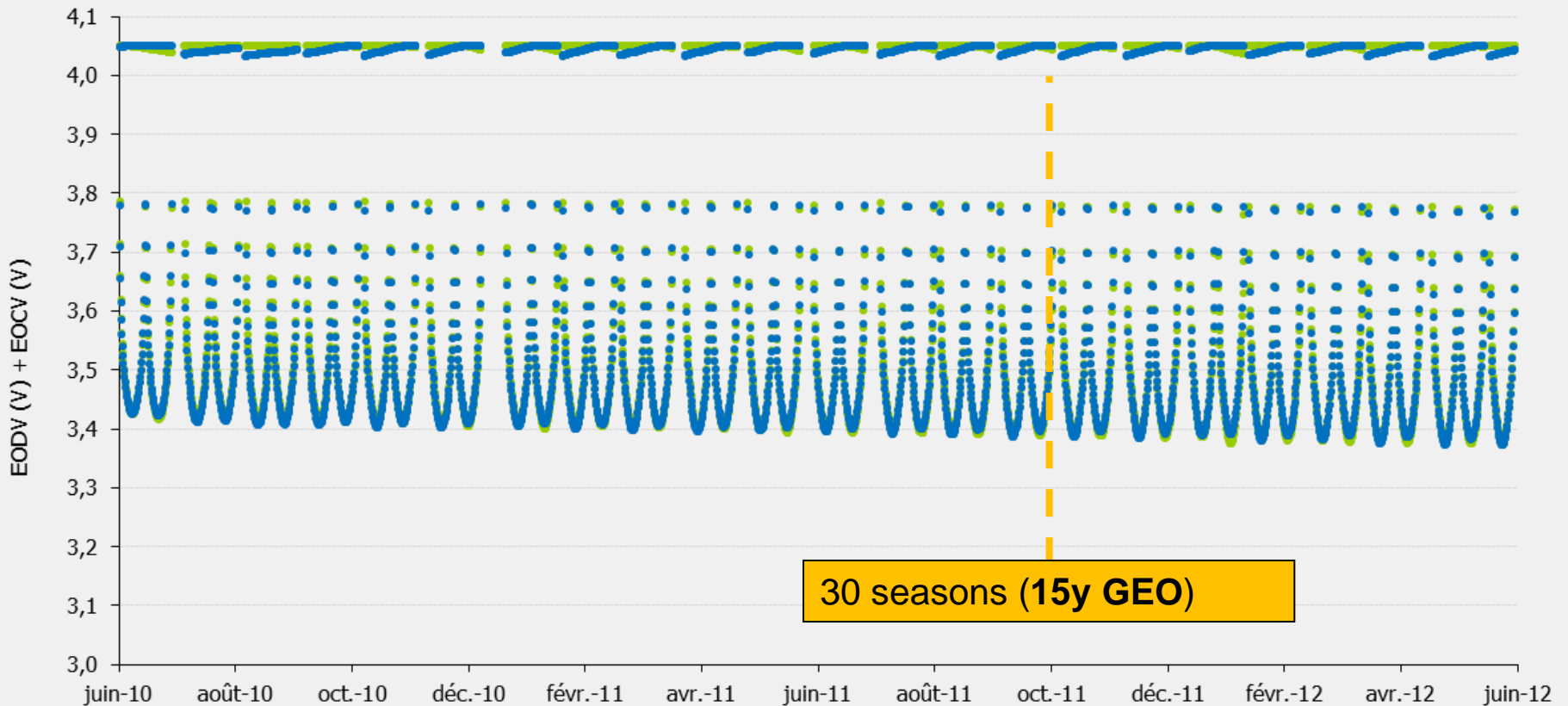
~30mV from season 1 to season 45

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VES16 cell cycling



VES16 cell life tests in **GEO**, 70% DoD, $E_{oCV}=4,05V$



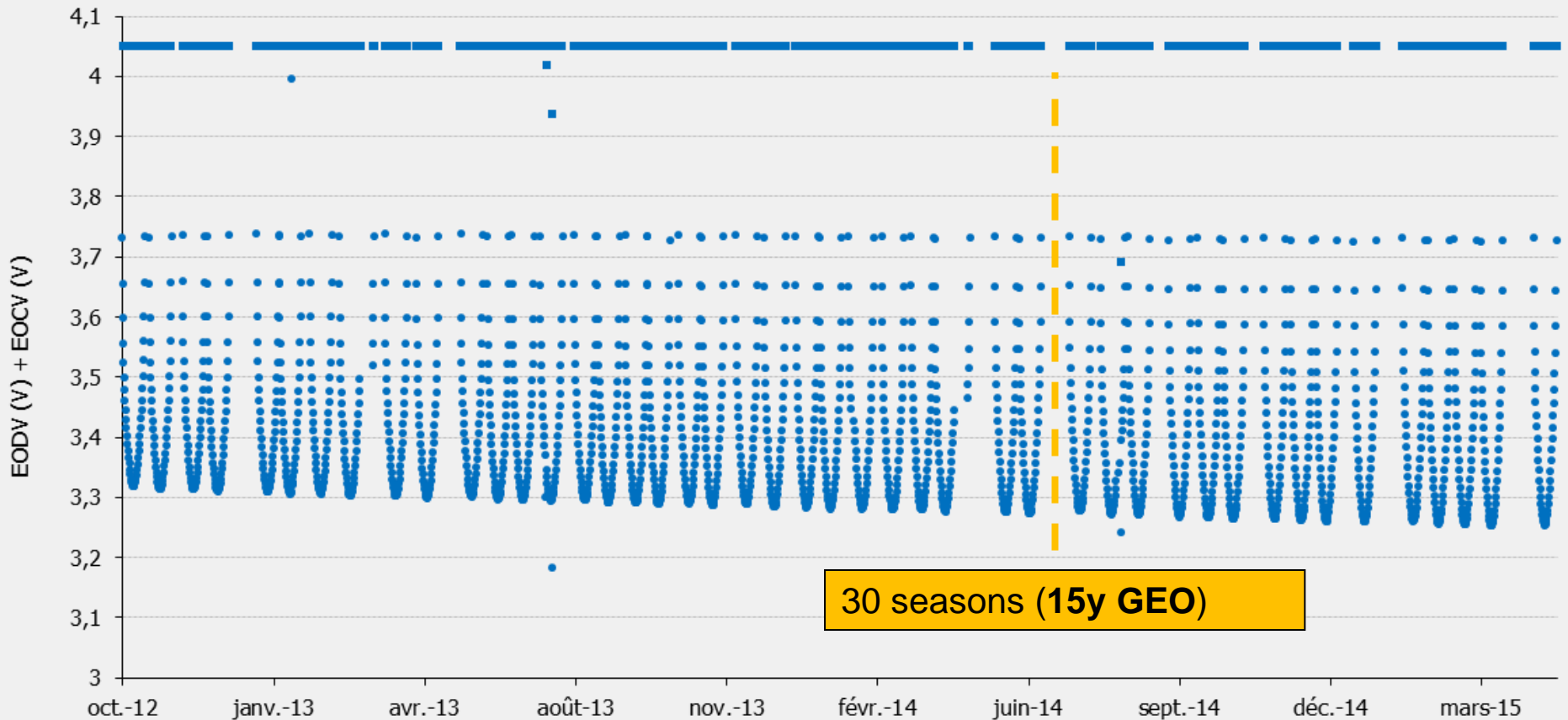
~50mV from season 1 to season 45

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VES16 cell cycling



VES16 cell life tests in **GEO**, **80% DoD**, $E_{oCV}=4,05V$



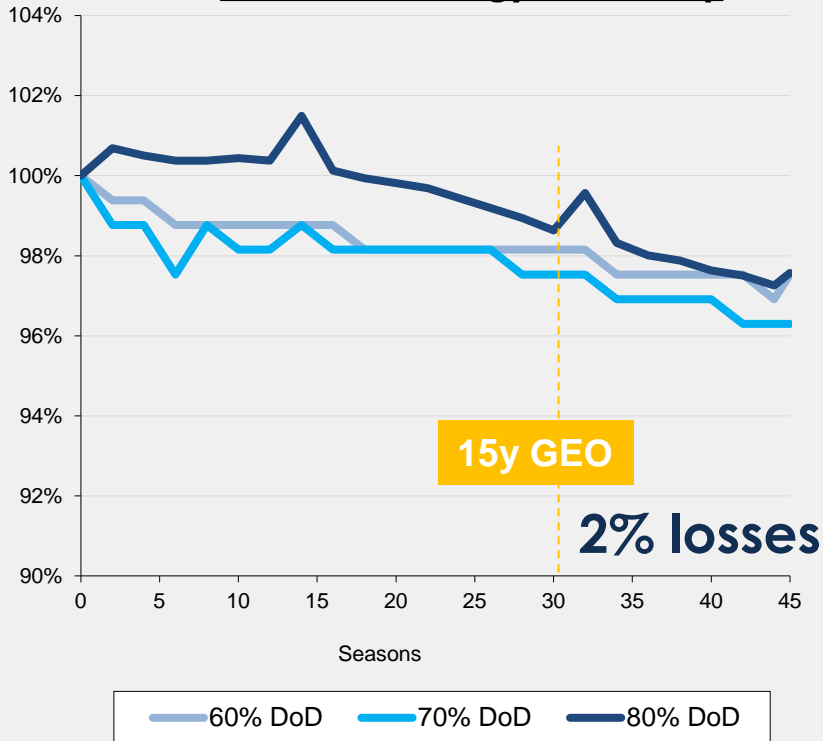
~65mV from season 1 to season 45

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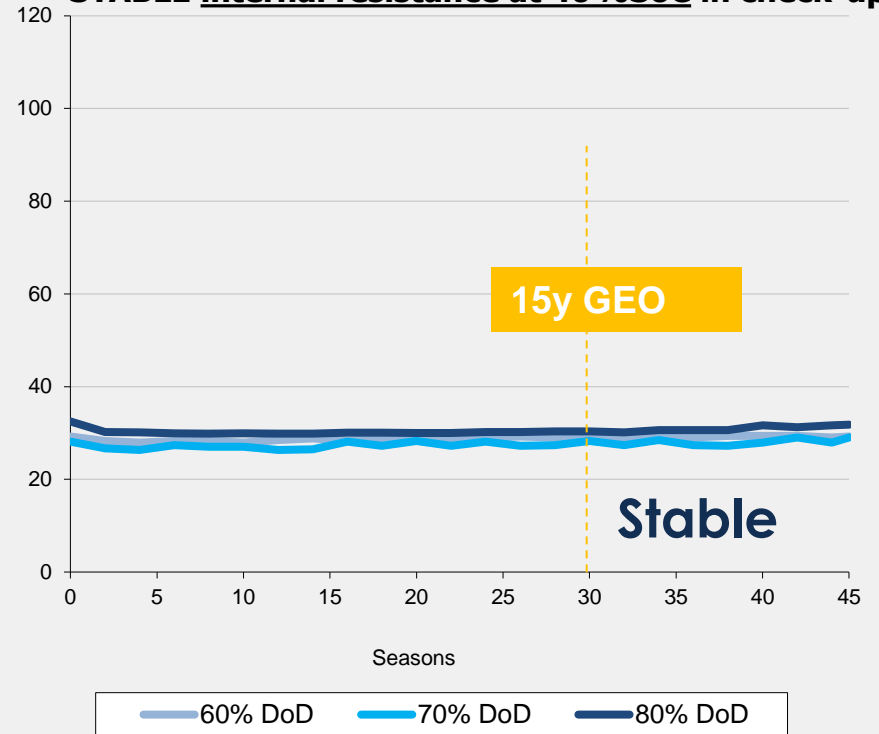
VES16 cell cycling



Variation of energy in check-up



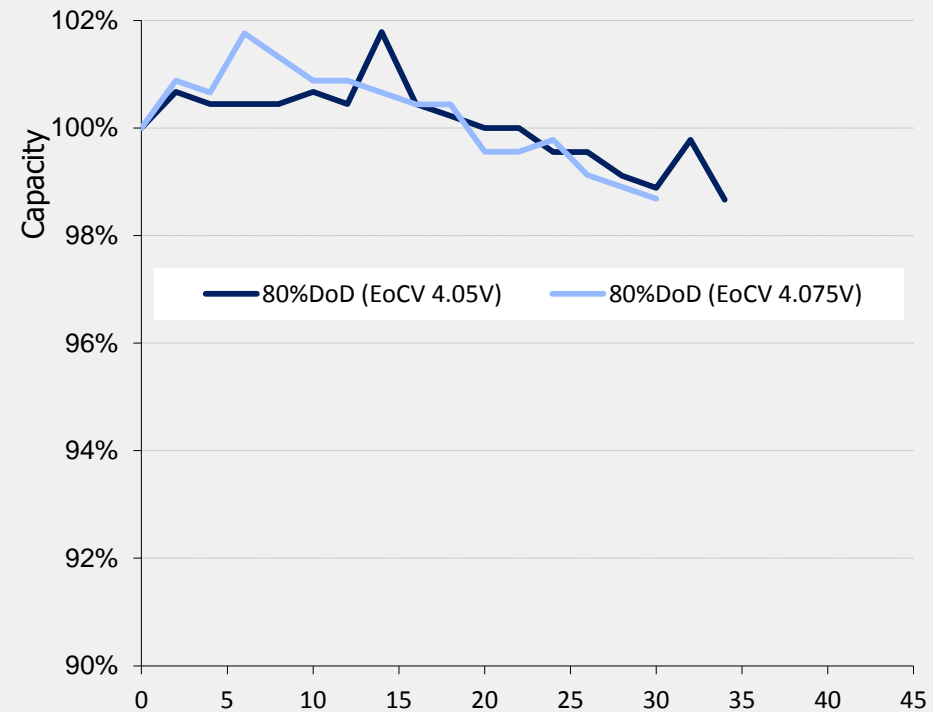
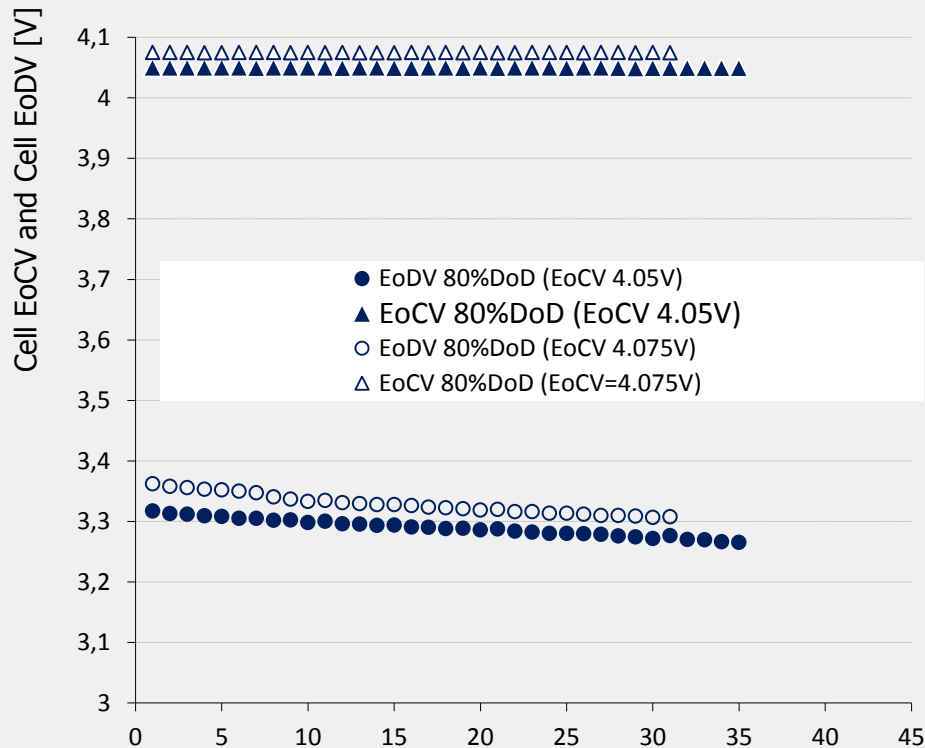
STABLE internal resistance at 40%SoC in check-up



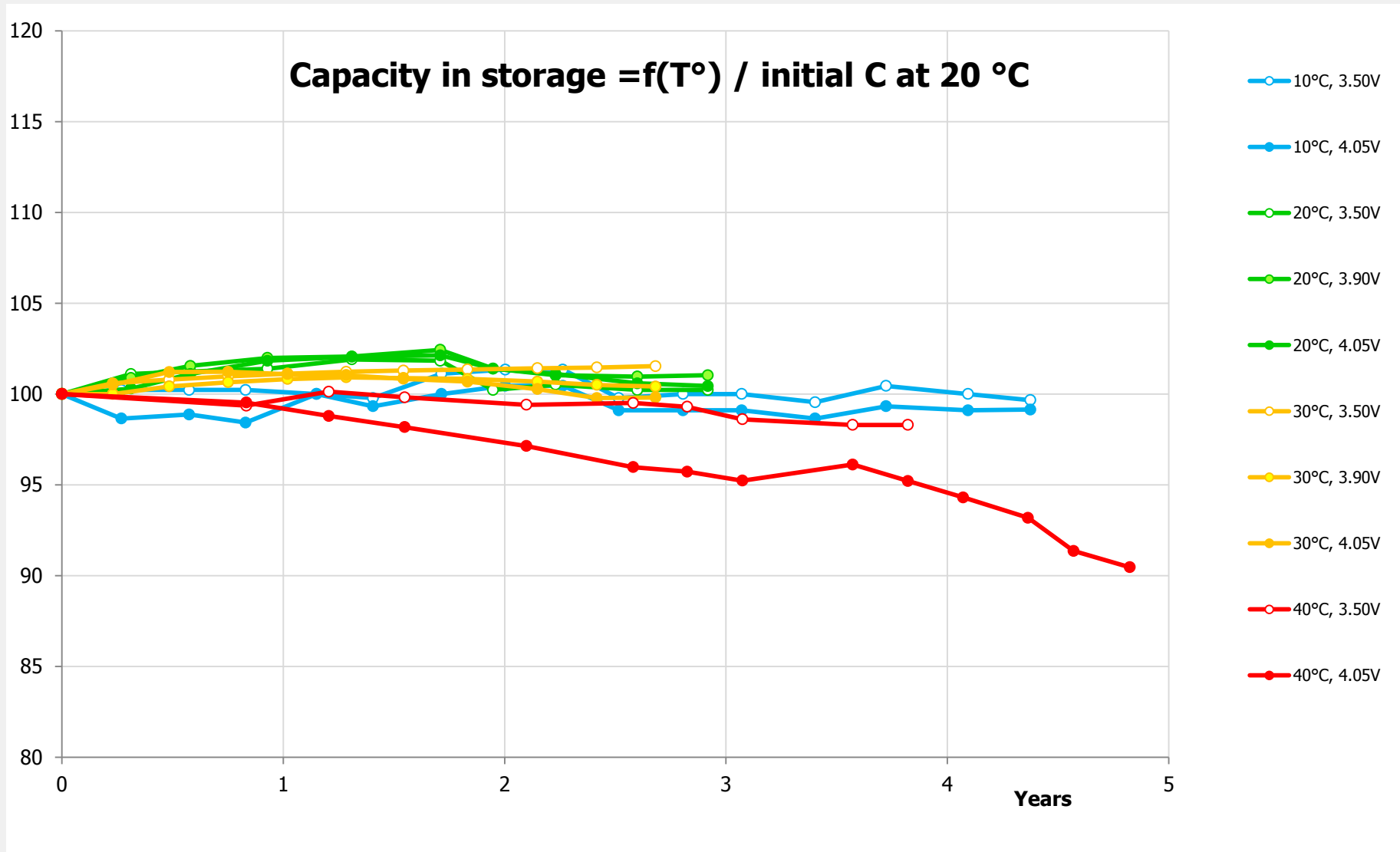
VES16 GEO cell cycling



EoCV from 4,05V to 4,075V @ 80% DoD => No impact !



VES16 cell : calendar losses

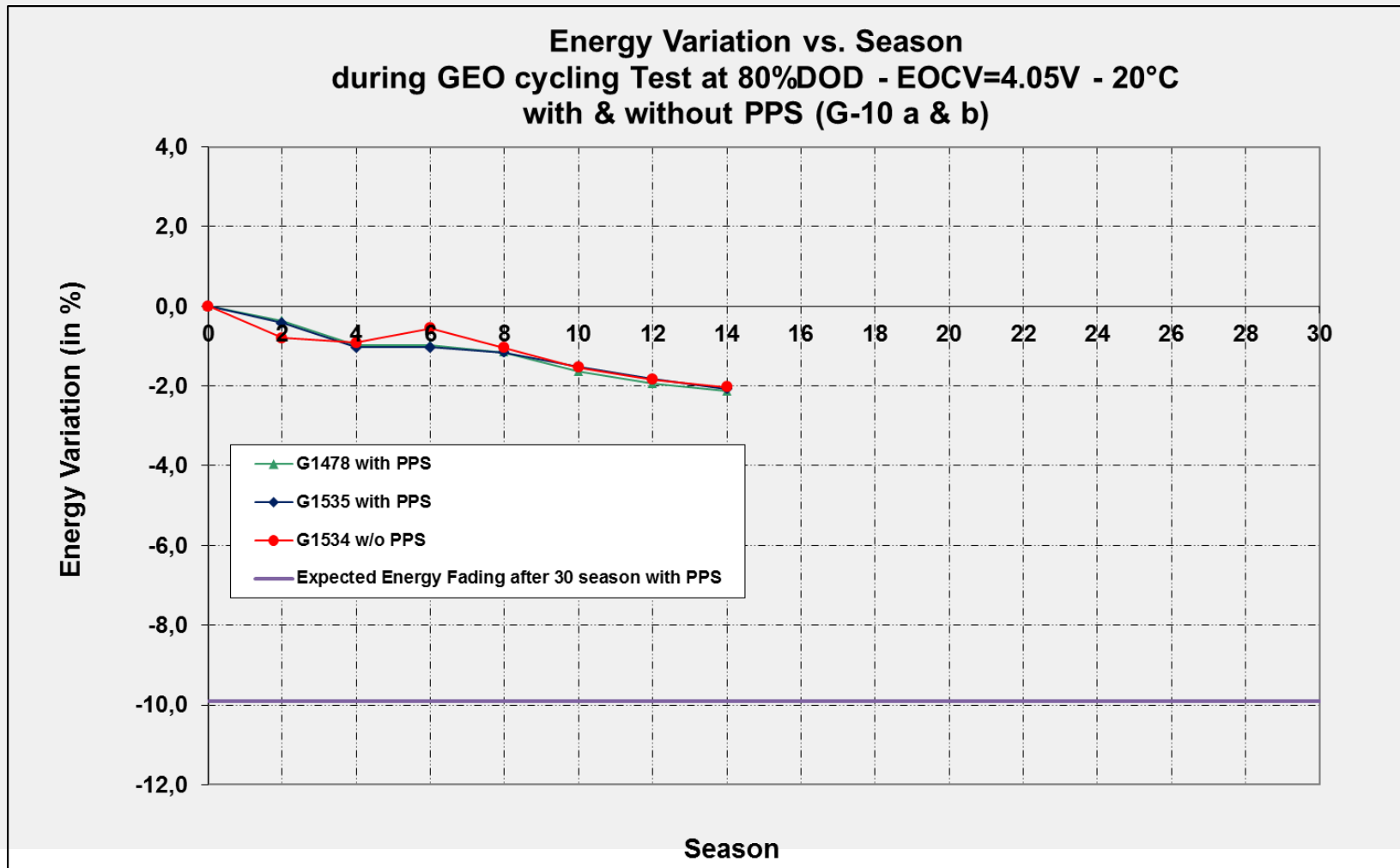


Impact of plasmic propulsion pulses (PPS)



2 PPS 10% / day during **equinox**

6 PPS 20% /day during **solstice**



VES16 GEO GEO cycling results SUMMARY



- 45 GEO seasons at **80% DoD and different EOCV with very low degradation (<2% for 15 years)**
- 5 years storage demonstrating **long calendar time**
- Ability to sustain **plasmic propulsion cycles**
- **Very stable internal resistance** whatever the DOD, EOCV, Duration



VES16 is highly relevant for **GEO missions**

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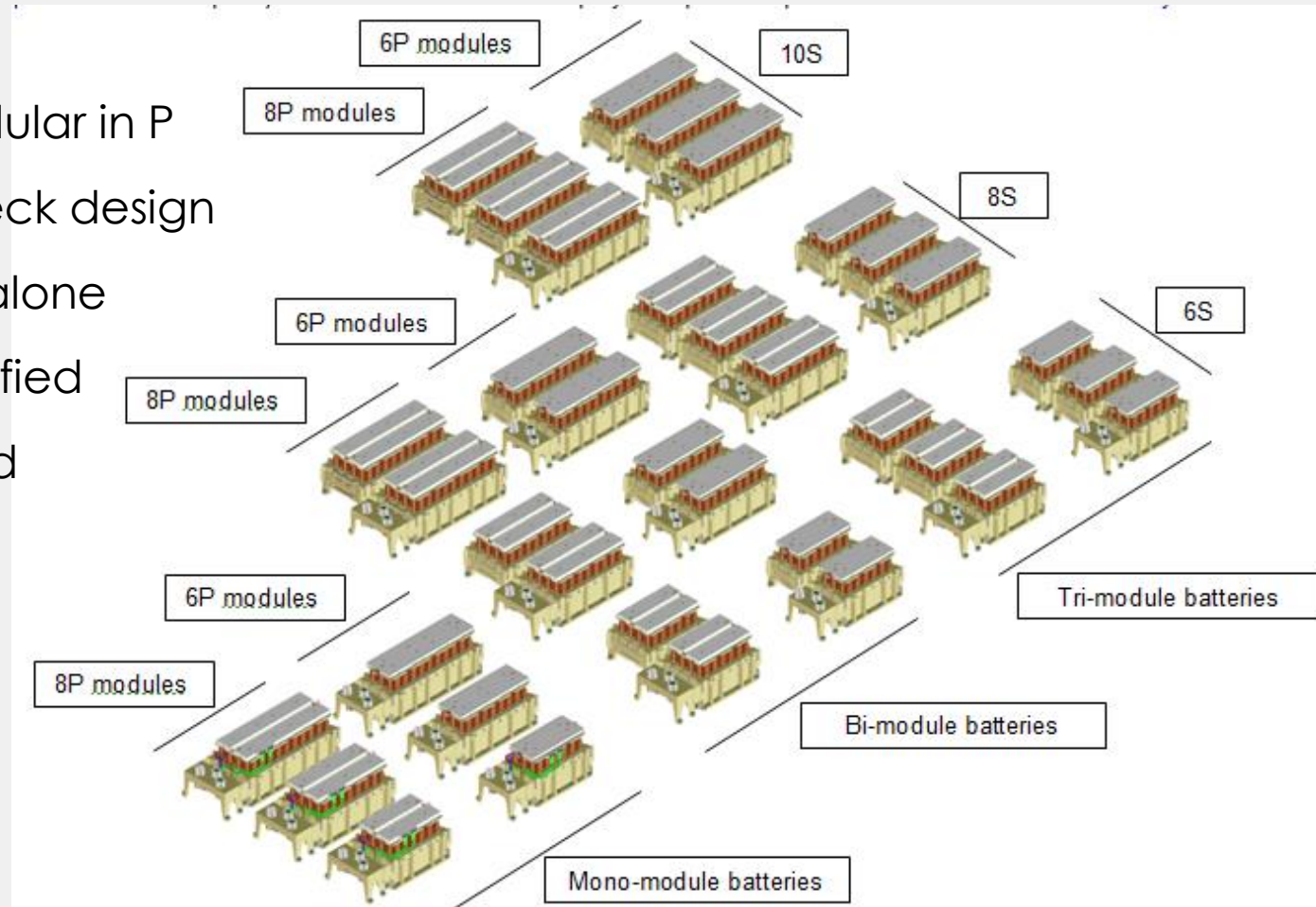


4

VES16 BATTERY DESIGN

A range of modules:

- Modular in S, modular in P
- One of double deck design
- Module or stand alone
- Mecanically qualified
- Thermally qualified
- ...



Conclusion



- **VES16 has been extensively tested for LEO and GEO missions**
- VES16 battery is **already in orbit**
- VES16 battery is « **plug and play** » : no need of by-pass management or electronics at spacecraft systems to command or operate the battery
- 2 leading european GEO spacecrafts families are planned to equiped with a VES16 battery (**MTG** and **Quantum** batteries)
- 17 LEO contracts (113 Satellites) including **Iridium Next** with 82 satellites

The VES16 battery is a good candidate for LEO 's but also for small GEO's ...



Merci

Vielen Dank

Dekuji

תודה לך, תודה!

Thank you for your attention, Questions...

谢谢

Tack



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