VES16 Batteries for LEO and GEO Satellites

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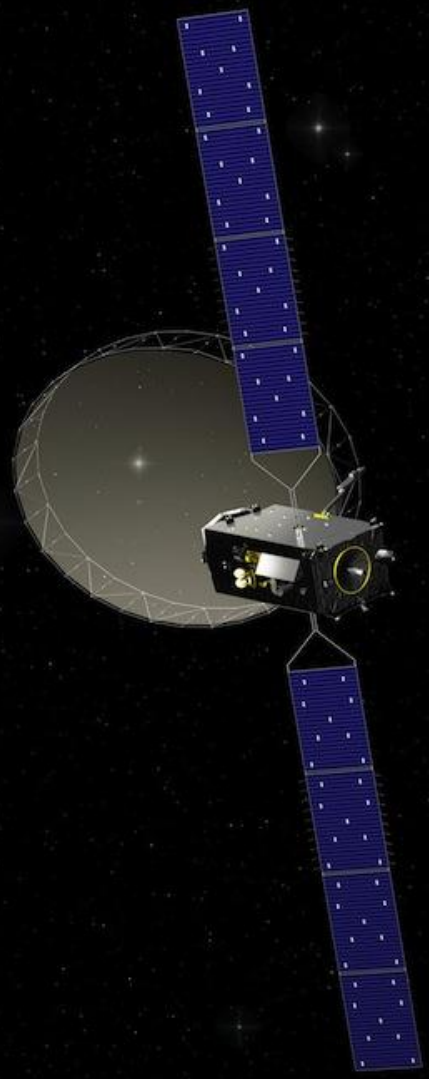


2019 Space Power Workshop
Torrance April 2nd, 2019

saft
a company of
TOTAL

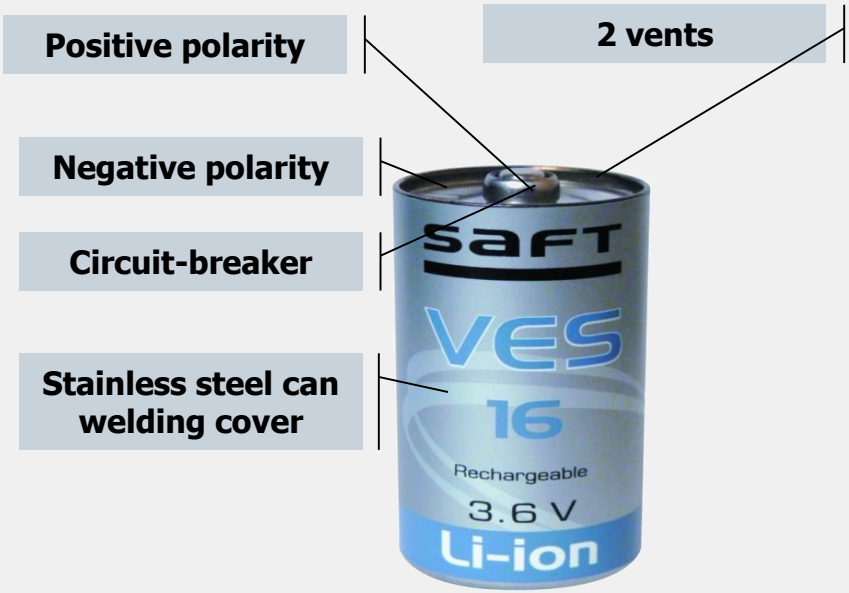
VES16 cell

- VES16 is a « D » size 16Wh (4.5 Ah) **space designed** Li-ion cell
- **Long life** & **low fading** NCA Li-ion technology
- **Specific negative electrode** material blend for LEO
- Re-use Saft heritage in VES180/VL48E GEO/LEO series
- **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**
- **75 Iridium Next Satellites (Since January 17)**

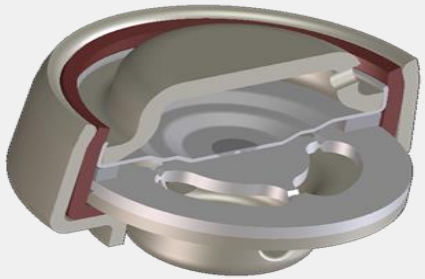
VES16 cell main features

– Main characteristics :



Dimensions (Ø x H)	33 x 60 mm (D-size)
Weight	≤ 112 g
Volume	0.051 dm^3
Voltage range	[2.7 ; 4.1] V
Nominal capacity	4.5 Ah on 4.1-2.7V @ C/2, 20°
Nominal energy	16 Wh on 4.1-2.7V @ C/2, 20°
Specific energy	> 155 Wh/kg
Internal resistance	≤ 35 mΩ @ 20% DoD
Best cycling temp.	[+0 ; +40] °C
Mechanical design margins	EWR & ECSS compliant

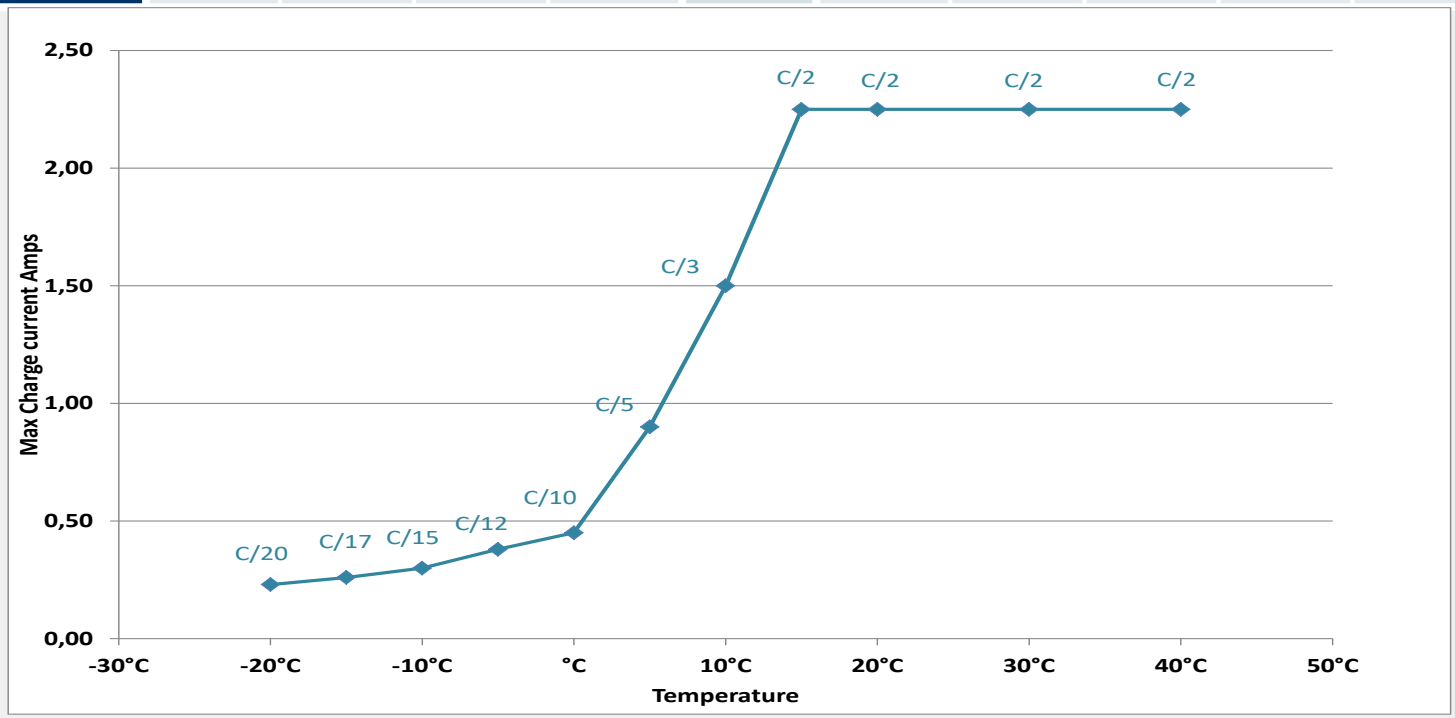
– LEO Electrode negative : high charge current
– Current breaker triggered with pressure
– 2 vents on cover : highly reliable safety device



VES16 charge current vs. temperature

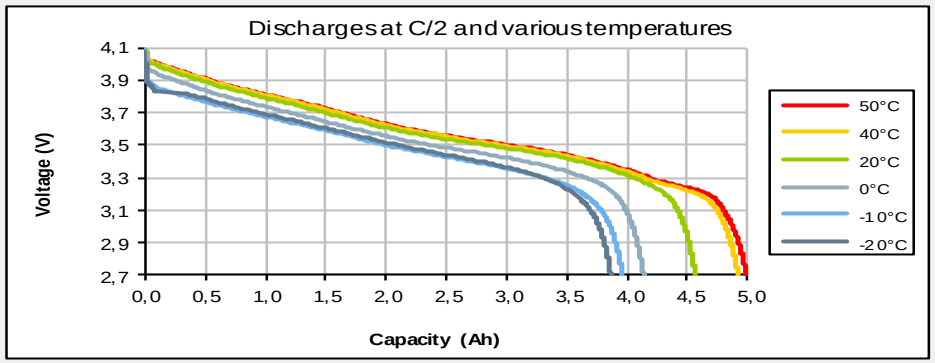
– High charge current capability (up to C/2 for 60 000 cycles)

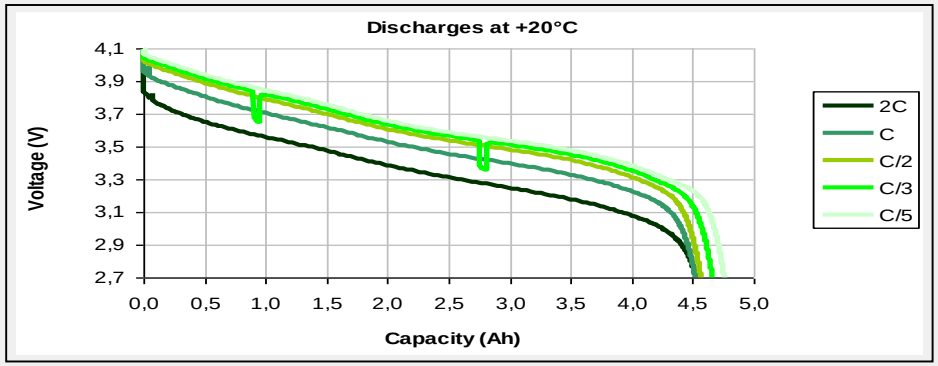
TRP Temp	-20°C	-15°C	-10°C	-5°C	0°C	+5°C	+10°C	+15°C	+20°C	+30°C	+40°C
Max Cell Ich	C/20	C/17	C/15	C/12	C/10	C/5	C/3	C/2	C/2	C/2	C/2
	0.23 A	0.26 A	0.30 A	0.38 A	0.45 A	0.90 A	1,25 A	2.25 A	2.25 A	2.25 A	2.25 A

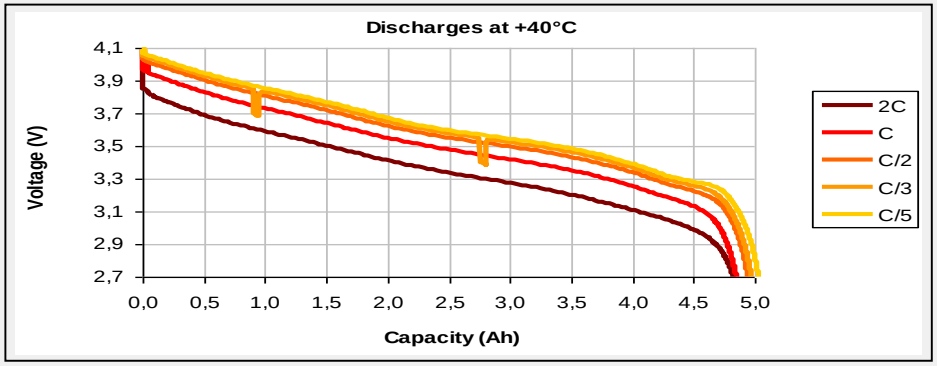


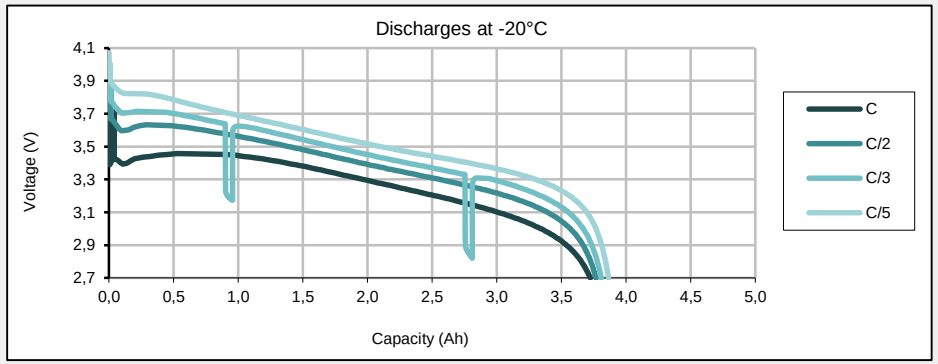
VES16 capacity vs discharge rate and temperature

– VES16 characterization from -20°C to +50°C, from 2C to C/5:



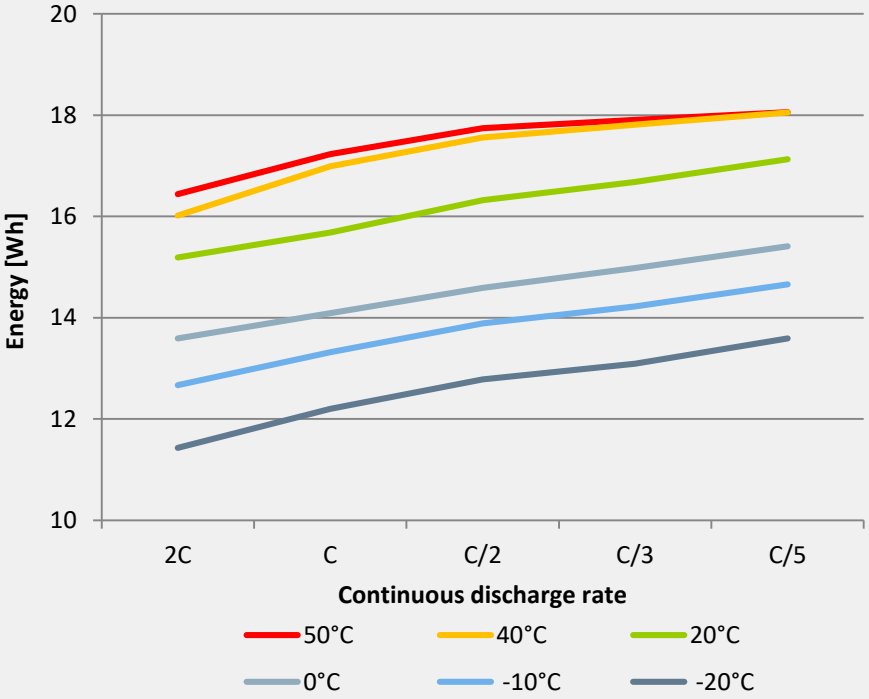


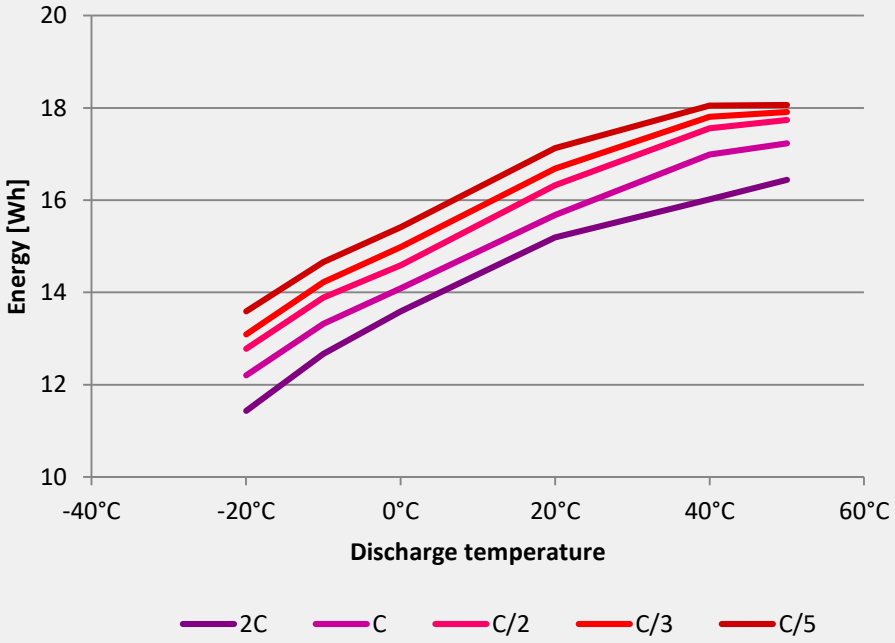




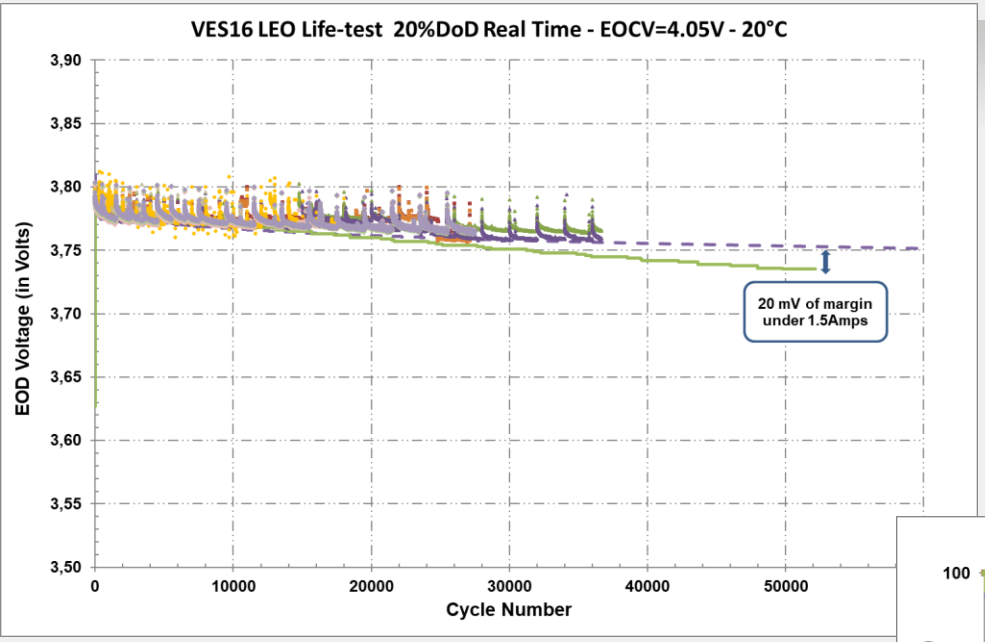
VES16 energy vs discharge rate and temperature

– VES16 characterization from -20°C to +50°C, from 2C to C/5:



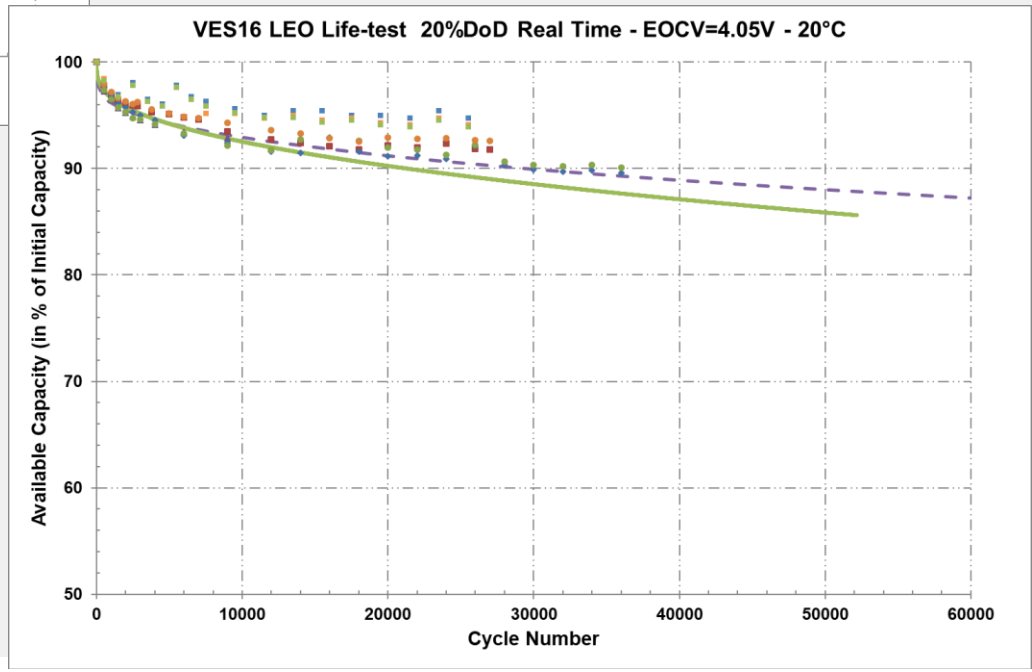


Real Time LEO cycling at 20%DoD



Discharge : C/3 - 35 min. ,
Charge C/5- 65 min

EODV evolution vs nb of cycles

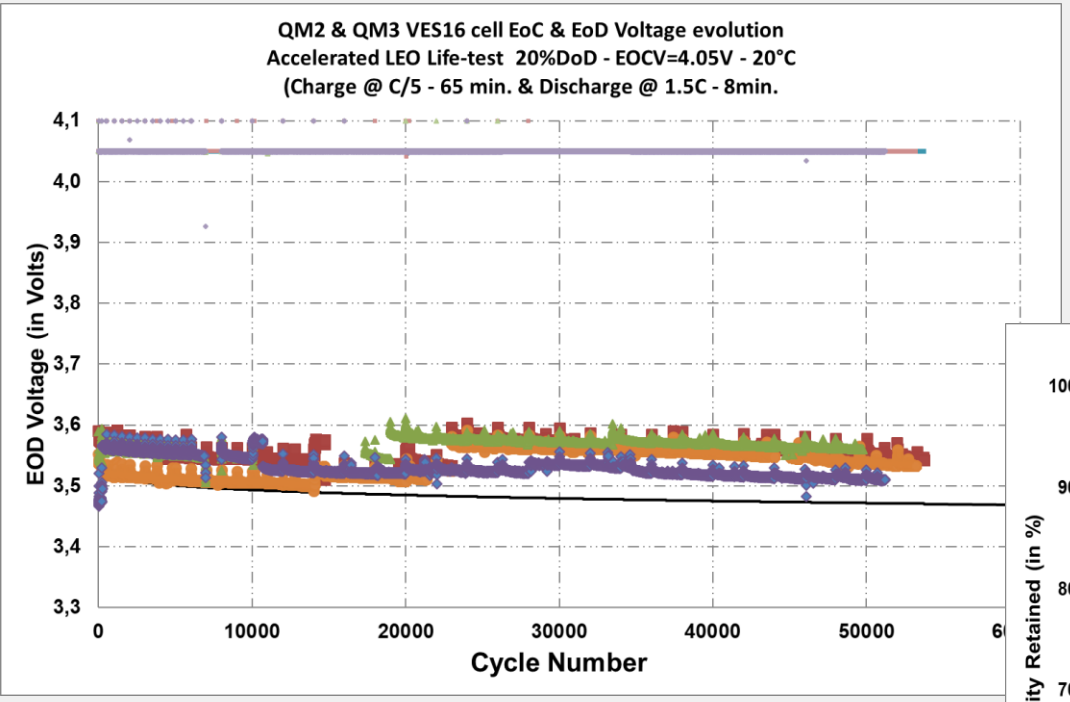


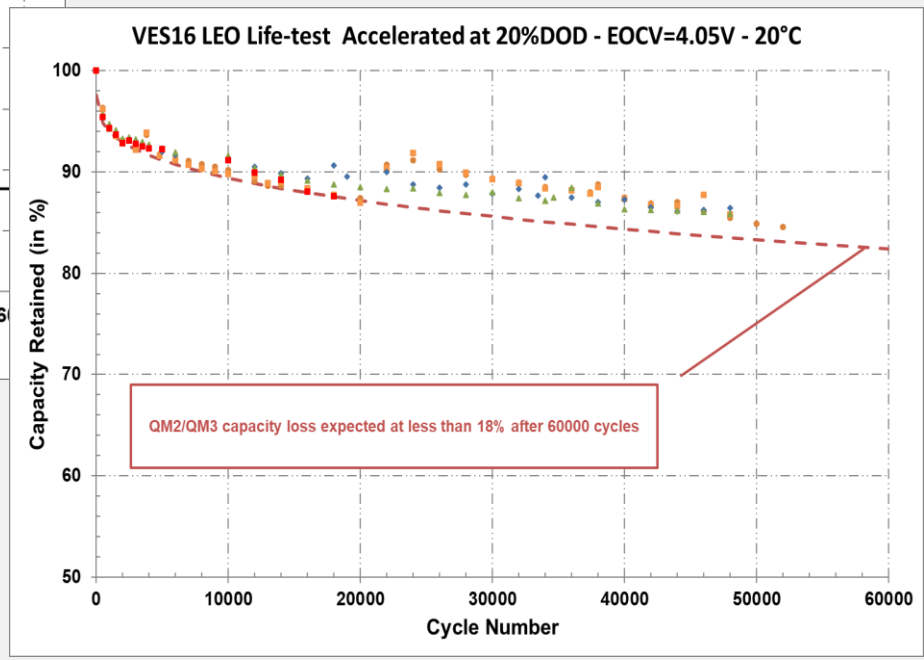
% Capacity vs nb of cycles

10 % Energy loss for 12 years LEO mission

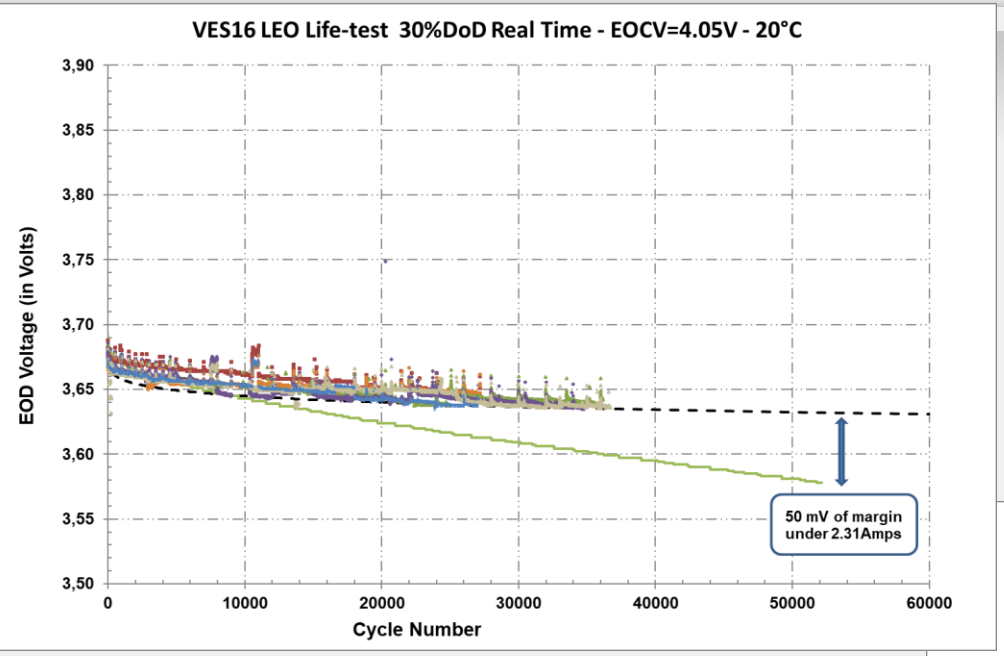
Accelerated LEO Cycling at 20%DoD

- Accelerated LEO 20 % DOD : Discharge 1.5C - 8 min. , Charge C/5- 65 min
- 56,000 cycles representing 10 years in orbit



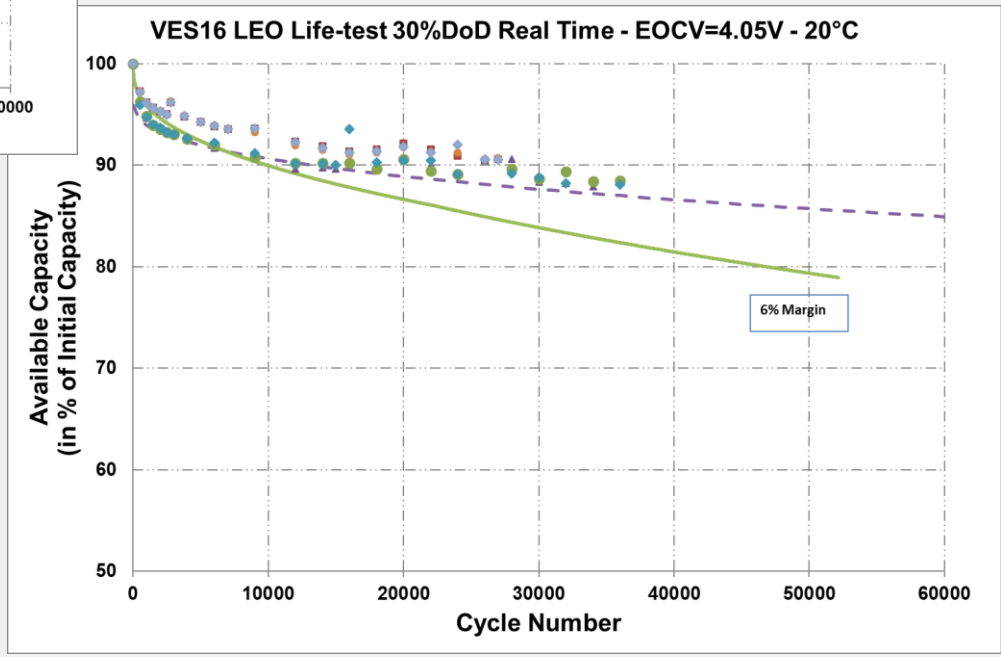


Real Time LEO cycling at 30%DoD



Discharge : C/2 - 35 min. ,
Charge C/3- 65 min

EODV evolution vs nb of cycles

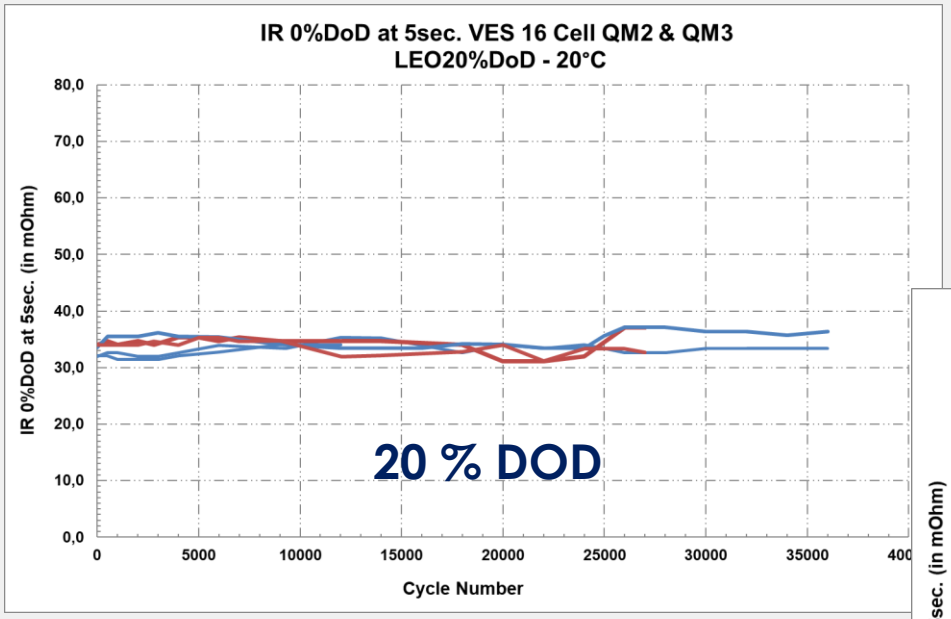


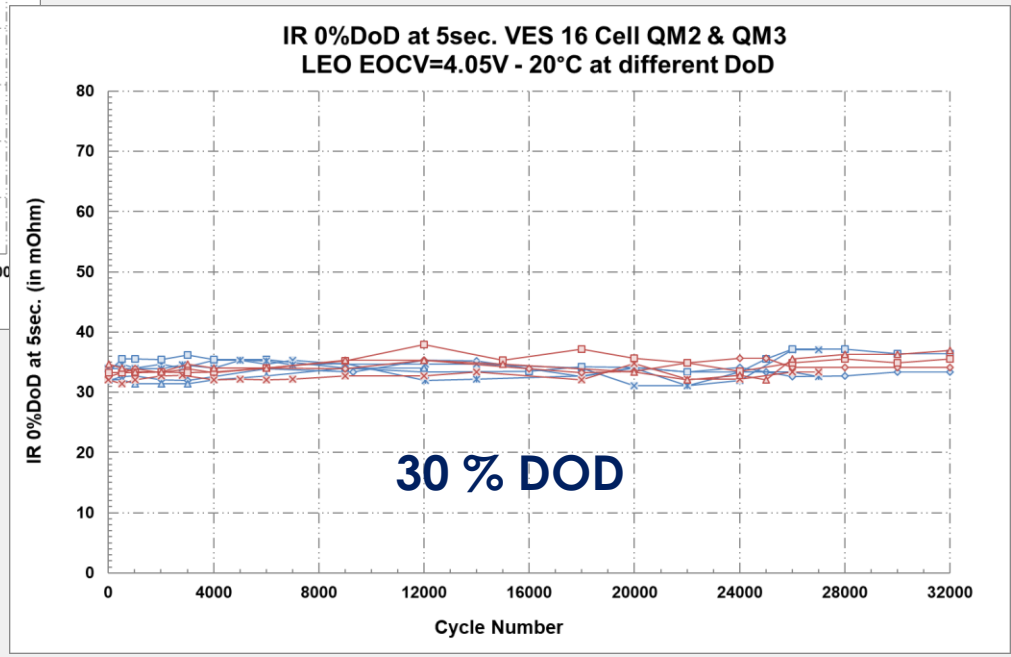
% Capacity vs nb of cycles

12 % Energy loss for 12 years LEO mission

Real Time LEO cycling at 20 and 30%DoD : Internal resitance

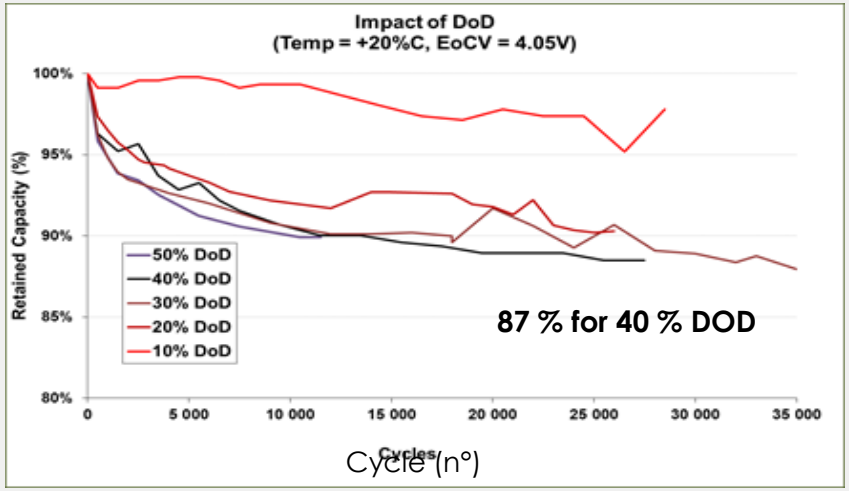
- Internal resistance stay constant even at C/3 rate 7 years testing 30% DOD
- +100 % increasing on most on 18650 cells even at lower DOD

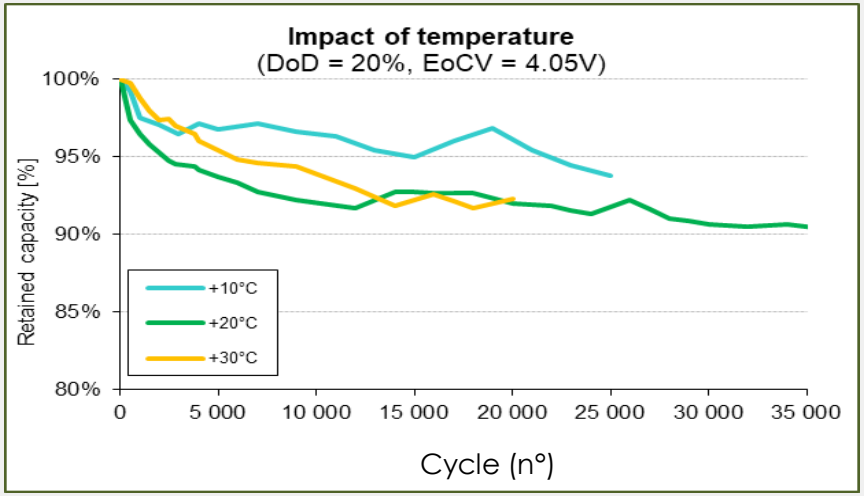


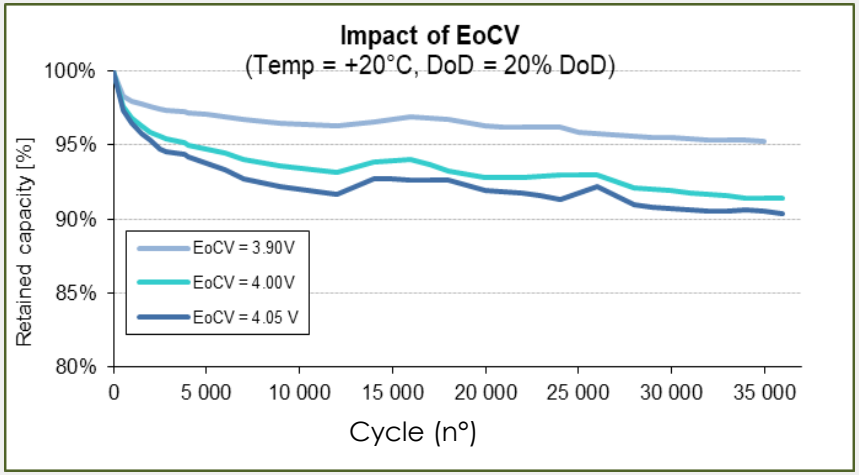


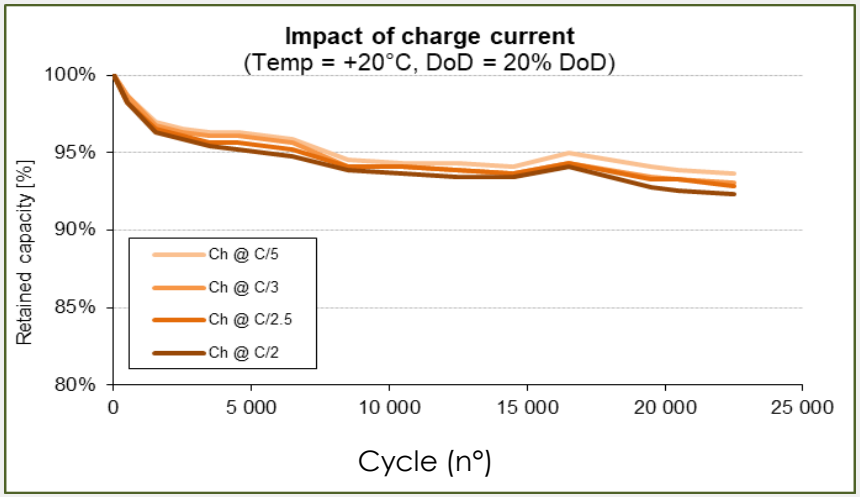
LEO - VES16 fading vs cycling conditions

- EOCV, temperature range, DOD , charge current range have limited impact on cell energy degradation.
- **Very robust cell for LEO applications using DOD up to 50 %**



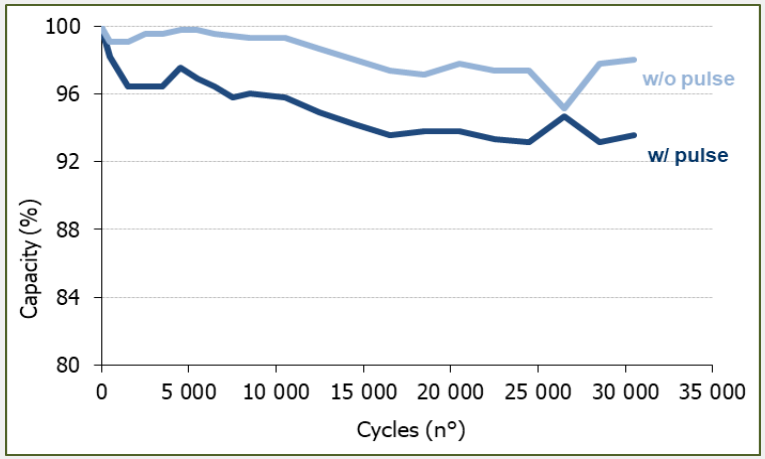


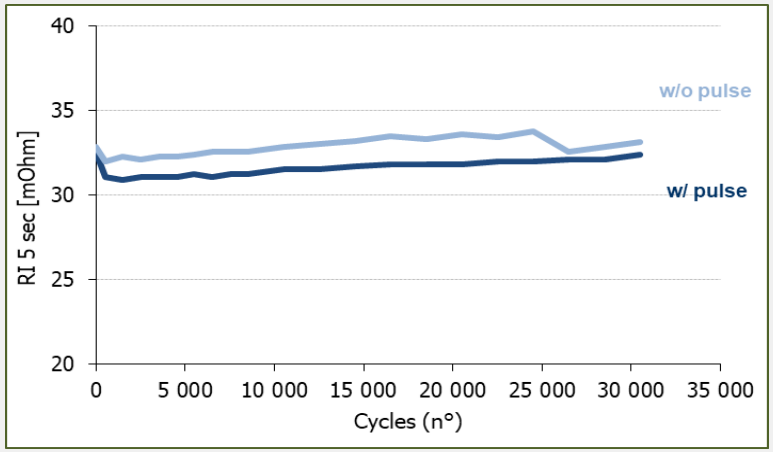




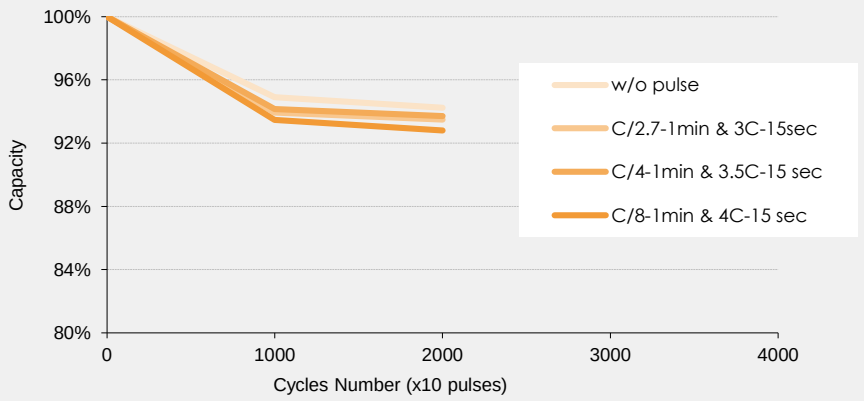
LEO – Radar Pulse + 20°C

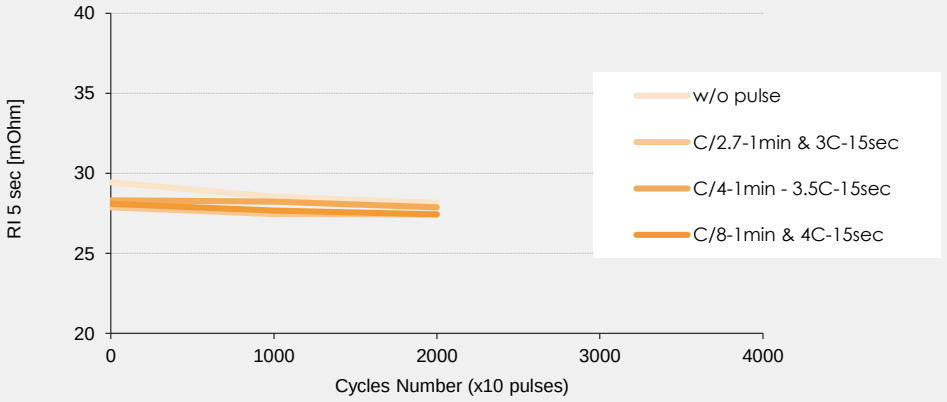
- Real Time, 19%DoD, 4.05V EoCV w/ and w/o pulse 1.5C-10 min





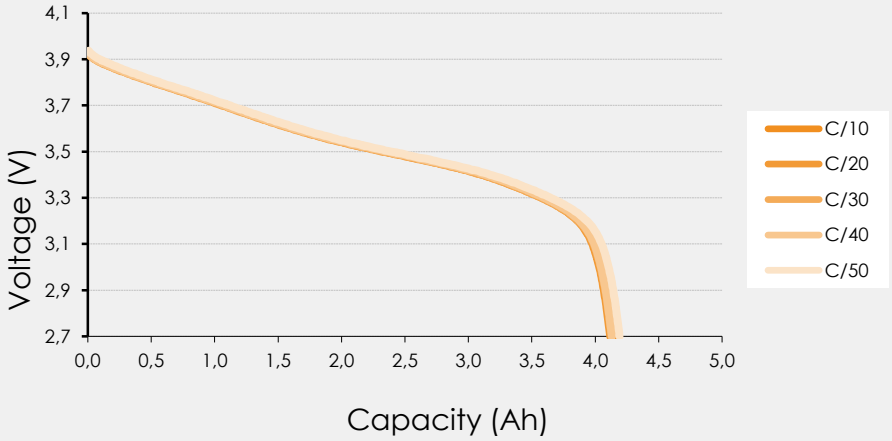
- Real Time, 19%DoD, 4.05V EoCV w/ and w/o 10 pulses 3C/3.5C/4C-15 s

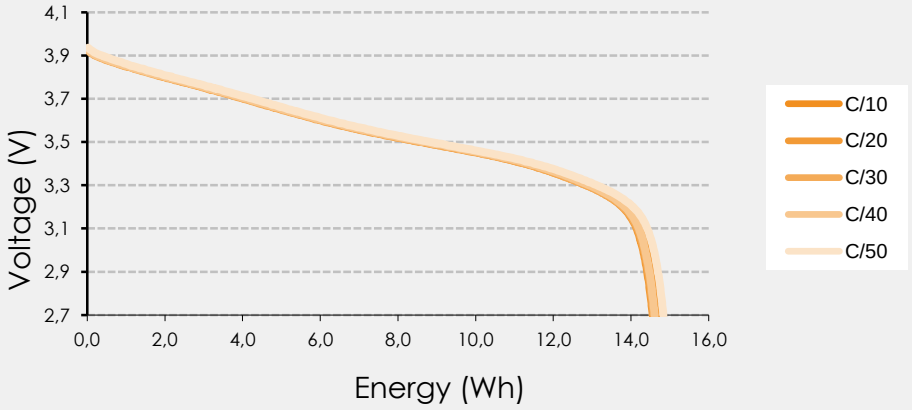




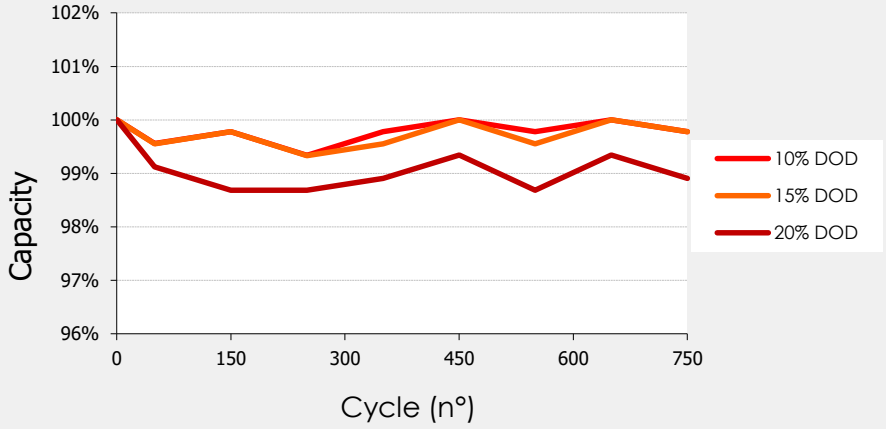
VES16 performances at extended low temperature

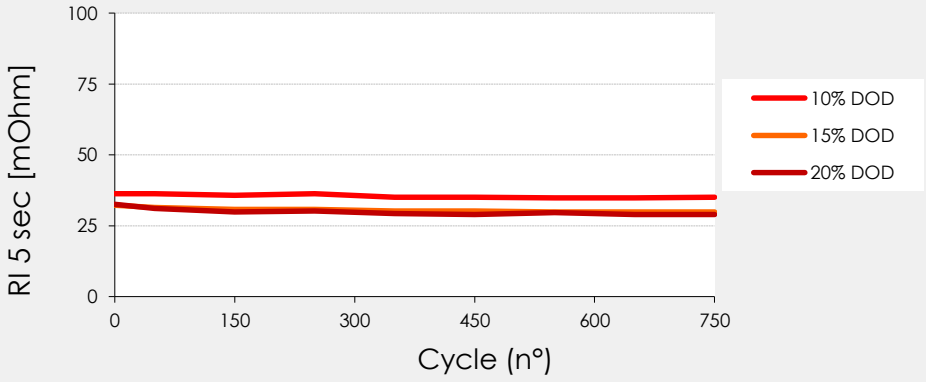
- Charge at -20°C and various current
  Discharge at +20°C and C/2





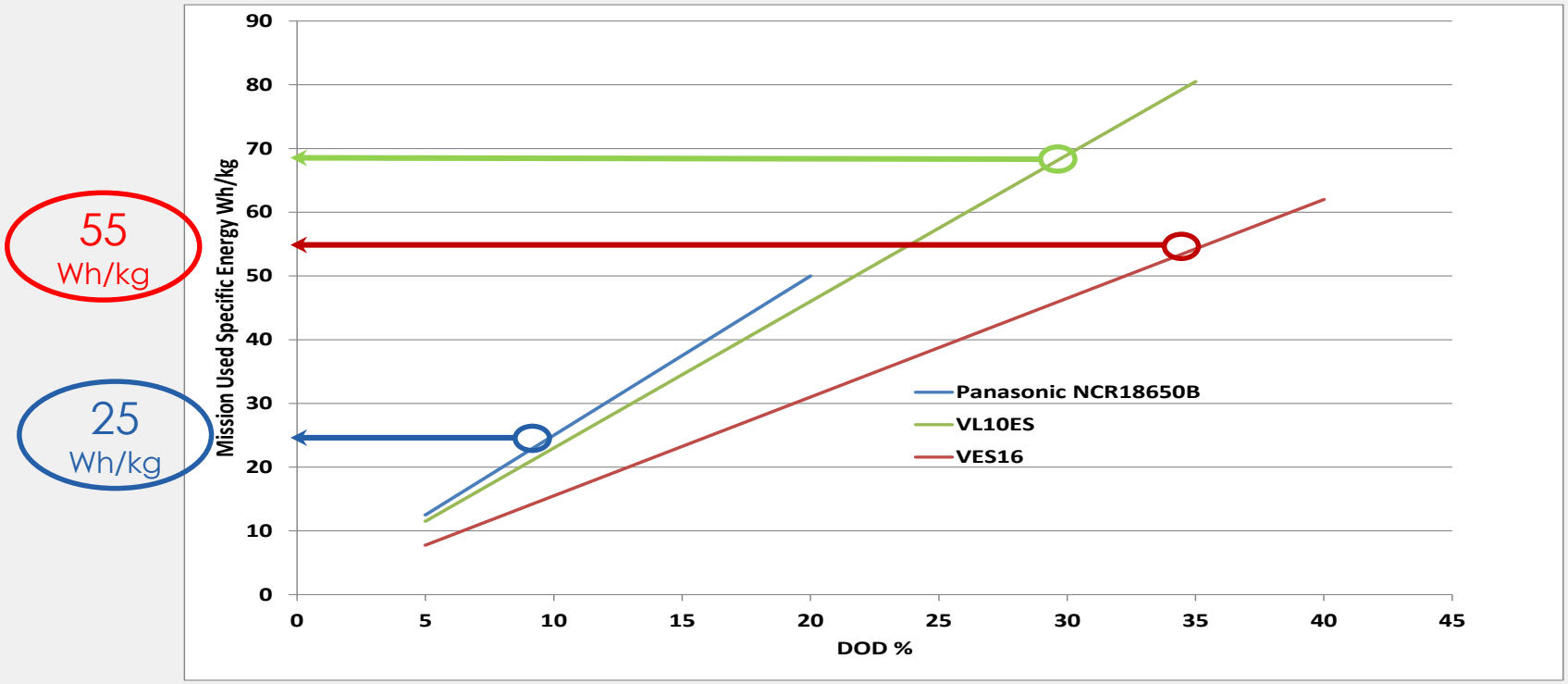
- VES16 cycling performances in LEO at 0°C
  750 cycles (completed)





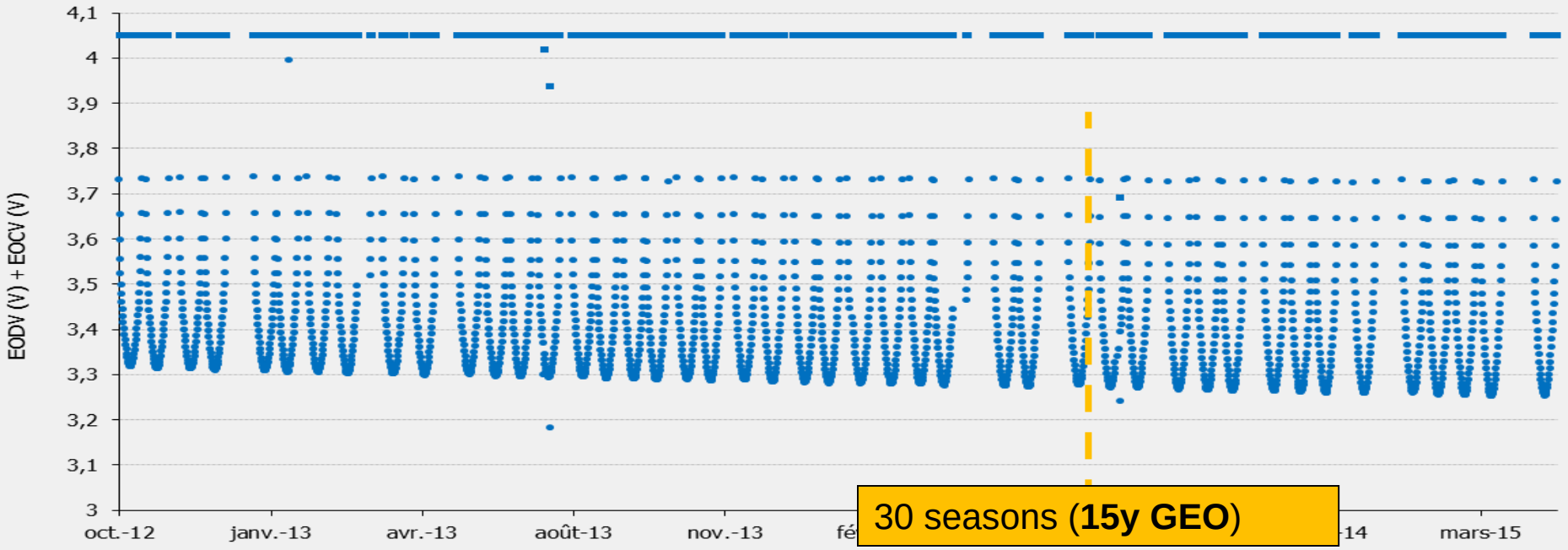
LEO Mission Used Energy comparison

- **BOL specific energy** is not the key parameter but **Mission used specific energy** which takes into account DOD figures
- VES16 Mission used specific energy is 55 Wh/kg to be compared to 25 Wh/kg for 18650 cells



GEO - VES16 accelerated cycling - 80% DoD

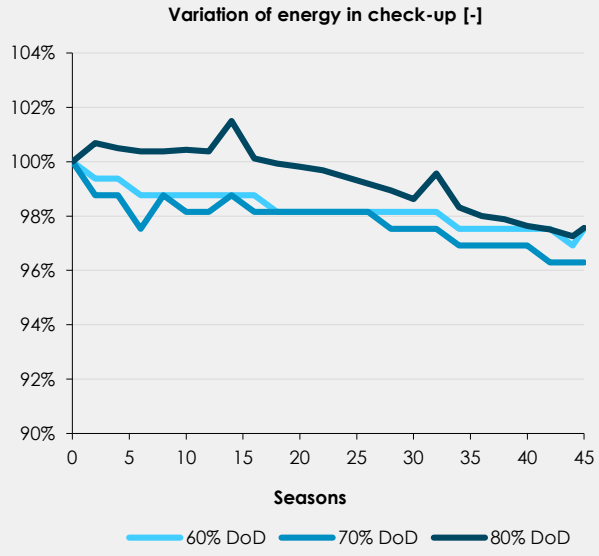
- VES16 cell life tests in GEO, 80% DoD, EoCV=4,05V
- 45 GEO seasons = 22.5 years

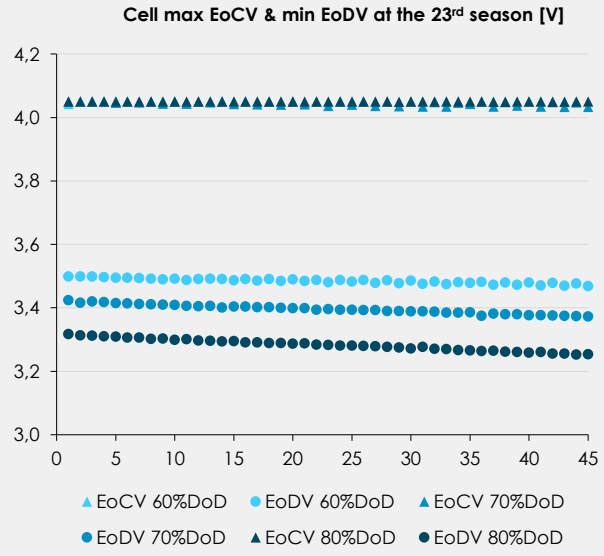


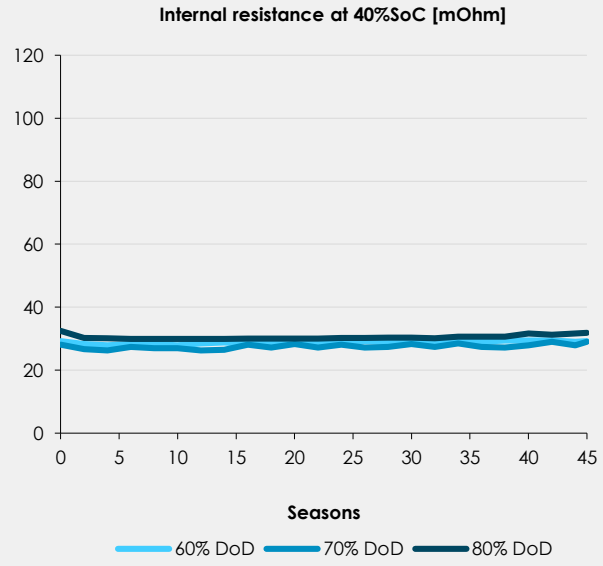
Synthesis of accelerated GEO lifetests

- Accelerated GEO life-test w/o solstice, 4.05V EOCV, +20°C:
  - 60% DoD
  - 70%DoD
  - 80% DoD

Energy loss below 4%, and stable internal resistance after 45 seasons and more. stable voltage

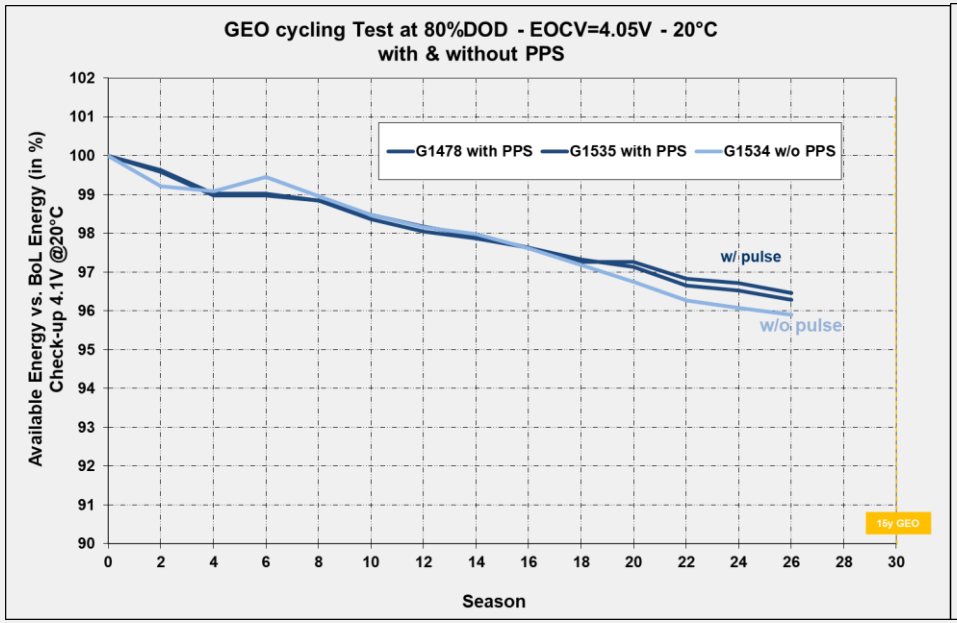


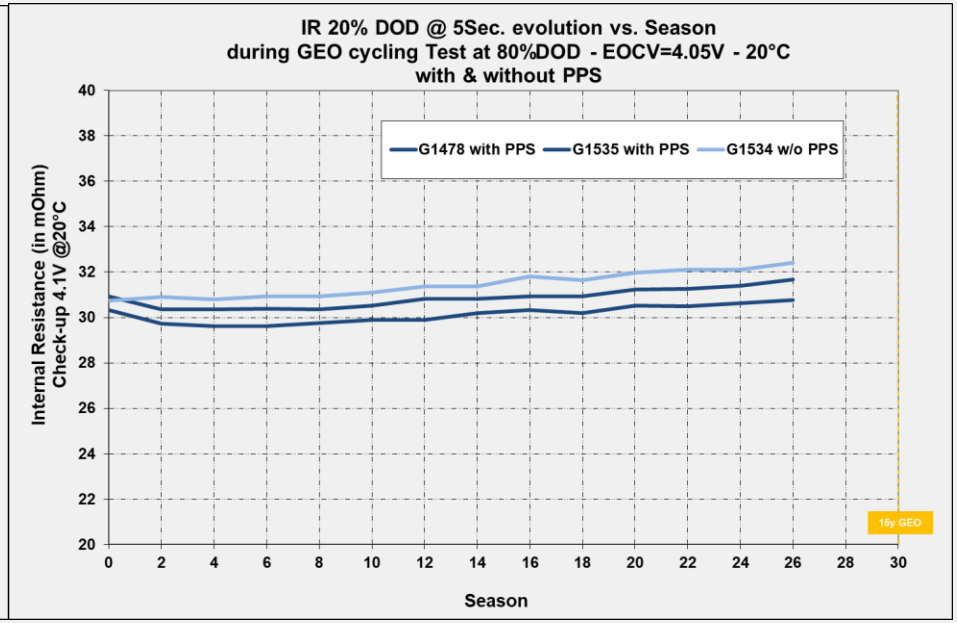




GEO – Semi-acc. 80% DoD w/ and w/o PPS

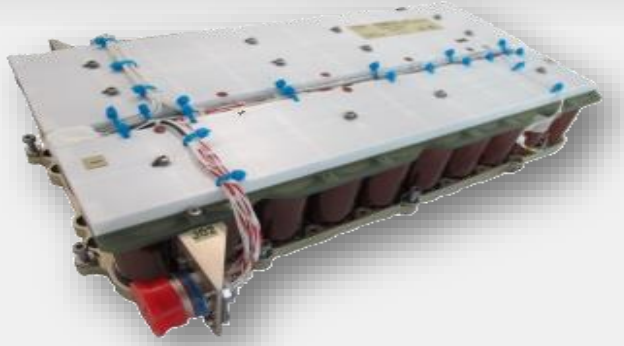
- Equinox: GEO 80% DOD and **2 PPS cycles at 10% DOD**)
- Solstice: **6 PPS/day at 20%DOD**
  - After 26 seasons, no significant impact of the Plasmic Propulsion System on cell performances





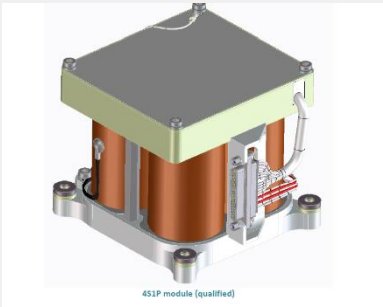
VES16 batteries single or double-deck

- Modular design P and S
- Individual cell autonomous balancing system (SBS) to ensure life time
- Heaters & thermistors (redunded)
- Connectors
- Individual cell telemetry for AIT



10S5P

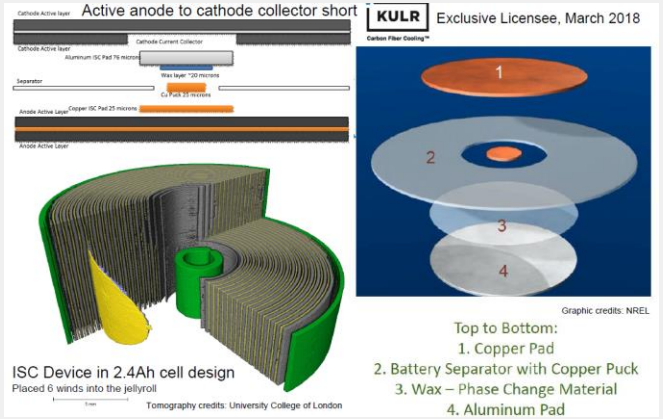
9S28P

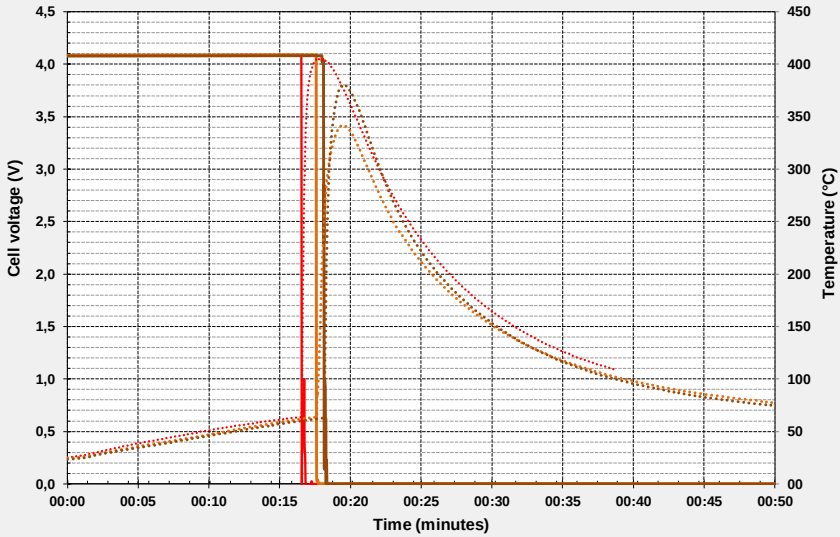


4S1P

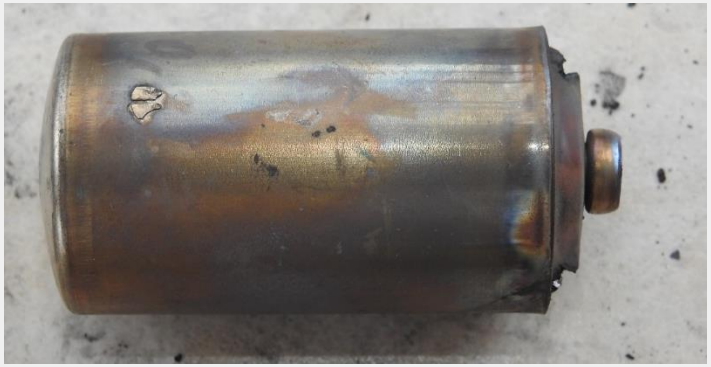
NASA/NREL/UCL Experiment at ESRF and DLS

- Cooperation work started with **NASA-JSC Houston and NREL** to evaluate/test VES16 safety
- 90 VES16 cells with **ISCD** (Internal Short Circuit Device) developed by NREL/KULR
- ISCD activation successfully performed on 10 cells at Saft using sand heater :
  - Activation temperature from 64 to 76°C
  - Gas release through the 2 vents : not violent
  - No fire and no cell can opening
  - Thermal Runaway Temp : up to 420°C





VES16 cell after ISCD activation

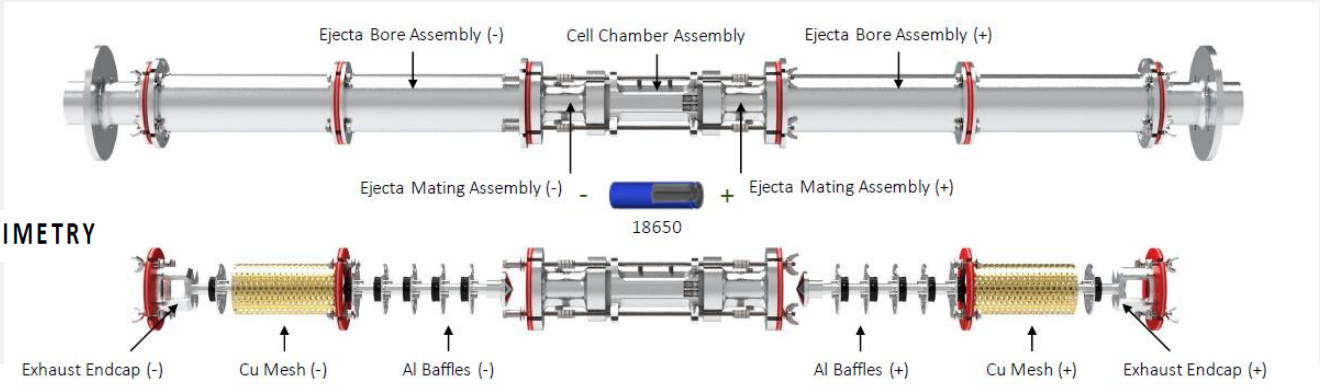


Vent locations : gas release after ISCD activation

NASA/NREL/UCL Experiment at ESRF and DLS

- **ESRF** (European Synchrotron Radiation Frequency) in Grenoble France and **DLS** (Diamond Light Source) Didcot near Oxford UK
- Objectives : analyze TR with in-situ Rx using Synchrotron beam line
  - Activate ISCD VES16 cells to analyze TR with in-situ Rx on 5 cells
  - Nail trigger on 4 cells
  - Thermal trigger on 7 cells
- TR propagation videos : 4-5 seconds activation
- Use of specific FTRC (Fractional Thermal Runaway Calorimeter) chamber to measure the TR energy dissipation

Beamline Configuration



FRACTIONAL THERMAL RUNAWAY CALORIMETRY

ESRF Oct 2018 Run 47 – ISCD D-cell

Cell type: D-cell
Capacity: 4.5 Ah
State of charge: 100 % (4.1 V)

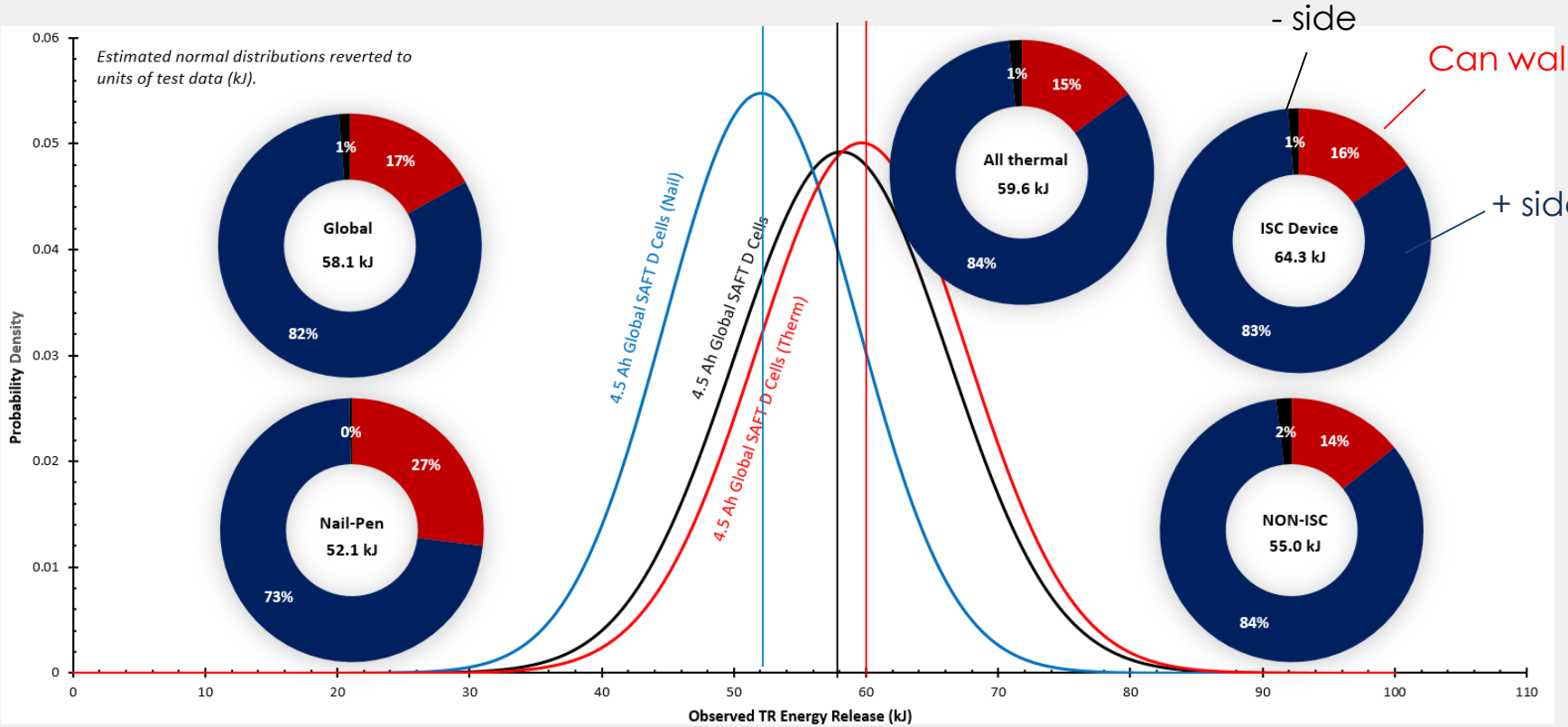
Bottom vent: None
Wall thickness: 380 µm
Orientation of cell: Upright (vent at top)
Location of ISCD radially: 6 winds in
Location of ISCD longitudinally: Middle
Side of ISCD in image: Right

Separator type: Normal
Positive current collector: Normal
Negative current collector: Normal

Location of FOV longitudinally: Middle
Frame dimension (Hor x Ver): 2016 x 1111 pixels
Pixel size: 10 µm

ESRF and DLS TR results : VES16 Heat rejection diagrams

S-FTRC RESULTS: SAFT VES16 (D-CELL)



TR energy release measurements from 52 to 64 kJ

ISCD result is the most accurate because it's most relevant to a latent defect induced internal short and requires less heat input to trigger,

NASA Findings to Date and Forward Work

- Cell design's response to TR is consistent and not violent
- No side wall or bottom breaches, 2 top vents consistently open
- TR response takes > 4 seconds to fully develop
- Very large gas generation over several seconds
- Need to perform calorimetric runs with our gas collection system in place

- Cell TR calorimetric output of 50kJ is very mild for 4.5Ah cell
  - LG MJ1 at 3.5Ah outputs 75kJ for comparison

- VES16 ISCD, thermal and Nail tests to be continued on more cells
- VES16 ISCD cell activation at battery level.

Conclusion

- VES16 has been extensively tested for LEO and GEO missions :
  - Very low energy decreasing for 18 years 80 % DOD GEO and 12 years 30 % LEO
  - Very stable internal resistance whatever the DOD, EOCV, Duration
  - Safe cell with reproducible internal short circuit behavior (venting without can opening and material ejection, no fire, not violent) and low TR energy
- VES16 battery is already in orbit on 81 Satellites : Teleos 1, Paktes 1A and 75 Iridium Next
- 3 leading European and US GEO spacecrafts families contracts with a VES16 battery (including MTG and Quantum batteries)
- Space IL Bereshit Moon probe that will land on moon 11th of April
- More than 35 LEO contracts including constellations and radar satellites

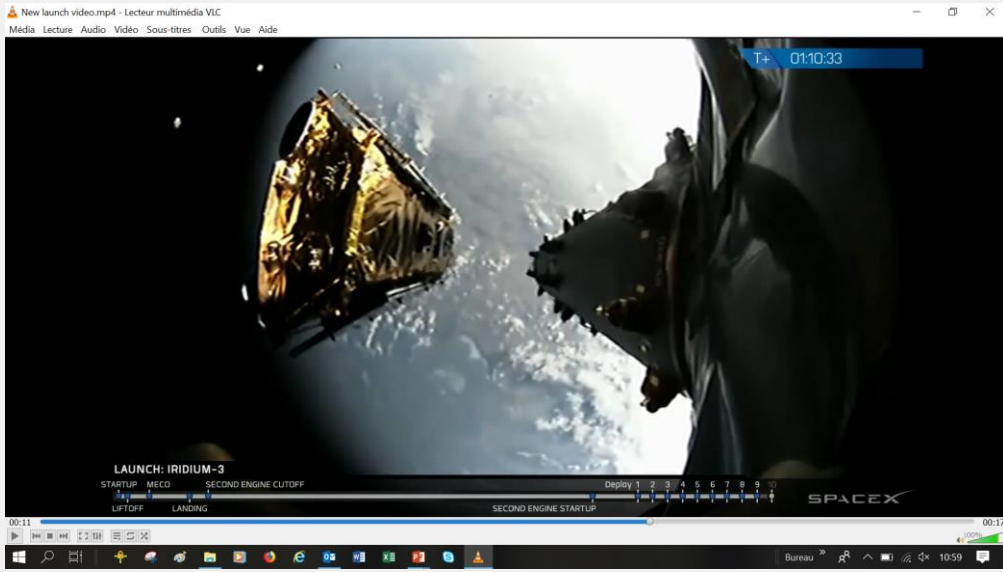
The VES16 battery flight proven for LEO /MEO and GEO's …

Iridium Next constellation completion

January 11th 2019,

Space X Falcon 9 placed successfully in orbit the 10 last Iridium next satellites.

The constellation is now completed with **75 satellites** (including 9 flying spares satellites).



Battery configurations 9S28P VES16

Battery Return of Experience on 75 VES16 batteries

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Merci
Vielen Dank
תודה, תודה לך!
Dekuji
Thank you
谢谢
Tack