ISCD Thermal Runaway Experiment performed on VES16 cells

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NASA Aerospace Battery Workshop

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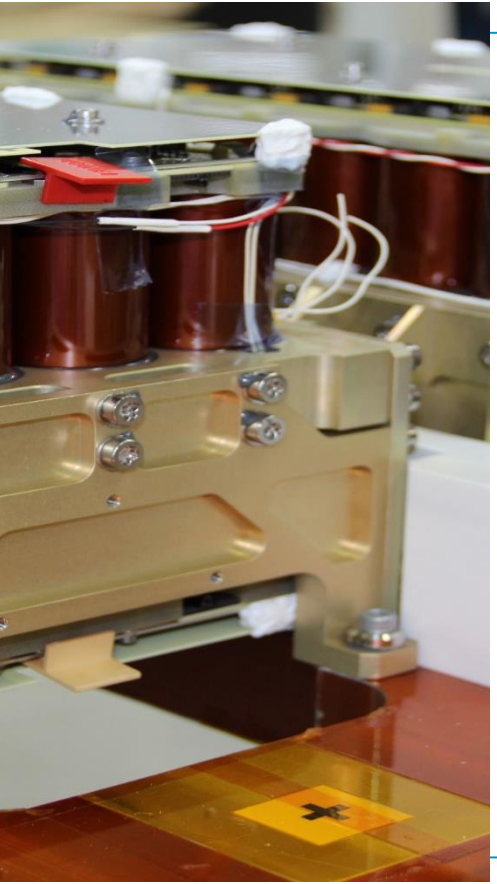
a company of TOTAL

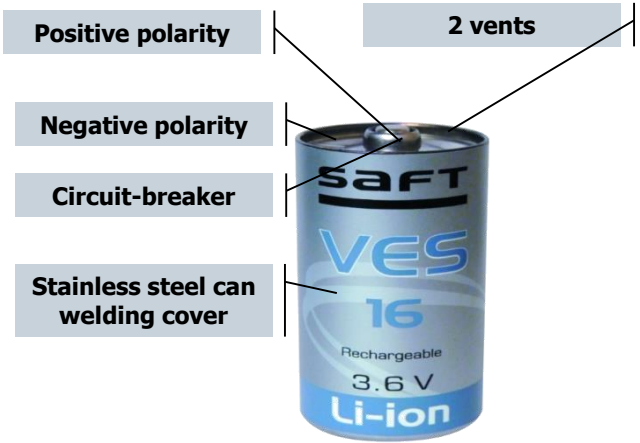
VES16 cell



- 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
- **Qualification** held **in 2011** under CNES contract
- Designed for **LEO satellite** batteries
  - **>60000 cycles** with less than **20%** losses
  - **up** to **40%** DoD
- **18 years GEO satellites with EOR/EPS**
- On orbit since 12/2015 on **TELEOS-1**
- **75 Iridium Next Satellites (Since January 17)**

VES16 cell main features

– Main characteristics :

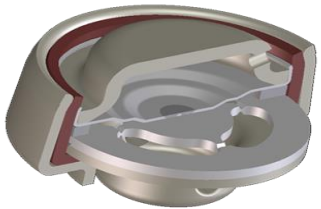


Dimensions (Ø x H)	33 x 60 mm (D-size)
Weight	≤ 112 g
Volume	0.051 dm^3
Voltage range	[2.7 ; 4.1] V
Nominal capacity	4.5 Ah on 4.1-2.7V @ C/2, 20°C
Nominal energy	16 Wh on 4.1-2.7V @ C/2, 20°C
Specific energy	> 155 Wh/kg
Internal resistance	≤ 35 mΩ @ 20% DoD
Best cycling temp.	[+0 ; +40] °C
Mechanical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

– LEO Electrode negative : high charge current

– Current breaker triggered with pressure

– 2 vents on cover : highly reliable safety device



ISCD on VES16

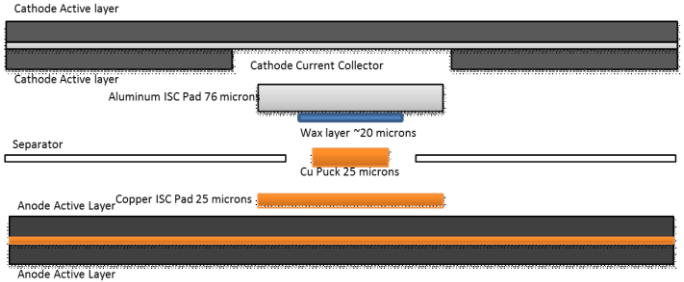
– Cooperation work started with **NASA-JSC Houston and NREL** to evaluate/test VES16 safety in 2018

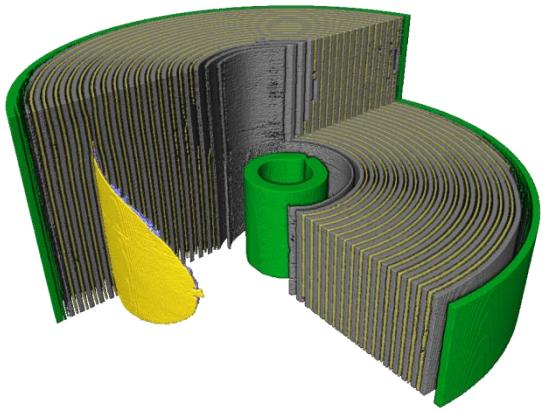
- To check the cell internal Thermal Runaway (TR) propagation using ISCD, nail, thermal
- To get statistics on cell behavior during TR : venting event and location, fire, explosion….
- To check the cell to cell propagation in case TR
- To perform calorimetric measurement to get the temperature mapping of the cells exhausted gases and particles
- To evaluate the total energy involved during the TR

NREL/Nasa Cell Internal Short Circuit Device

KULR
Carbon Fiber Cooling™

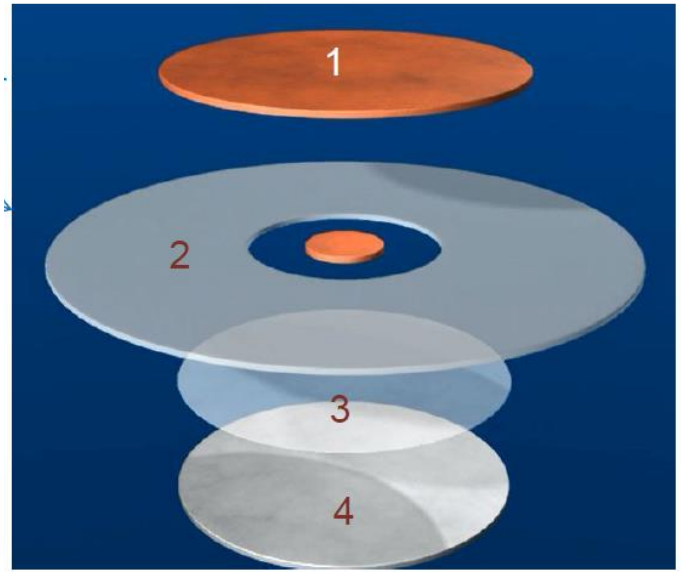
Active anode to cathode collector short





ISC Device in 18650 cell design

Placed 6 winds into the jellyroll



Graphic credits: NREL

Top to Bottom:
1. Copper Pad
2. Battery Separator with Copper Puck
3. Wax – Phase Change Material
4. Aluminum Pad

2010 Inventors:
- Matthew Keyser, Dirk Long, and Ahmad Pesaran at NREL
- Eric Darcy at Nasa

US Patent # 9,142,829 issued in 2015

Thin (10-20 μm) wax layer is spin coated on Al foil pad

Wax formulation used melts ~57°C

Tomography credits: University College of London

2016 Award Winner

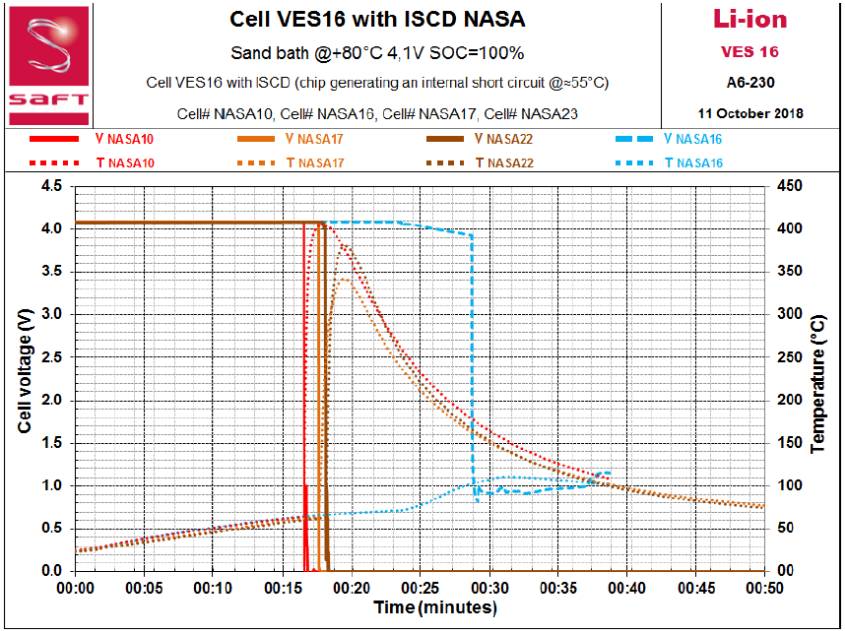
ISCD insertion on VES16

- 90 VES16 cells have been equipped with ISCD
- ISCD have been supplied by NREL/KULR with adapted thickness and Saft separator
- ISCD have been directly placed onto the positive electrode during the winding operation to get a better positioning
- Formation procedure has been adapted with 3 steps at ambient temperature
- 90 cells have correctly filled and formed : capacity and internal resistance values were conform versus removed active material quantity.

ISCD activation on VES16

– 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

TR Nasa Test plan

- Nasa has developed a TR test on 18650 based on Internal Short Circuit ISC Device since 2010.
  - The principle to they perform in-situ high speed tomography using high speed detector to get the TR front and internal cell propagation videos.
  - They use the European Synchrotron (ESRF) in Grenoble and DSL in UK to get the high frequency signal (millisecond) with a calorimetric chamber (ISCD, high temperature, nail test)
  - They also perform TR reproducibility tests on 90 cells, calorimetry tests, external short, overcharge, nail test to determine the TR energy in Houston lab

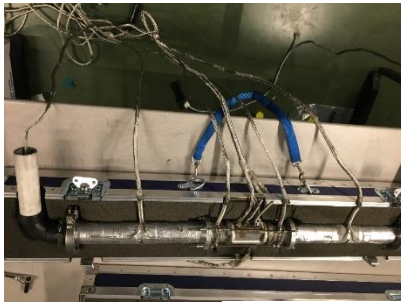
Nasa/NREL/UCL Experiment at ESRF and DLS

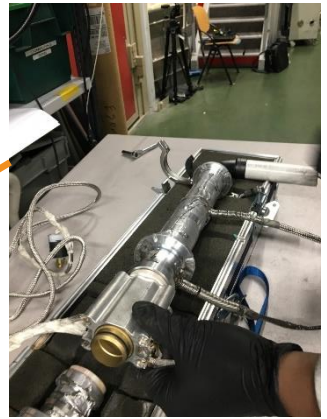
- **ESRF** (European Synchrotron Radiation Frequency) in Grenoble France and **DLS** (Diamond Light Source) Didcot near Oxford UK
- Objectives : analyze TR with in-situ high speed tomography using Synchrotron beam line
  - Activate ISCD VES16 cells to analyze TR with in-situ Rx on 10 cells
  - Nail trigger on 5 cells
  - Thermal trigger on 10 cells
- Use of specific FTRC (Fractional Thermal Runaway Calorimeter) chamber to measure the TR energy dissipation

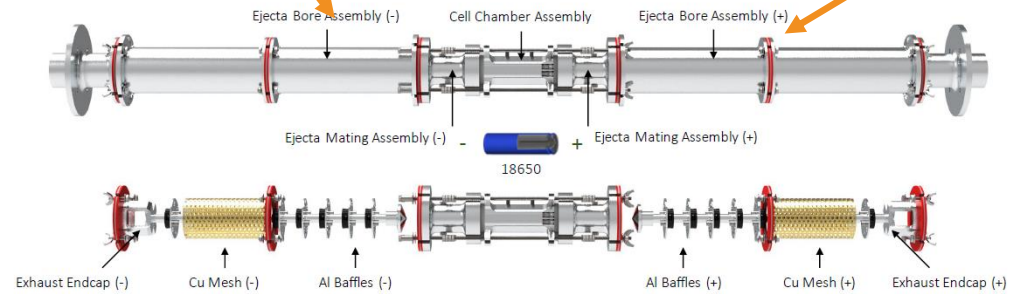
Beamline Configuration

FTRC Nasa equipment : Fractional Thermal Runaway Calorimeter

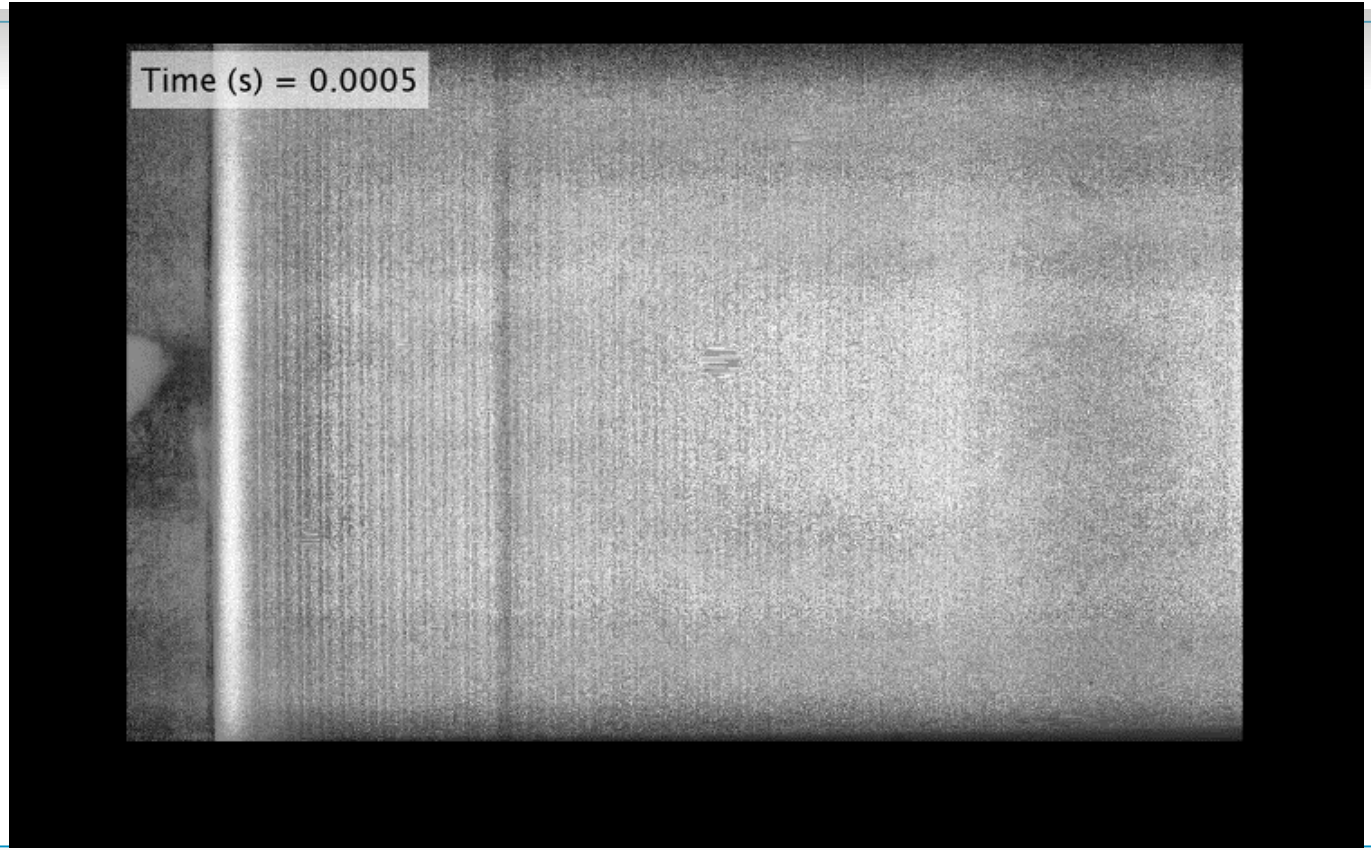
- To heat the cells until TR
- To perform thermal mapping using 54 thermal sensors and measure TR energy
- to adapt top and bottom vents or ruptures
- to recover and analyze ejection particles and powder in baffles and Cu meshes



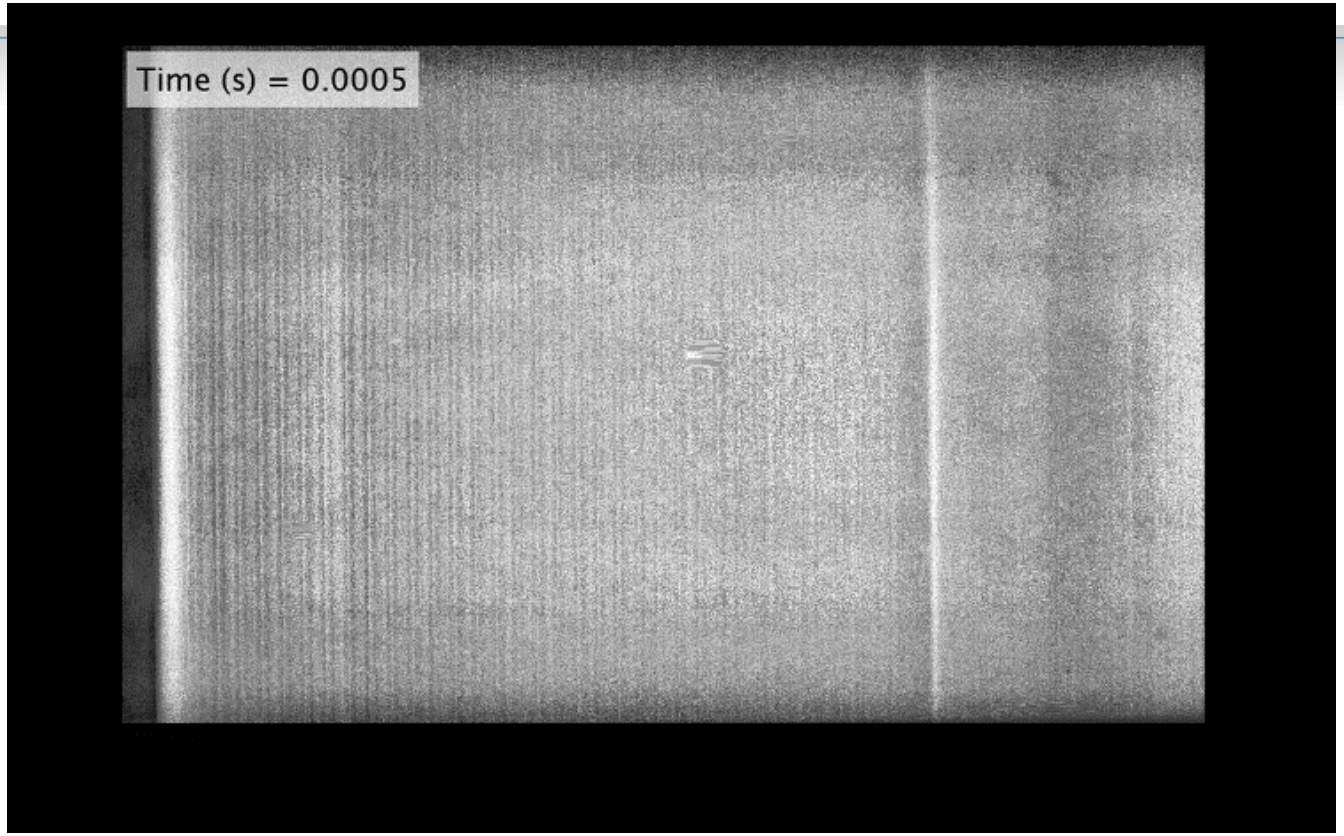




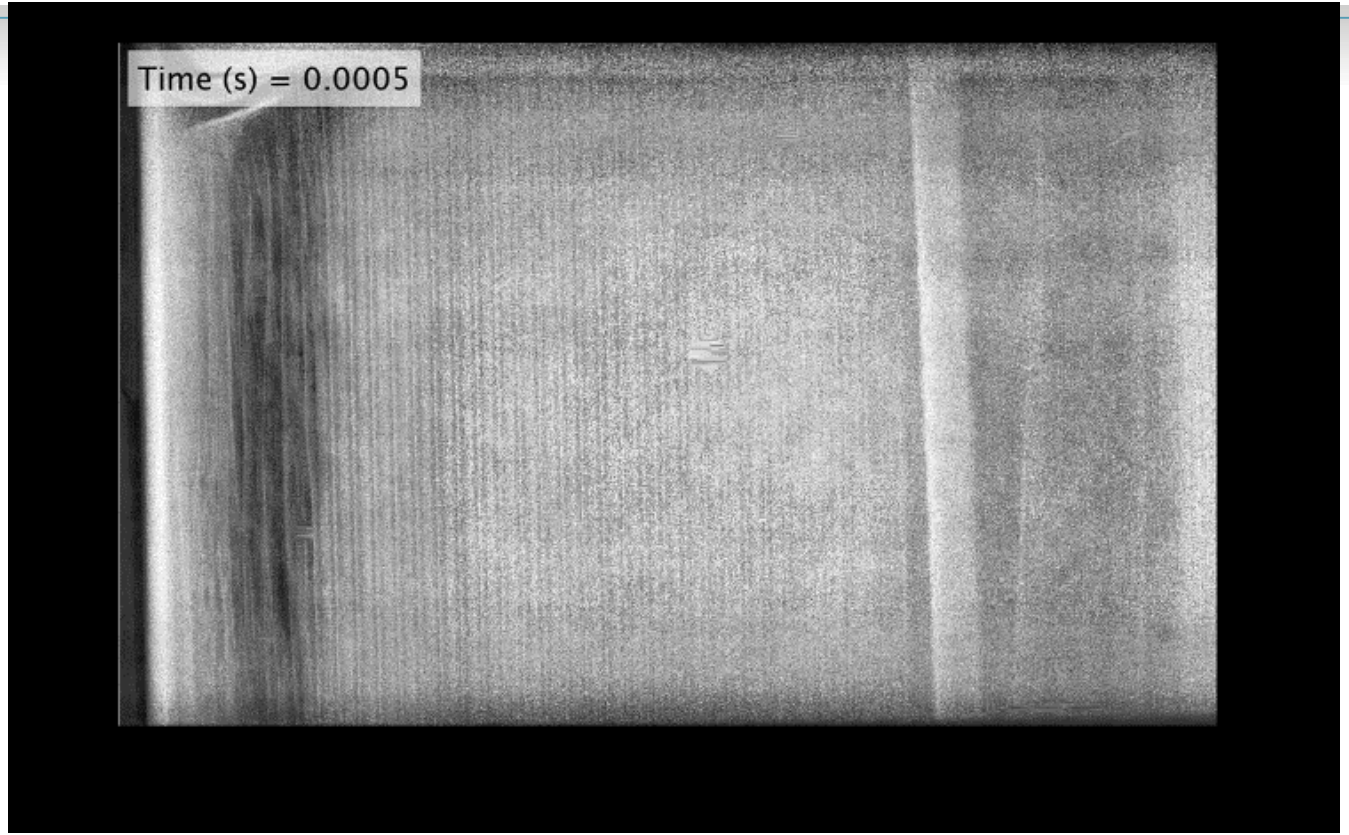
Nail Test



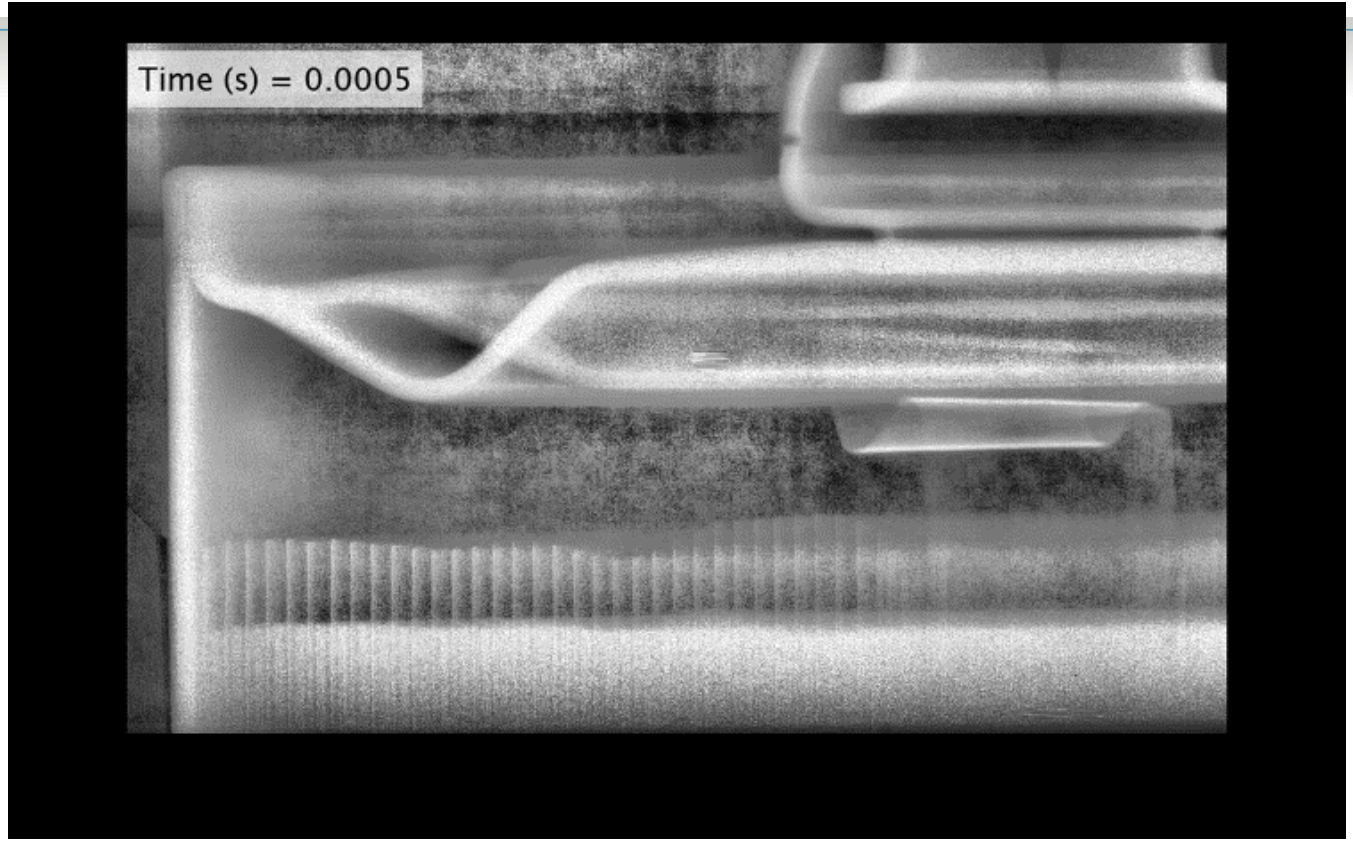
Thermal Run-Away with temperature ramp-up to 250°C



ISCD Triggering Test



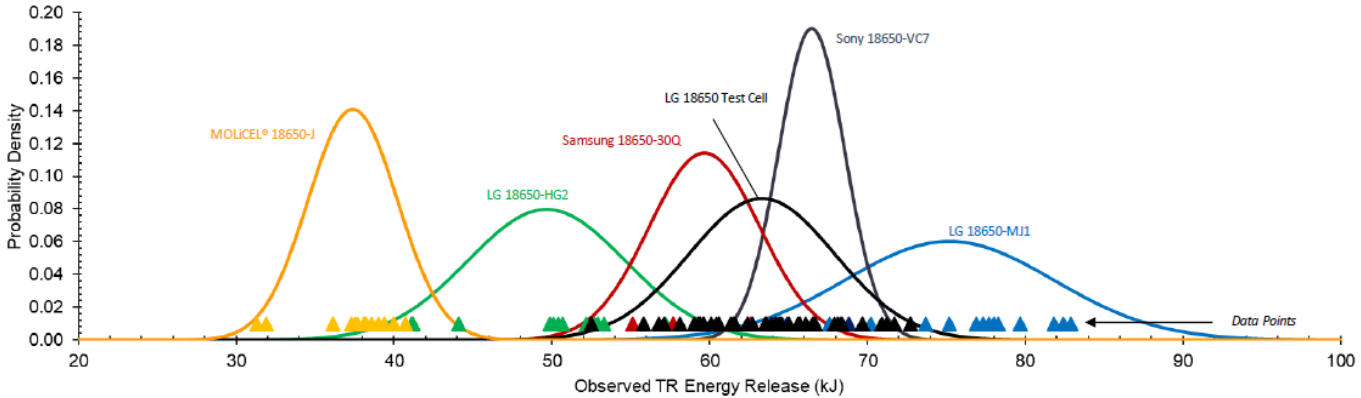
ISCD triggering test : top cover



Run 45 – ISCD D-cell – Post Test Carcass

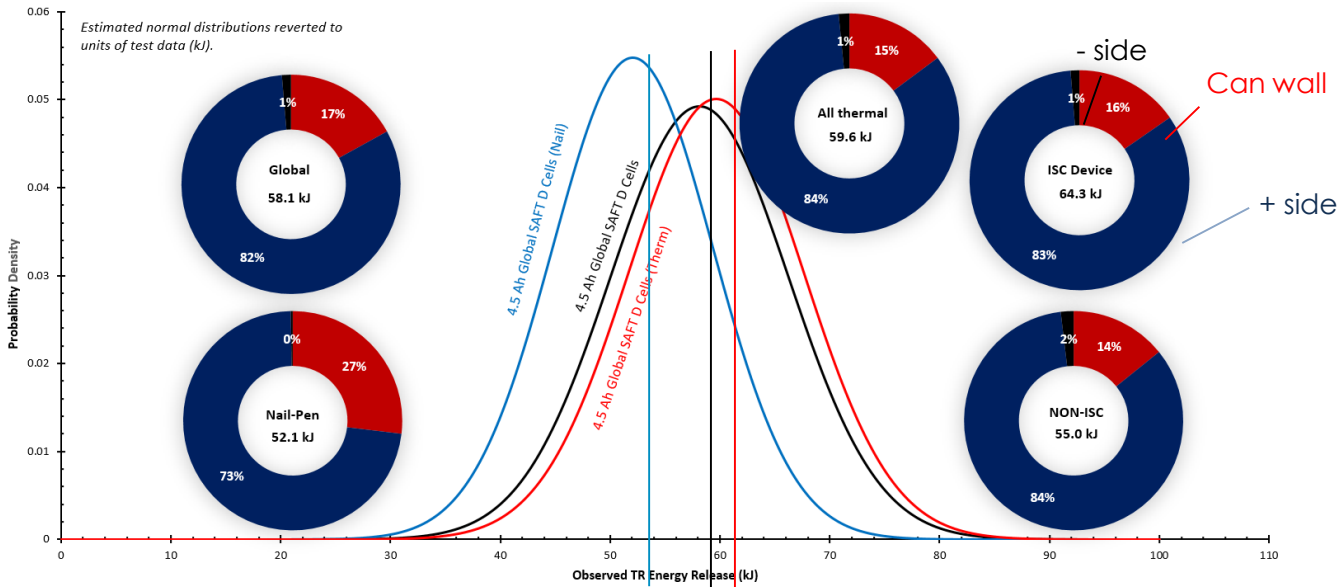
Nasa equipment : Total TR Energy Release

- Higher Energy cells (LG-MJ1) release more energy and have more violent ejection with lower remaining cell mass (Molicell J)
  - Normal distribution created from the raw data
  - But not linear relationship between cell stored energy and total energy release during TR
  - Worst value for LG-MJ1 with 75.2 kJ



ESRF and DLS TR results : VES16 Energy Release 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,

VES16 Results and analyses

- Cell design's response to TR is consistent and not violent whatever are the triggered conditions (ISCD, Heat, nail)
- No side wall or bottom breaches, 2 top vents consistently open
- TR response takes more than 4 seconds to fully develop whereas it takes less than 0.5 s for 18650
- Very large gas generation over several seconds
- Contrary to previous status VES16 TR Energy release is less (54-58 kJ) than 18650 cells (75 kJ for MJ1) with 30 % energy more
- No particle ejection : only fumes and gas

Nasa Findings to Date and Forward Work

The main question is : why VES16 exhibit specific behaviour vs 18650 ?

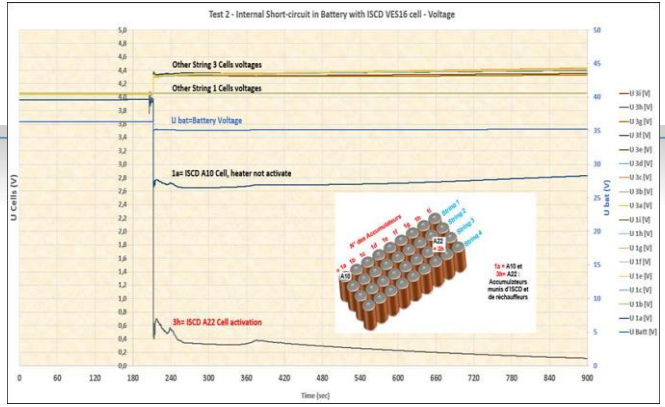
- ✓ Impact of electrolyte quantity per Ah (1,8 g/Ah for MJ1 compared **to 4.3 g/Ah for VES16**) : electrolyte acts as an active cooling part with liquid/gas heat exchange.
- ✓ Impact of robustness of the stainless steel thick can and the cover weld
- ✓ Gas release via 2 vents

Follow-on

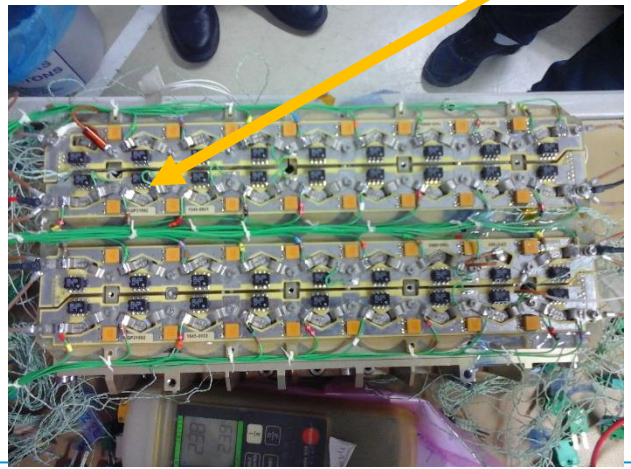
- **80 additional ISCD cells** have been provided for Nasa for **reproducibility tests** experiment
- KULR has already supply ISCD for Saft test plans (NDA in place and price proposal)
- VES16 ISCD, thermal and Nail tests to be continued on more cells to increase statistics
- VES16 ISCD cell activation **at battery level 9S8P configuration** with 2 ISCD to be triggered.

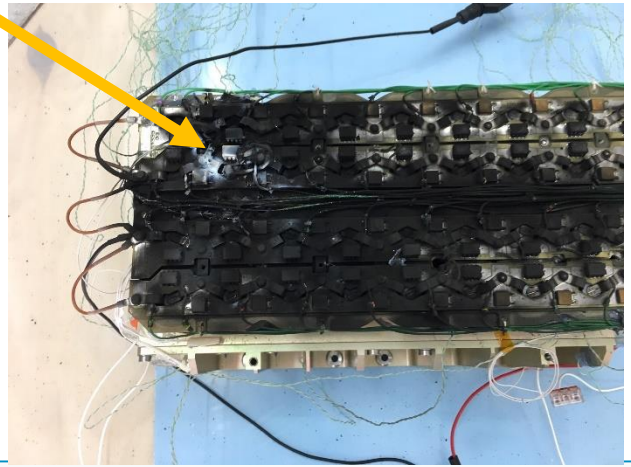
9S8P Battery VES16 ISCD Triggering

- TR on cell# 2 with gas ejection on the two vents as expected with fumes
- PCBA burned with flame due to gas temperature
- No cell to cell propagation
- Other Battery strings voltage remained constant



ISCD Cell# 2

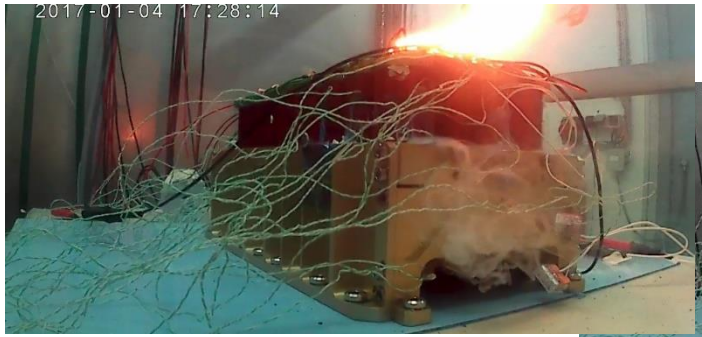




9S8P Battery VES16 ISCD Triggering

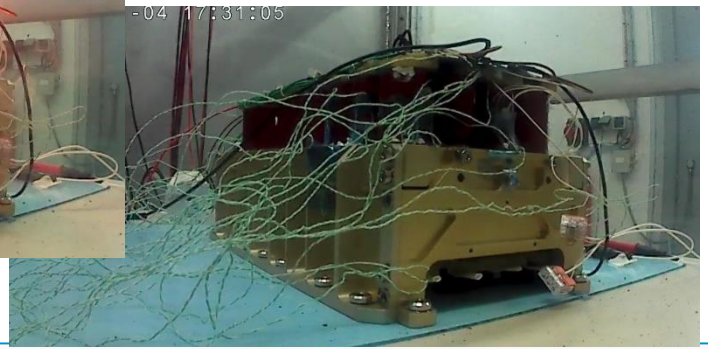
T0

T0+10 seconds



T0+20 seconds

T0+3 mins



Acknowledgements

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