The European Commission’s science and knowledge service

Joint Research Centre

European Commission

Safer lithium ion batteries by preventing thermal runaway propagation

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Joint Research Centre (JRC) European Commission

eMove360° Battery Conference 2019

Munich, 16 October 2019

European Commission

Outline

- European Commission's JRC and its Battery Laboratory
- Battery Safety Testing: Thermal Runaway and Thermal Propagation
- Summarising Thermal Propagation Standards
- Regulatory Landscape

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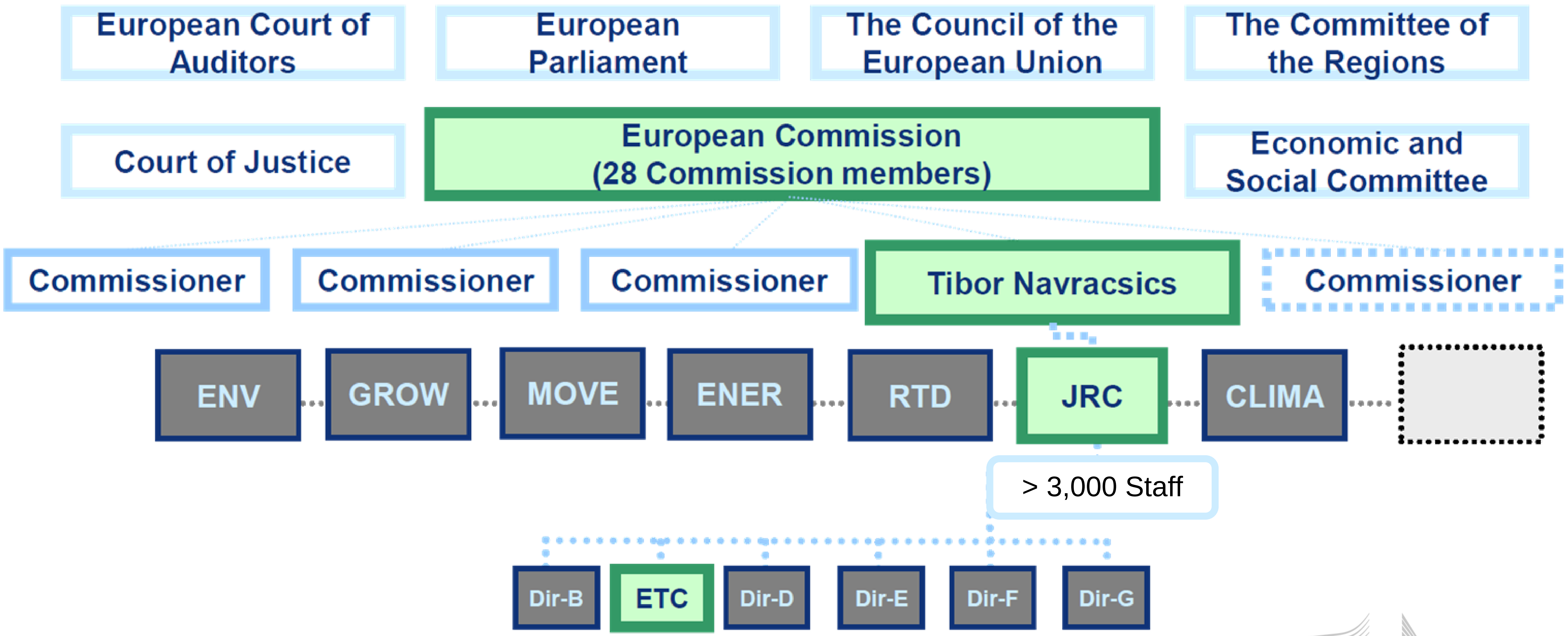
Panorama of the European Union



JRC Directorate for Energy, Transport & Climate

Petten, Netherlands

Seville, Spain

Ispra, Italy

~ 350 Staff
Petten
Ispra
Seville

JRC Mission:

As the science and knowledge service of the Commission, our mission is to support EU policies with independent evidence throughout the whole policy cycle.

⇒ **Independent of national or commercial interests…. for the European citizen**

Battery lab Petten

(2012 up to now)

- 3 cyclers (96 channels) with impedance analysers
- 3 potentiostats
- 2 environmental chambers
- 12 temperature chambers
- 3 glove boxes
- STA with in-line FTIR&GC/MS analysis
- IR camera thermal imaging
- X-ray Computed Tomography
- Scanning Electron Microscopy (SEM)
- 2 Accelerated rate calorimeters (ARCs)
- XRD (in-situ, in-operando)

Battery lab Petten

(Current EU H2020 projects)

Lithium Batteries for Second Use

LibforSecUse: Lithium batteries for second use

This study was carried out as part of the EMPIR project 17IND10. The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR participating states

- Develop validated impedance based measurements – Residual capacity – diagnostic tool

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CarE-Service

Circular Economy Business Models for innovative hybrid and electric mobility through advanced reuse and remanufacturing technologies and services

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776851

- Demonstrate circular economy business models entailing re-use, remanufacturing and recycling of components and materials

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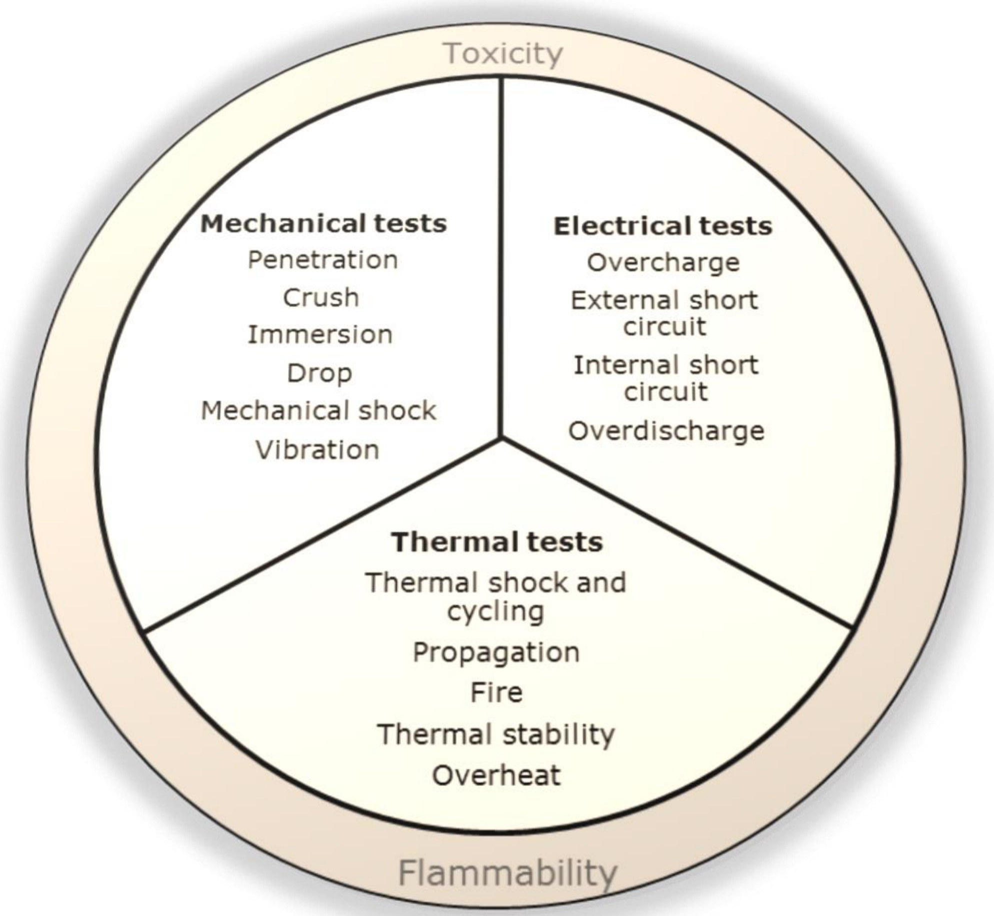
Battery Safety Testing



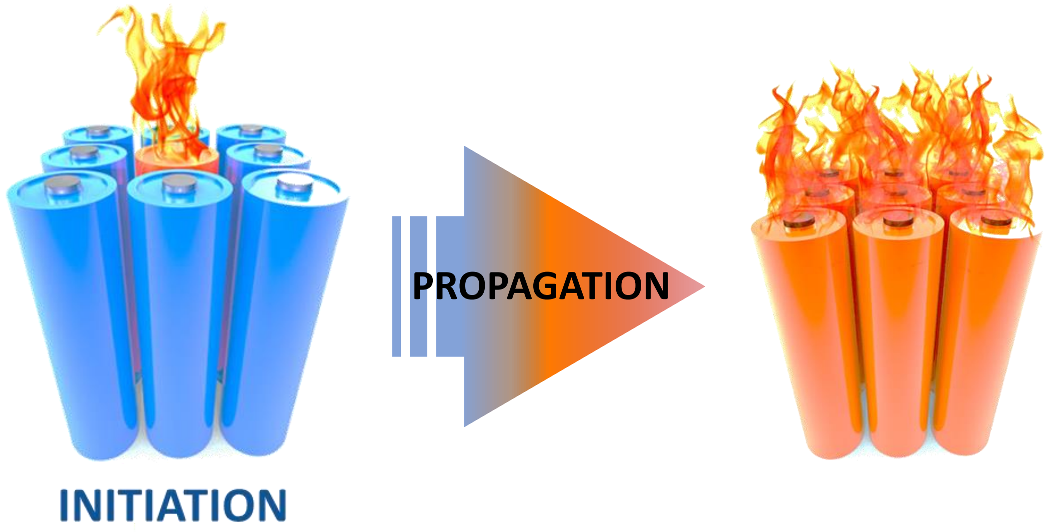
Chapter 8 in Emerging Nanotechnologies in Rechargeable Energy Storage Systems. Micro and Nano Technologies
Authors: A. Pfrang, A. Kriston, V. Ruiz, N. Lebedeva, F. di Persio, L. Boon-Brett.
Edited by: L. M. Rodriguez-Martinez and N. Omar
Elsevier, 2017
http://www.sciencedirect.com/science/book/9780323429771

Battery Safety Testing: Thermal Runaway

Battery Safety Testing: Thermal Propagation

Workshop March 2018, JRC Petten, NL

- Thermal runaway: mechanisms and influencing factors
- Thermal propagation
- Thermal runaway initiation methods, fit-for-purpose testing related to external and internal abuse triggers
- Safety strategies
- Cost and performance penalty



Workshop Report

http://publications.jrc.ec.europa.eu/repository/bitstream/JRC113320/kjna29384enn.pdf
https://ec.europa.eu/jrc/en/event/workshop/workshop-safer-li-ion-batteries-preventing-thermal-propagation

Thermal runaway: initiation methods (mechanical)

Nail or needle penetration	multi-layer damage and the outcome of the test is very dependent on multiple factors accessibility of certain cells restricted extensive manipulation (drilling of the pack casing required)	Local damage
Blunt rod	deforms the most outer electrode layers and eventually creates a short circuit; damage of separator followed by single or multilayer strike suitable for pouch cells, cylindrical cells, seldom applied for prismatic hard case	
Crush	crush impact is a useful method to assess the robustness of a system, possibly not suitable as TP triggering method	
Pinch	requires access to the cell from two opposite directions, possibly not suitable as TP triggering method	
Water immersion	does not only damage the battery itself, but also the electronics built into the battery presence of water also severely changes thermal properties of cells surrounding possibly not suitable as TP triggering method	Global damage

Thermal runaway: initiation methods (electrical)

Overcharge	adds additional electric energy to the system some cells are equipped with passive protection devices like a circuit interrupt device (CID), which might need to be disabled/manipulated prior to testing preparation and wiring of the module to connect to a single cell needed high voltages and currents might be needed when the cell contains stable separators
External short-circuit	does not necessarily lead to TR in all types of cells (current might not be high enough to cause TR for a single cell) similar difficulties as discussed above for overcharge

Global damage

Thermal runaway: initiation methods (thermal)

Heat	adds significant energy (thermal) to the system, adds unwanted preheat to adjacent cells manipulation for installation the heating device required multi-layer (separator) failure	Global damage
Laser impact light beam	single or multilayer failure potentially very small impact area special openings of the housing required uneconomical, complex set – up specific equipment required	Local damage

Thermal runaway: initiation methods (internal)

<table>
<tr><td>Nickel particle method</td><td>incorporation of particles followed by applying pressure

significant manipulation (high effort; cells must be specially prepared by the cell manufacturer and have to be transported to the lab), possibly not reliable</td><td rowspan="4">significant manipulation

single layer failure</td></tr>
<tr><td>Metals with low melting point implantation</td><td>heat exposure for melting introduced metal</td></tr>
<tr><td>Wax based implantable device</td><td>implantation of a device allows simulation of different types of ISC : 1) anode to cathode, 2) anode to positive current collector, 3) positive current collector to negative current collector and 4) cathode to negative current collector</td></tr>
<tr><td>Shape memory alloy implantable device</td><td>SMA material pierces the separator as it bends when heated</td></tr>
<tr><td>Internal heating device</td><td>heating device installed inside the cell

local heating occurs

significant manipulation at cell level and higher levels</td><td></td></tr>
</table>

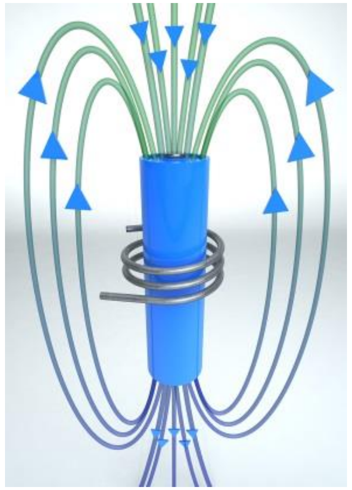
Local damage

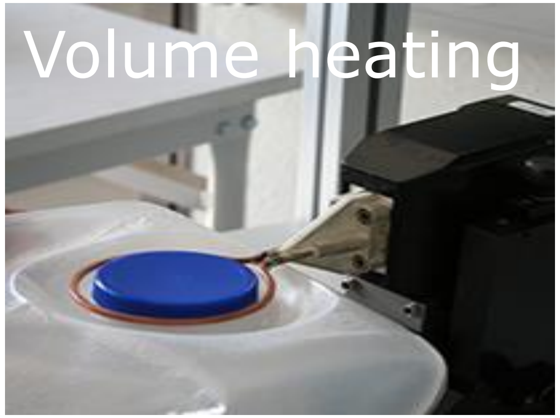
Thermal runaway: initiation methods

- No perfect TR initiation method available to imitate a realistic internal short circuit (ISC)
- Selection of an initiation method needs to consider scenario to be tested and purpose of the test (mimic realistic scenario *vs.* worst case scenario)
- To simulate the dynamics of internal and external damages is challenging
- Development of new initiation methods might make sense…

Thermal runaway: Inductive heating initiation

Why?



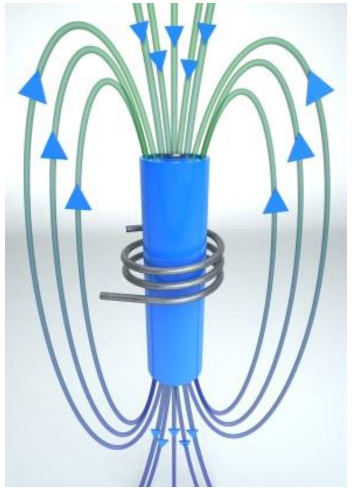


How?

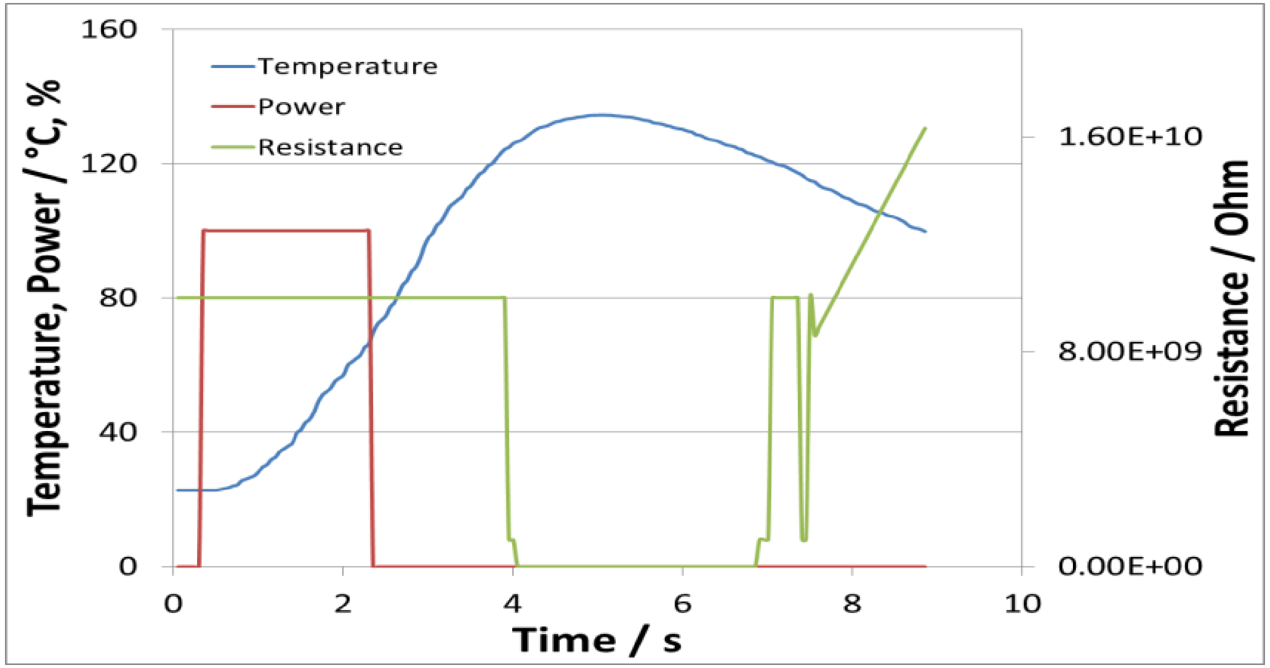
Alternating electromagnetic field generates a local current (eddy current) which in turn generates heat in any closed loop conductors, e.g. Al, Cu, graphite, NMC

- Does not require direct contact: less manipulation may be needed
- Coil geometry is not limited in shape and size

Thermal runaway: Inductive heating initiation

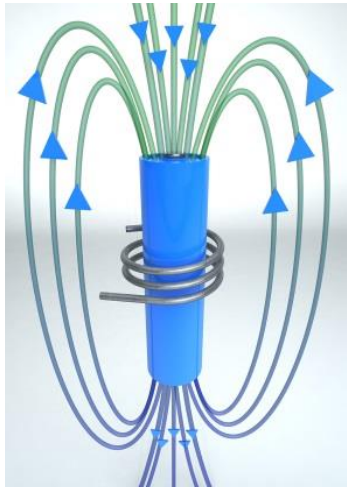


18650 mockup cell

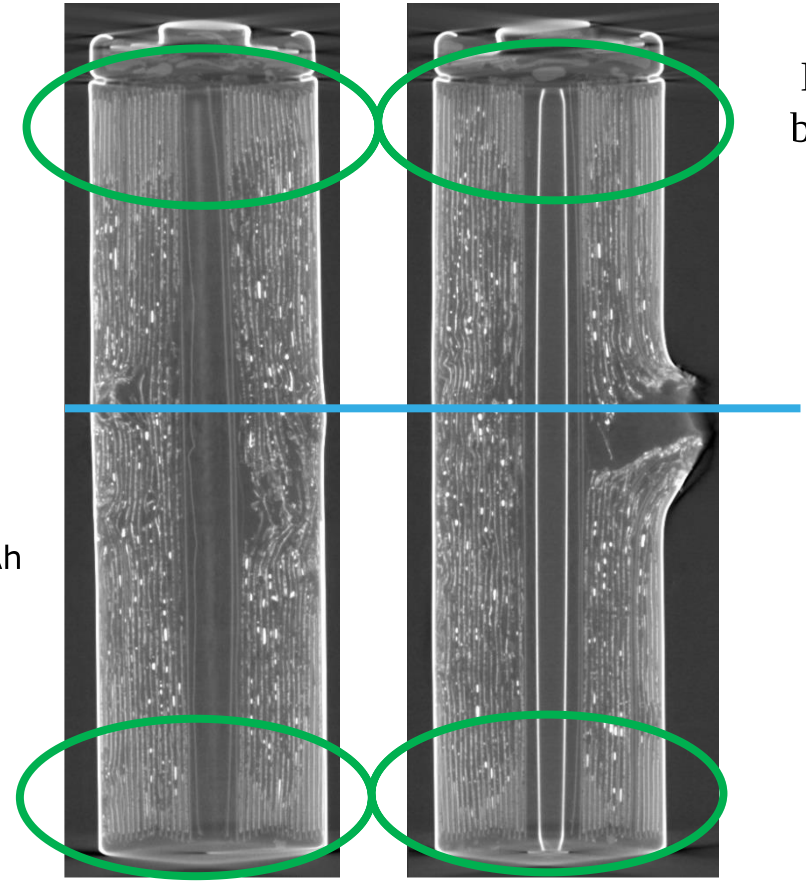


- Only few seconds are needed to melt / damage the separator locally and short the cell

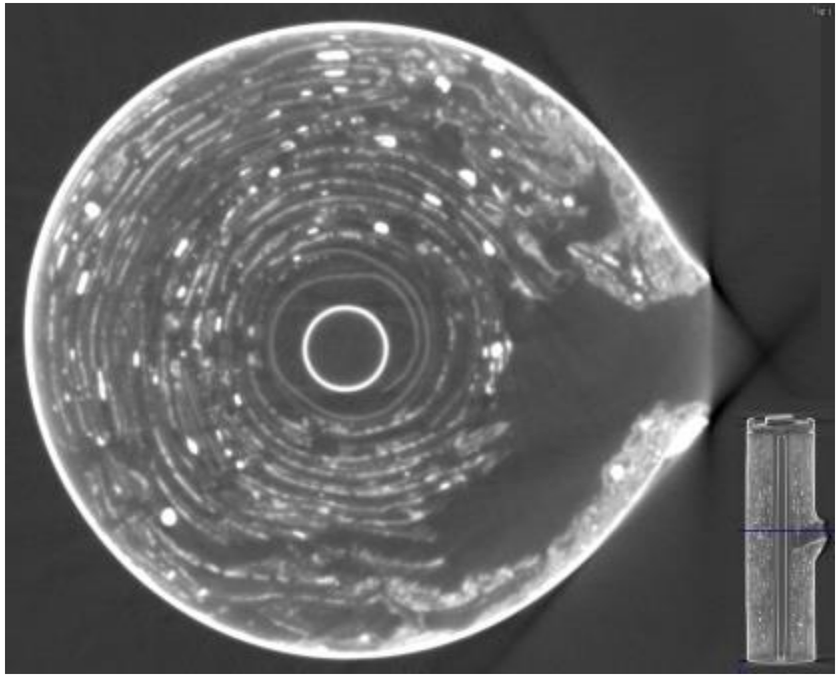
Thermal runaway: Inductive heating initiation



18650 3.1 Ah



Less damage at
both ends of cell



Thermal runaway: Inductive heating initiation

Pouch cell 39Ah

Prismatic cell 96 Ah hard casing

- Inductive heating was demonstrated to initiate thermal runaway on cylindrical, pouch and prismatic cells
- Fast initiation (within seconds)
- Requires only small amount of energy (few % of electrical energy content)
- Damage cell locally
- Further optimization is possible and required (e.g. coil geometry, frequency)
- **Publication to be submitted soon for publication**

https://wiki.unece.org/display/trans/EVS+17th+session;
EVS17-E1TP-0600 [EC]Progress on thermal propagation testing.pdf

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Summarising TP Standards: e-Mobility

Thermal propagation testing in Standards - <u>Automotive applications</u>

Standard	Level of test	Test title	SOC	Initiation method
SAE J2464:2009	M, P	Passive propagation resistance test	100%	Heating 1 cell until TR or 400 ºC in <5min *
SAND99-0497:1999	M, P	Partial short circuit test	100% (>95% after charge in 4h)	Hard short circuit (≤ 5mΩ - 10 min)
SAND2005-3123:2005	M, P	Partial short circuit test	100%	
SAND2017-6925:2017	M	Failure Propagation Test	100% (several SOCs if multiple test articles are available)	Heating, electrical (overcharge or cell short circuit) or mechanical (puncture, impact or crush) *
UL 2580:2013	M, P	Internal fire exposure test	Max. operating SOC	Heating until TR in < 10min *

M: Module level P: Pack level, SOC: State of charge, TR: thermal runaway

* Alternative methods allowed

Summarising TP Standards: other applications

Non-automotive applications

Standard	Application
UL 9540A:2018	Energy Storage Systems
VDE-AR-E 2510-50:2017	Stationary storage
IEC 62619:2017	Industrial applications, including stationary applications
NAVSEA SG270-BV-SAF-010:2011	Navy systems
JSC-20793 Rev D:2017	Spacecraft
RTCA DO-311:2008	Aircraft installations
Telecordia GR-3150:2015	Backup power
SAND2014-17053:2014	Civilian and military applications
UL 1973 Ed.2:2018	Light electric rail, stationary and vehicle auxiliary applications

Currently under development

Standard	Title
ISO 6469-1 Revision	*Electrically propelled road vehicles – Safety specification – Part 1: On-board rechargeable energy storage system (RESS) Amendment 1 Safety management of thermal runaway propagation*
SAE AS6413	*Performance based package standard for lithium batteries as cargo on aircraft*
SAE J2464 Revision	*Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System Safety and Abuse Testing*
ANSI/AIAA S-136	*Battery Safety Standard for Space Applications*
GB XXXXX XXXX	*Lithium ion traction battery used in electrically propelled road vehicles Safety specifications*

Summarising TP Standards

- Many initiation methods suggested, often alternatives allowed
- Typically 100 % SOC
- Location of initiation cell under discussion
- Generally quite flexible test description

Module level
Pack level

- Heating: SAE J2464, UL 2580, UL 1973, IEC 62619,
  Hard Short Circuit (≤ 5mΩ -10 min): USABC, Freedom
- Overcharge ($2I_t$) : RTCA DO-311

resistive heating
thermal conductive heat transfer
laser
thermite

No Fire + No explosion

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Regulatory landscape: regulations *vs.* standards

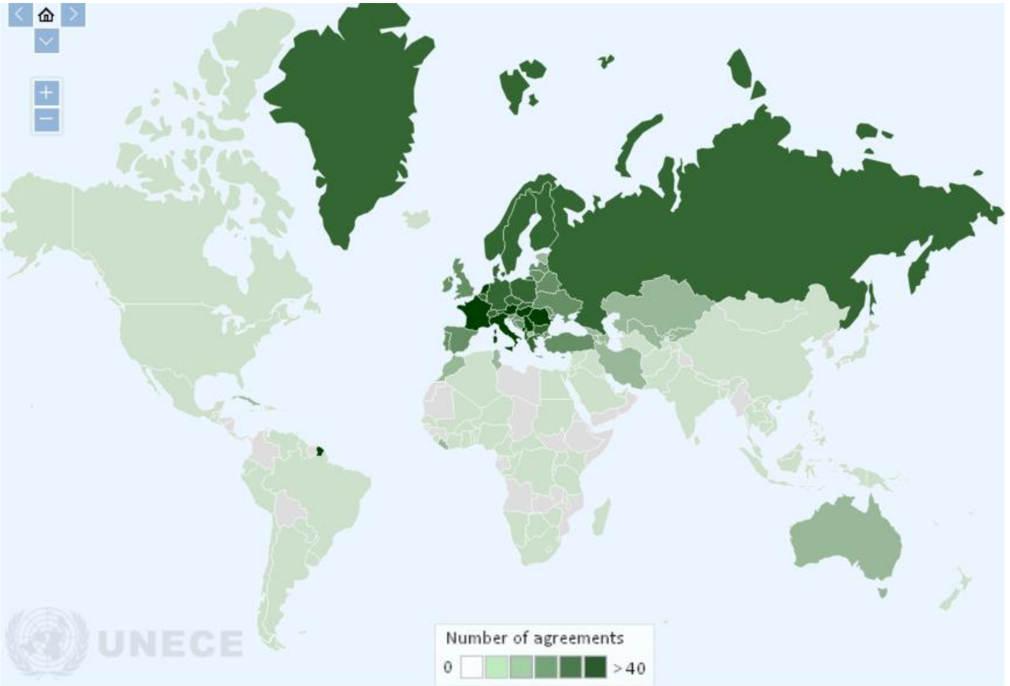
Regulations	**Standards**
Mandatory – Legally binding – Force of law	Voluntary
Issued by governmental authorities	Issued by standardisation bodies – committees with technical people
With pass / fail criteria	Often no pass / fail criteria
Sets requirements – public interest	Sets rules, guidelines or characteristics for activities / products / services / processes

Standards may be used as the starting point for writing a regulation

Regulations can make reference to a standard (or part of it) making it mandatory

World Forum for the harmonization of vehicle regulations (WP.29)

UN/ECE Economic Commission for Europe



http://www.unece.org/trans/main/welcwp29.html
https://wiki.unece.org/pages/viewpage.action?pageId=3178628
https://www.unece.org/?id=39145

- Working Party WP.29 on Passive Safety (GRSP)
- 1998 Agreement on Global Technical Regulations (GTRs)

- Informal Working Group: Electric Vehicle Safety (EVS)
- GTR No. 20 phase 2 work ongoing (Phase 1 established in 2018)

UN R100 agreed in 1996

Revision 02 into force from July 2013 and mandatory for vehicles from July 2016

- Revision 03: Upcoming

European Commission

Global Technical Regulation-Electric Vehicle Safety

2013	2016	2018	2019	2020 and beyond
January	**December** GTR phase 1 submitted to GRSP	**March** WP29 decision	possible adoption in WP29.AC1	requirements become applicable

Approval of *GTR phase 2*

Work on phase 2

Thermal propagation, etc.

http://www.unece.org/fileadmin/DAM/trans/doc/2017/wp29/ECE-TRANS-WP29-2017-143e.pdf

Global Technical Regulation-Electric Vehicle Safety: JRC experimental campaign

Narrow down init. methods

Select equivalent test(s)

Refine test description

tbd

Pack, Vehicle

Verification and finalization of method

- Round robin tests
- Practical aspects
- Define robust evaluation methods (e.g. gas analysis)

Ongoing

Module

Evaluate repeatability, reproducibility

- Check proposed test descriptions (also with testing bodies)
- Round robin tests
- Define pass/fail criteria

Ongoing

Short stack

Analyse influential factors on the outcome

- Temperature, SOC…
- Cell configuration
- Spark source

Late 2018 - early 2019

Cell & material

Comparison of initiation techniques

- Trigger energy/energy release
- Repeatability

+ ARC, DSC

Global Technical Regulation-Electric Vehicle Safety: JRC experimental campaign- Cell level

- ***Initiation methods***

  heating, rapid heating, inductive heating, steel nail penetration, ceramic nail penetration (IEC TR 62660-4)

- ***Battery types***

  graphite/NMC: cylindrical 21700 4Ah, prismatic 96Ah, pouch 39Ah, pouch 40Ah

- ***Assess***

  impact of un-defined/poorly-defined testing conditions

- ***Monitor***

  cell surface temperature, voltage evolution (drop), heating rate, venting (y/n) and occurrence of Thermal Runaway (y/n)

https://wiki.unece.org/display/trans/EVS+18th+session;
EVS18-E1TP-0200 [EC]Progress on thermal propagation testing.pdf

Conclusions and outlook

- TP is recognized as a critical failure of Li-ion battery packs
- Many open questions for testing (e.g. test scenario, initiation method, cell location)
- Inductive heating as possible new initiation method
- Several standards describe TP tests (more standards are in development)
- Improved understanding of processes (e.g. by modelling) supports development of fit-for-purpose tests

https://www.youtube.com/watch?v=6u2Gjiudcas&feature=youtu.be&list=PL1252954EBE4EAC2B Movie

https://visitors-centre.jrc.ec.europa.eu/virtual-tour/batterytesting/en/ 360˚ virtual tour

Thanks

Any questions?

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