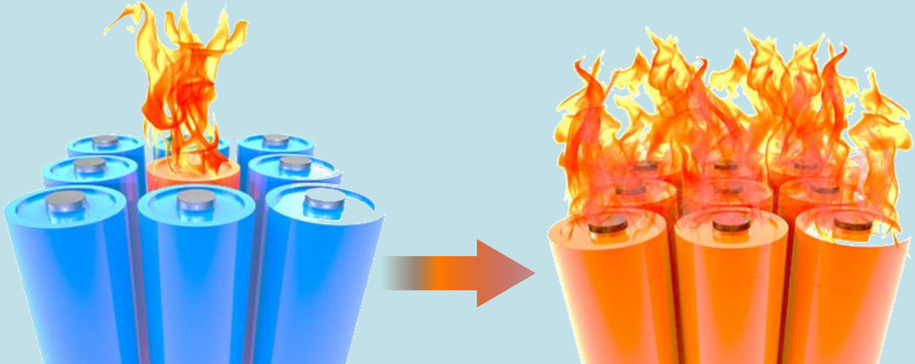
The European Commission's science and knowledge service

Joint Research Centre

Progress on thermal propagation testing

Akos Kriston, Andreas Pfrang, Vanesa Ruiz, Ibtissam Adanouj, Franco Di Persio, Marek Bielewski, Emilio Napolitano, Lois Brett

January 2019



European Commission

Outline

- **JRC experimental TP activity**

- Status of initiation methods test campaign
- Short assessment of current methods

- First preliminary test results:
  New initiation method (inductive heating)

JRC experimental TP activity

Cell & material

Comparison of initiation techniques

- Trigger energy/ energy release
- Repeatability

+ ARC, DSC

Short stack

Analyse influential factors on the outcome

- Temperature, SOC…
- Cell configuration
- Spark source

Module

Evaluate repeatability, reproducibility

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

Pack, Vehicle

Verification and finalization of method

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

Narrow down init. methods

Refine test description

Select equivalent test(s)

JRC experimental TP activity

Cell & material

Comparison of initiation techniques

- Trigger energy/ energy release
- Repeatability

+ ARC, DSC

Short stack

Analyse influential factors on the outcome

- Temperature, SOC…
- Cell configuration
- Spark source

Module

Evaluate repeatability, reproducibility

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

Pack, Vehicle

Verification and finalization of method

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

Narrow down init. methods

Refine test description

Select equivalent test(s)

Outline

- JRC experimental TP activity

- **Status of initiation methods test campaign**
- Short assessment of current methods

- First preliminary test results:
  New initiation method (inductive heating)

Screening test of initiation methods

- **Initiation methods** (4): Heating, Nail, Rapid heating (Canada), Ceramic nail (IEC TR 62660-4)
  - **Inductive heating as a new initiation method (IEC 62619 informative Annex B)**
- **Battery type** (4):
  - **graphite/NMC: *21700 4 Ah, BEV 96 Ah, Pouch 39 Ah, Pouch 40 Ah***
- Assess impact of un-defined/poorly-defined testing conditions

Monitor: cell surface temperature, voltage evolution (drop), heating rate, venting (y/n) and occurrence of TR (y/n)

Updated general test matrix

Initiation method	Automotive battery type				
Cell type	21700 4 Ah	BEV 96 Ah	Pouch 39 Ah	Pouch 40 Ah	Total
Heating	3	4	4	4	15
Nail	4	3	4	4	15
Ceramic nail	4	4	3	4	15
TRIM method	4	4	4	3	15
Total	**15**	**15**	**15**	**15**	**60**

Updated general test matrix

Initiation method	Automotive battery type				
Cell type	21700 4 Ah	BEV 96 Ah	Pouch 39 Ah	Pouch 40 Ah	Total
Heating	3	4	4	4	15
Nail	4	3	4	4	15
Ceramic nail	4	4	3	4	15
TRIM method	4	4	4	3	15
Total	**15**	**15**	**15**	**15**	**60**

Green: tests have been performed

Assessment of current test description

Test	Low severity	High severity	Comment
Nail Ceramic nail	Stop nail at a certain voltage drop (mV)	Penetrate until event	Every cell has different voltage drop
Heating	1 heater	2 heaters	The heating power per heater kept constant. Increasing the energy intake.
TRIM	Lowest possible e.g. 250 °C for pouch	600 °C until event	Varying soaking temperature and time

European Commission

Outline

- **JRC experimental TP activity**

- Status of initiation methods test campaign
- **Short assessment of current methods**

- First preliminary test results:
  New initiation method (inductive heating)

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)
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.

Local damage

Global damage

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

Note: they damage the cell globally

European Commission

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
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

European Commission

Initiation methods (cell internal)

Local damage

Nickel particle method	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.	significant manipulation single layer failure
Metals with low melting point implantation	heat exposure for melting introduced metal	
Wax based implantable device	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.	
Shape memory alloy implantable device	SMA material pierces the separator as it bends when heated	
Internal heating device	heating device installed inside the cell local heating occurs significant manipulation of both at cell level and higher levels (module, pack)	

Ideal initiation method

Goal: Imitate realistic internal short circuit and simulate the dynamics of internal and external failures

Properties:

- Damaging the separator locally
- No major damage to the cell case

- Controllable and minimal energy input to avoid overheating of adjacent cells and unwanted side reactions
- Minimal manipulation at pack level (manipulation is needed, though)

Further steps

- Conclusion of initiation test campaign (at ZSW, Ulm) expected February 2019
- Improve understanding of the different failure mechanism caused by different methods (e.g. local and global effects)
- Procurement of stack-level TP testing has started
  - **Further collaboration with Canada on TRIM method on short stack and module initiation (together with other methods)**
- *Regular discussions with other parties are appreciated*

Outline

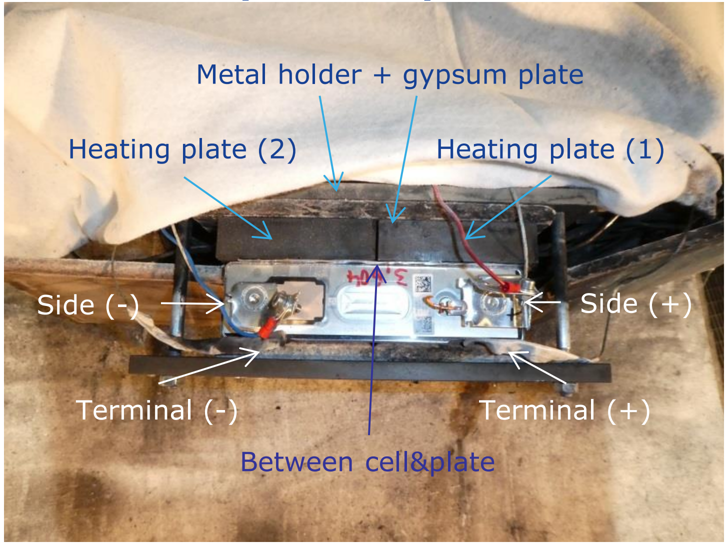
- JRC experimental TP activity

- Status of initiation methods test campaign
- Short assessment of current methods

- **First preliminary test results:**
  New initiation method (inductive heating)

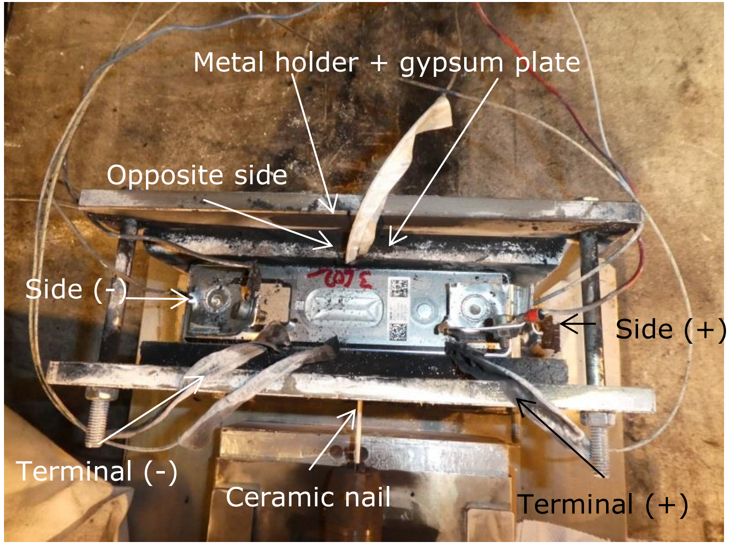
Testing preparation 96Ah prismatic

Heating method (Global)



- Cell's side is fully covered by the heater
- Heating power: 1.6kW (cell's energy 160Wh)

Ceramic nail penetration (local)



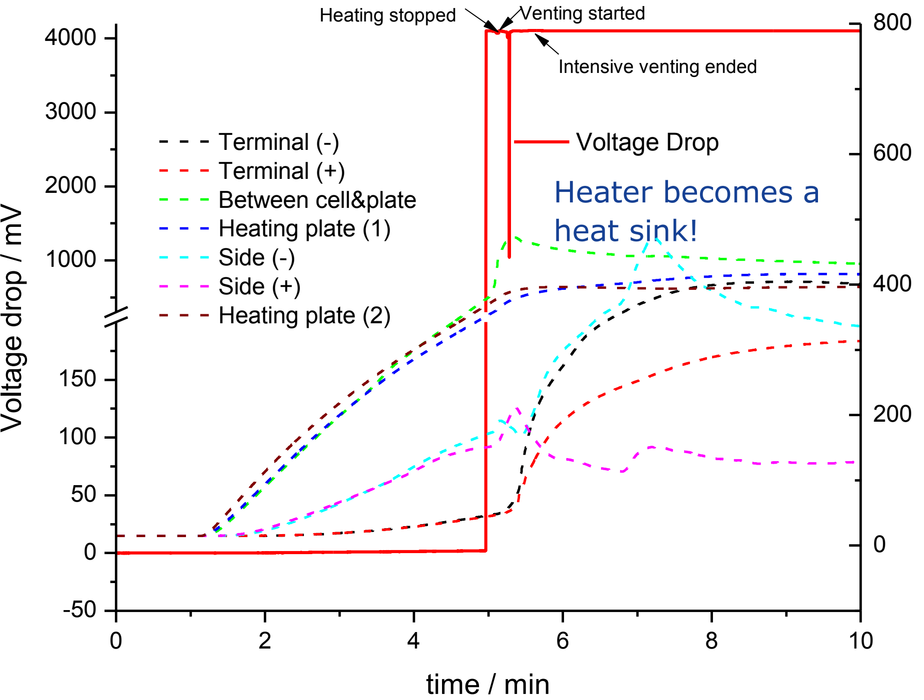
- 3 mm diameter 30° ceramic nail
- 0.1 mms^{-1}, stopping at 5 mV voltage drop

TC at the center of the cells

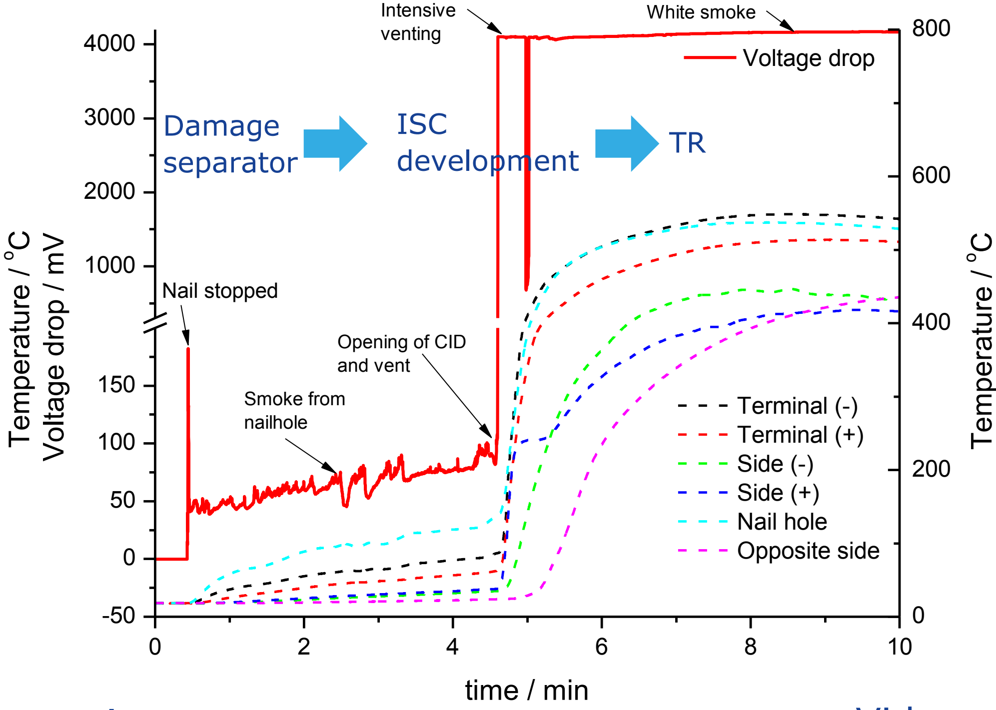
European Commission

Comparison of initiation techniques

Heating method



Ceramic nail penetration



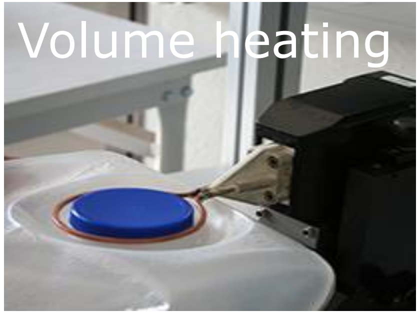
Despite similar final outcome (e.g. maximum temperature and venting), the development of the chain of failure is different!

Video

European Commission

Alternative ISC – Inductive heating

Why?



How?

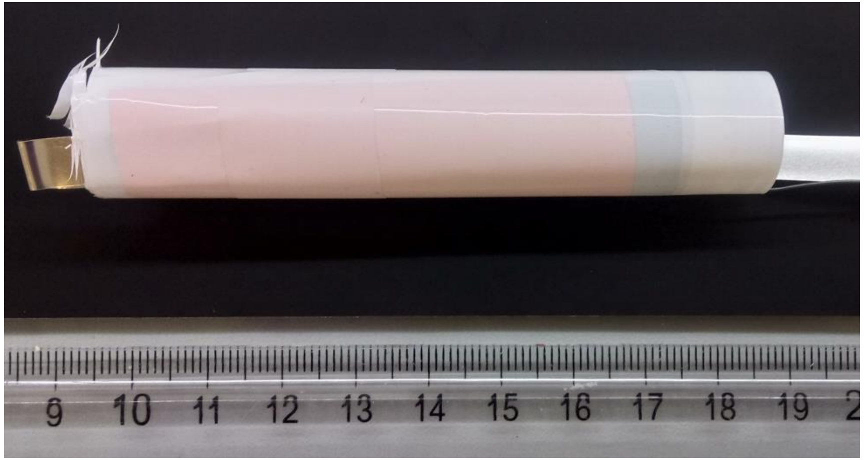
Alternating electromagnetic field generate local current (eddy current) which in turn generate heat in any closed loop conductors, e.g. Al, Cu, graphite, NMC

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

Mock up cells

Battery grade Al-foil, Cu-foil and Celgard separator are rolled mimicking the jelly-roll

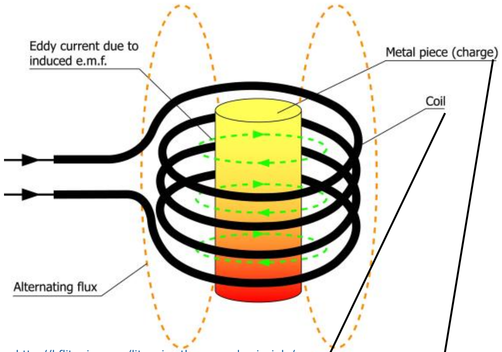
18650 cell



Pouch cell

Working principles and test setups

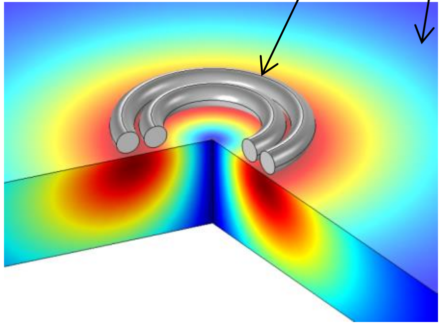
Cylindrical



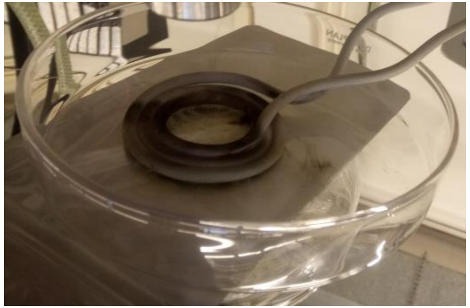
http://hflitzwire.com/litz-wire-theory-and-principle/

Other geometries?

Pouch, prismatic

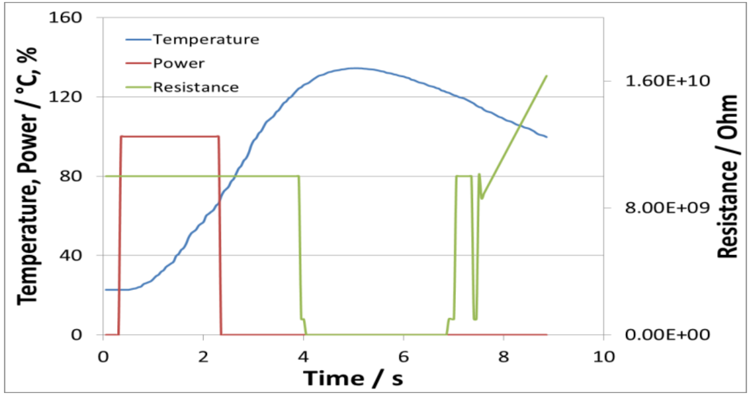


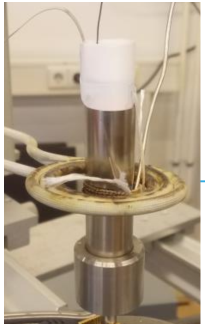
COMSOL Simulation case study
https://www.comsol.com/multiphysics/induction-heating



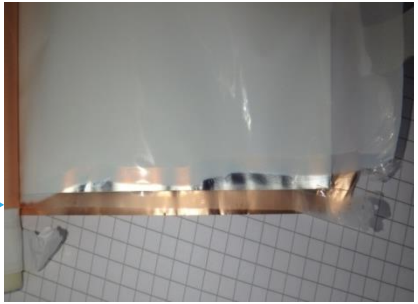
Note: Not optimized, standard solution!

Mock-up cell tests on 18650 type





Locally melted area



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

Preliminary results on single cells

*The current device was not optimized for short on ‘on’ time, therefore the heating energy is just a rough approximation.

Cell	Power, heating time*	Result
#1, 18650 3.1 Ah	1.2 kW for 2 s: ca. 6.5% of cell’s energy, single coil around the cell	TR with fire, T_{max}=830°C. TR happened during heating. The case opened near the coil.
#2, 18650 3.1 Ah	1.2kW for 1 s, ca. 3.3% of cell’s energy, single coil around the cell	TR with fire, T_{max}=734°C. TR happened during heating. The case also opened near the coil.
#3, 18650 3.1 Ah	1 kW for 0.5 s, ca. 1.5% of cell’s energy, single coil around the cell	TR with fire, T_{max}=741°C. TR happened several seconds after the heater was switched off. The pouch opened near the coil.
#4, Pouch, 39 Ah	1.2 kW for 2 s, ca. 0.41% of cell’s energy. The coil is placed parallel to the surface at the middle of the cell	TR with fire, T_{max}=ca. 400°C The pouch opened near the coil.
#5 Pouch, 39 Ah	1.2 kW for 1 s, ca. 0.2% of cell’s energy. The cell was placed between the coil.	TR without fire, T_{max}=420°C The cell ruptured at the side but not under the coil.
#6, Prismatic, hard Al case, 96 Ah	2.4kW for 3 s, ca. 0.78% of cell’s energy	TR with fire, T_{max}=550°C. The case opened near the coil.

- Locally damage the cell
- Works fast
- Needs small amount of energy

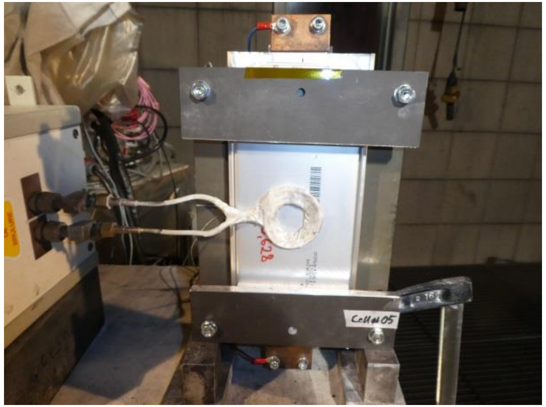
Video 18650, #3

Energy input

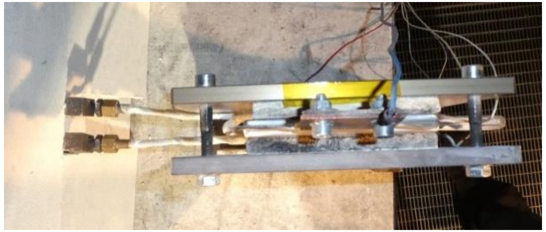
Method	Energy / Cell electric energy
Nail / Ceramic nail	Mechanical
Normal heating test	40-100%
Rapid heating test (TRIM)	~5% (according to Canada)
Inductive heating test	0.5-3%

- Most probably the additional energy is less important at cell level as it was shown by JRC's TR model (EVS16-E1TP-0400)
- The local effect is more important

Pouch cell tests

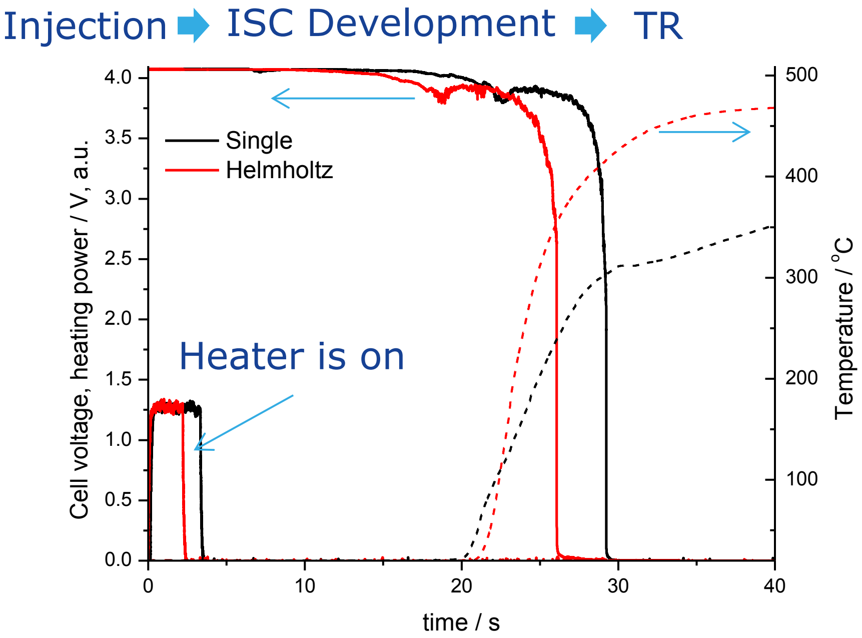


Single coil #4



Double (Helmholtz) coil #5

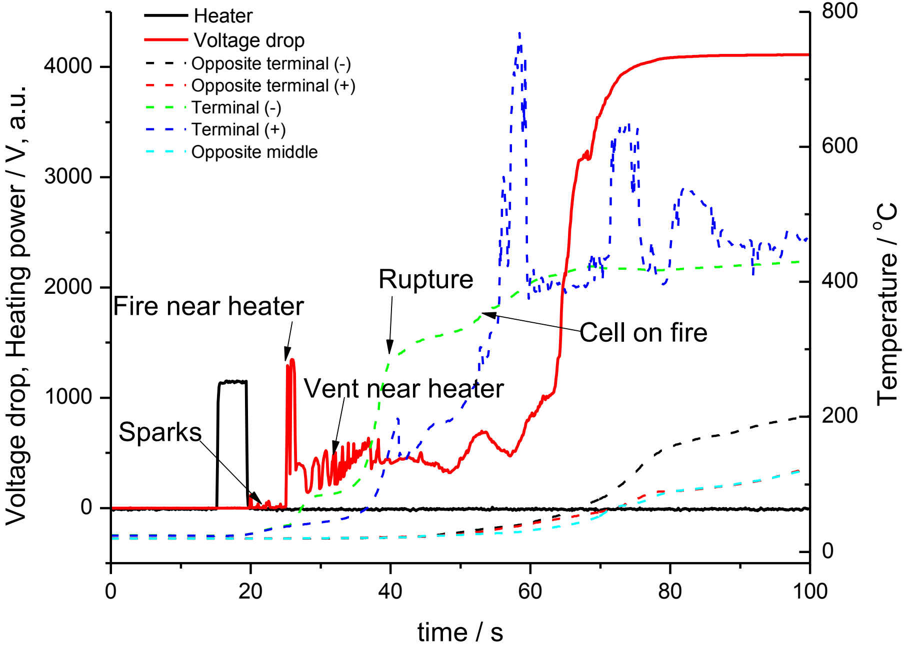
Video



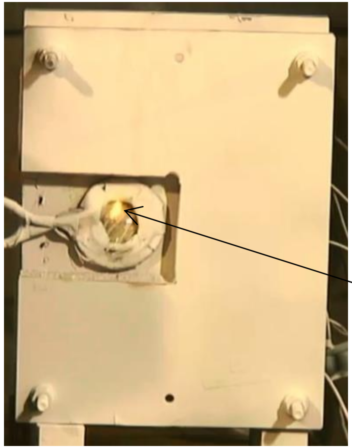
European Commission

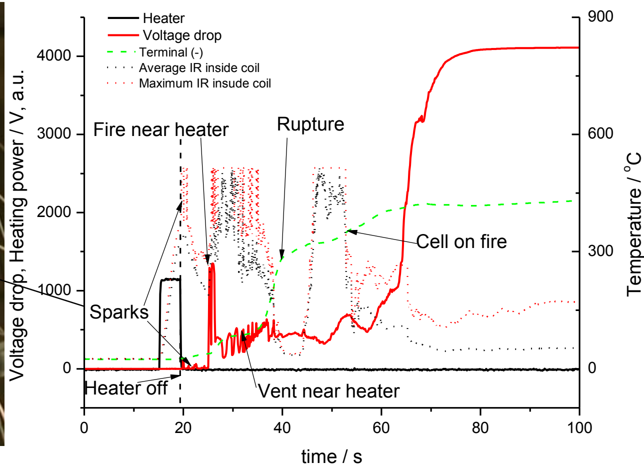
Prismatic cell 96 Ah with hard casing #6

Injection ➡ Propagation ➡ TR



Internal propagation of ISC





Sparks appeared after the heater was off. The sparks are attributed to local ISCs, i.e. spot welding effect.

Video

Mechanism of failure induced by inductive heating

Inject energy locally for few seconds then stop heating → Heats up inside → Damage/melt separator locally → ISC starts to develop → Thermal event or thermal runaway happens

Heats up the case

No external energy during ISC development

Summary, findings

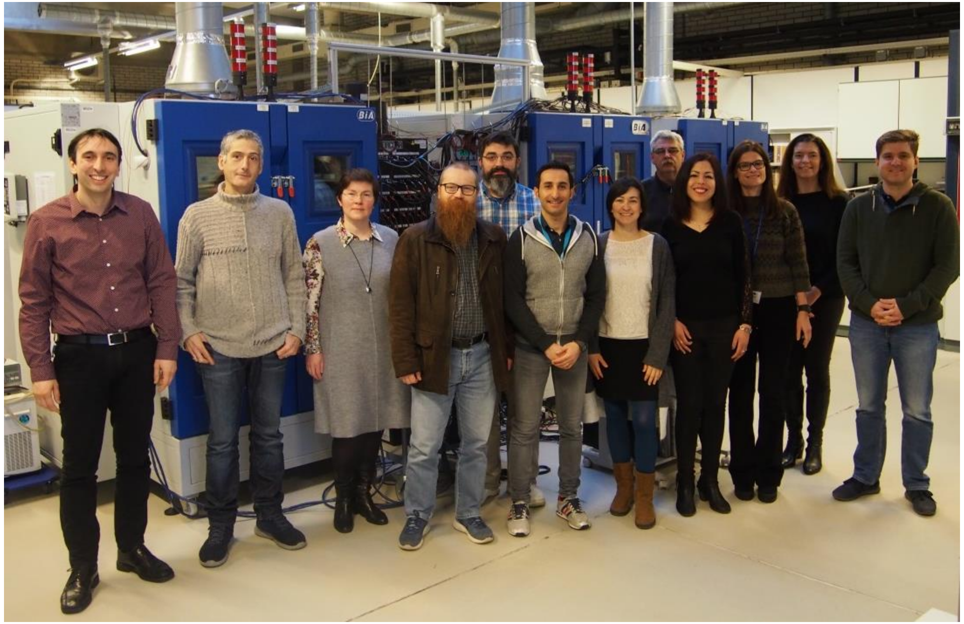
- Initiation test campaign is progressing as planned
- Need for concise initiation method description
  - **Open parameters can lead to different thermal event severity**
- Ideally **local** initiation for realistic representation of ISC
- Inductive heating is a potential initiation method
  - **Energy injection -> ISC development -> TR**
  - **Further optimization is needed. <u>Ready to share experience!</u>**

Acknowledgement *BATTEST group*

Franco Di Persio Ricardo Da Costa Barata Denis Dams

Natalia Lebedeva Emilio Napolitano Ibtissam Adanouj Lois Brett

Andreas Pfrang Marek Bielewski Vanesa Ruiz Akos Kriston



European Commission

Stay in touch

EU Science Hub: ***ec.europa.eu/jrc***

Twitter: ***@EU_ScienceHub***

Facebook: ***EU Science Hub - Joint Research Centre***

LinkedIn: ***Joint Research Centre***

YouTube: ***EU Science Hub***

European Commission