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Joint Research Centre

Progress on thermal propagation testing

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Outline

- Thermal propagation testing in standards
- JRC experimental TP activity
- Screening test of initiation methods
- Simulation of thermal runaway uncertainty
- Estimation of thermal runaway probability

Thermal propagation testing in standards

Scope:

- Review of existing standards in various applications
- Analysis of gaps and fitness for purpose
- On-going standardisation efforts

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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)

Screening test of initiation methods

- **Initiation methods** (4+): Heating, Nail, Rapid heating (Canada), Ceramic nail (IEC TR 62660-4)
- **Battery type** (4): all graphite/NMC: *21700 4 Ah, BEV 96 Ah, Pouch 39 Ah, Pouch 56 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)

General test matrix

Initiation method	Automotive battery type				
	21700 4 Ah	BEV 96 Ah	Pouch 39 Ah	Pouch 56 Ah	Grand Total
4.1 - Heating	3	3	3	3	12
4.2 - Nail	3	3	3	3	12
4.3 - Ceramic	3	3	3	3	12
4.4 - Rapid heating	3	3	3	3	12
Grand Total	**12**	**12**	**12**	**12**	**48**

12 further tests have been purchased replacing overcharge tests, but the testing plan has not been defined yet

Execution of tests

- Initiation level tests to be performed at ZSW, Ulm

  October 2018 to January 2019

- Procurement of stack-level TP testing has started

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Simulation of thermal runaway uncertainty

System analysis

- Determine governing equations, factors
- Create invariants by dimensional analysis

Uncertainty / severity analysis

- Vary independent variables
- Estimate severity of TR

Sensitivity analysis

- Determine the most influential factors and their interactions
- ANOVA, SOBOL Random forest etc.

Survival probability

- Nominal logistic
- Weibull or other

Governing equations

$$Q_{cell} = Q_{trigger} + \Sigma Q_{chemical} + Q_{electrical} - Q_{cooling}$$

$$m_{cell} C_p \frac{dT}{dt}$$

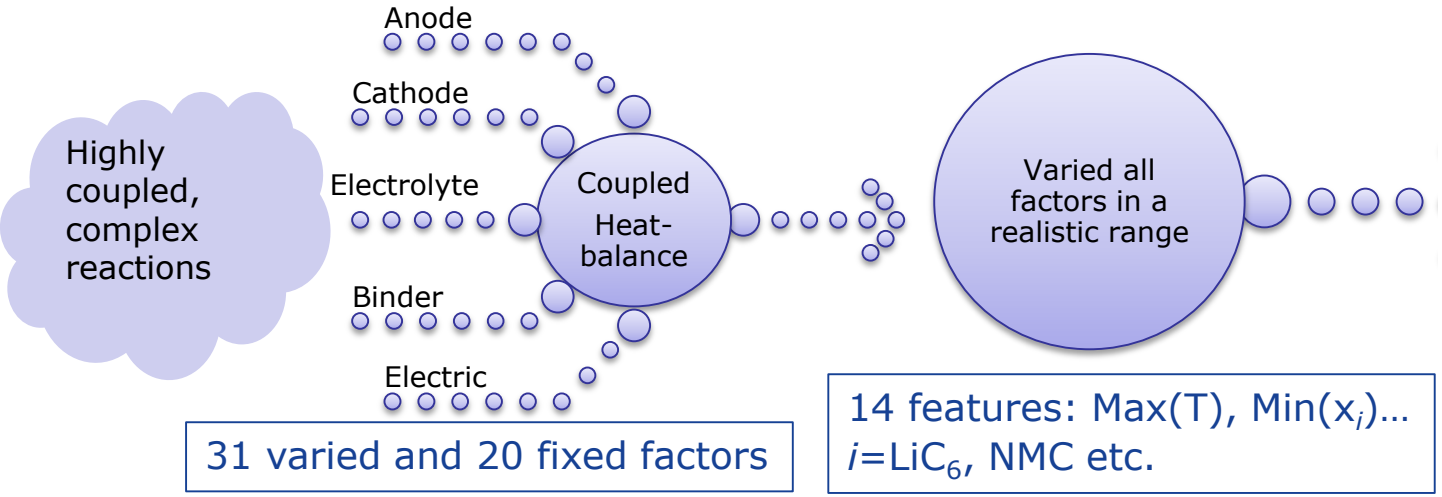
$$R_i = \frac{\mathrm{d}x_i}{\mathrm{d}t} = -A_i x_i \exp\left(-\frac{E_i}{k_B T}\right)$$

$$A_{surf}\left[\varepsilon \cdot \sigma\left(T_{cell}^4 - T_{amb}^4\right) + h_{conv}\left(T_{cell} - T_{amb}\right)\right]$$

Introducing new independent factors, e.g.:

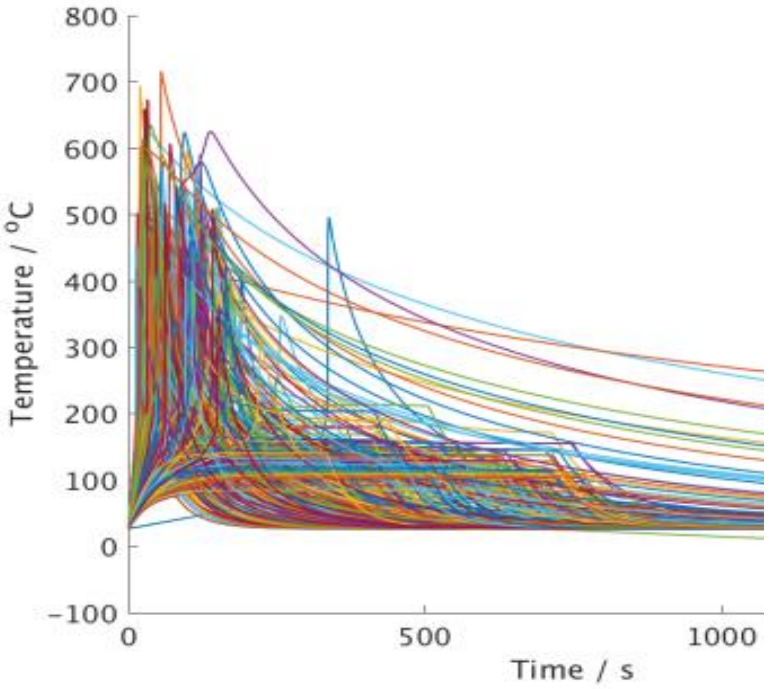
- Resistance ratio (R_{ext}/R_{int})
- Surface to volume ratio

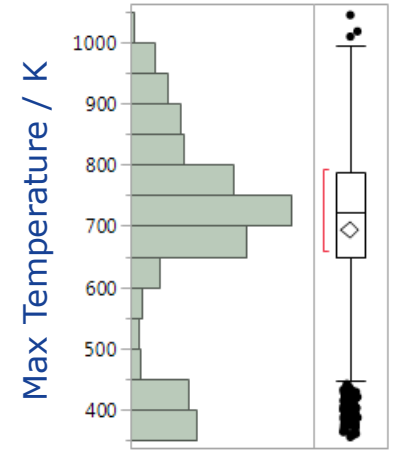
Simplified model to assess uncertainty

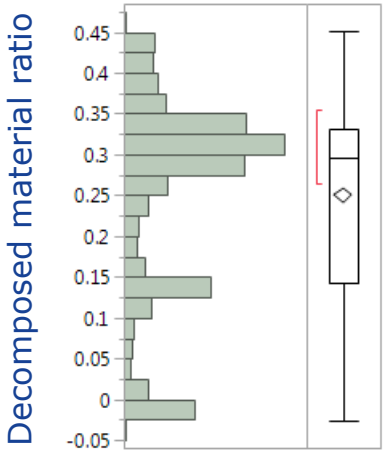


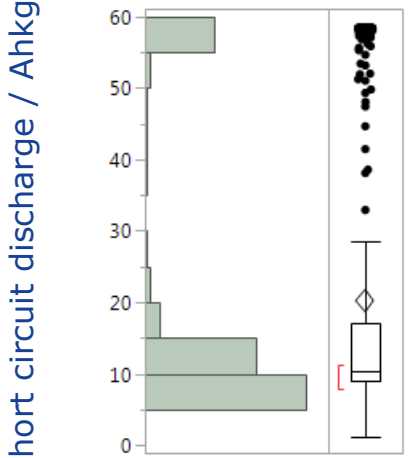
- What are the most important parameters?
- Is TR sensitive to trigger energy?
- What is the expected uncertainty of TR?
- What is the probability of TR?

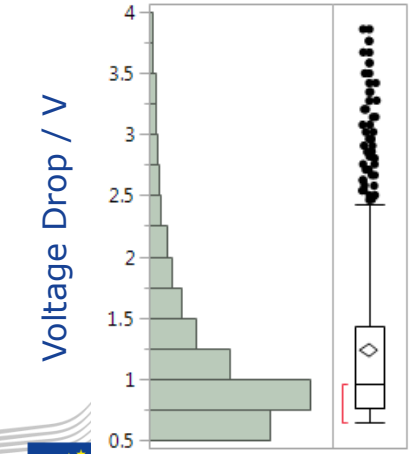
Uncertainty analysis



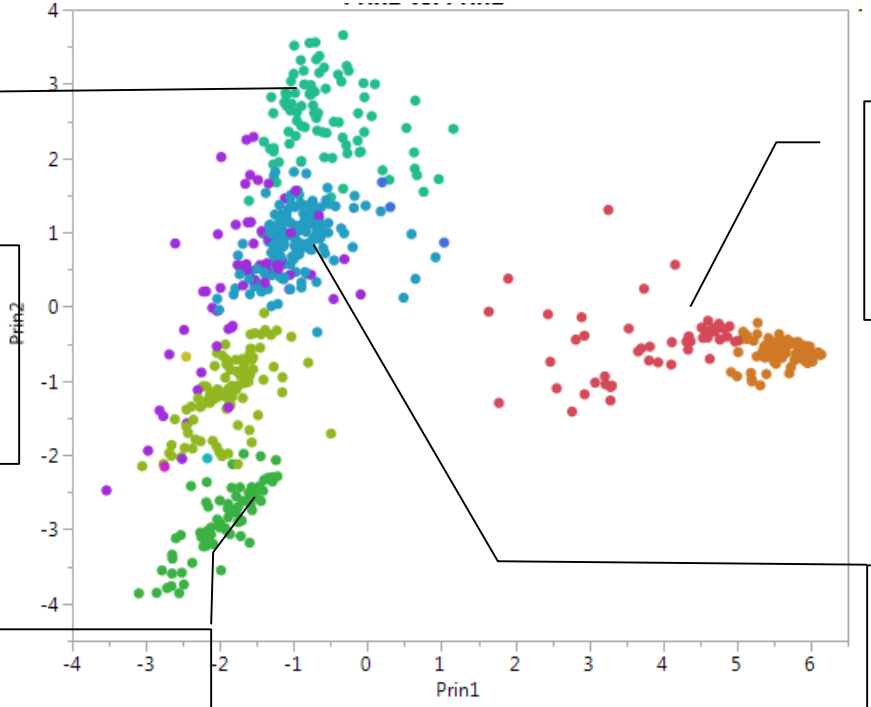








Severity analysis



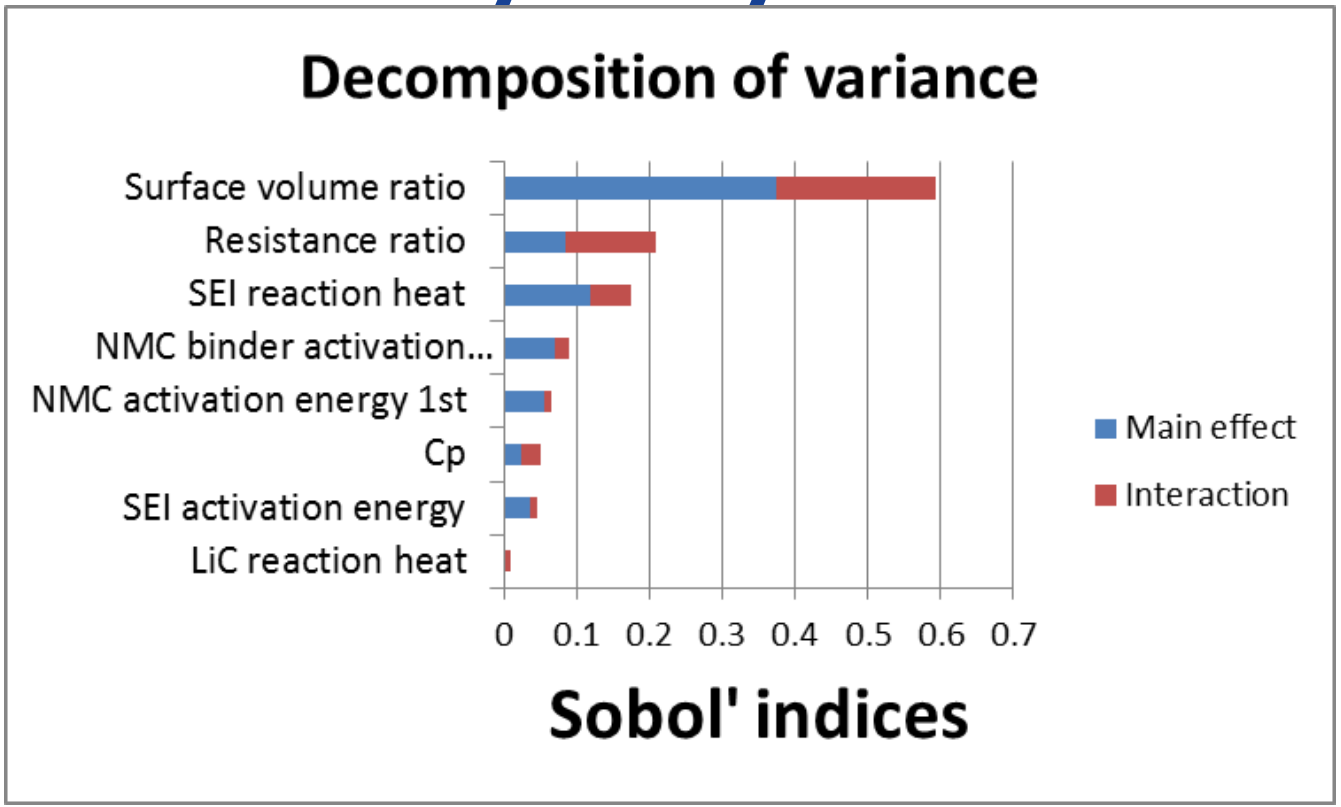
$T_{Max, average}$=408°C
22% electric discharge
Anode consumed
40% NMC left

$T_{Max, average}$=122°C
Only electric discharge
High surface to volume ratio
LiC_6 and NMC consumed

$T_{Max, average}$=570°C
16% electric discharge
All materials consumed

$T_{Max, average}$=452°C
20% electric discharge
Anode consumed
30% NMC left

Global sensitivity analysis



Shao Q. at al. (2017), Comput. Methods Appl. Mech. Engrg., 474–496
Saltelli, at al. 2008, Global Sensitivity Analysis. The Primer, John Wiley & Sons.

What are the most important factors?

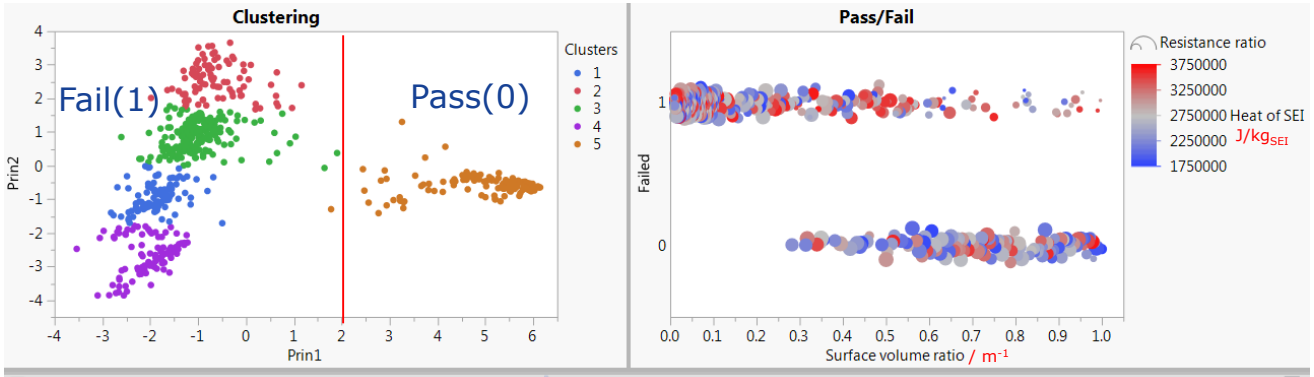
Most significant factors:

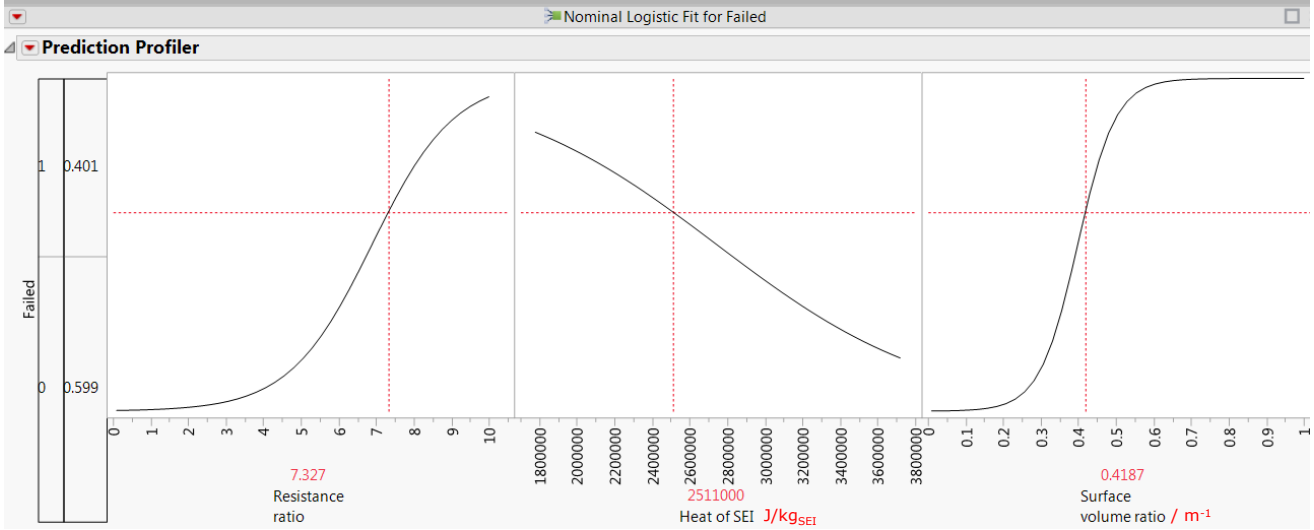
1. Surface to volume ratio
2. Resistance ratio (R_{ext}/R_{int})
3. SEI decomposition reaction heat

No evidence is found that the trigger energy has significant effect within the considered parameter uncertainty

Note: It's effect can be more complex/non-linear, though.

Estimation of failure probability of TR





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Summary, findings

- The most important design factors: surface to volume ratio and heat of SEI decomposition
- The most important test factor (i.e. controllable): resistance ratio (R_{ext}/R_{int})
- TR probability very sensitive to variation of resistance ratio
- Hard short (<1) results in TR with high probability irrespective of other parameters
- Tests in soft short region are stochastic in nature and requires more replications

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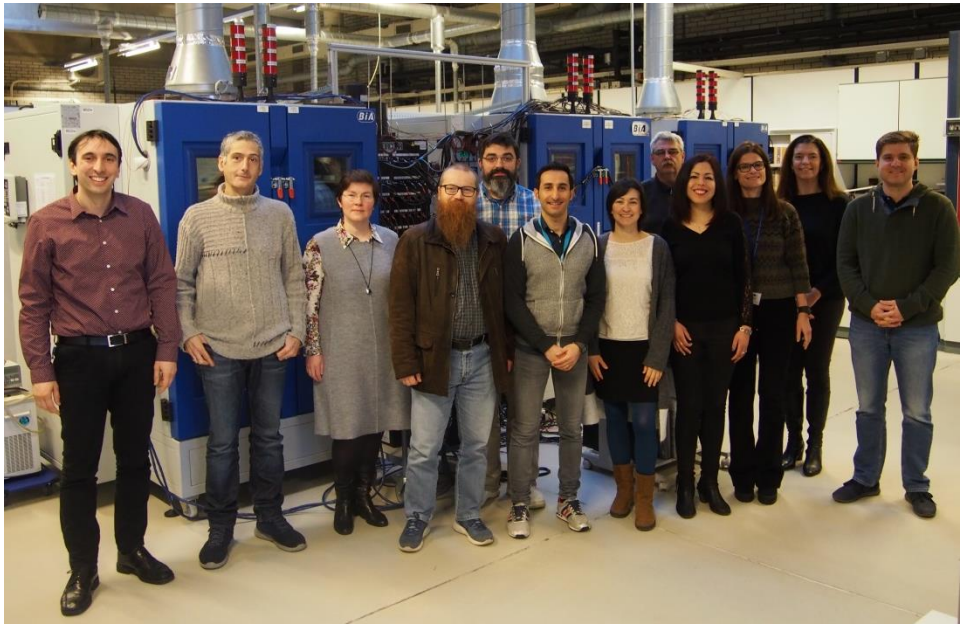

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