Thermal Modelling of Thermal Runaway Propagation in Lithium-Ion Battery Systems

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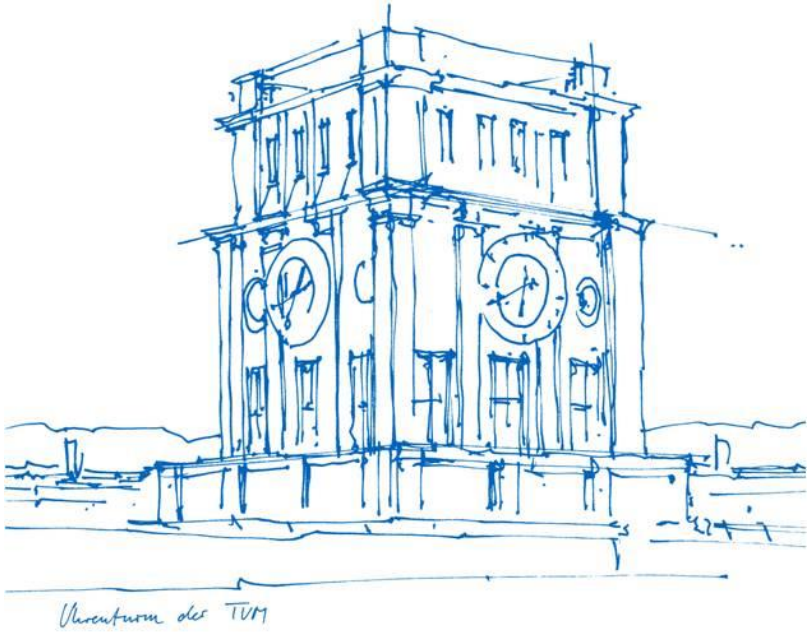
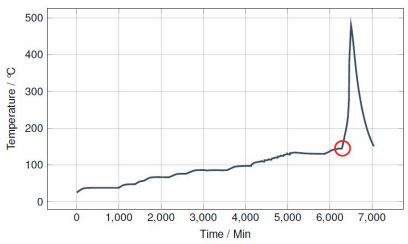
Petten, 8th & 9th March 2018

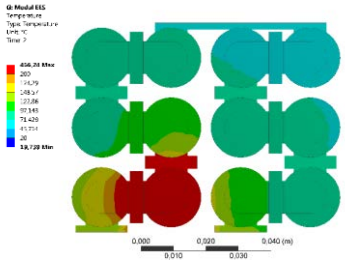


Agenda

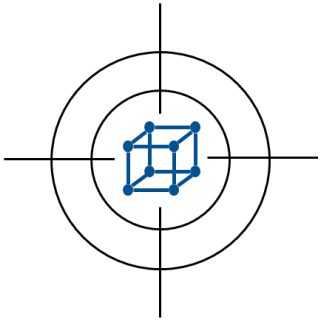
Method to investigate abusive behaviour



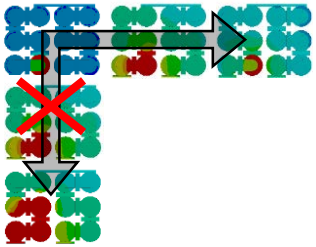
Simulation model for thermal runaway propagation (TR-P)



Limitations of accurate modelling of TR-P



Mitigation strategies of battery TR-P



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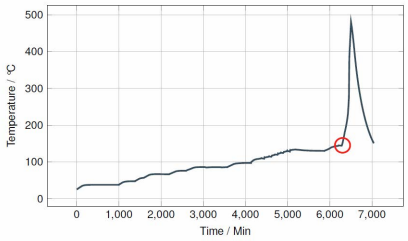
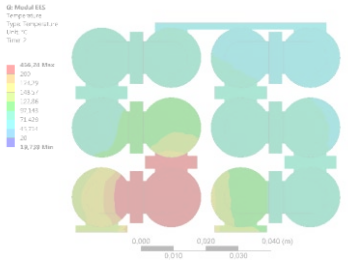
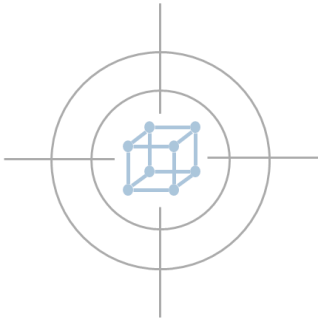
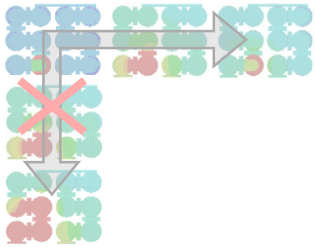


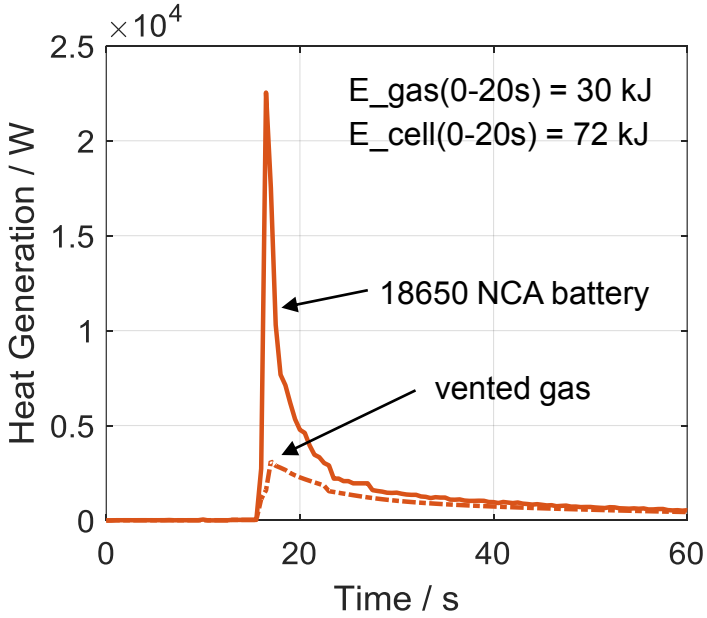






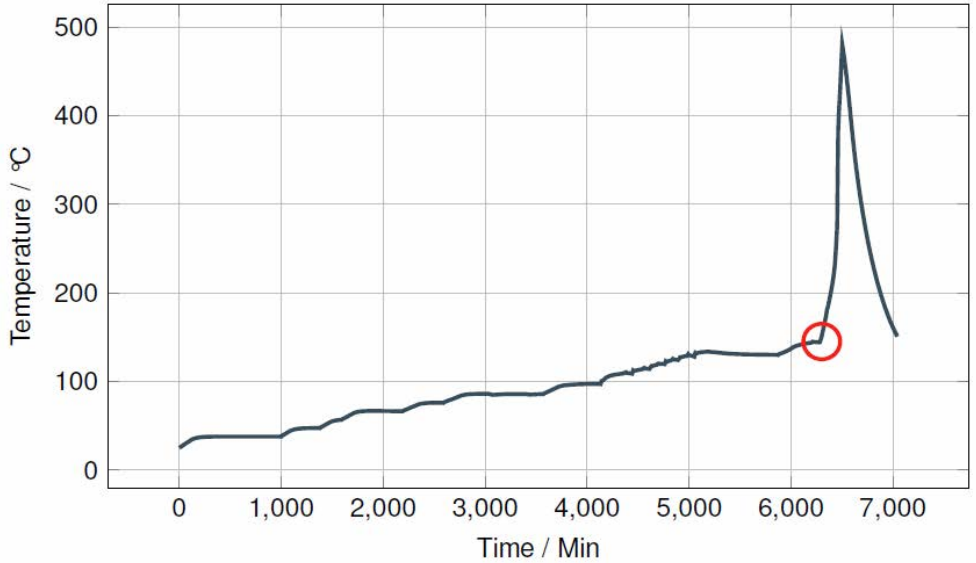
Empirical method to investigate abusive behaviour

Measure heat generation rate of a nail penetrated battery inside a calorimeter



Empirical method to investigate abusive behaviour

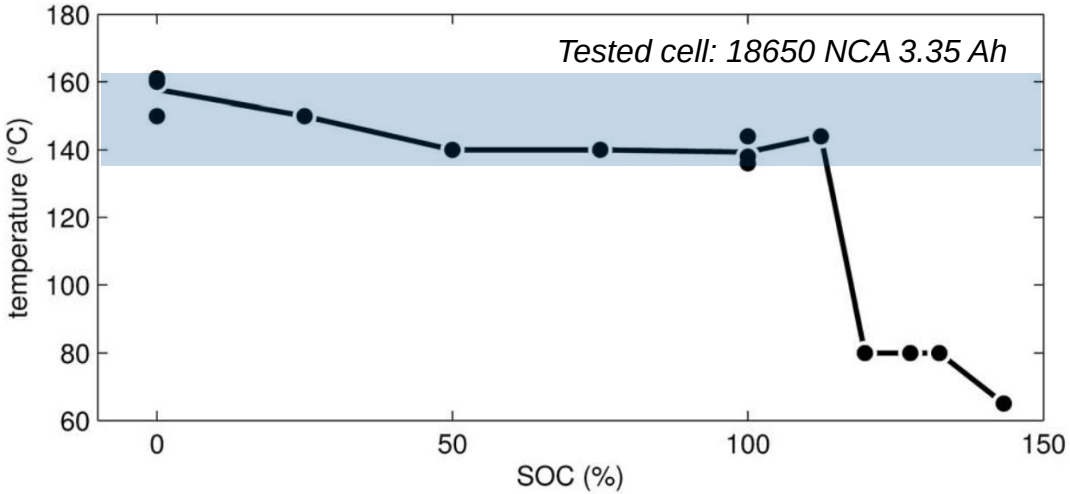
Measure trigger temperature of thermal runaway with heat-wait-seek method



Empirical method to investigate abusive behaviour

Measure trigger temperature of thermal runaway: compare to literature

[Golubkov A., Royal Society of Chemistry, Vol. 5, 2015]



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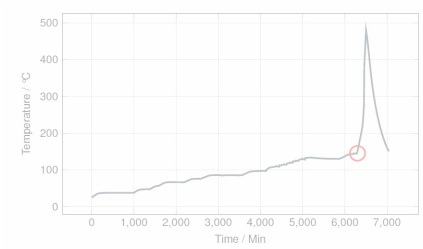
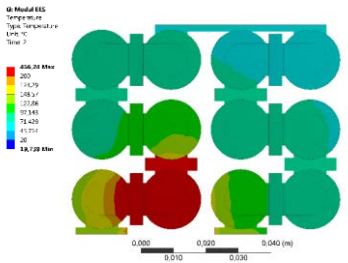
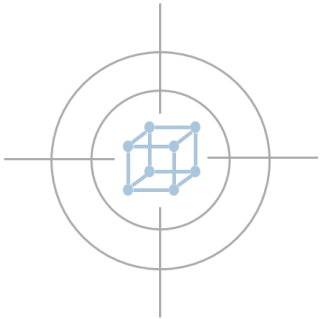
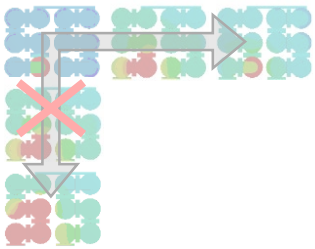


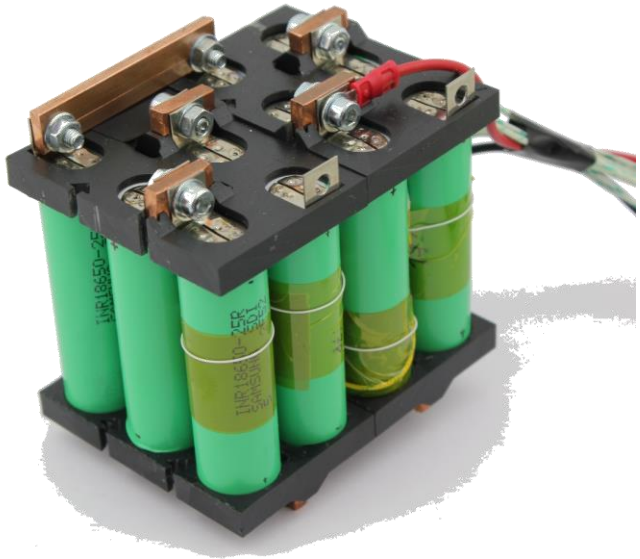




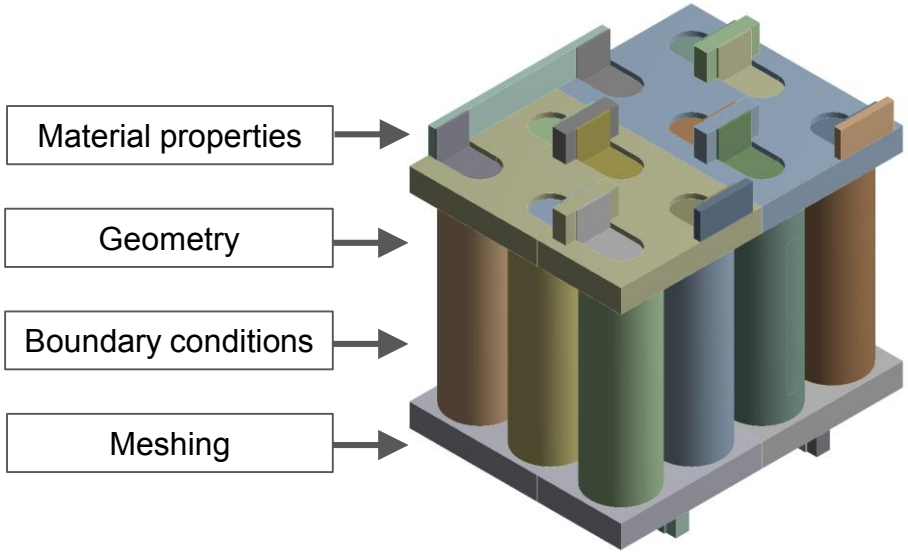


Conductive thermal model for TR propagation

Lithium-ion battery module (12s1p)



FEM-model of lithium-ion battery module



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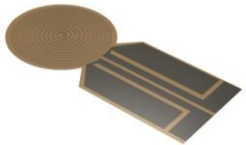


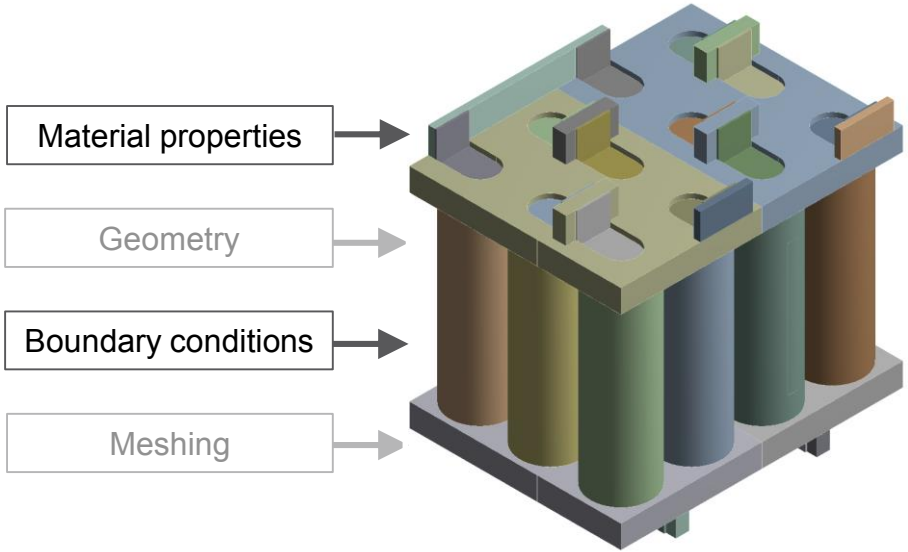
Custom Hot Disk / Literature:

- Heat capacity
- Thermal conductivity (anisotrop)

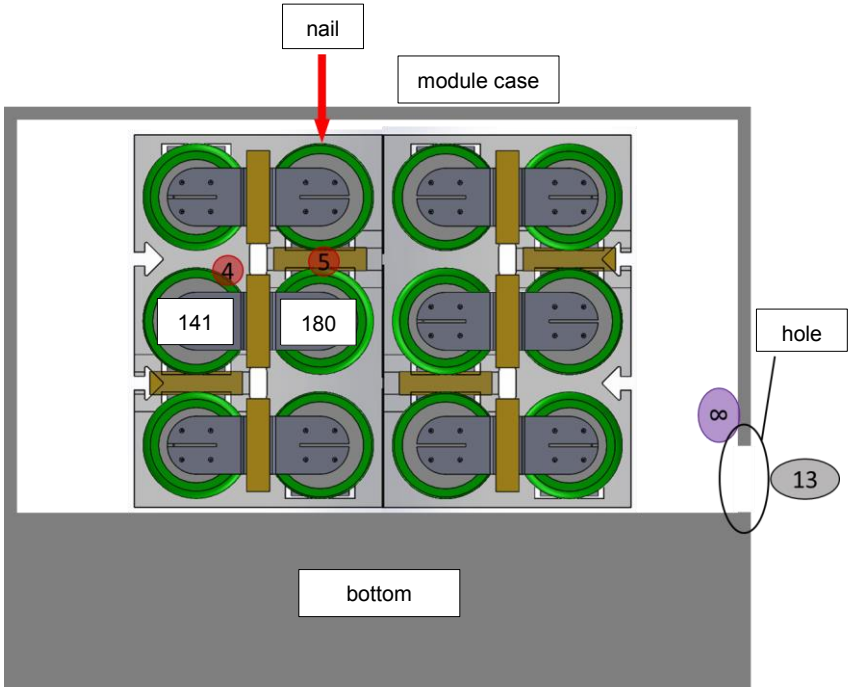
ARC/Calorimeter:

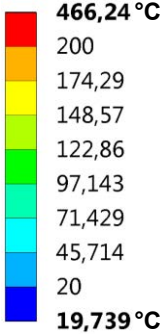
- Heat generation rate
- Heat capacity
- Trigger temperature of thermal runaway

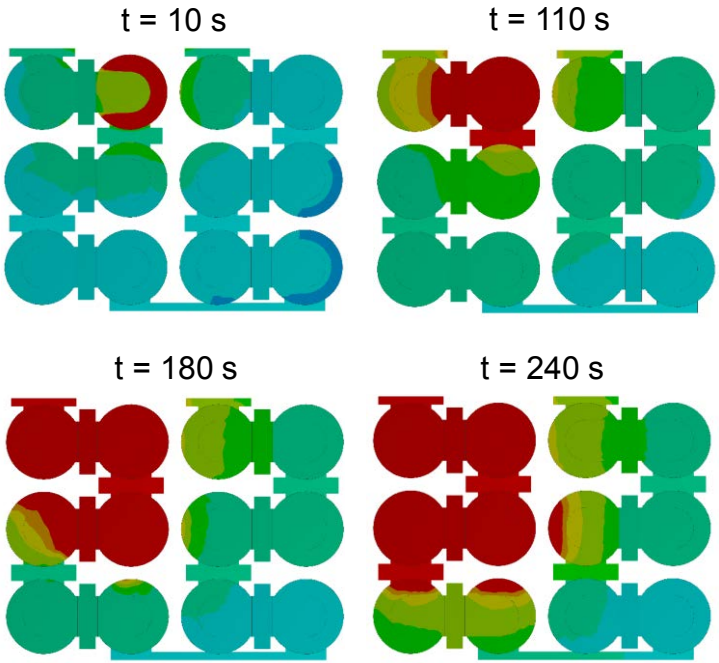
FEM-model of lithium-ion battery module



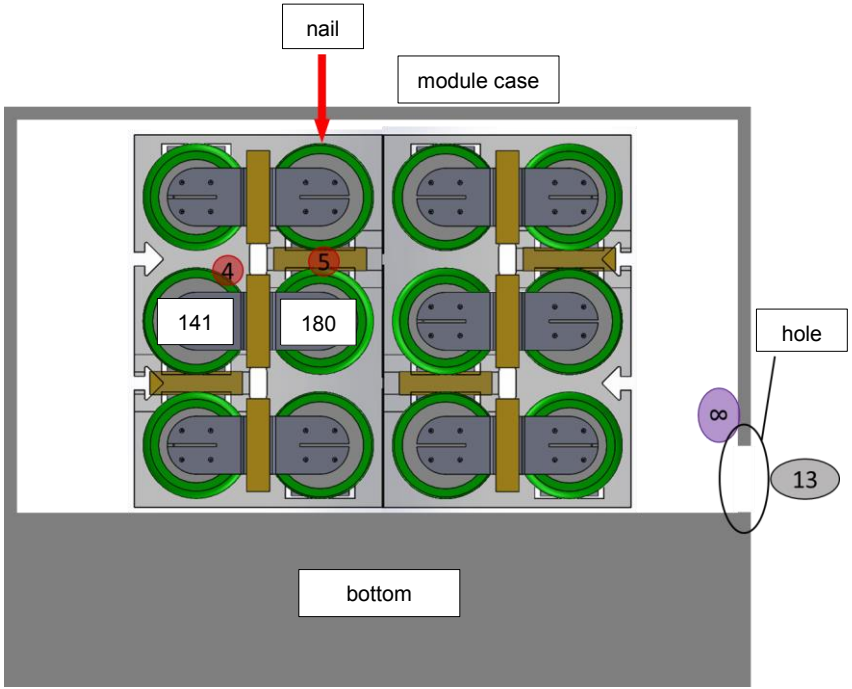
Simulation: 12s1p module
nail penetration of a single cell

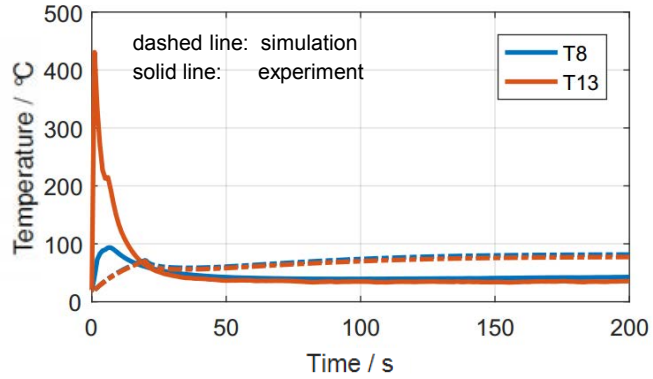


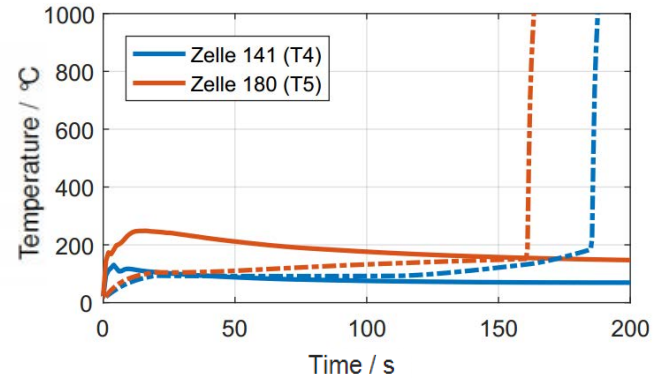




Experiment: 12s1p module nail penetration of a single cell







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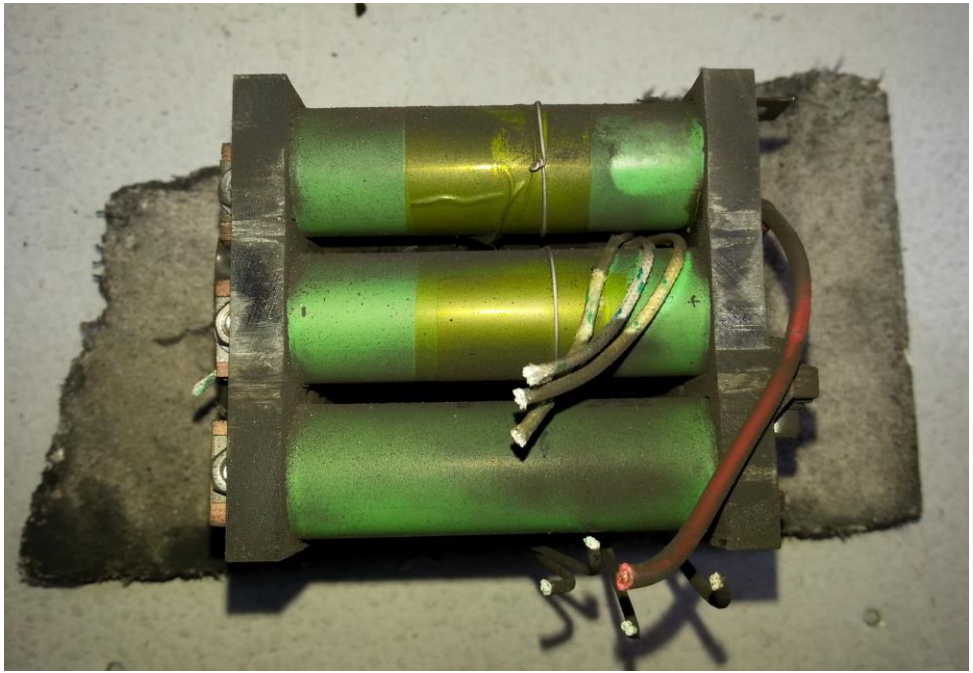


Experiment: 12s1p module nail penetration of a single cell

Results:

- Conductive thermal model approach cannot describe the TR-P of experiment
- Heat release of gas and direction of gas flow have a strong influence on TR-P

→ Implementing gas flow / venting necessary

→ CFD model

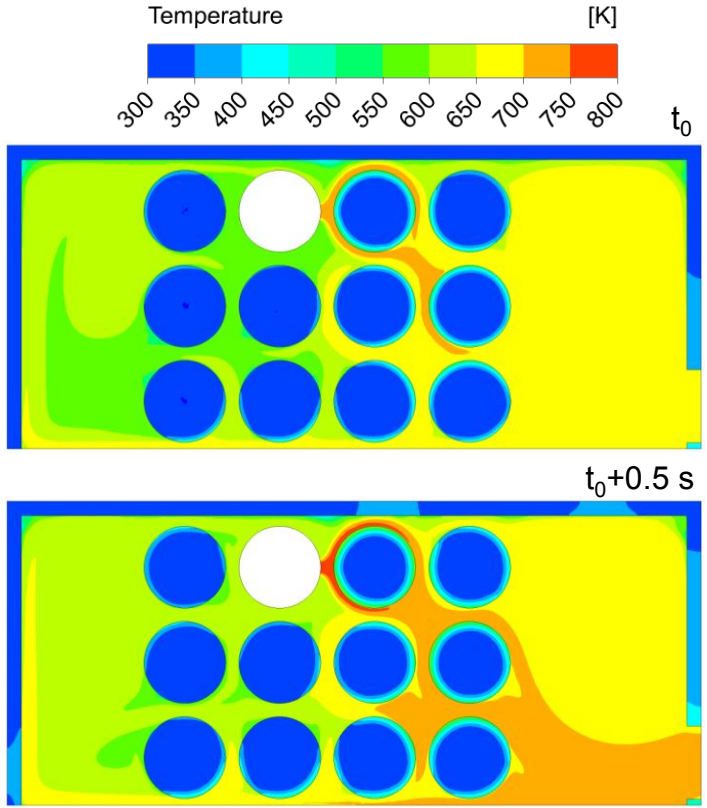
1st CFD model approach for TR propagation

Model assumptions:

- 2D, k-ε model for turbulence
- $v_{fluid,inlet}$ = 215 m/s [Coman P.T., JoP 307 (2016)]
- $T_{fluid,inlet}$ = measured data
- Vent position extracted from module experiment
- Gas = similar specs like hydrogen

Neglected:

- Cell connector → heat transfer via solid bodies
- Heat generation of nail penetrated cell



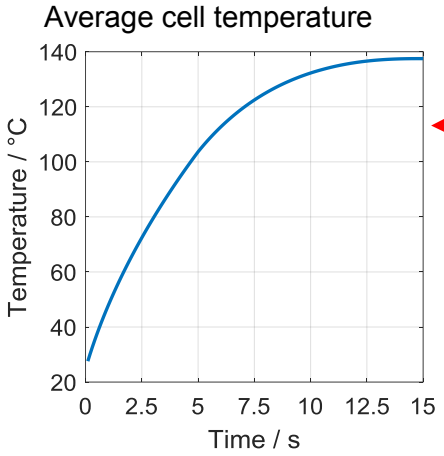
1st CFD model approach for TR propagation

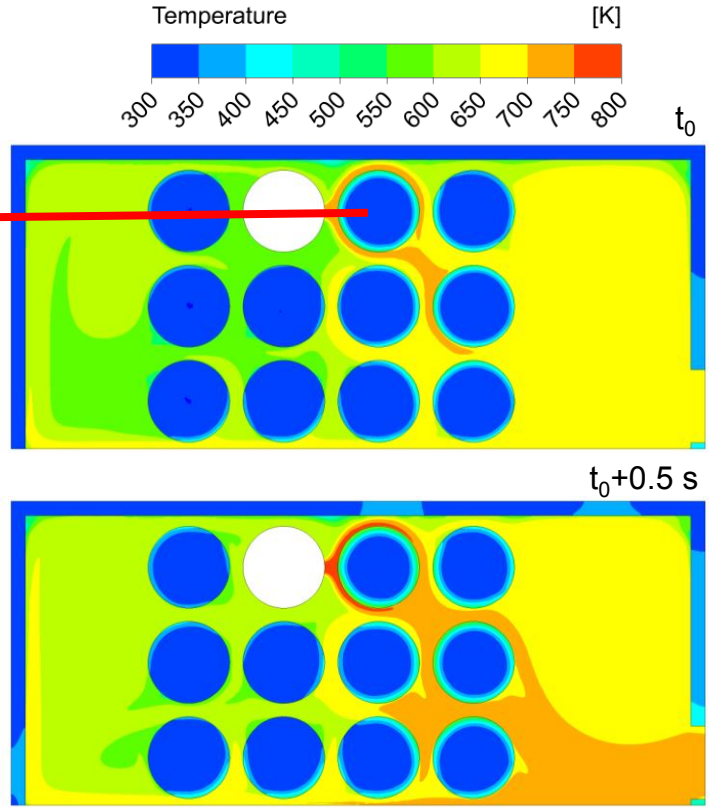
Results:

- $t > 0$; $T_{fluid} >> T_{initial}$
- $t > 0$; $T_{outlet} >> T_{initial}$
- $t > 0$; $T_{cells} >> T_{initial}$
- Direction of gas flow

Problem:

- 3D CFD simulation is time consuming
- Uncertain input parameters
- Experiment (nail penetration) not suitable





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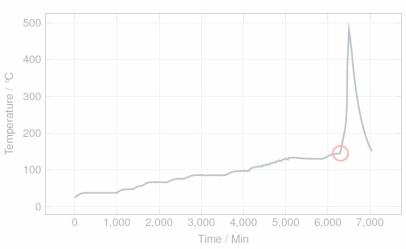
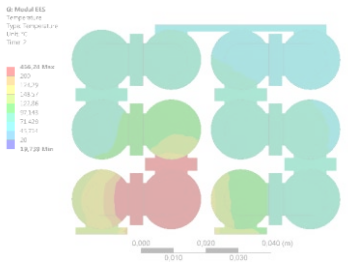
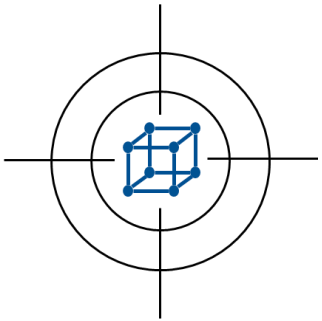
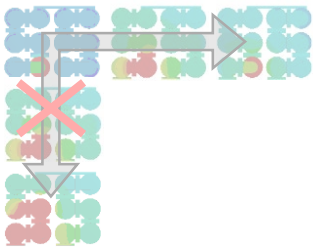








Limitations of accurate of modelling TR-P

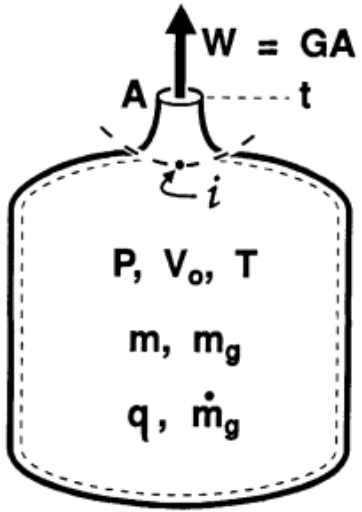
General:

- Temperature dependent material properties for > 100 °C not available
- 3D-CFD simulation is time consuming

Understanding and describing venting by a model needs accurate data on

- Vent size and vent position
- Heat release, mass rate, velocity of vented gas

→ Missing information makes it hard to simulate TR-P with simplified thermal models, especially if venting gas occurs



venting model
[Leung J.C., AiChE, Vol. 38, No. 5, 1992]

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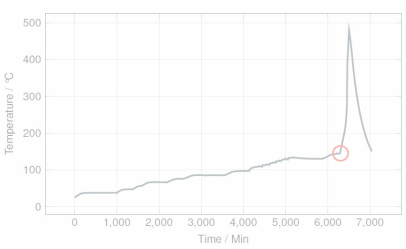
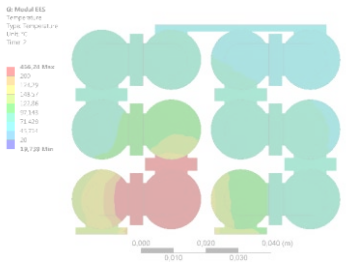
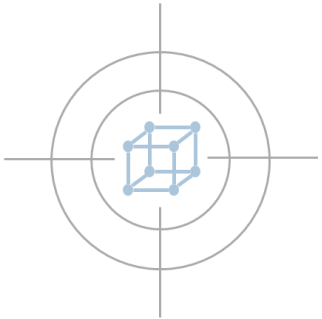
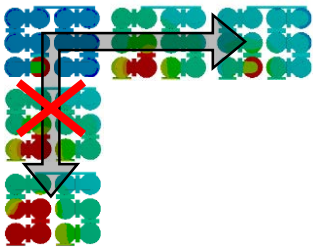
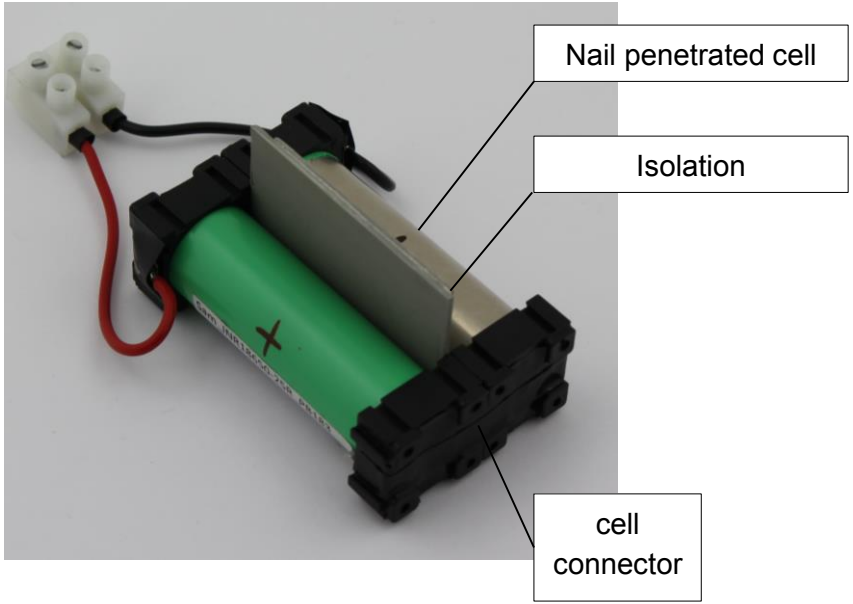


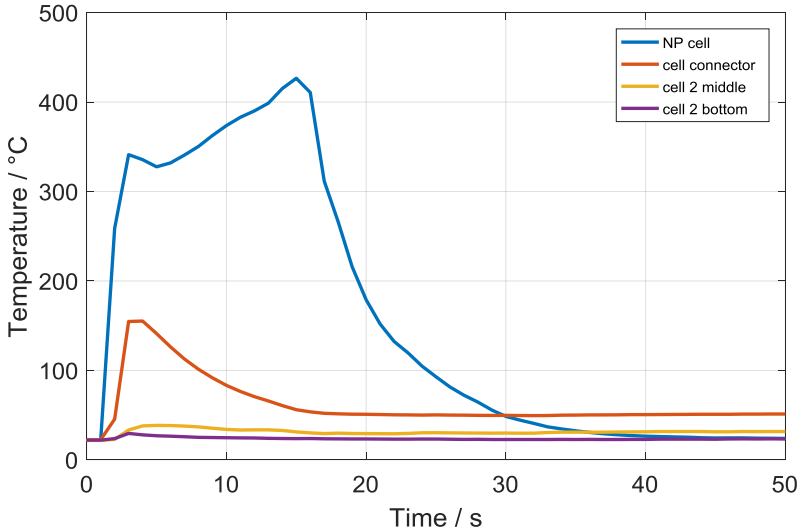






Experimental results of a 2s1p module for nail penetration of a single cell





- In the beginning rapid temperature increase of cell connector due to opened berst

→ Isolation prevents TR-P

Mitigation strategies of battery TR-P

Ideas:

- Increase **trigger temperature** of thermal runaway (by changing separator)
  PE, PP/PE/PP, PE-based with ceramic coating

- Use of **electrical fuses** → reduce released electric energy during internal short circuit
  e.g. Tesla uses wire bonding which act as fuses too

- Increase **heat dissipation** of battery module
  by lower ambient temperature or increased thermal capacity e.g. phase-change-material

- Additional **thermal resistance** between cells

- **Protect** neighbor cells **of venting gas** (define predetermined breaking points on cell)

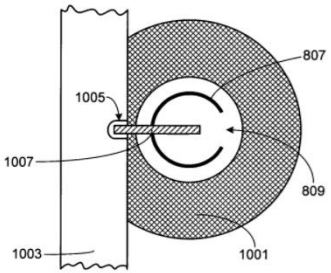


FIG. 10

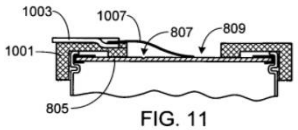


FIG. 11

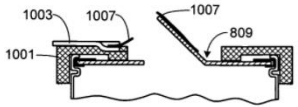


FIG. 12

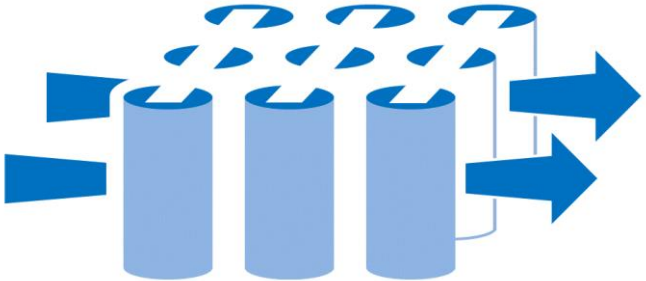
[Tesla Motors Inc., 2010, patent US8241772 B2]

Summary

- Venting gas during TR can have a strong influence on TR-P inside a battery module
- Conductive thermal models cannot represent TR-P if venting occurs inside a (half-)closed battery module
- Approach to implement heat transfer by gas looks promising and shows qualitativ the TR-P behavior

➡ More information on physical properties and behavior of venting gas during TR are necessary

➡ Standardised abuse testing regarding TR-P by venting gas is required



Team Battery Systems

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