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Joint Research Centre

Progress on thermal propagation testing

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Outline

Standards

- **Standards**

Status

- Screening of initiation methods
- Test Matrix
- Sensitivity analysis

Evaluation

- Different pass/fail criteria
- Issues with the assessment of egress time

Thermal propagation testing in standards

Scope:

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

Thermal propagation testing in Standards - Automotive applications

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 < 5 min *
SAND99-0497:1999	M, P	Partial short circuit test	100% (>95% after charge in 4h)	Hard short circuit with a ≤ 5mΩ conductor for 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) *
IEC 62660-3:2016. Ed1	C=IEC 62619:2017 Ed1=IEC62133 M, P	Internal short circuit test	100%	C= Ni particle method *. M= e.g. IEC 62619:2017 (heating *) P= under consideration for ISO 12405-3
IEC TR 62660-4:2017. Ed1	C (pouch, cylindrical, prismatic)	Candidate alternative test methods for the internal short circuit test of IEC 62660-3	Max. SOC specified by the manufacturer	Ceramic nail indentation
UL 2580:2013	M, P	Internal fire exposure test	Max. operating SOC	Heating until TR in < 10min *

* Alternative methods allowed

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

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Thermal propagation testing in Standards

Non-automotive applications	
Standards	**Aplication**
UL 9540A:2018	Energy Storage Systems
IEC 62619:2017	Industrial applications
VDE-AR-E 2510-50:2017	Stationary storage
JSC-20793 Rev D:2017	Spacecraft
IEC 62133-2:2017	Portable applications
Telecordia GR-3150:2015	Backup power
SAND2014-17053:2014	Civilian and military applications
IEC TR 62914:2014	Portable applications
NAVSEA SG270-BV-SAF-010:2011	Navy systems
SBA S1101:2011	Industrial applications
IEEE 1625:2008	Mobile devices
RTCA DO-311:2008	Aircraft installations
JIS C8714:2007	Portable 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
UL 1973 Revision	Standard for batteries for use in light electric rail (LER) applications and stationary applications

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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)

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Screening initiation methods

Objective:

- Compare the current (GTR) and other candidate initiation methods
  - **Which is the most suitable method?**
  - **In case several methods are selected: Are they equivalent? Are they robust enough? Are they sensitive to testing conditions?**

- Evaluate TR assessment
  - **What are the characteristics of TR?**
- Collect statistics about reproducibility and repeatability

Design of screening tests

1. Initiation methods (5): Heating, Nail, Overcharge (?), Rapid heating (Canada), Ceramic nail (IEC TR 62660-4)
2. Battery type (4):*21700 4 Ah, BEV 96 Ah, Pouch 32 Ah, PHEV2 26 Ah*
3. Assess impact of open/poorly defined testing conditions (2): on next slides

Monitor: cell surface temperature, voltage evolution (drop), heating rate, venting (y/n) and evaluate if TR is happened (y/n)

General test matrix

Initiation method	Automotive battery type				
Row Labels	21700 4 Ah	BEV 96 Ah	Pouch 32 Ah	PHEV2 26 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 - Overcharge	3	3	3	3	12
4.5-Rapid heating	3	3	3	3	12
Grand Total	**15**	**15**	**15**	**15**	**60**

Testing open parameters/conditions

According to GTR Phase 1 the test description has several open parameters which may have a significant influence on the outcome. The aim of this test is

1. To identify those parameter values which have the highest probability to reach and not to reach TR,
2. To test and to evaluate their effects on testing outcome

Open parameters of heating test (GTR Phase 1)

- **Area of the heater is not defined**
- **Heating rate/power is not defined**
- **Temperature of the heater is not defined** (stop heating when T>300°C at the other side but this is not the heater's temperature. Too high temperature of the heater can melt the cell)
- **Temperature measurement point is not defined fully** (opposite to the heater, but where? e.g. in the middle?)

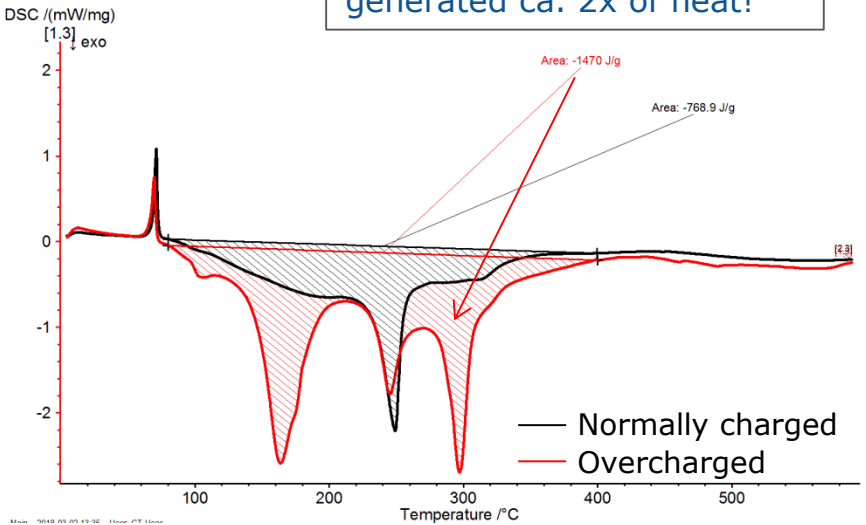
Open parameters of overcharge (OC) test (GTR Phase 1)

- **Current rate is in a wide range 1/3-1C**
- **Is this C-rate enough for TR?**
- **Effect of built-in safety device?**

Other issues:

- **Is OC a comparable initiation method regarding internal energy?**
- **Is it a single failure** (OC+ISC)**?**

At 36% OC the anode generated ca. 2x of heat!



DSC and TG signal of differently charged graphite anodes

Also in:
E.P. Roth et al. / Journal of Power Sources 134 (2004) 222–234
D. Below et al. / Solid State Ionics 179 (2008) 1816–1821
H. Maleki et al. / Journal of The Electrochemical Society, 146 (9) (1999) 3224-3229

Open parameters of nail test (GTR Phase 1)

- Diameter of the nail is >3 mm quite a wide range
- Speed is in a wide range (0.1-10 mm/s)
- Angle of the nail is in a wide range (20-60°)
- Position and direction is not specified
- Depth of penetration is not specified
- Remove the nail or not after penetration? How fast?

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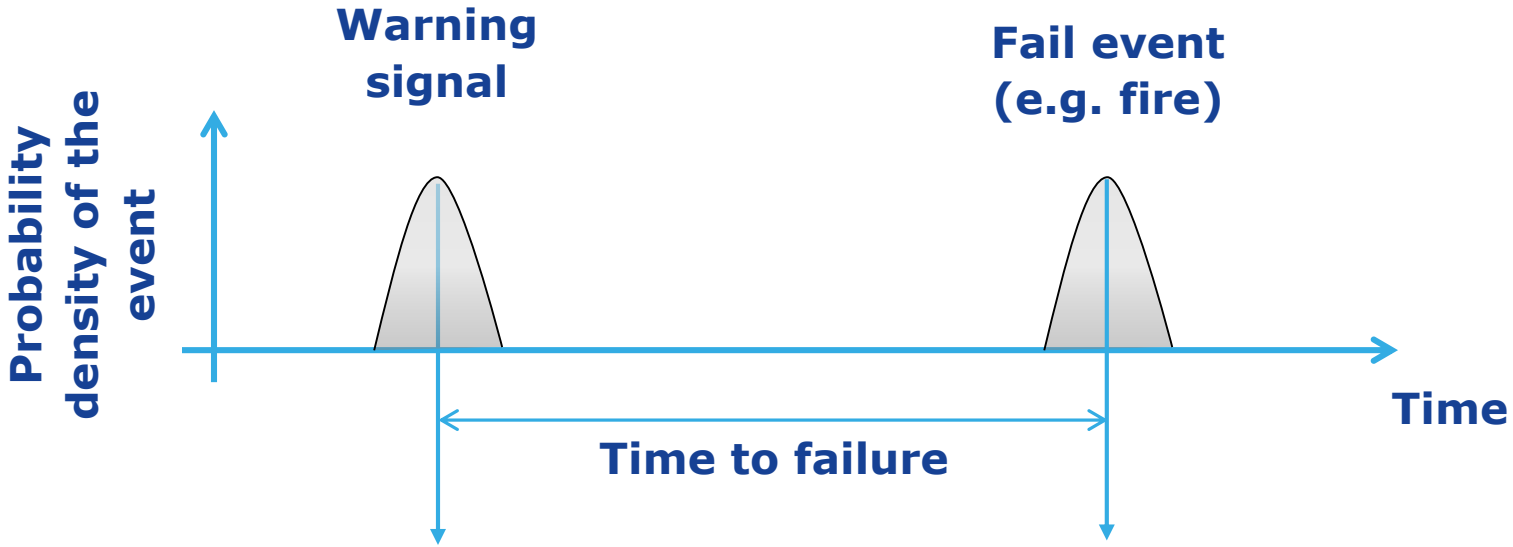
Pass/fail criteria of thermal propagation

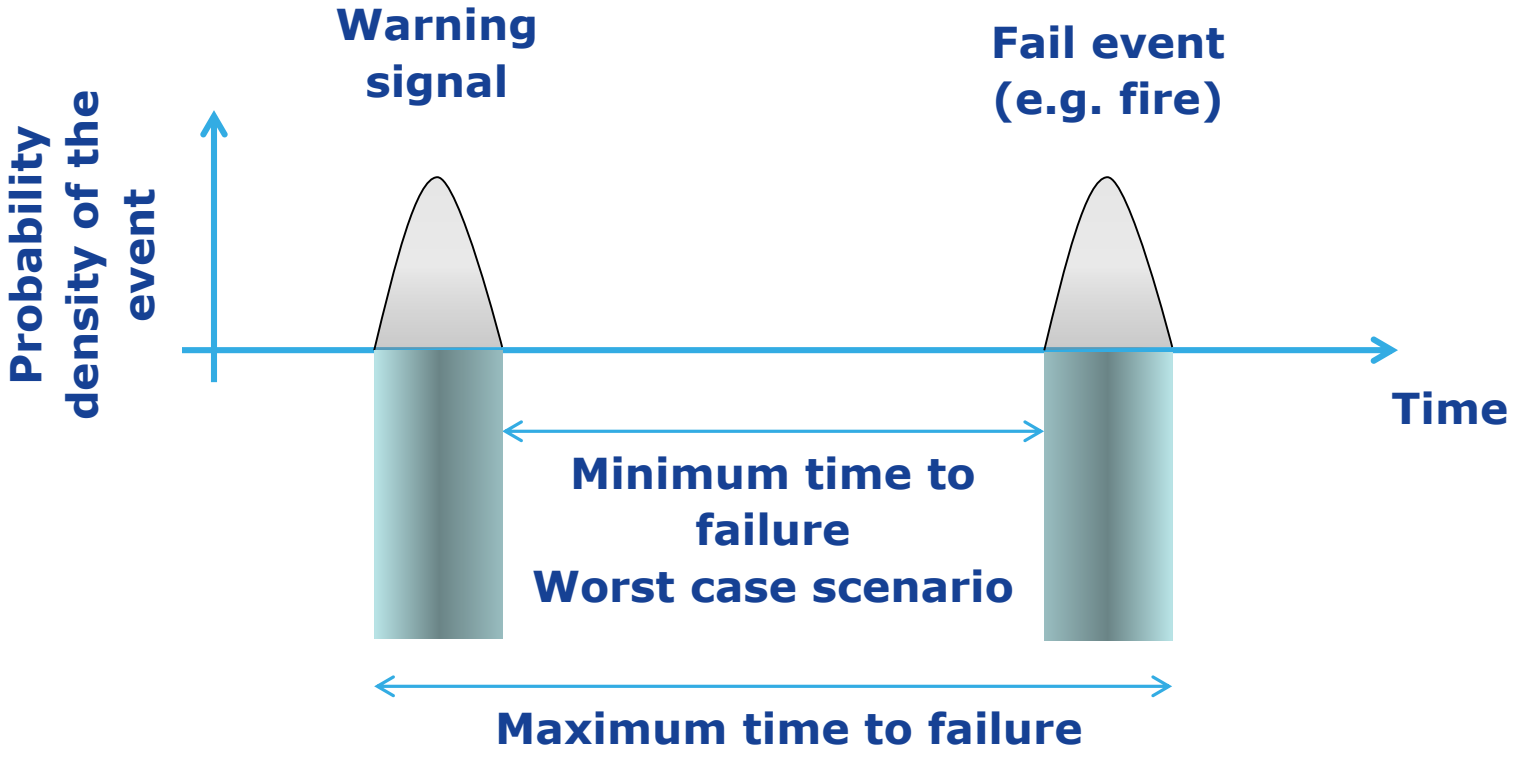
Option 1	*Option 2*	*Option 3*
Thermal propagation not allowed	Containment	Allow enough time for egress

- *Option 1-2 can be assessed by standard GTR methods*
- *Option 3 needs further statistical consideration*
  - **Variation of egress time and its statistical distribution**
  - **Agree on significance level for comparison.**

Time to failure

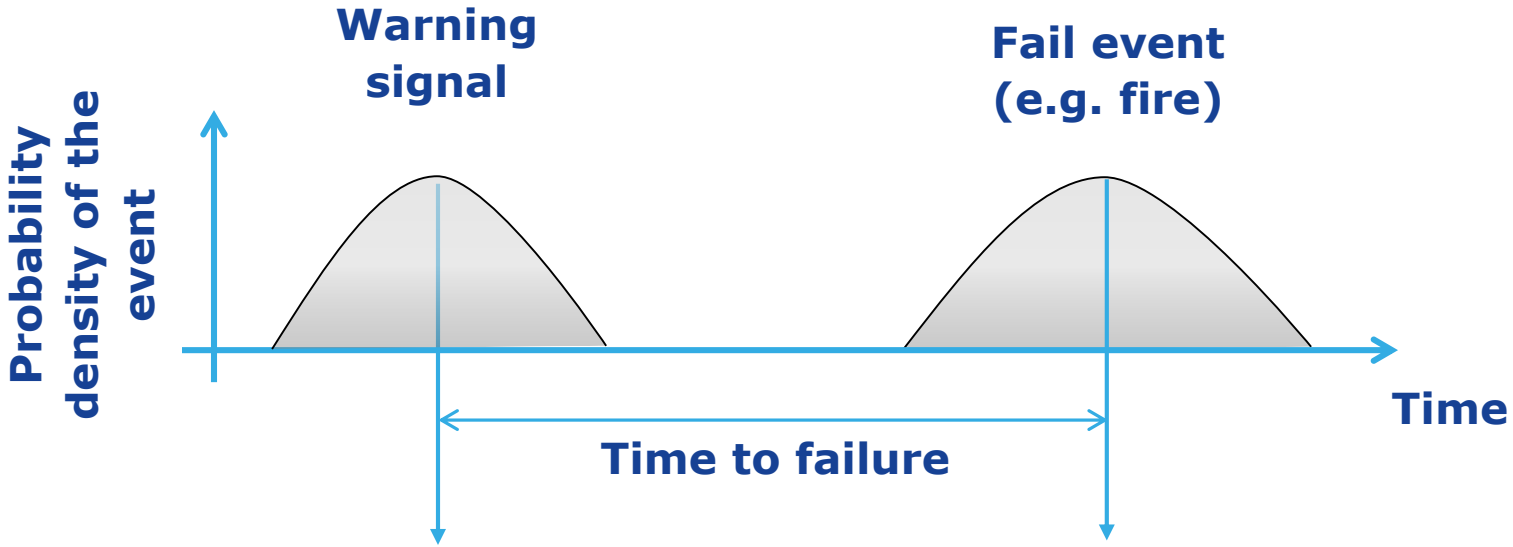


Time to failure (distribution)

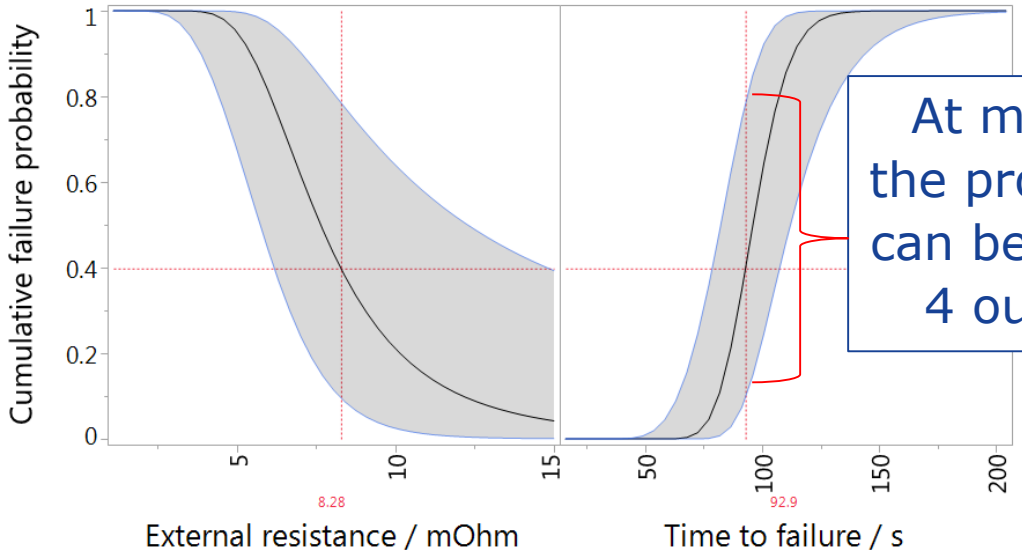


Is there enough time for egress?

Time to failure



Assessment of time to failure (illustration)



At middle times only the probability of failure can be determined, e.g. 4 out of 10 will fail.

- **If the test is passed, how probable is it that the passenger has indeed sufficient time for egress in all cases?**
- **What is a practical confidence interval? 95%?**

Acknowledgement *BATTEST group*

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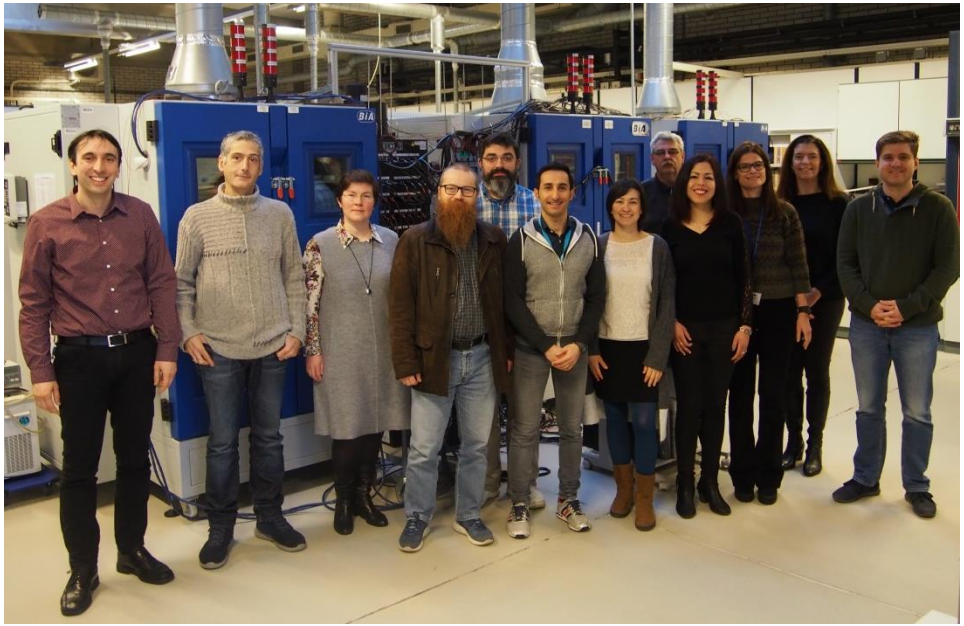

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