RECHARGE

Packaging Construction Requirements

UN IWG batteries Classification

03-12-2025

Geneva, UN, Room S4.

THE ADVANCED RECHARGEABLE AND LITHIUM BATTERIES ASSOCIATION

CONTENT

- Criteria for the packaging definition
- Technical analysis of the criteria definition
- Criteria proposed default values

Process for the new classification of a cell or battery

Test the battery T1-T8

Test the battery T9-13
(100%SOC and/or X% SOC)

Classify the battery fully charged and as transported

Apply packing instruction according to type and status

Cat 1: PI944 (P911) UN 3600 and 3601 type A-B to D damaged, liable to react	Cat 2: PI943 (P909) UN 3600 to 3603 type A-B to E-F, unverified TT, waste mix, damaged	Cat 3:PI942 (P908) UN 3600 and 3601 type A-B to E-F unverified TT but not liable to react, And UN 3602 and 3603, unverified TT, liable to react	Cat 4: PI941 (P903) batt. UN 3600 to 3603 type A-B to E-F verified TT,	Cat 5: PI940 (SP188) UN 3602 and 3603 type D to E-F, verified TT, all SOC And UN 3600 and 3601 type D to E-F, verified TT, known SOC

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Criteria for the packaging definition

Based on the identified hazard, additional criteria (compared to the UN regulation) applicable to batteries packaging:

- Heat dissipation/absorption related to propagation of the Thermal Runaway
- Material combustible property related to the fire risk
- Material resistance to perforation related to the bursting risk of batteries.

Gas containment is not addressed, as no practical solution is identified.

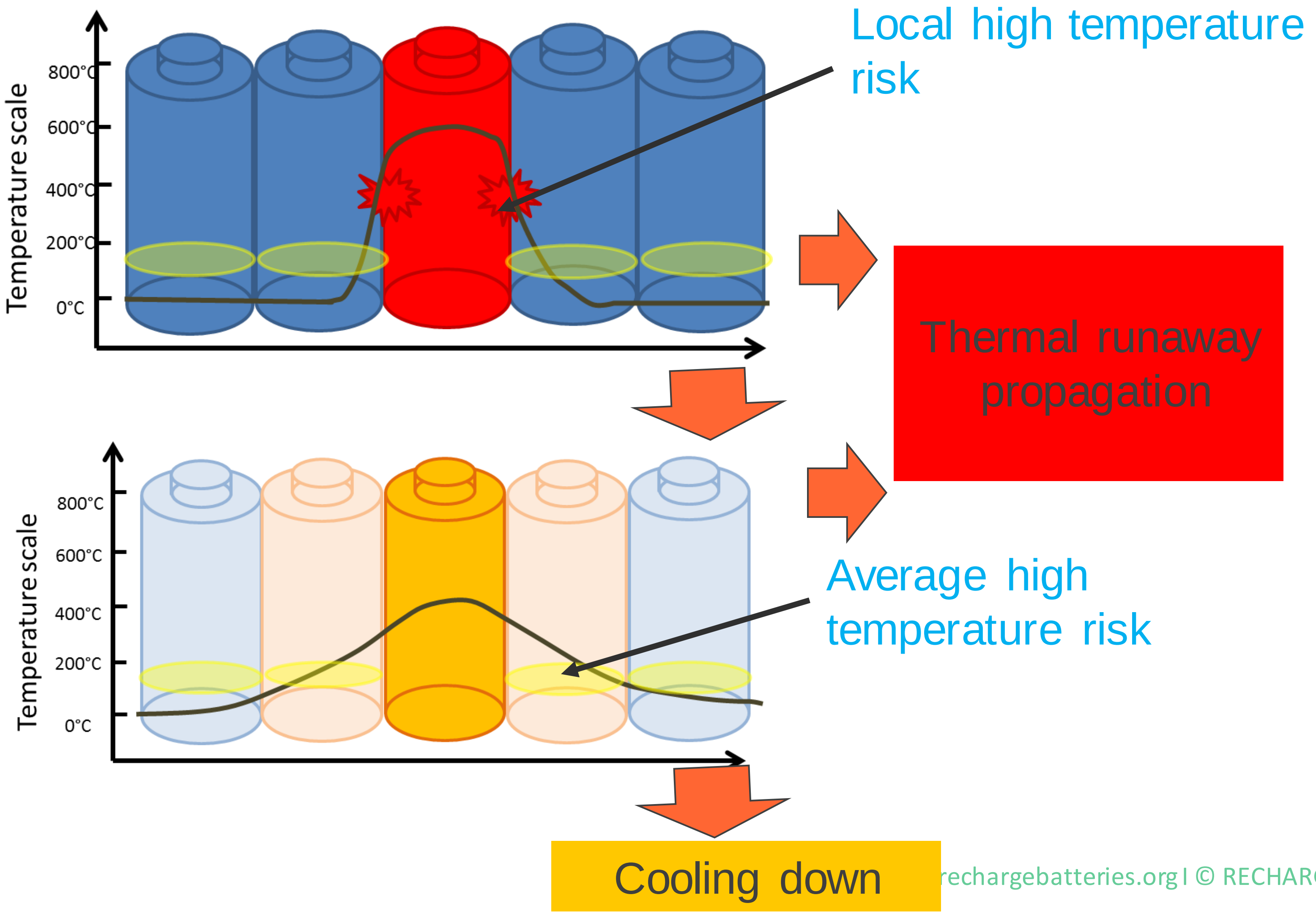
Technical analysis: heat dissipation/absorption

Thermal model description

Cases of propagation

(in addition to flame propagation)

Thermal profile in case of 1 cell/battery runaway

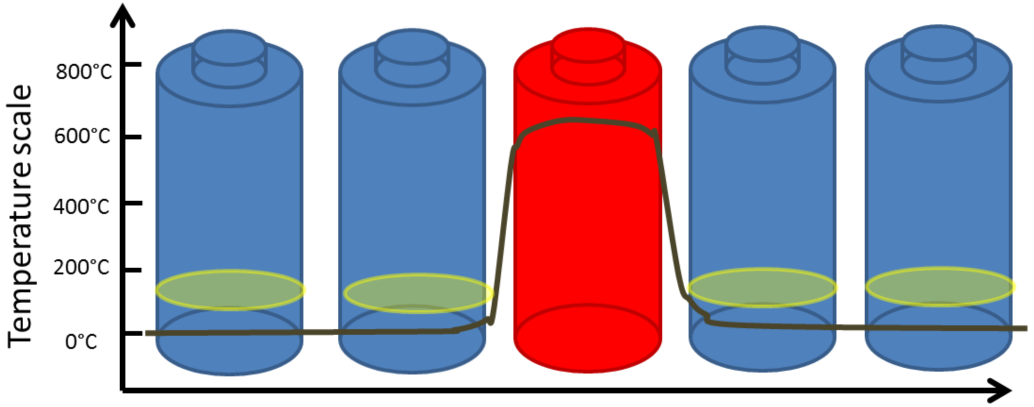


Technical analysis: heat dissipation/absorption

Thermal model description, cases of

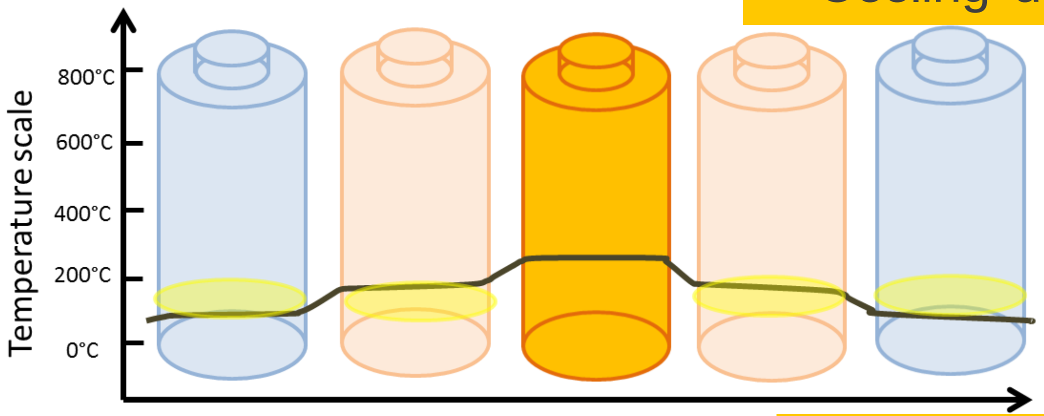
Propagation prevention

Thermal profile in case of 1 cell/battery runaway



Local high temperature risk mitigated by distance/thermal insulation

Cooling down

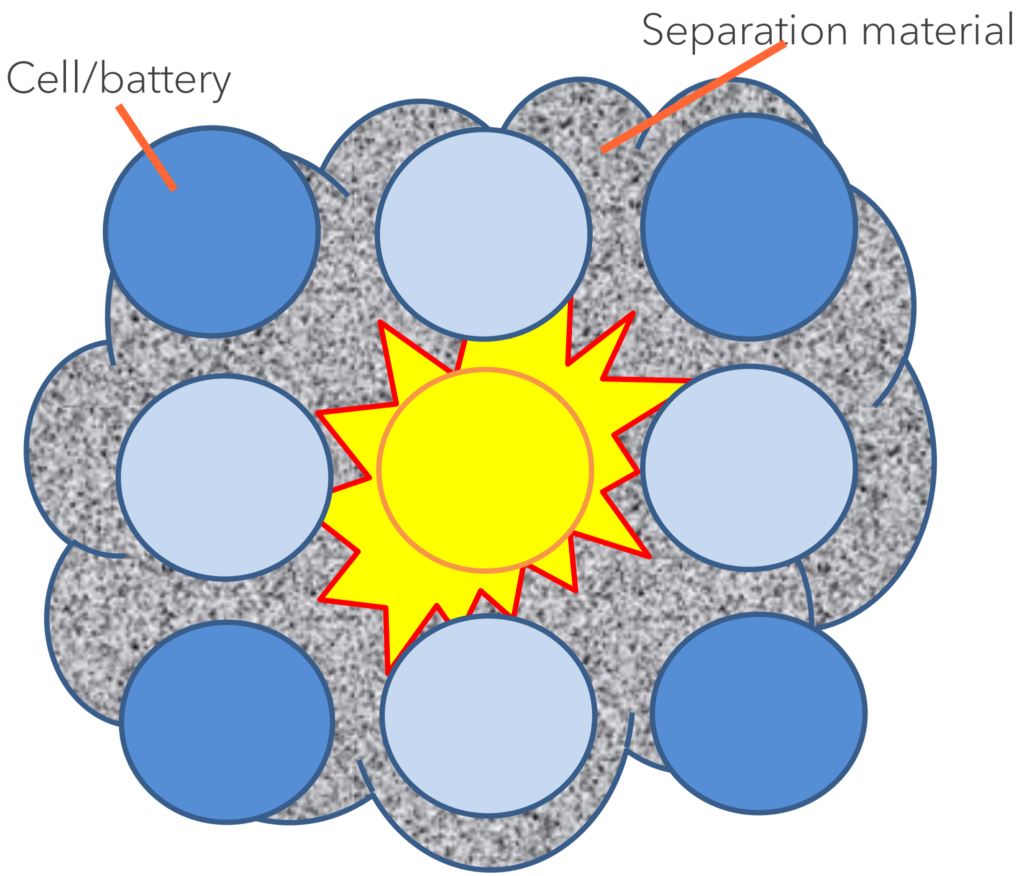


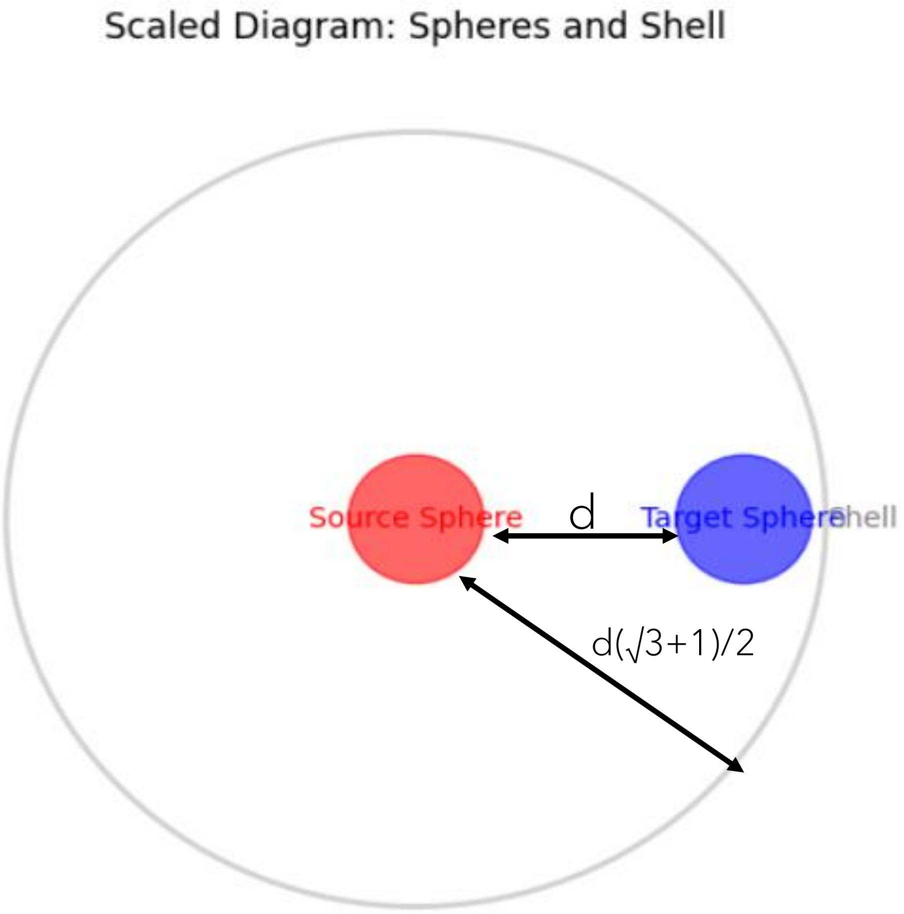
Temperature homogeneity improved during cooling

Cooling down

Technical analysis: heat dissipation/absorption

Thermal model description for 1 cell/battery in Thermal runaway inside a package:





Packaging properties : heat absorption/dissipation

The thermal model enable to calculate the heat absorption and the Minimum Safe Distance to ensure the target battery temperature remains below 100°C, therefore preventing propagation:

Solid material or air can follow the same rule (for air, distances are larger because of the small specific heat, so the radiation effects are less important and the heat transfer is facilitated by convection). The calculated rule is as follows (see annex)

Minimum Safe Distance (MSD) $d\,(m) > (T_{tr}/335-1.73)/(Cp_{mat} * D_{mat}))^{1/3} / (1.366*200) * Wh$ **(Eq 3)**

With Ttr the measured Thermal Runaway maximum temperature, Cpmat and Dmat the specific heat (lJ/kgK) and density (kg/m3) of the material used, and Wh the battery energy (Wh).

default values in absence of test: use the materila Cp and D, and use Ttr of 1400°C (reprenting a maximum heat of reaction of 7 kJ/Wh battery,)

Examples of safe distances MSD of typical materials, for a fully charge battery of 20 Wh reacting at 870°C

	vermiculite	sorbix	Pyrobub.	Absorbant	sand	Water based gels	mineral wool	nineral wool HD	card board	air
kg/m3	90	170	270	820	1530	1000	50	100	200	1,2
kJ/kgK	1	0,84	0,84	0,84	0,83	4,14	0,84	0,84	1,51	1,005
MSD (cm)	**1,6**	**1,3**	**1,1**	**0,8**	**0,6**	**0,4**	**2,0**	**1,6**	**1,0**	**6,6**

Examples of safe distances of typical materials, for a 40% SOC charge battery of 20 Wh reacting at 580°C (for air, a shielding to reduce direct radiation may be needed, depending on the real radiation factor of the product;

MSD (cm)	**0,2**	**0,2**	**0,1**	**0,1**	**0,1**	**0,1**	**0,2**	**0,2**	**0,1**	**0,8**

Packaging properties: combustibility

Proposed definition for non-combustible material (based on the UN Manel of test and criteria, section 33.2.4.3.1, definition for a method for determination of powder materials flammability)

Non combustible material means a material that does not propagate a flame and where the smoldering reaction doesn't progress for more than 200 mm over 20 minutes, after an ignition by a hot flame (minimum temperature 1 000 °C) from a gas burner (minimum diameter 5 mm)

Alternative definition could be derived from the ADR Preliminary screening test: combustion duration more than 45 second for a distance of 100 mm).

For the packaging criteria, 3 levels of materials are proposed, when a combustibility property is requested:

Level 1: flame exposure 90s (corresponding to a large battery reaction, or several small batteries)

Level 2: flame exposure 20 s (corresponding to a single battery TR reaction, producing less than 25 l gas).

Packaging properties : perforation resistance

The perforation resistance is directly related to the pressure of ejection of the bursting part. (see explanation).

Default values:

- level 1 resistance of the external wall of the package at 50 kPa (725 PSI) (test by i.e. burst strength test TAPI_T_810)
- level 2= no specification but reference to UN group 2 packaging.

Example of material for level 1 :

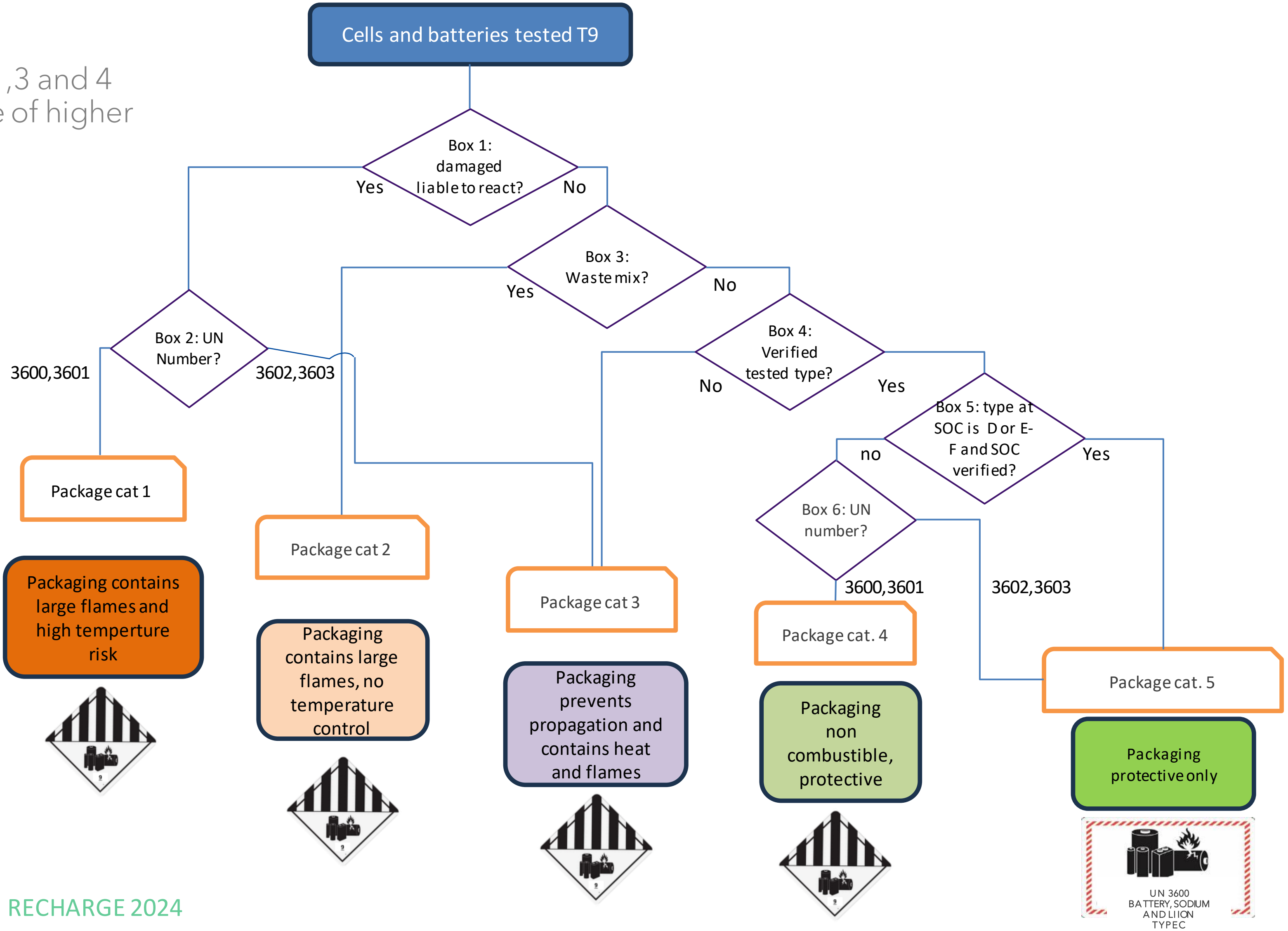
Material	Typical Thickness for High Burst Strength	Notes
Corrugated Cardboard	Heavy-duty triple-wall board (≈ 12–15 mm)	Max ratings usually **up to 600 PSI**; 725 PSI likely requires lamination or fiberboard reinforcement.
Plywood (Wood)	6–12 mm	Wood panels easily exceed 725 PSI burst resistance; commonly used for crates.
Plastic Sheets (HDPE, PET)	3–6 mm	High-density polyethylene or PET sheets can withstand >725 PSI if properly supported; often used for rigid containers.
Metal Sheets (Steel, Aluminum)	0.5–1 mm	Metals easily surpass 725 PSI; even thin gauge steel or aluminum will resist this pressure.

Packaging categories

	Shipment condition	Type E-F	Type D	Type C	Type A-B
product state	*Risk in transport*				
Tested type verified, mitigations including low SOC, air gap or other verified mitigations	*Thermal Runaway risk limited when product is protected by the packaging.*	general provision or strong, rigid outer packaging, or casing PI 940 No short circuit/no activation (*equivalent SP188*)	general provision or strong, rigid outer packaging, or casing, non combustible material PI 940 No short circuit/no activation (*equivalent SP188)*	PG II or Strong, rigid outer Packaging, or casing >12kg non combustible material PI 941 No short circuit/no activation (*equivalent P903*)	PG II or Strong, rigid outer Packaging, non combustible material or casing >12kg l PI 941 No short circuit/no activation (*Equivalent P903*)
New product not tested, D&D not liable to react, product recalls, products after TR.	*The thermal runaway risk is not verified (so considered type A) Packaging mitigation role by individual protections and propagation prevention (gaps or others)*	Not applicable	Not applicable	Not applicable	PG II +similar to P941 and Propagation prevention by separations (gaps) or others methods (passive safety) PI 942 (*equivalent P908 / P910)*
Waste batteries	*The conditions of the product and the absence of product protection generate a TR risk. Packaging fire containment for small batteries.*	forbidden	forbidden	forbidden	PG II based on P909 with revisions, specific packaging testing PI 944 (*equivalent P909)*
D&D batteries liable to react	*The risk is high of Thermal runaway, and the consequence should be mitigated by the packaging. Containment for large batteries needed*	forbidden	forbidden	forbidden	PG I and similar to PI942, + temperature containement. PI 943 (*equivalent to P911*)

Packaging categories selection

Packages of categories 1,3 and 4 can replace any package of higher category



Packaging categories based on hazards

UN 3600 to 3603 *means type Type A-B to E-F fully charged*
Type A-B to E-F *refers to the type as tested at SOC of transport*.
VerifiedTT: *means: batteries verified as compliant to the tested type*

property	Cat 1: PI944 (P911) UN 3600 and 3601 type A-B to D damaged, liable to react	Cat 2: PI943 (P909) UN 3600 to 3603 type A-B to E-F, unverified TT, waste mix, damaged	Cat 3: PI942 (P908) UN 3600 and 3601 type A-B to E-F unverified TT and SOC but not liable to react, And UN 3602 and 3603, unverified TT, liable to react	Cat 4: PI941 (P903) batt. UN 3600 to 3603 type A-B to E-F verified TT (no SOC requirement)	Cat 5: PI940 (SP188) UN 3602 and 3603 type D to E-F, verified TT, no SOC requirement And UN 3600 and 3601 type D to E-F, verified TT, verified SOC
Tested type at 100% SOC	A-B and C	A-B by default because of Mix	A-B to E-F	A-B to E-F	A-B to E-F
Tested type at transported SOC (100% if unknown)	A-B and C	A-B, as SOC unknown	C to EF when SOC known, or type at 100%SOC	A-B to C	D to E-F
verified TT 38.3	yes		no	yes	Yes
Heat dissipation/absorption	Level for TR 1400°C all batteries in the propagation zone+ max external temp.	Level for TR 1400°C, no propagation prevention	Propagation prevention: MSD Level per Wh for TR temperature measured at transported SOC(or 100% SOC or 1400°C)	No	No
Resistance to perforation	yes	yes	no	no	No
Resistance to fire	Level 1: large flame	Level 1: large flame	Level 2 small flame	level 2 small flame	No
UN package, group	Yes G I	Yes G II	Yes G II	Yes, G II	No

Technical analysis: heat dissipation/absorption

For solid materials absorbing heat in the packaging: diffusion mainly, emission and convection neglected.

The model considers the total heat transmitted from a battery in TR to similar neighbor batteries in the package, until the temperature Tthresh (temperature of TR initiation in the battery) is achieved.

- from the source battery, with energy produced by the thermal runaway $Q_{TR} = m_{batt} \cdot Cp_{batt} \cdot (T_{tr} - T_{amb})$
- to the target batteries (n neighbors) receiving the energy $Q_{thresh} = m_{batt} \cdot Cp_{batt} \cdot (T_{thresh} - T_{amb})$. T_{thresh} is the temperature of TR initiation in the battery.
- And to the packaging material receiving the energy $Q_{mat} = m_{mat} \cdot Cp_{mat} \cdot (T_{thresh} - T_{amb})$. The material and the batteries are at the same temperature), and dissipated outside the packaging Q_{leak} .

The key condition to avoid the propagation is that the eat produced by the TR is absorbed in the package and the initial+neighbor batteries at a temperature below $T_{thresh.}$ the condition equation is: $Q_{TR} < Q_{leak} + Q_{mat} + (n+1) \cdot Q_{thresh}$

then $m_{batt} \cdot Cp_{batt} \cdot (T_{tr} - T_{amb}) < Q_{leak} + m_{mat} \cdot Cp_{mat} \cdot (T_{thresh} - T_{amb}) + (n+1) \cdot m_{batt} \cdot Cp_{batt} \cdot (T_{thresh} - T_{amb})$.

Simplified in : $\mathbf{(T_{tr} - T_{amb}) / (T_{thresh} - T_{amb}) < Q_{leak} / Q_{thresh} + (m_{mat} / m_{batt}) \cdot (Cp_{mat} / Cp_{batt}) + (n+1)}$ **(Eq 1)**

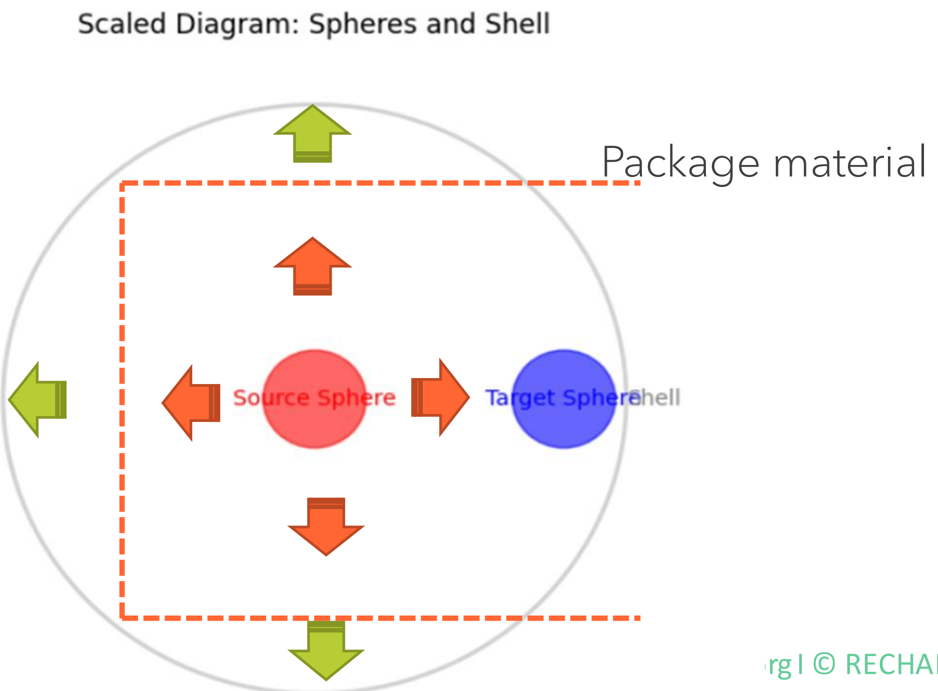
Technical analysis: heat dissipation/absorption

$$(T_{tr} - T_{amb}) / (T_{thresh} - T_{amb}) < Q_{leak} / Q_{thresh} + (m_{mat} / m_{batt}) \cdot (Cp_{mat} / Cp_{batt}) + (n+1)$$

The model enables to define worst case conditions for package categories to ensure prevention of the TR propagation

In absence of information on the packaging design, the worst case considers the TR on the box side, no heat dissipation (Q_{leak} =0), and minimum neighbors number(minimum heat think): 6 close neighbours (4 around, 1 above 1 below)

Case of the cell/battery close to the casing side: the new worst case is then only 1 neighbor (packaging format similar to fixture used for the TR propagation test, but with same distance to next battery and to package): in this case we consider heat dissipation by conduction mechanism in the material (1 face only) and conduction through the packaging (5 faces of the package)



Technical analysis: heat dissipation/absorption

Simplification is possible for Qleak as long as the packaging surrounding the battery has isotropic thermal properties. As for any applicable package, the maximum heat arriving at the target battery is limited (because the battery cannot exceed 100°C), therefore the heat flow is limited to typically 400W/face per Kg of battery.

Compared to this limitation, the heat flow through the package (such has a cardboard for the more insulative material) and finally dissipated at the surface of the package by air convection are not limiting (see specific discussion and diagram of transversal temperature examples) .

As a result, the calculation is still valid if Qleak per face is assimilated to one of the 6 neighbours.

Technical analysis: heat dissipation/absorption

Discussion for the simplification of Qleak:

Qleak as long as the packaging surrounding the battery has isotropic thermal properties. As for any applicable package, the maximum heat arriving at the target battery is limited (because the battery cannot exceed 100°C), therefore the heat flow is limited: typcally per kg/battery it is 1400 kJ divided by 6 faces and 600 seconds: 400 W/face

Compared to this limitation, the heat flow through the package (such has a cardboard for the more insulative material) and finally dissipated at the surface of the package by air convection are not limiting (see specific discussion anddiagram of transversal temperature examples)

As the minimum safe distance (MSD) is practically more than 4 cm per kg battery (see models examples fro water based materials), then the minimum surface per face of the package becomes more than 2.5 larger than the battery face.

The heat dissipated from the cardboard surface Qconv=h·A·(T−Tamb)A = area in m2 and h = natural convection coefficient for air ≈ 10 W/m²·K, or 800 W/m²· at 100°C. This is higher than the heat flow passing through the cardboard nand coming to the cardboard from the intitation battery,

Data for reference: Air: λ ≈ 0.026 W/m·K
Mineral wool: λ ≈ 0.035 W/m·K→ Slightly higher conductivity means the insulation warms up faster near the source, reducing the thermal gradient and allowing more radiation to reach the target.
Specific heat per unit volumeAir: cp × ρ ≈ 1005 × 1.2 ≈ 1206 J/m³·K
Mineral wool: cp × ρ ≈ 840 × 50 ≈ 42,000 J/m³·K

Technical analysis: heat dissipation/absorption

For air-gaps: model must include thermal diffusion, radiation and convection.

The model enables to define worst case conditions for package categories to ensure prevention of the TR propagation

In absence of information on the packaging design, the worst case considers heat dissipation by the box sides is similar to the heat storage in a neighbour, with the condition that it is at the same distance than the neighbor battery.

For Lithium batteries, the following values can be used: T_{thresh} = 100° C, T_{amb} =20° C, Cp_{batt}=1.0 kJ/kg/K

then it simplifies in a condition for the packing material simply related to the Ttr

$$\mathbf{m_{mat} .Cp_{mat} / m_{batt} > T_{tr} /80 -1,25 - n}$$

Technical analysis: heat dissipation/absorption

$$m_{mat} . Cp_{mat} / m_{batt} > T_{tr} / 80 - 1{,}25 - n \qquad \text{(Eq 2)}$$

The safe distance between batteries can then be calculated based on the volume occupied by the insulative material. The radius R of the sphere occupied by the material can be expressed as a proportion of the safe distance d: R= d * (1 + SQR(3))/2

m_{mat} = density . Volume = D_{mat} . 4/3 .PI . R^3 = D_{mat}. 4/3 . PI . (d*1.366)^3

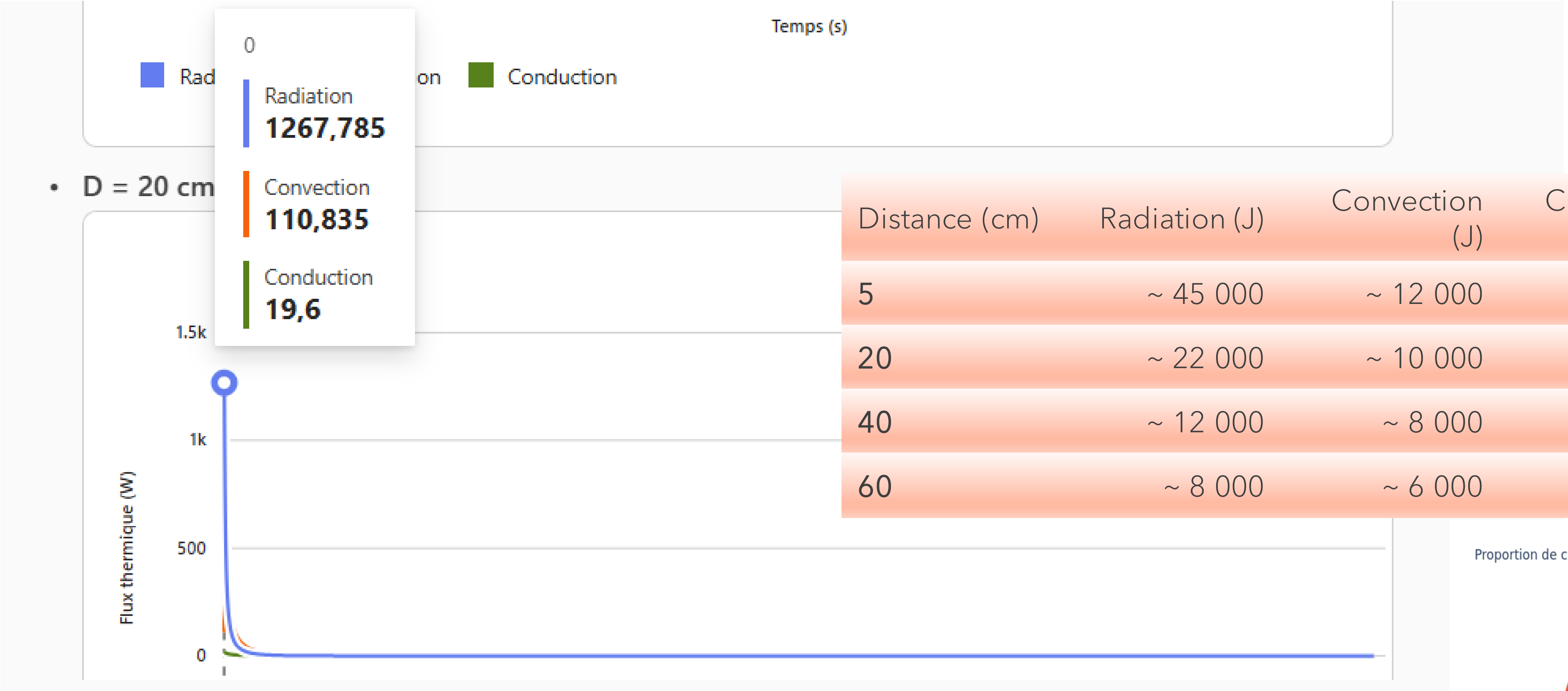
Then with Eq (2) d > 1/1.366 * [(T_{tr}/80-7.25)/(Cp_{mat}* D_{mat}* 4/3*PI)]^1/3

or , per Kg of batt cells, d > (T_{tr}/335-1.73)/(Cp_{mat}* D_{mat}))^1/3 / 1.366 (Eq 3)

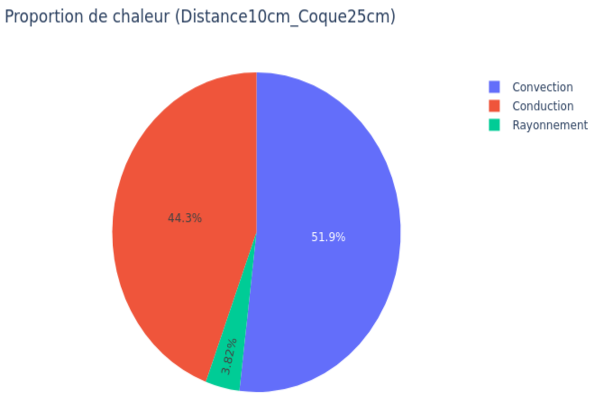
Finally , the Kg of battery can be replaced by the Wh battery, using the ration 200 Wh/kg battery.

Technical analysis: heat dissipation/absorption

Example of the calculation of heat flows with air gap : D=20cm, 100g à 1000° C

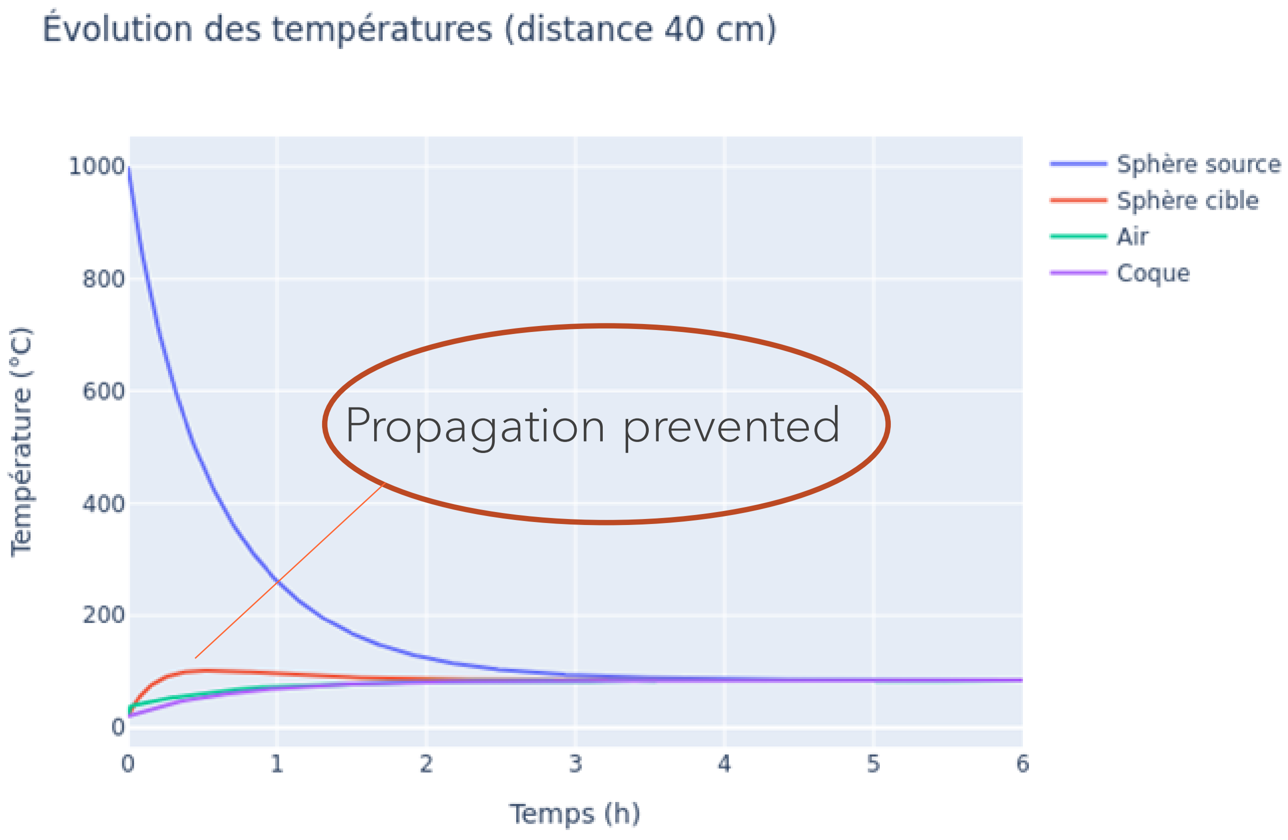


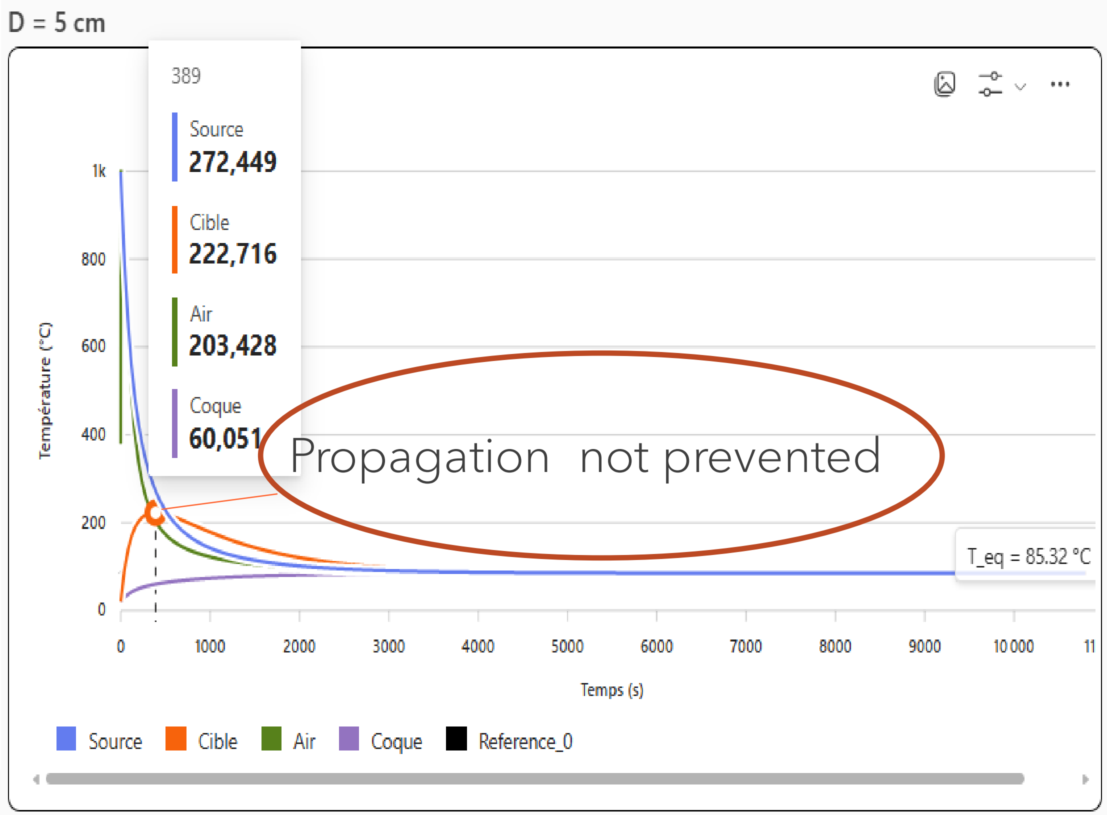
Distance (cm)	Radiation (J)	Convection (J)	Conduction (J)	Total (J)
5	~ 45 000	~ 12 000	~ 18 000	~ 75 000
20	~ 22 000	~ 10 000	~ 2 000	~ 34 000
40	~ 12 000	~ 8 000	~ 500	~ 20 500
60	~ 8 000	~ 6 000	~ 200	



Technical analysis: heat dissipation/absorption

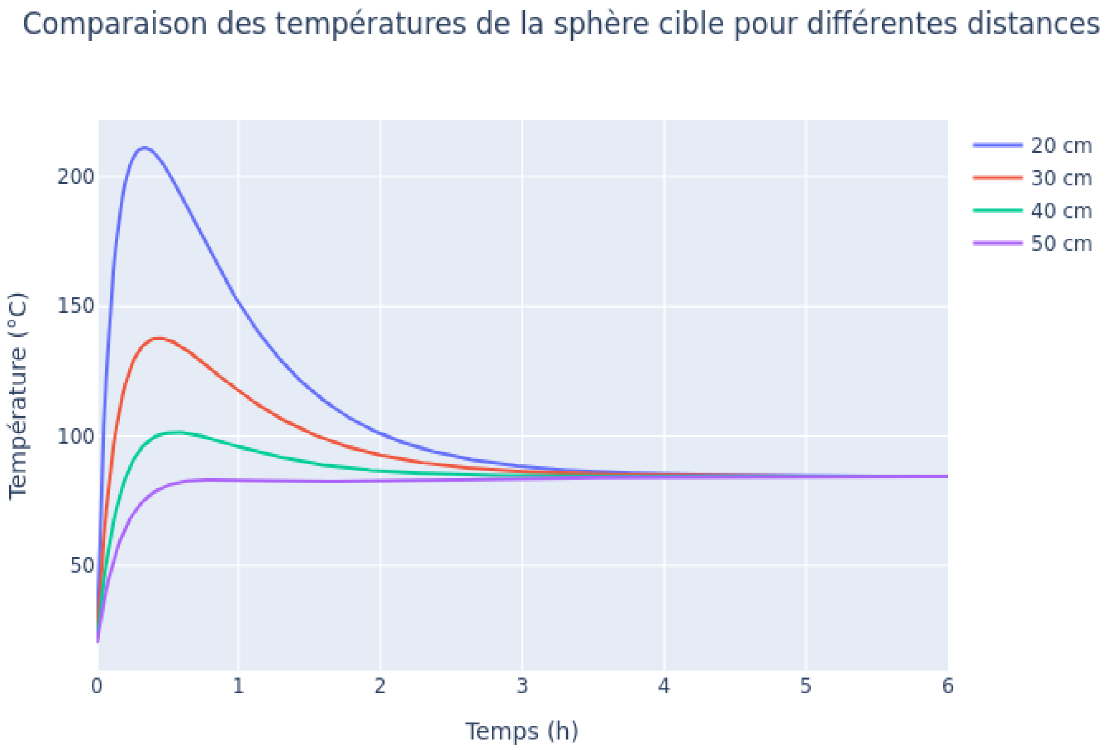
Example of air gaps: Calculation of the heat flows for a battery of 100 grams with a neighbour at 5 or 40 cm : temperature can exceed 200 ° C on the target battery, even if the final temperature is below 100° C: TR propagation risk not controlled.



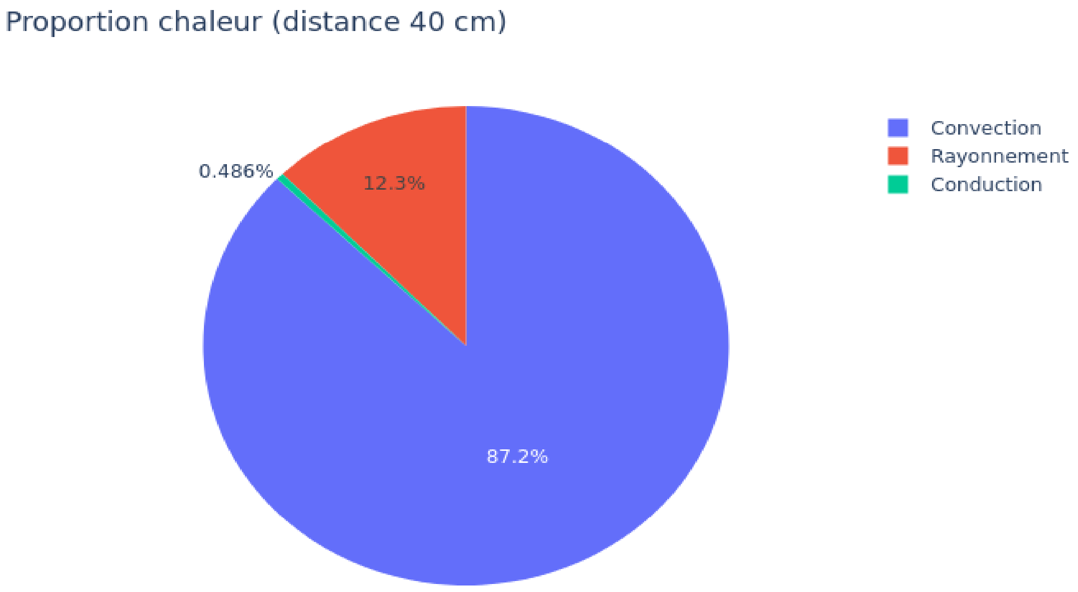


Technical analysis: heat dissipation/absorption

Example of air gaps: effect of distance in air to reduce radiation



Mainly convection at longuer distances

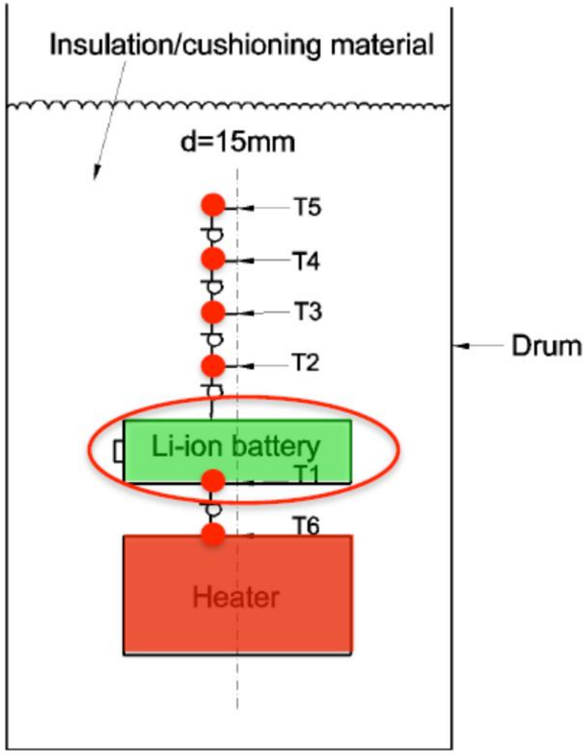


Packaging tested: the case of transport of waste batteries

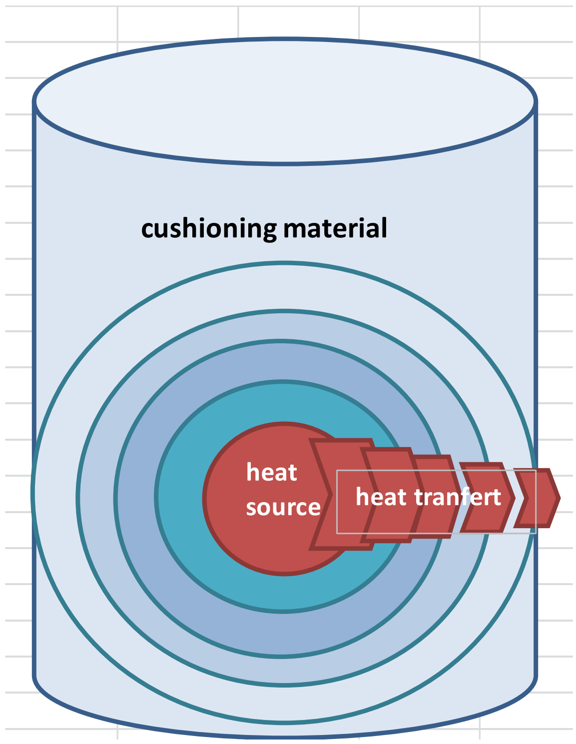
Comparison of a model and a thermal runaway heat propagation test

Reference to ACCUREC – RECHARGE published communication of tests results in ICBR conference, 2014.

Test description: (ACCUREC)



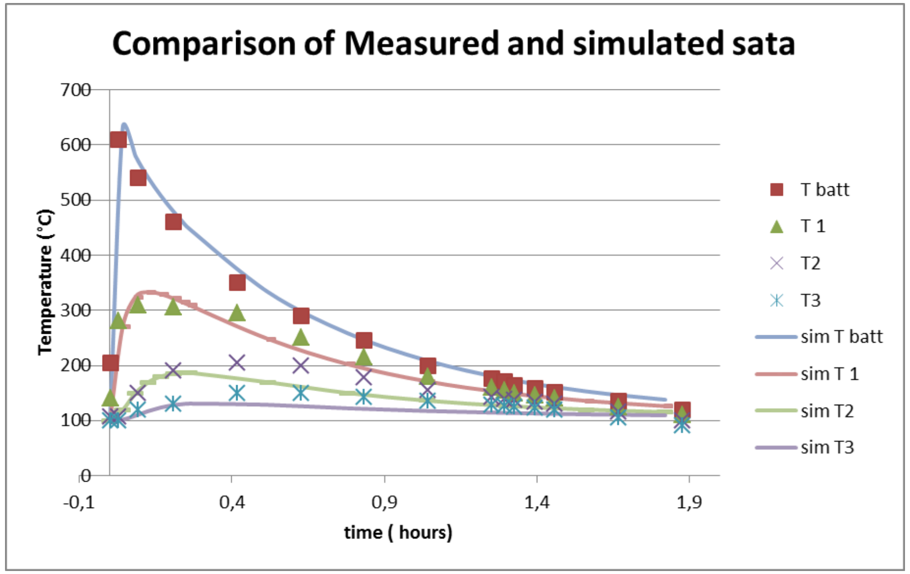
Model description:



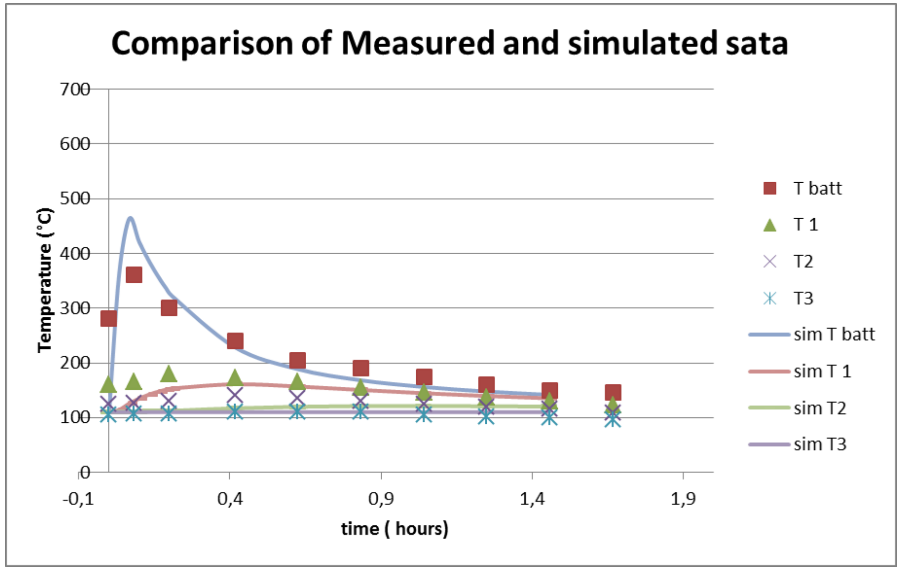
Test and model comparison

The simulation is showing acceptable results for the cell temperature and the different layers of the cushioning materials during the cooling phase.

Vermiculite



Sand



The thermal runaway energy calculation is robust

- The simulation allows to recalculate the total heat emitted during the runaway: the results are reported in the table.
- They are compared to a reference energy release for Li-ion cell run away without flames of 870 kJ/cell kg (ref. 2)

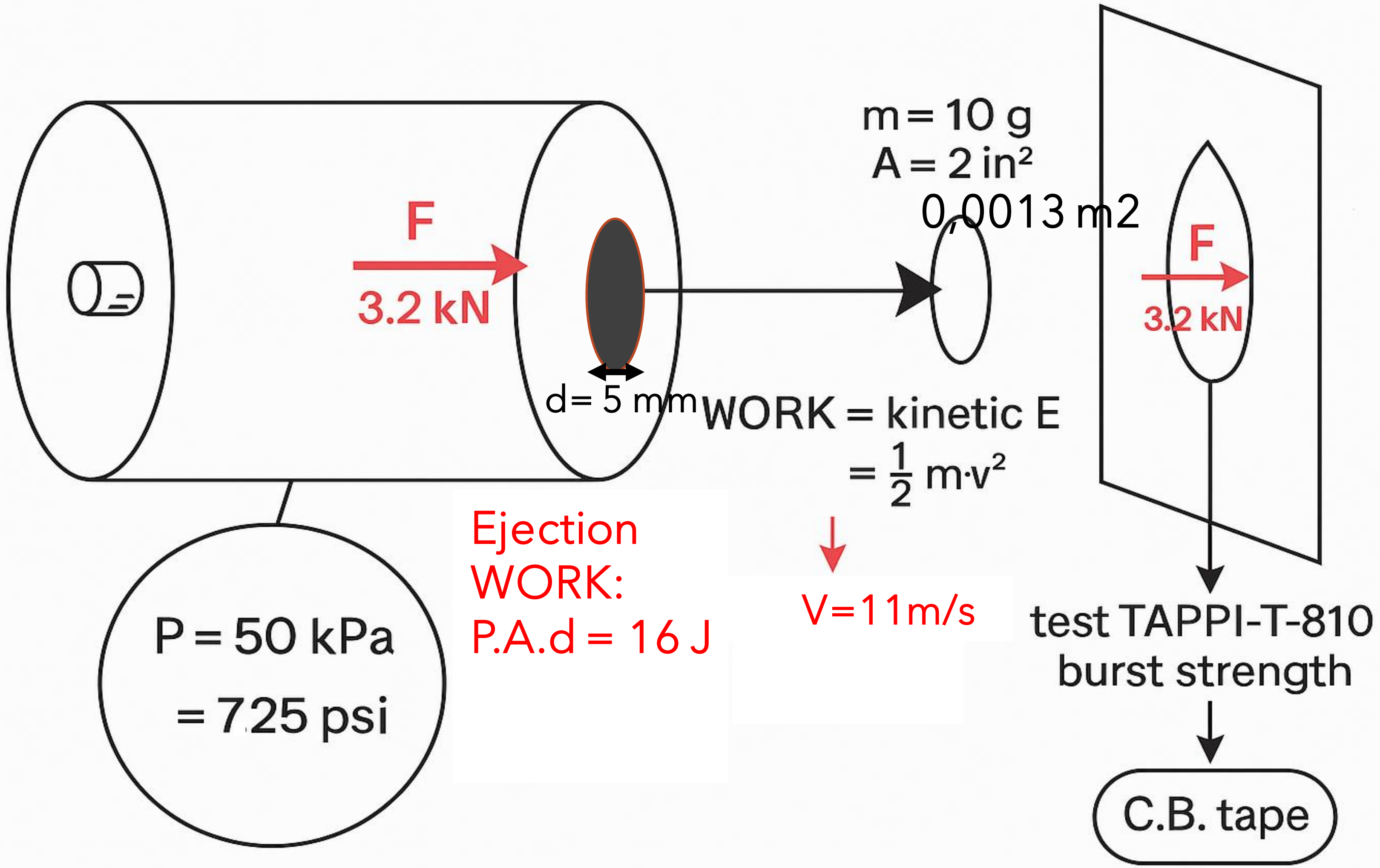
	Calulated heat release (kJ/cell kg)	% theoritical heat release
sand	500	58%
absorbent	700	81%
Pyrobubbles	800	93%
sorbix	800	93%
Vermiculite	800	93%

The runaway energy used as reference is always larger than the one measured during the tests

Ref 2: RECHARGE, Li-ion safety, July 2013, http://www.rechargebatteries.org/communication/recharge-positions/

Technical analysis: Resistance to perforation

Diagram explaining that the rupture pressure of the ejected part is direct applied on the package and represents the perforation pressure



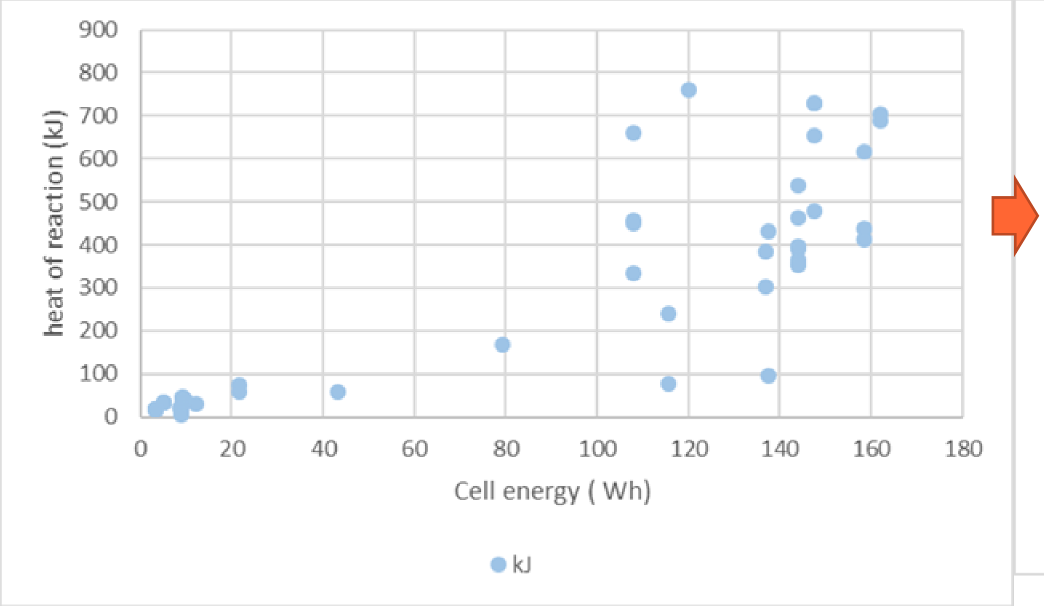
Materials > 725 PSI burst strength

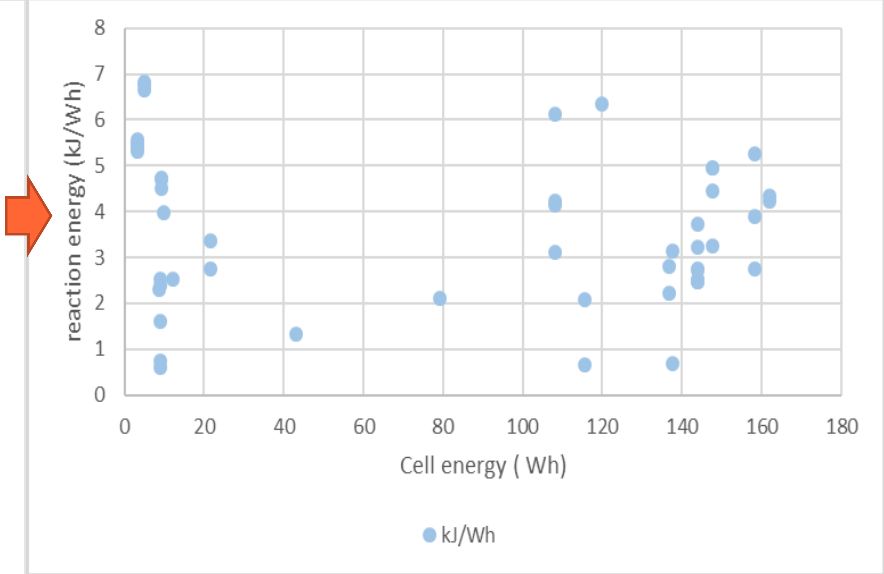
Supporting data for the maximum TR reaction temperature

- Recharge presentation of the UN IWG (Geneva, Dec 6, 2017).

Thermal runaway heat of reaction* of all Li-ion chemistries, various type of abuse:

- Maximum reaction heat of Li-ion cells is roughly proportional to the cell size.
- Maximum Reaction heat per Wh is equivalent for large and small cells.
- But the reaction is sometimes limited (particularly for low SOC cells- see specific slides)
- Always **less than 7 kJ/Wh (or 1.5 MJ/Kg):** compared to other combustibles, about 20-40 times less energy than than plastic, fuel, and other combustible



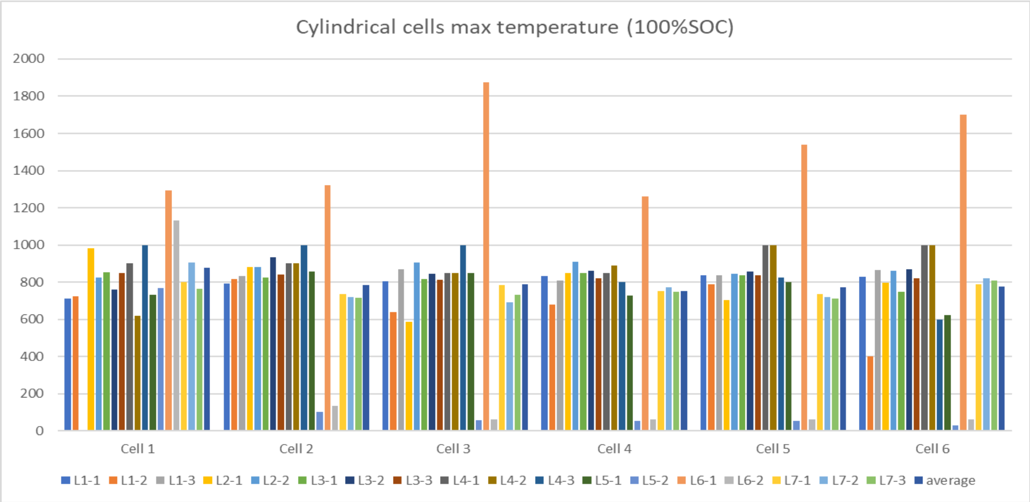


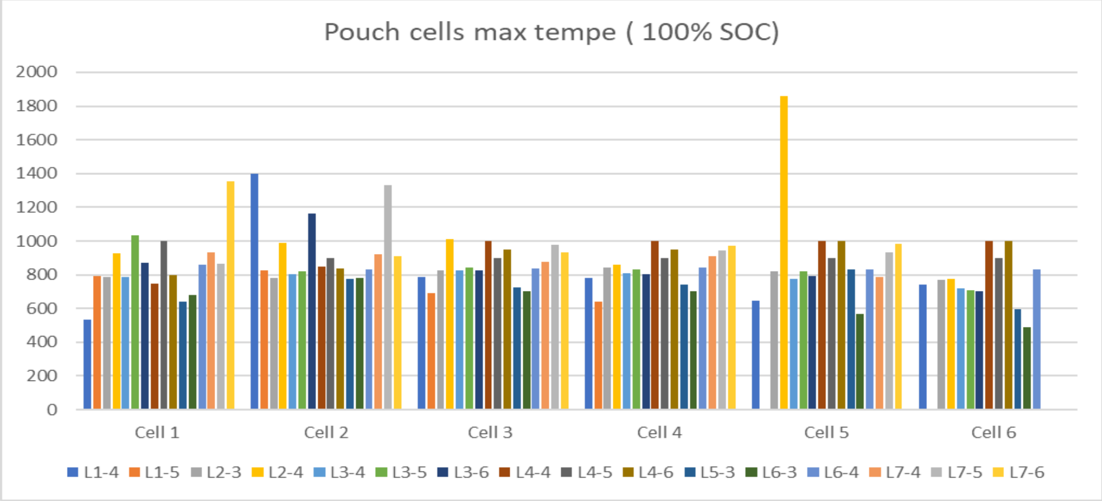
*Calculated based on the maximum temperature of cells/batteries and specific heat

Supporting data for the maximum TR reaction temperature

Report of the UN IWG testing labs results (circulated Dec 4, 2020).

The temperature measured statistically is around 1000°C maximum. This is significantly below the 1400°C calculated with a combustion energy of 7 kJ/Wh.





RECHARGE

Thank you

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