Thermal propagation

China
2019.01

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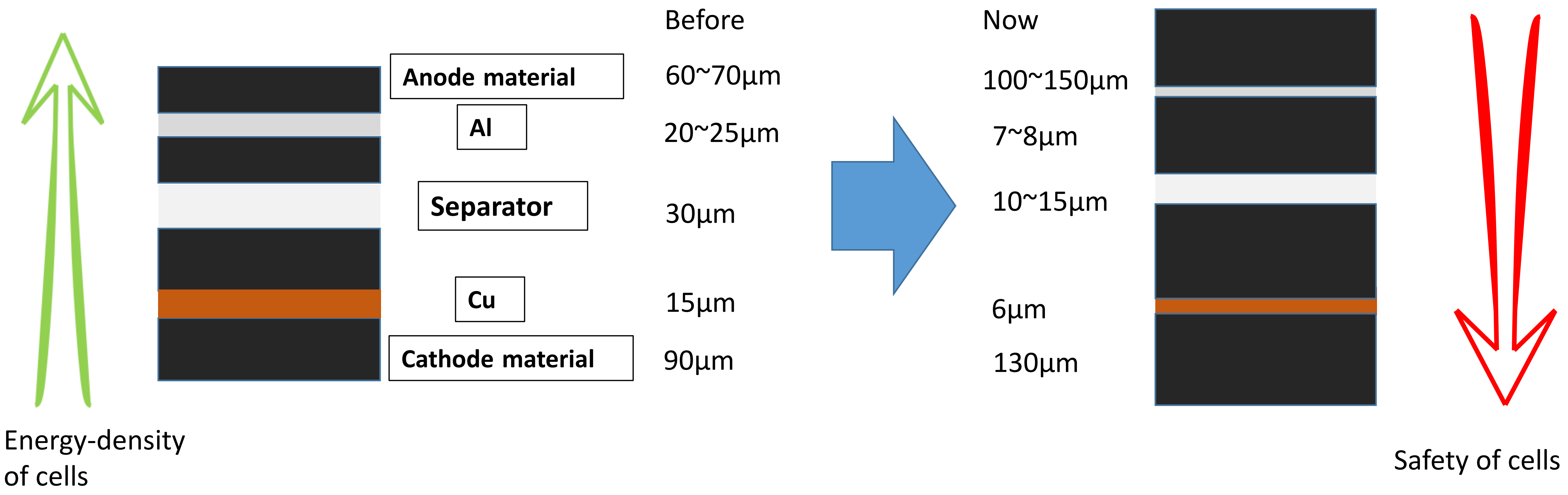
The necessity of thermal propagation

- Manufacturers devote themselves to improve energy density of batteries.
- Techniques firstly used by manufacturers to improve energy density of batteries is changing the parameters of the pole piece.

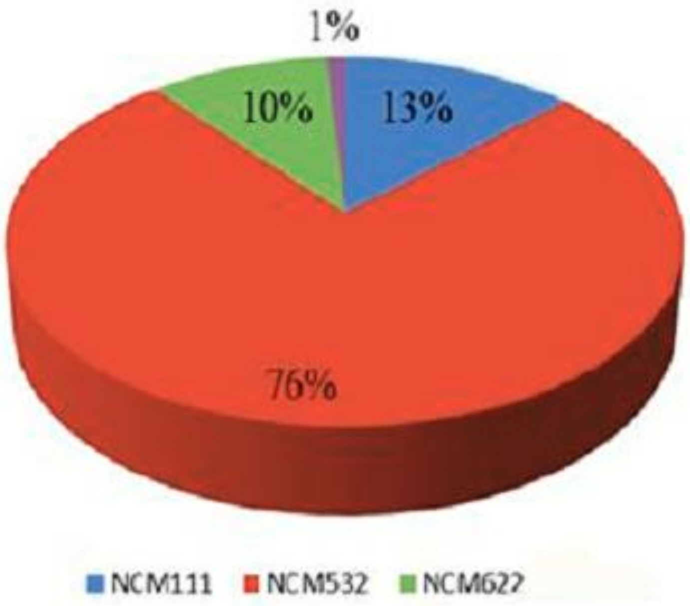


Thinner separator and thicker coating material increased risk of internal short circuit in the battery

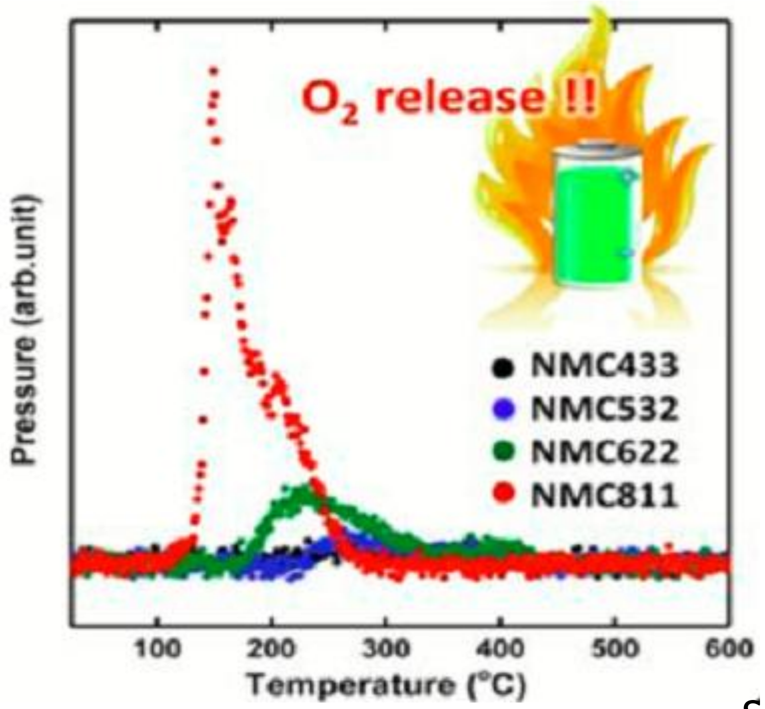
The necessity of thermal propagation

- Another techniques are used by battery manufacturers to improve energy density of batteries is the use of high nickel anode material.

High nickel anode material like 532、622、811are widely used.



The results show that the higher the content of nickel, the worse the thermal stability



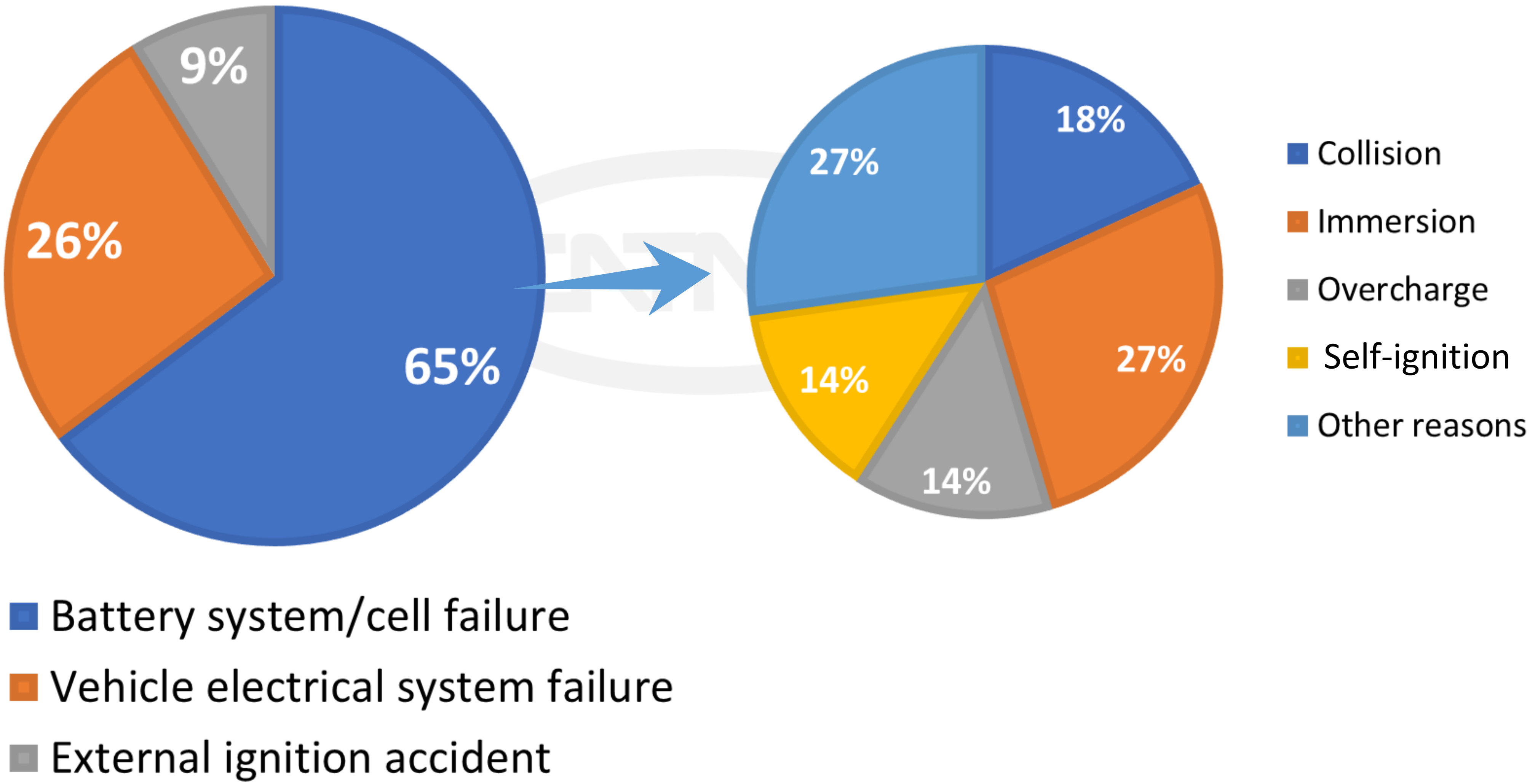
Energy-density of cells

Safety of cells

The results show that the higher the content of nickel, the worse the thermal stability

The necessity of thermal propagation

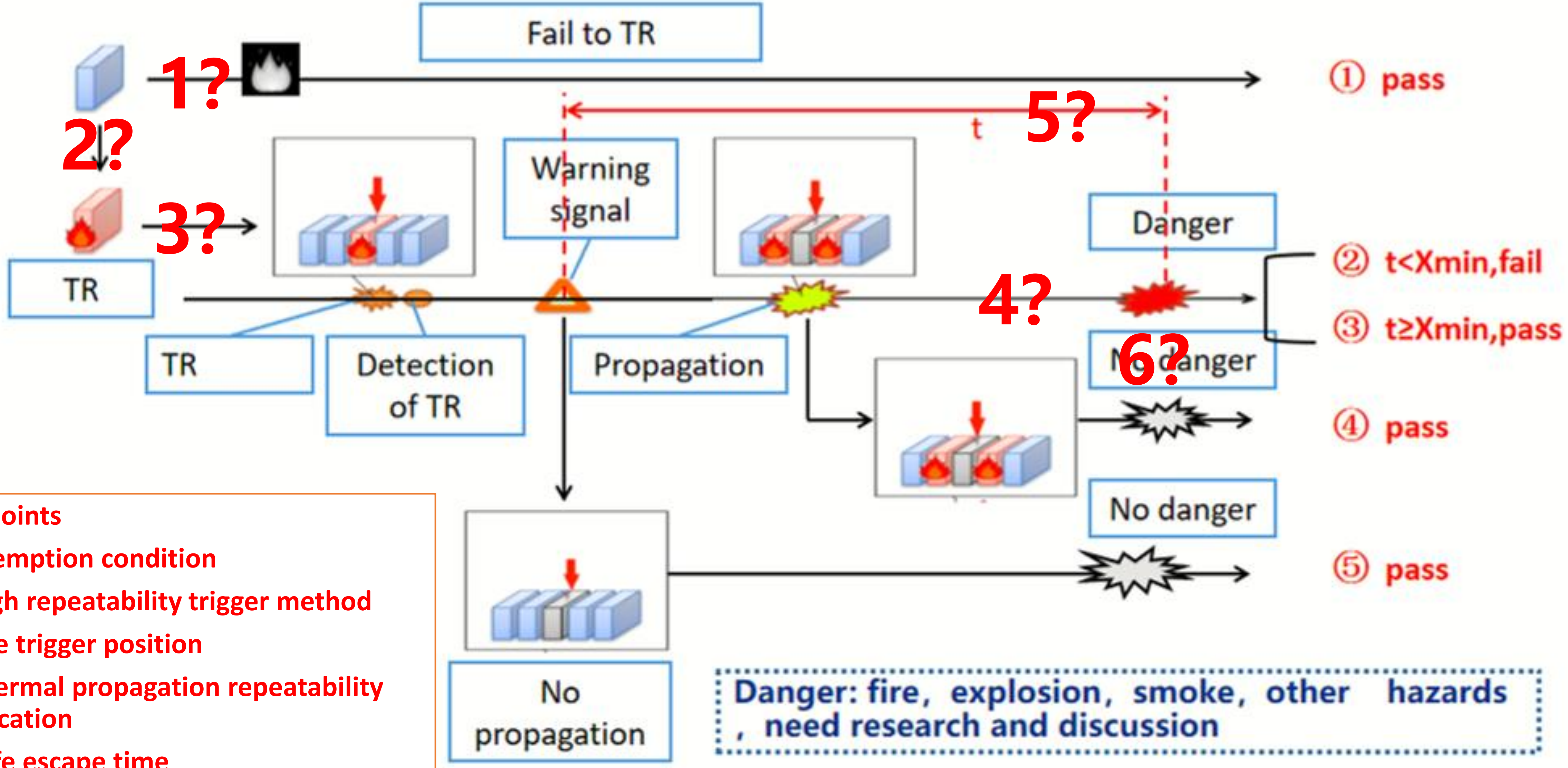
- Number of accidents： 34
- Data Sources： China Ministry of Industry and Information Technology



Specific questions in the white paper

No.	Questions	Note
(A)	Is thermal propagation due to an internal short single cell thermal runaway a problem in the field?	Important. But hard to get the field data because of the uncontrollable combustion.
(B)	Simulation of a single cell thermal runaway	Important. Purpose of this test, evaluates the ability of a DUT/vehicle to withstand a single cell thermal runaway caused by internal short circuit. The initiation method should simulate the internal short.
(C)	Elimination of Detection and Intervention Technologies	No.
(D)	Ignition of vented gases and other risks	No conflict
(E)	Evaluation Criteria	No conflict
(F)	Repeatability and Reproducibility	Important. How to evaluate?
(G)	Manipulation of test-device	Important. Depend on the test method.
(H)	Specifics of initiation methods and environmental conditions	Important. Depend on the test method. Which method is acceptable for simulate internal short circuit?
(I)	Re-testing and re-homologation	No conflict. Same as other tests.
(J)	Documentation requirements	No conflict.

Specific questions in the white paper



Danger: fire, explosion, smoke, other hazards , need research and discussion

Key points

1, Exemption condition

2, High repeatability trigger method

3, The trigger position

4, Thermal propagation repeatability verification

5, Safe escape time

6, Specific contents of the danger

Specific questions in the white paper

➢ We will continue to conduct research in the following areas

1, Exemption condition

When a single cell can pass some certain tests, or decided by energy density, material system, etc.

Present a proposal at the next meeting

2, High repeatability trigger method

Researching on the heating parameter with high repeatability by heating tests

Will show some research progress and all will be done in this year

3, The trigger position

Researching on the influence of trigger position by test and simulation

We will show some results in the next meeting

4, Thermal propagation repeatability verification

Japan has studied the repeatability for both heating and penetration, both showed good repeatability

China will also do these tests and hope to show some results in the last meeting this year

5, Safe escape time

It's 5 min in phase 1, China will continue to do some work.

6, Specific contents of the danger

Fire and explosion are definitely danger. Smoke and gas need further research.

Research progress of heating to initiate TR

➢ Research Process

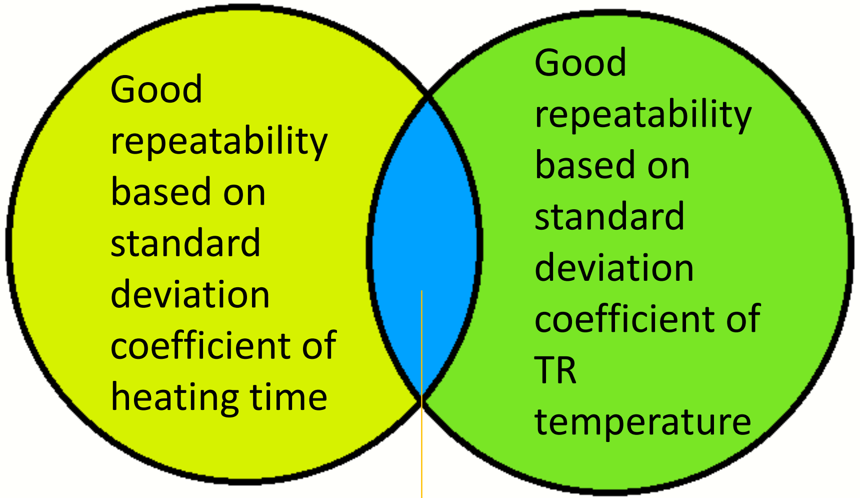
Type of cells	Heating power	Heating tests	Data analysis	Formula
Ternary cylinder Ternary pouch Ternary prismatic LFP cylinder LFP pouch LFP prismatic ……	Power 1 Power 2 Power 3 Power 4 Power 5 Power 6 Power 7 ……	Test 1 Test 2 Test 3 Test 4 Test 5	the standard deviation coefficient of heating time and thermal runaway temperature	For each type of cells, it is desirable to get a function of the heating power
Cell classification	Different heating powers for each type of cells	5 tests for each power	The standard deviation coefficient was calculated from the 5 tests for each power	Method is shown in the next slide

Research progress of heating to initiate TR

➢ Research Process

☐ Screening method for test conditions

All test conditions



Target conditions
Other necessary constraints(low applied energy, low heating time)

For different types of cells, it is desirable to get a function of the heating power related to the energy and weight of the cell to ensure the good repeatability of initiation and control the energy introduced into the system.

$$P_{heat} = f(E_{cell}, m_{cell})$$

Research progress of heating to initiate TR

➢ Research Process

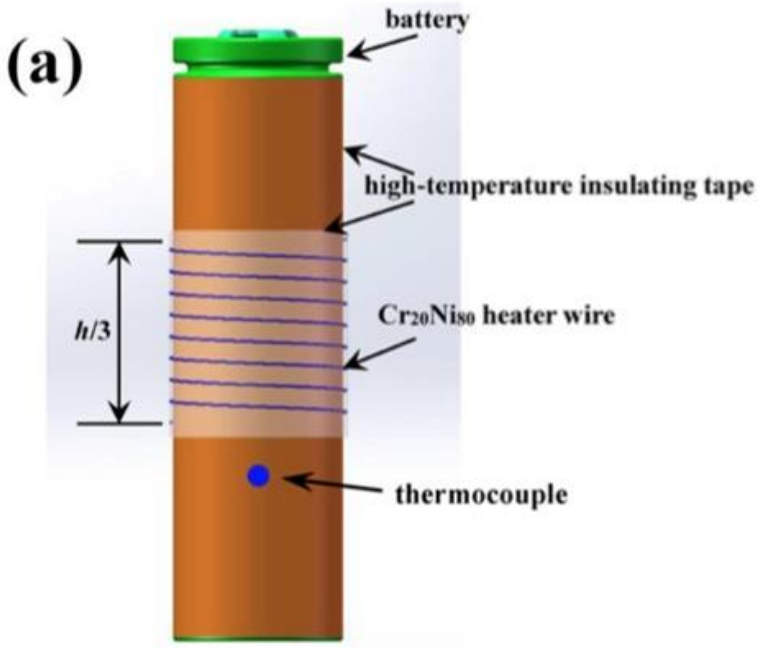
We plan to conduct testing and research on more than 15 products.

18650 Cylindrical		21700 Cylindrical		Pouch		Prismatic	
LFP	NCM	LFP	NCM	LFP	NCM	LFP	NCM
1#	3#	/	6#	7#	10#	13#	16#
2#	4#	/	/	8#	11#	14#	17#
/	5#	/	/	9#	12#	15#	18#

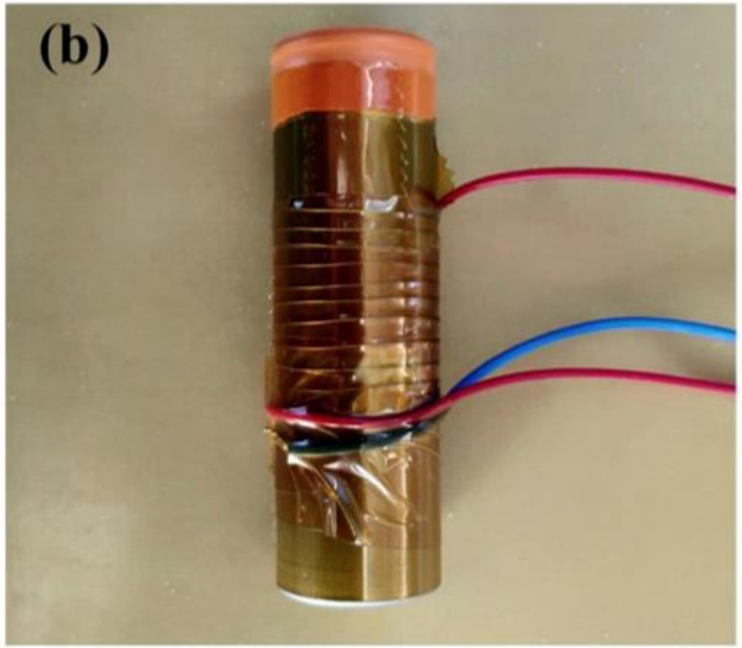
Plan to do
Researching
Finished

Research progress of heating to initiate TR

➢ **Test device and photo of heating for cylinder cells**



（a）Heating conditions for cylindrical cells



（b）Photo of test sample and device

Research progress of heating to initiate TR

➢ Samples and heating powers

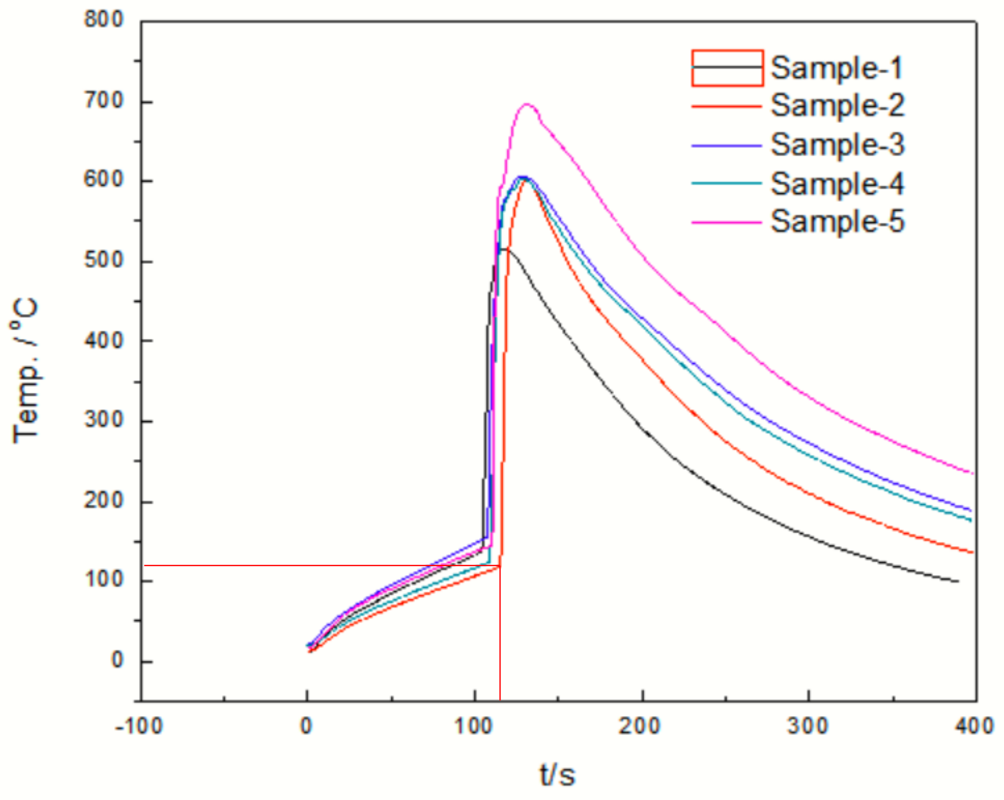
- ➢ 3 kinds of cylinder cell have been tested
- ➢ 7 heating powers were studied

18650-2.2Ah-7.92Wh、18650-3.0Ah-10.95Wh、21700-4.5Ah-16.20Wh							
Heating power	40W	60W	80W	100W	120W	140W	160W

Research progress of heating to initiate TR

➢ Analysis of data

Item	18650-3.0Ah-10.95Wh-80W	
No.	Heating time/s	Trigger temp./℃
1	104.00	145.30
2	110.00	116.60
3	106.00	160.70
4	107.00	133.30
5	108.00	150.20
Standard deviation	2.24	16.92
Average	107.00	141.22
Standard deviation coefficient	0.02	0.12



Research progress of heating to initiate TR

➢ Summary of test results and analysis

Sample	Heating power	40W		60W		80W		100W		120W		140W		160W	
	Item	Heating time/s	Trigger temp./℃	Heating time/s	Trigger temp./℃	Heating time/s	Trigger temp./℃	Heating time/s	Trigger temp./℃	Heating time/s	Trigger temp./℃	Heating time/s	Trigger temp./℃	Heating time/s	Trigger temp./℃
18650-2.2Ah-7.92Wh	Standard deviation coefficient	0.24	0.34	0.17	0.28	0.05	0.32	0.05	0.03	0.07	0.61	0.15	0.15	0.11	0.09
18650-3.0Ah-10.95Wh	Standard deviation coefficient	0.03	0.03	0.01	0.06	0.02	0.12	0.23	0.17	0.19	0.23	0.12	0.15	0.05	0.07
21700-4.5Ah-16.20Wh	Standard deviation coefficient	0.05	0.08	0.04	0.05	0.03	0.06	0.04	0.03	0.05	0.05	0.1	0.13	0.04	0.06

Research progress of heating to initiate TR

➢ **Photos of heating tests**

18650-2.2Ah-7.92Wh
heating power： 100W

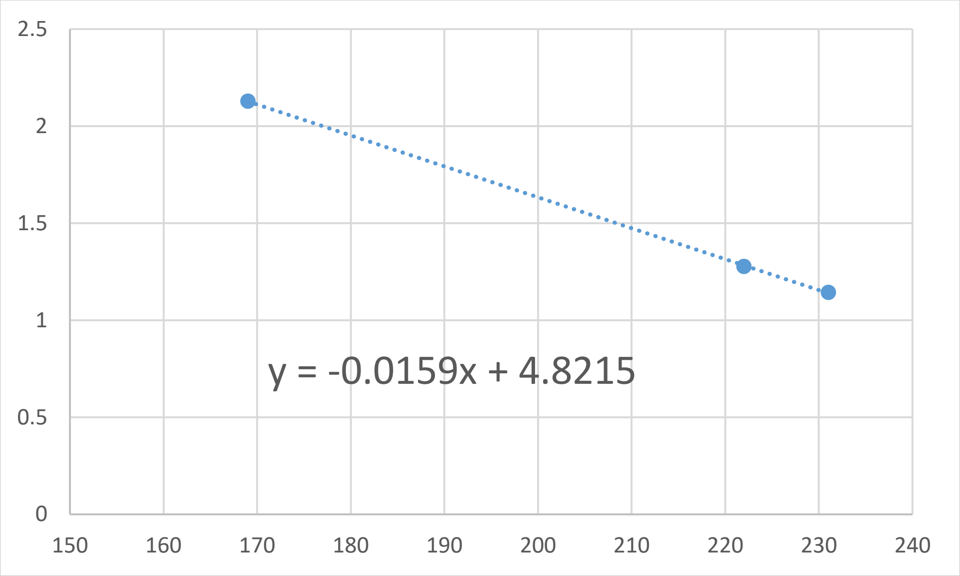
18650-3.0Ah-10.95Wh
heating power： 60W

21700-4.5Ah-16.20Wh
heating power： 100W

Research progress of heating to initiate TR

➢ **4 kinds of cylinder cells tested and a linear fitting was done to get a recommendation of beat heating power**

Sample	Mass（g）	Energy（Wh）	Heating power（W）	Energy density（Wh/kg)	Heating power/Mass （W/g）
18650-2.2Ah-7.92Wh	47	7.92	100	169	2.127659574
18650-3.0Ah-10.95Wh	47	10.8	60	222	1.276595745
21700-4.5Ah-16.20Wh	70	16.2	80	231	1.142857143



$$\frac{P_{heat}}{m_{cell}} = -0.0159\frac{E_{cell}}{m_{cell}} + 4.8215$$

$$P_{heat} = -0.0159E_{cell} + 4.8215m_{cell}$$

Research progress of heating to initiate TR

- For cylindrical batteries, we will continue to study the optimal heating power of another 3 kinds of batteries, verify the accuracy of the method, and further adjust the curve.
- Due to the limitations of the number of samples and tests, although not all heating conditions can be exhausted, it is sufficient to support the selection of heating power to ensure the high reproducability and repeatability of thermal runaway.
- The optimal heating power selection method for pouch and Prismatic cells will continue to be studied.

Research progress of self-heating

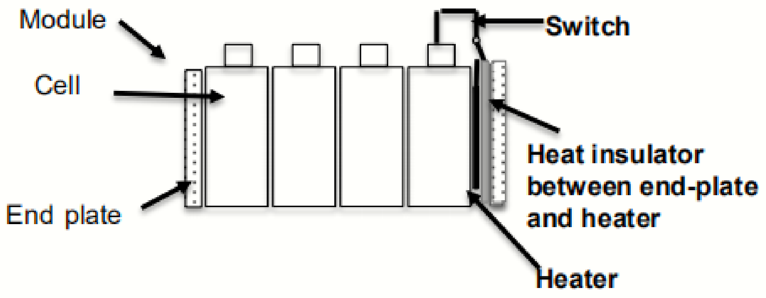
➢ Introduction

- The remarkable feature of this method is that there is no additional energy compared to a fully charged cell
- The purpose of this method is to use the energy discharged by the battery itself, heating a physical resistance to trigger the battery go to thermal runaway
- Easy for assembling
- Possible for automatic control
- …

Research progress of self-heating

➢Test set up： self-heating method

- Test procedure(brief，see the attachment for details)：
  - Assembly
  - Switch on, start self-heating
  - Switch off once thermal runaway



The resistor we used in this

Type	Dimension	Rated capacity	Suitable cell
Metal insulated	130*90*3mm	300~600w (approx. 5 w/cm^2)	Pouch & Prismatic

Proposed heater selection rule

- The resistance sealed without "heated and flushed metal" exposure
- Resistor selection: wouldn't melt cell can/pouch package, and heating power should smaller than the continuous current interrupter that the cell can bear, but enough for thermal runaway initiation
- The heater should parallel to the cell surface, and similar area with the contacted cell surface is preferred, which wouldn't lead additional gap between cell-cell or cell-end plate.
- …

Research progress of self-heating

➢Test set up： self-heating method （detailed draft）

Pre-condition	• Temperature: 25±2℃ • Humidity: 15%~90% • Air condition: ≤10m/s • Voltage acquisition accuracy: ±0.5mV • Atmospheric pressure : 86kpa~106kpa • Resistance acquisition accuracy:±2mΩ
Process	① Module preparing 1.Choose suitable heater, proposed heater selection rule: a)The heater wouldn't melt cell can package, and heating power should smaller than the continuous current interrupter that the cell can bear, but enough for thermal runaway initiation. b)The heater should parallel to the cell surface, and similar area with the contacted cell surface is preferred, which wouldn't lead additional gap between cell-cell or cell-end plate. 2.Assemble self-heating resistance in the end of module by modifying module. ② Propagation test 1.Connect the self-heating resistance with the initiation cell, which is from the positive electrode (or negative electrode) to the heating resistance, see Figure 1 2.Any external wires need be acquired, which provides the way to charge the disperse units of the modified module. 3.Heating area of the self-heater is directly contacting the cell surface and it is not larger than the surface of that. 4.The heater position is correlated with the temperature sensor position, which is described in Figure 2. 5.The state of charge (SOC) shall be adjusted. 6.After installation, the self-heater should be reached to its fixed power, which depends on the energy of the battery pack. 7.Turn off the switch, when thermal runaway occurs. The current and voltage should be observed in period.. 8.The test shall be conducted at an indoor test facility or in a shelter to prevent the influence of wind.

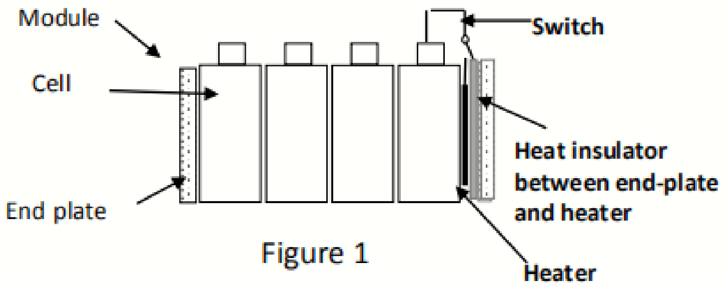


Figure 1

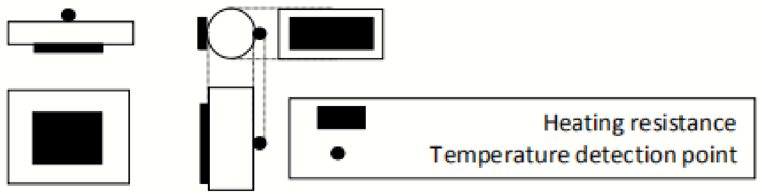
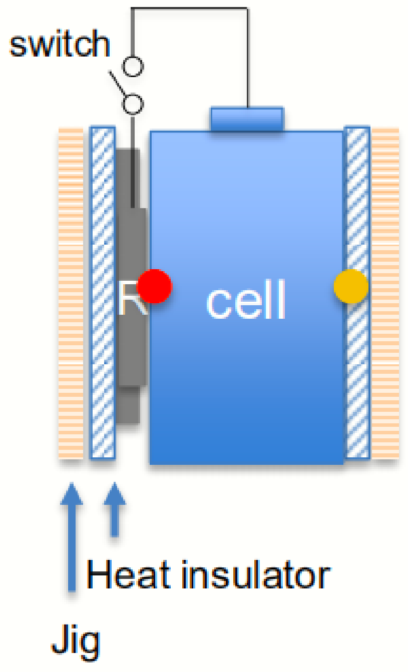


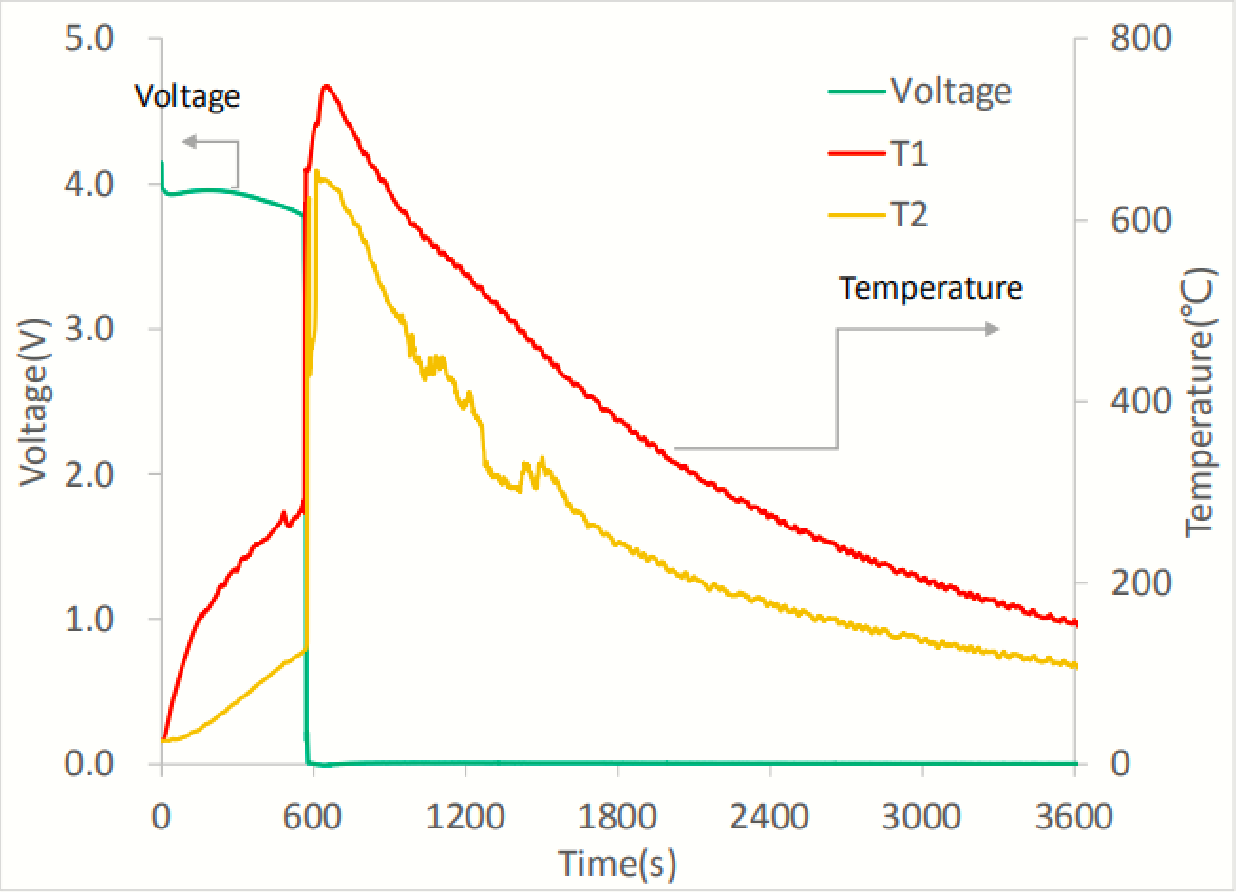
Figure 2

Research progress of self-heating

➢ Single cell test result_ An example

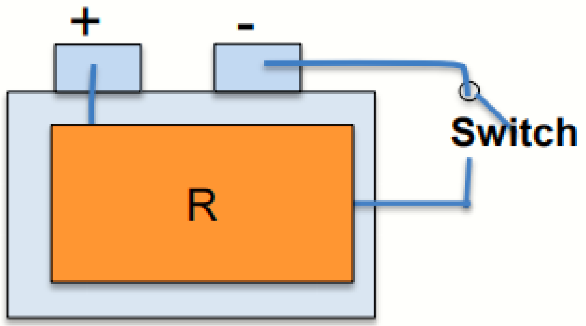
- Prismatic





Research progress of self-heating

➢ Energy transformation



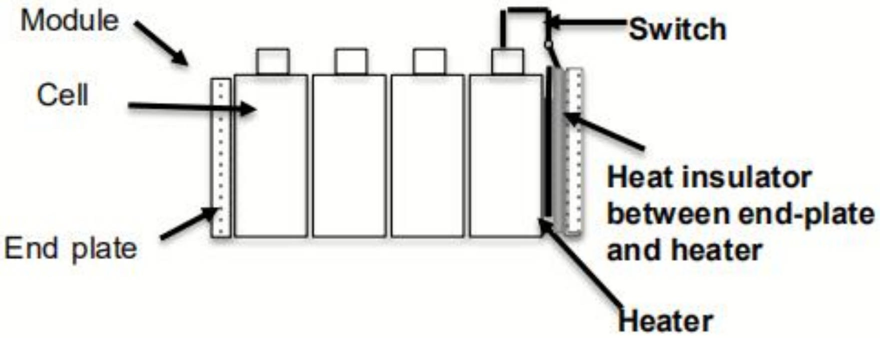
- **Q : Energy release before cell thermal runaway**, $Q = \int_0^{t1} i dt$
- **Q_b : Total Energy absorbed by the heating resistance**, $Q_b = \int_{T0}^{T1} C_{p\_h} * m_h * dT$
- **Q_c : Dissipated heat with the environment**, $Q_c = \int_{T0}^{T1} h * A dT$, h=5 W/(m²*K)
- **Q_d: Radiant Energy**, $Q_d=\varepsilon*A*\sigma*(T_1^4-T_2^4)$, $\sigma=5.67*10^{-8}W/(m^2*K^4)$

Sample	Q(kJ)	Q_b(kJ)	Q_c(kJ)	Q_d(kJ)	$(Q_b+Q_c+Q_d)/Q$
Example	~198.4	~5.1	~2.3	~1.9	~4.7%

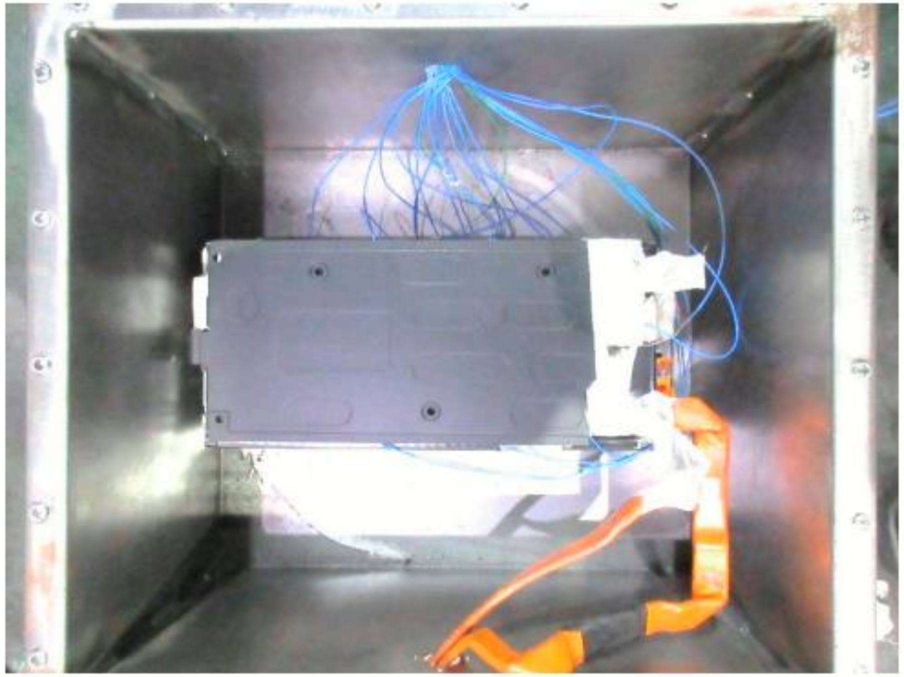
Research progress of self-heating

➢Module level test result _ An example

- Prismatic module-1
  - 1P4S



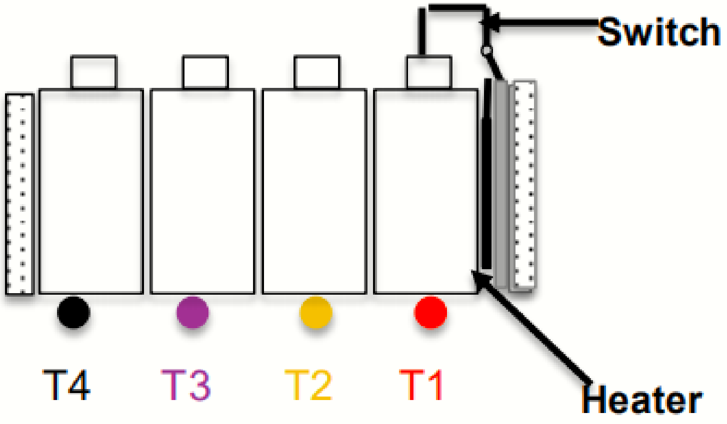
- Triggered cell :
  - ~95%SOC
- Measured data include :
  - Cell and module voltage
  - Bottom temperature of the cell
  - Photographs before , during and after the test

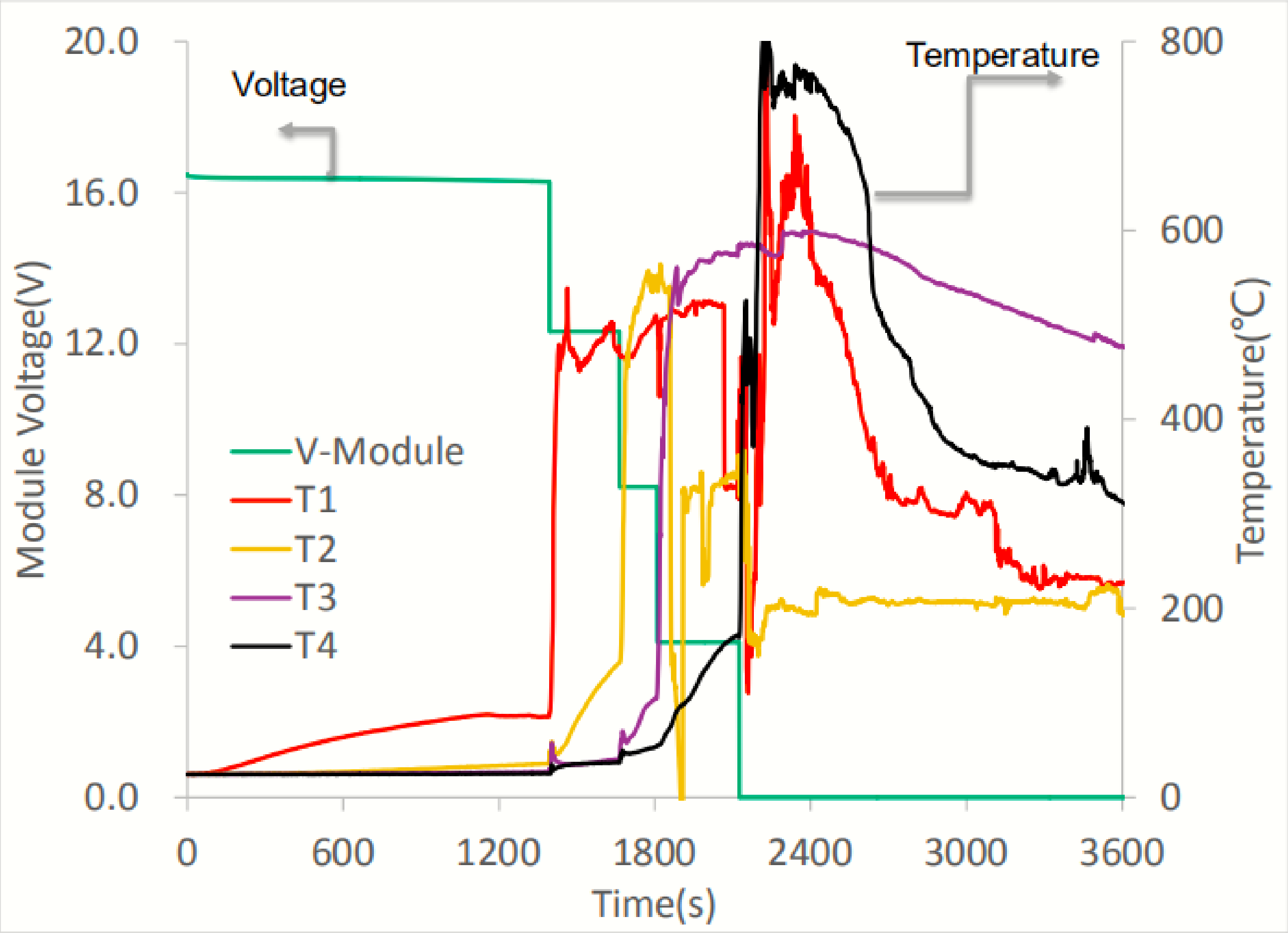


Research progress of self-heating

➢Demo pack test result _ An example

- Thermal runaway propagated to the other cells.





Research progress of self-heating

➢Summary

- Draft heater selection rules have been proposed
- No additional energy during the Self-Heating test， and most of the energy(normally <5% heat capacity effect and heat dispersant) is re-entered into the battery by Self-Heating;
- We will continue to study the method, including heater development, procedure standardize and automatic control switcher etc.

Main content of the next meeting

1，Proposal of Exemption condition

2，Research progress of heating to initiate TR

3，Partial results of research of the influence of trigger position

Thanks for your attention!