# Thermal propagation

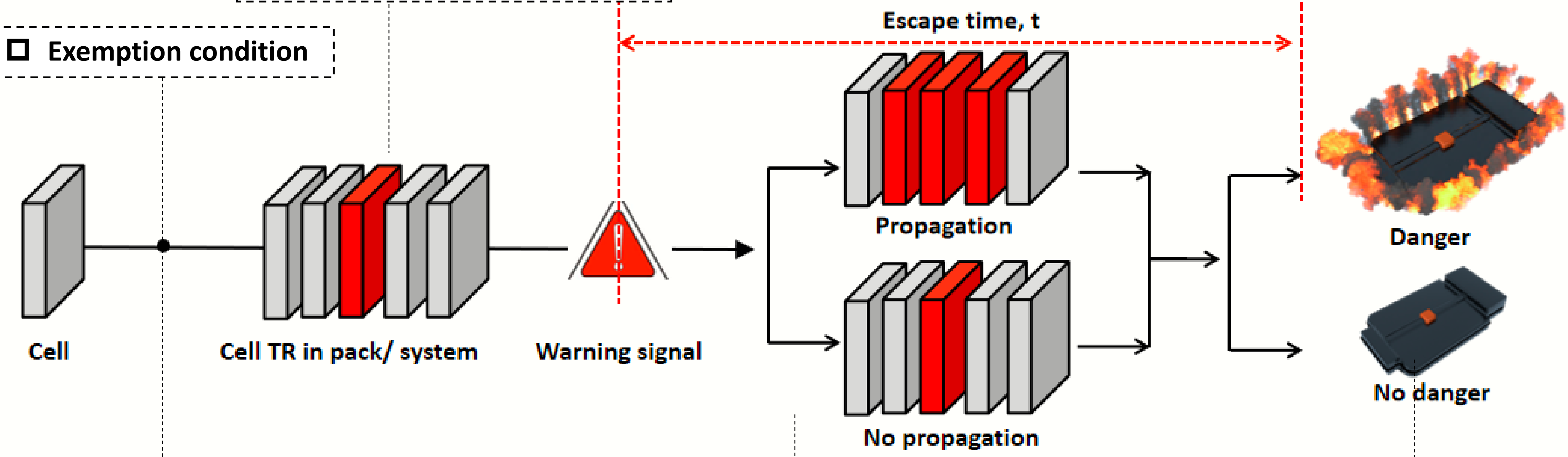
China
2019.06

# Thermal propagation process and problems to be solved

**☐ Escape time** EVSTF-08-57e by JP&KR&CN
- ➢ How long is enough for different applications?

**☐ Trigger target and position**
- ➢ Worst case & Operational, under research

**☐ Exemption condition**




**☐ Trigger method:**
- ➢ Mechanism of TR, under research
- ➢ **Trigger method** CA/JRC/JP/KR/CN
- ➢ **Repeatability of TR** EVS1541-616 [CHN]
- ➢ **Influence to TP of trigger method**

**☐ Repeatability of results of TP**
- ➢ Same method for same sample
- • EVS16-E1TP-0600 [JP],EVS1532-611 [JP]
- ➢ Different method for same sample

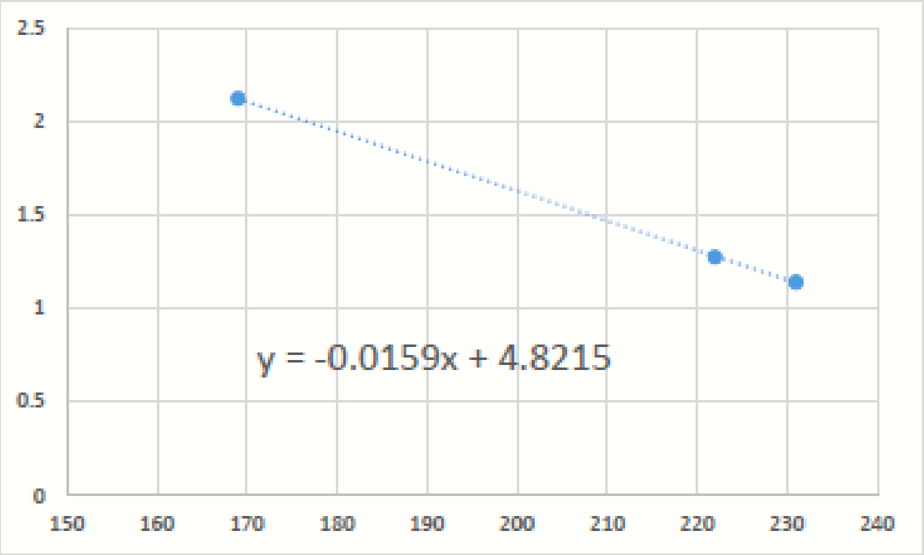
**☐ Specific contents of the danger**
- ➢ Fire or explosion, confirmed
- ➢ Toxic and combustible smoke, under research.

# Contents

# Research progress of heating to initiate TR

- **At the last meeting, we showed the test results of 3 kinds of cylindrical cells and obtained a preliminary results.**

| 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

## ➢ Experimental study on the 4th cylindrical cell to verify the conclusion of the previous test

## ➢ Sample information

- **21700 Cylindrical NCM**
- **Capacity： 4.8Ah**
- **Mass： 73.0±0.5**
- **Internal resistance： ≈15mΩ**

## ➢ Test result

| 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./℃ |
| 21700-4.8Ah-17.28Wh | Standard deviation coefficient | 0.13 | 0.07 | 0.16 | 0.11 | 0.05 | 0.09 | 0.12 | 0.09 | 0.13 | 0.12 | 0.18 | 0.12 | 0.16 | 0.14 |

# Research progress of heating to initiate TR

➢ **The photoes of the 4th cylindrical cell**

**Before**

**After**

21700-4.8Ah-17.28Wh

**heating power： 80W**

# Research progress of heating to initiate TR

- **The 4th kind of cylinder cell was tested and a linear fitting was done**

| Sample | Mass（g） | Energy（Wh） | Heating power（W） | Energy density（Wh/g) | Heating power/Mass （W/g） |
|---|---|---|---|---|---|
| 18650-2.2Ah-7.92Wh | 47 | 7.92 | 100 | 0.169 | 2.127659574 |
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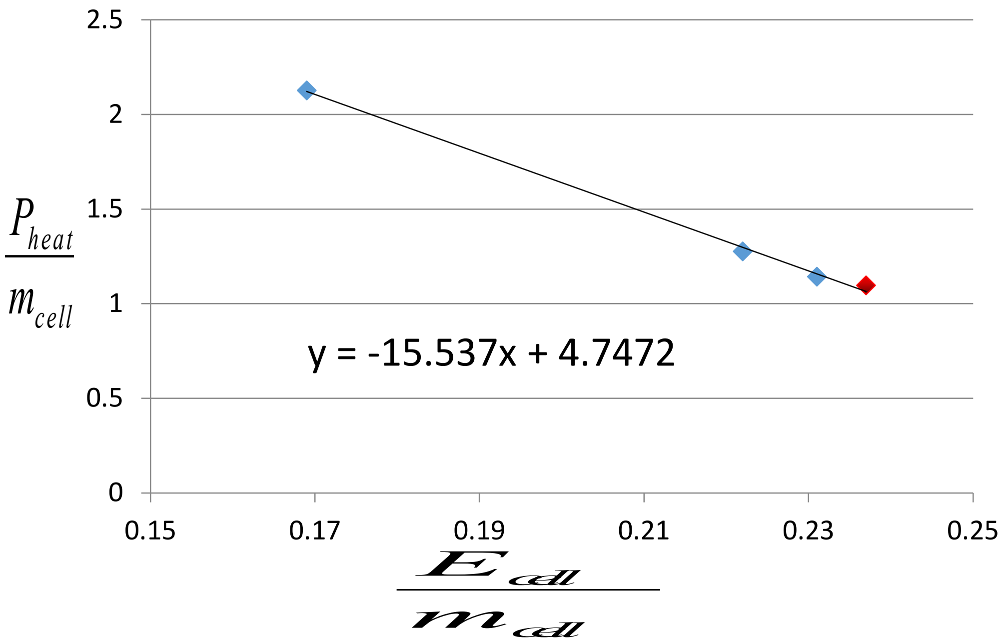
| 21700-4.8Ah-17.28Wh | 73 | 17.28 | 80 | 0.237 | 1.095890411 |




$$\frac{P_{heat}}{m_{cell}} = -15.537\frac{E_{cell}}{m_{cell}} + 4.7472$$

$$P_{heat} = -15.537E_{cell} + 4.7472m_{cell}$$

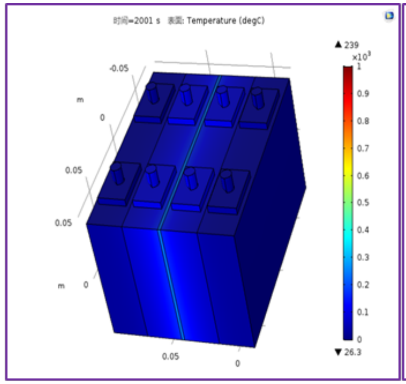
# Research progress of heating to initiate TR

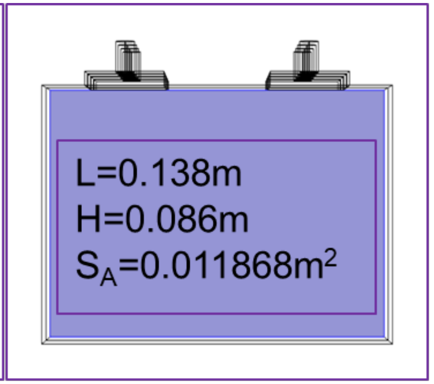
- **This formula is valid for cylindrical NCM/graphite lithium ion cells.**
- **As the energy density gets higher, there will be an inflection point, and we will clarify this inflection point through further experiments next meeting.**

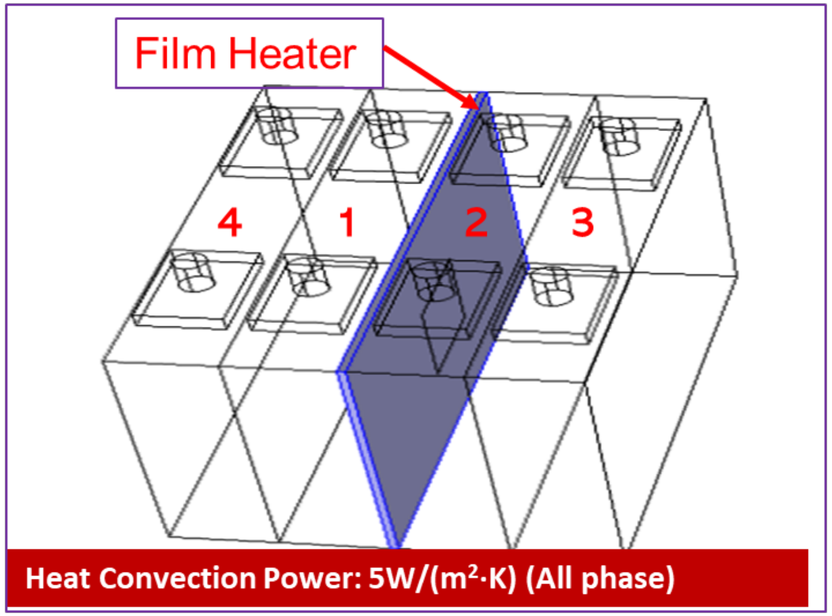
# Contents

# The influence of heating power to the results of TP

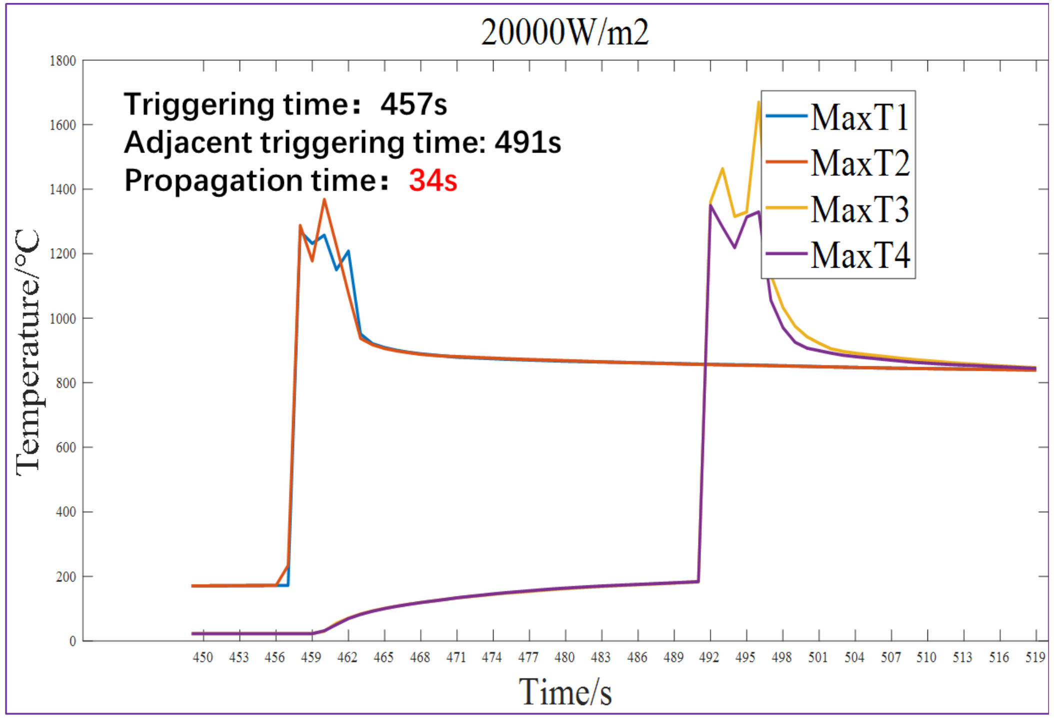
## ➢ Simulation research






- Total battery energy: 600000 J;
- Battery constant heat capacity: 1100J/(Kg·K);
- Density: 2100kg/cm3;
- Air gap between batteries: 5mm;
- Ambient temperature 25 °C;
- TR temperature： 150℃。



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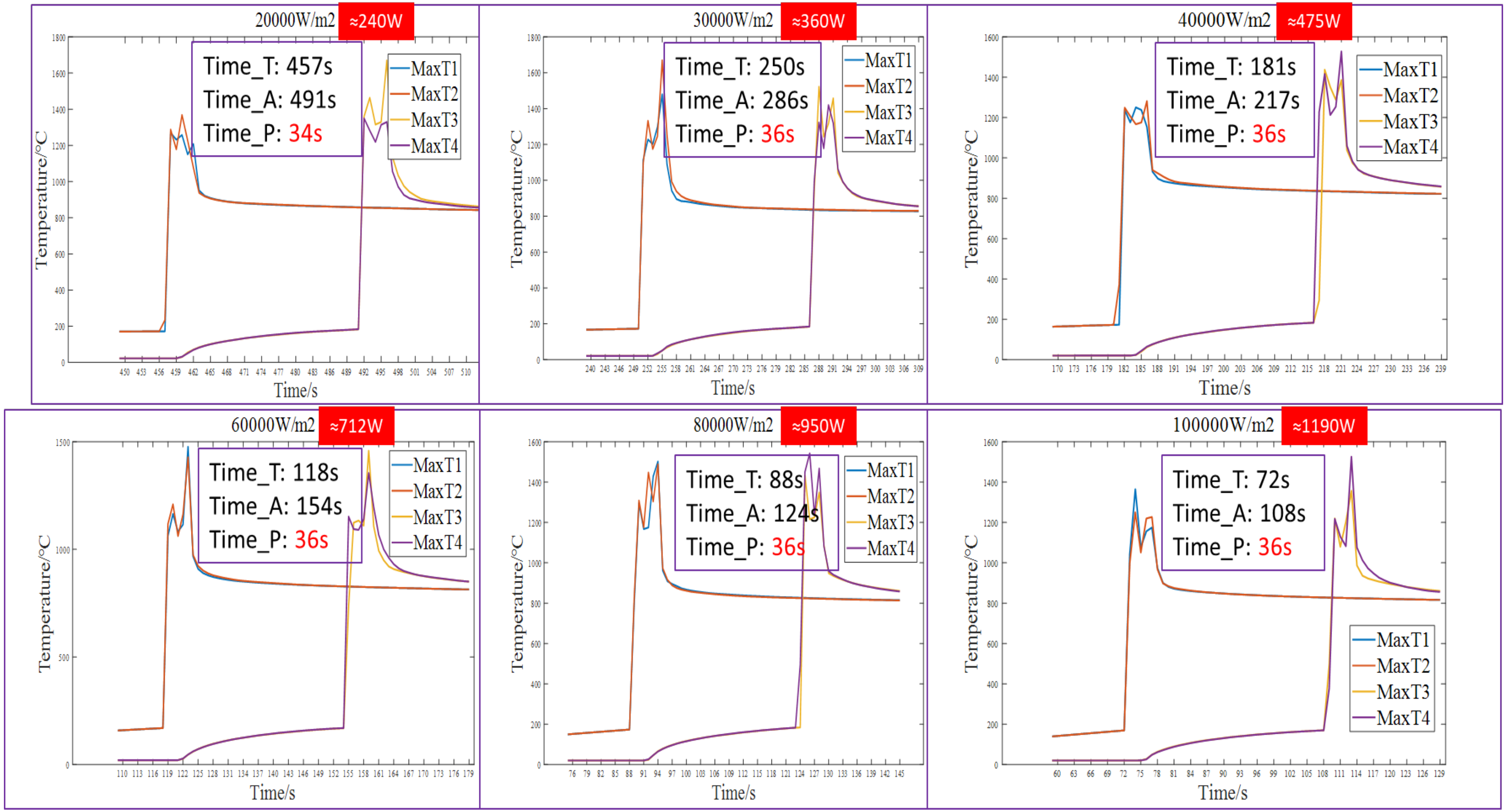

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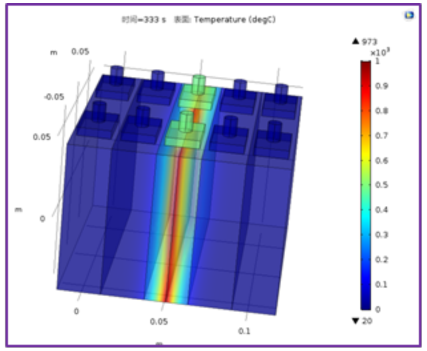

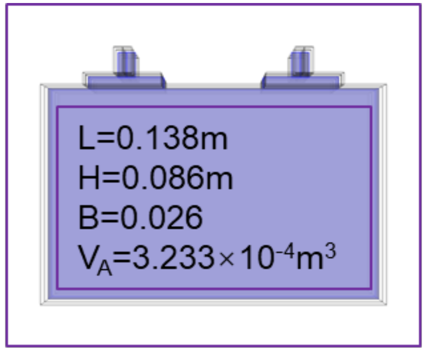


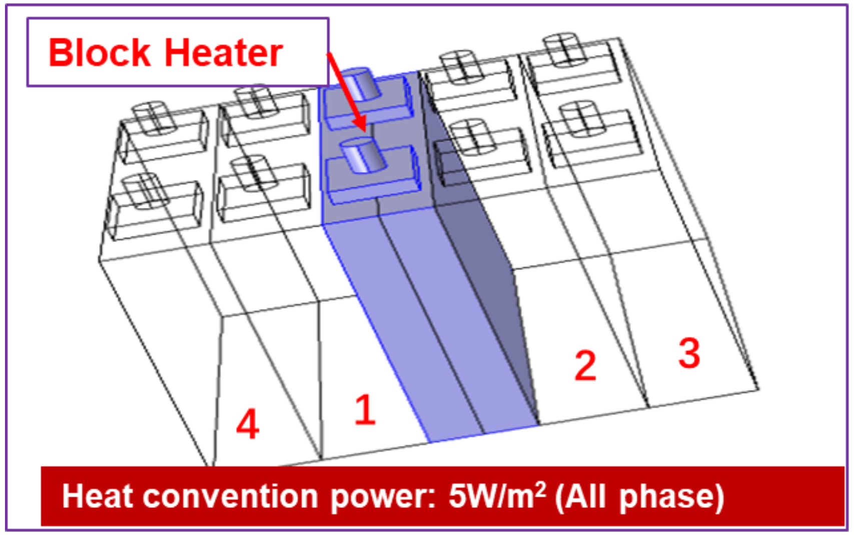


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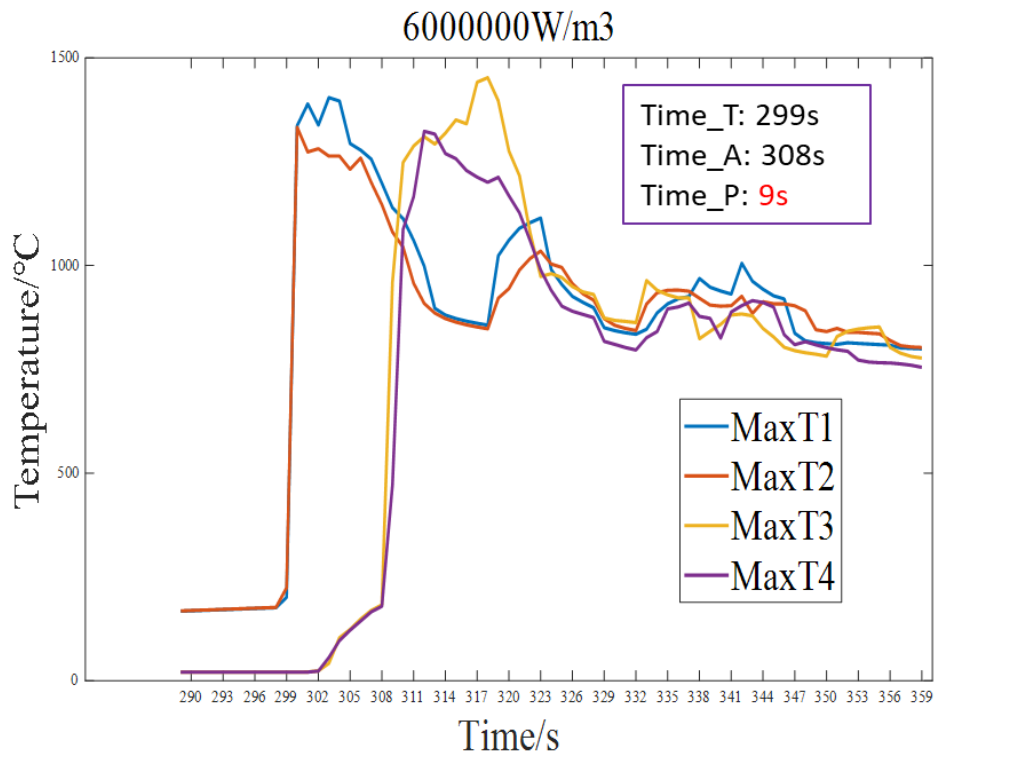

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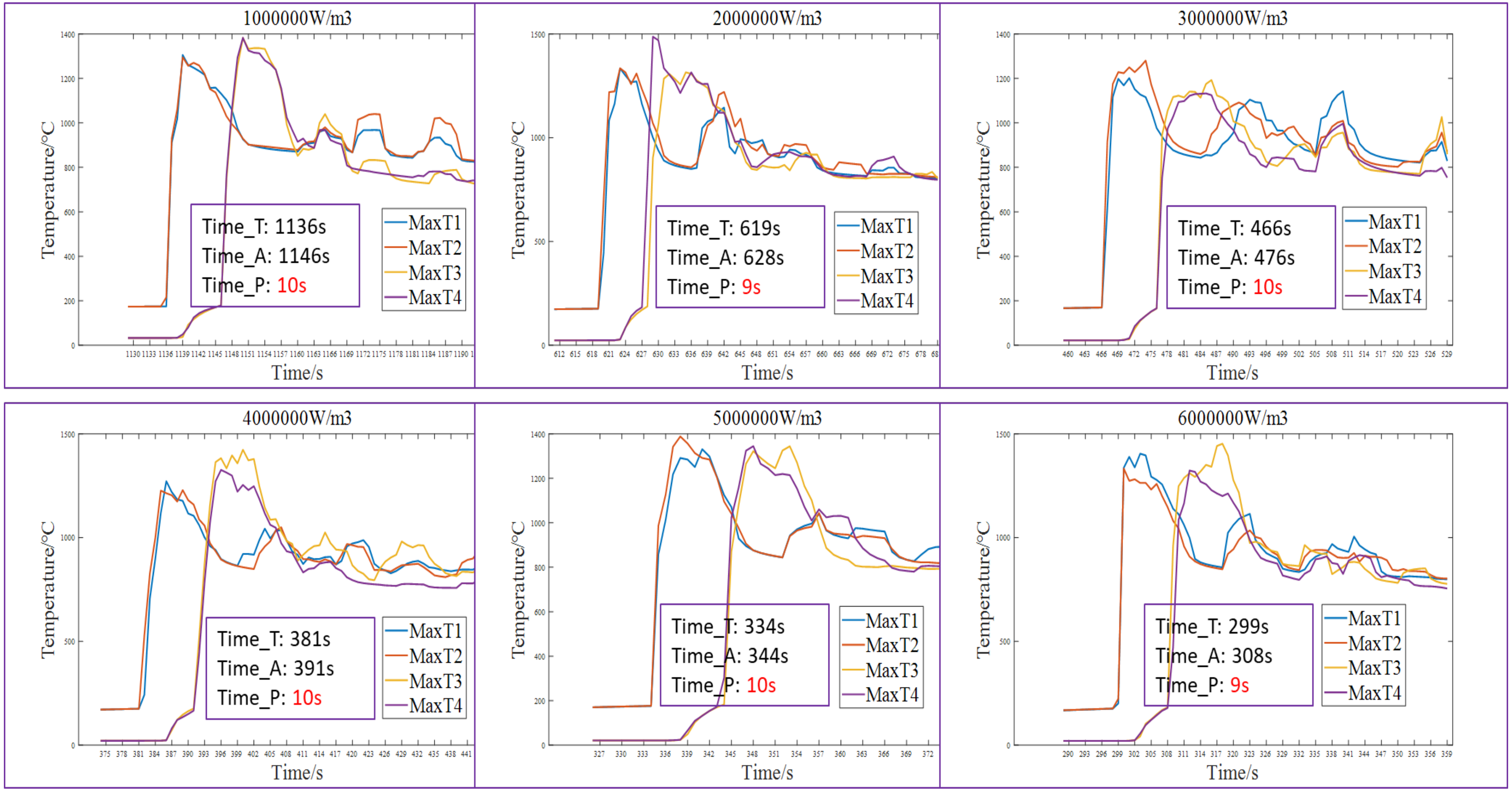
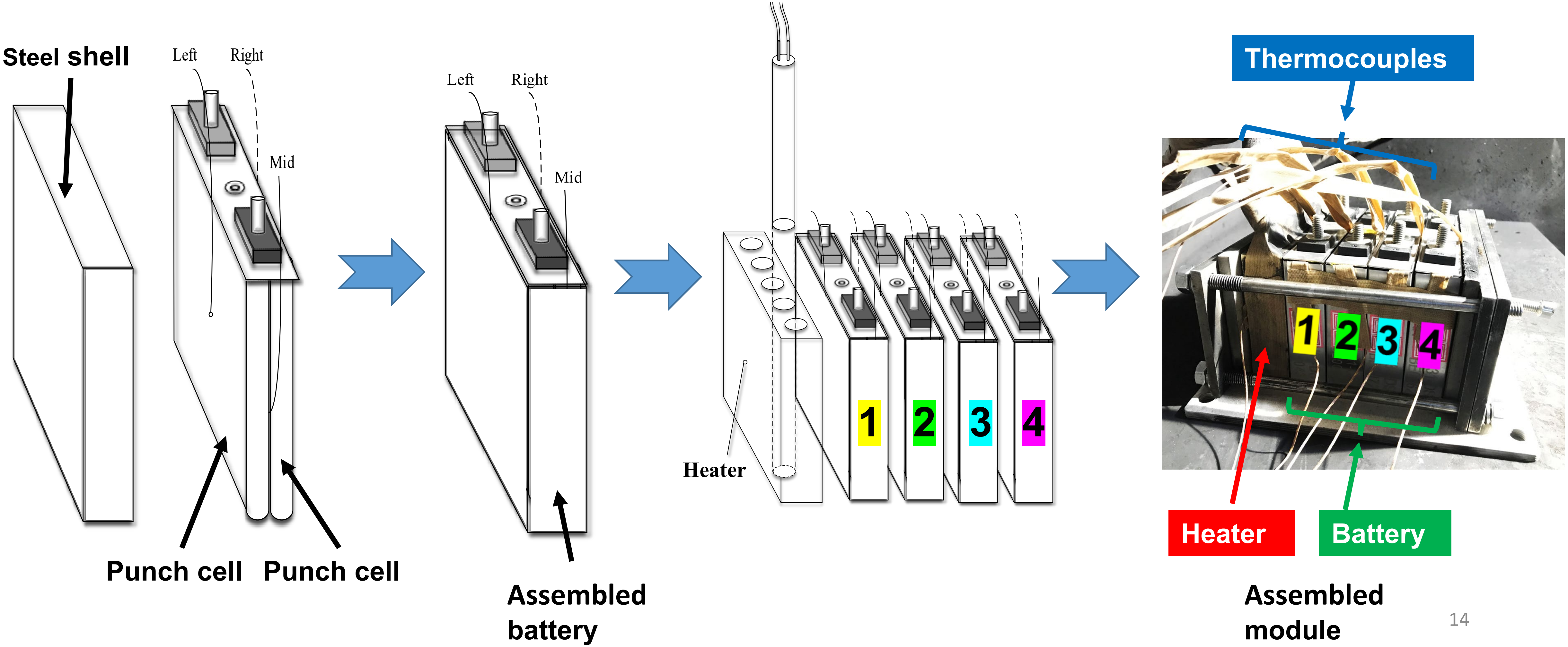


# The influence of heating power to the results of TP

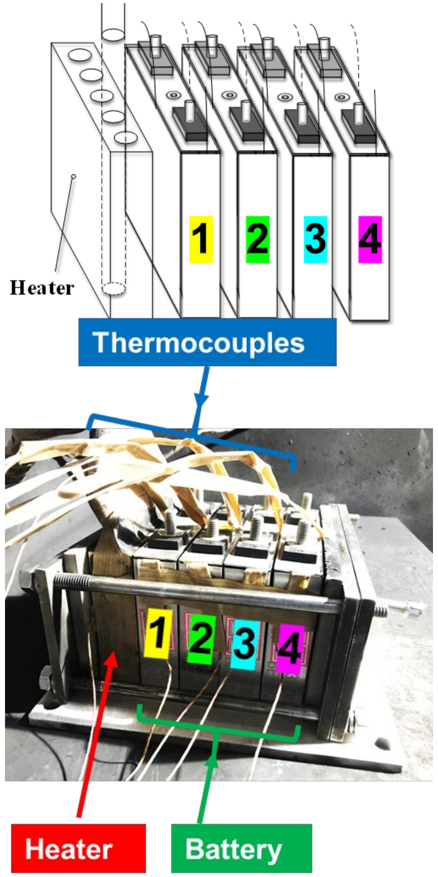
## ➢ Experimental research

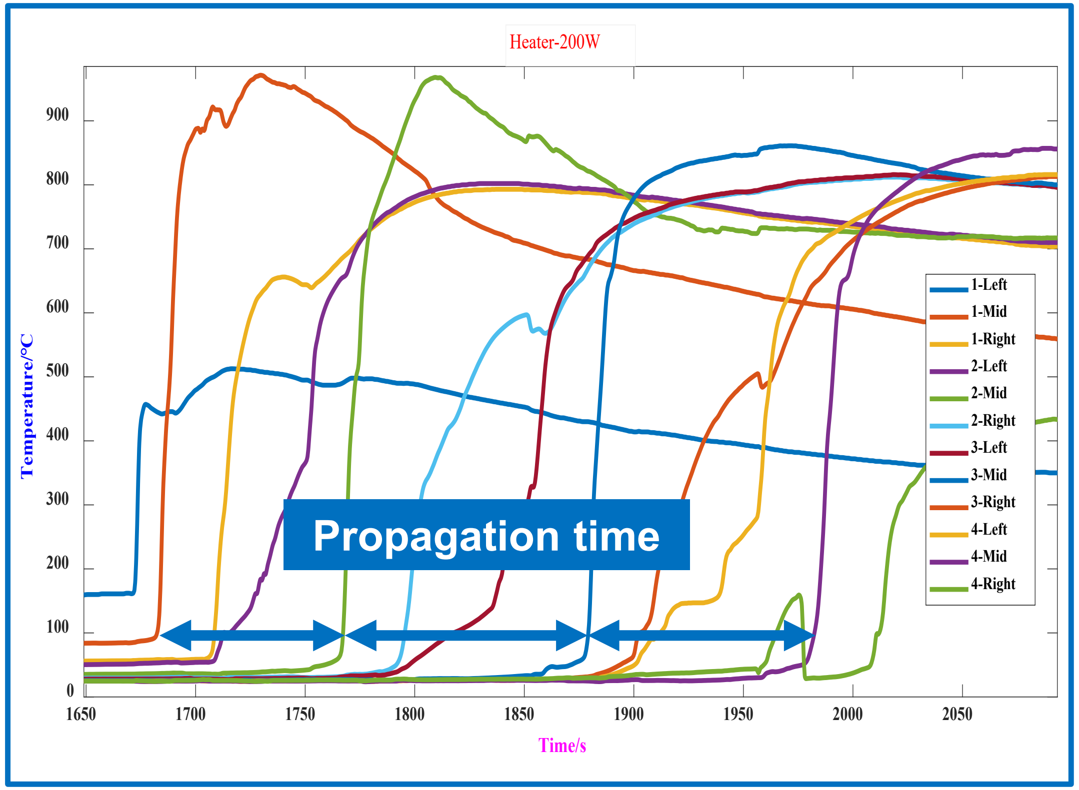


# The influence of heating power to the results of TP

## ➢ Experimental research

- Cathode：NCM；
- Anode：graphite；
- cell Capacity：25Ah；
- SOC：100%；
- Cell voltage range：2.5-4.2V
- Cell mass：720g；
- Battery dimension: L148mm * H89mm * T28mm



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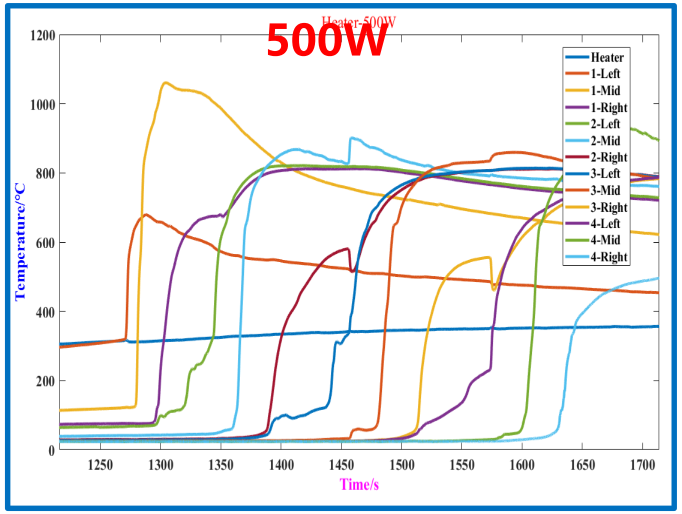
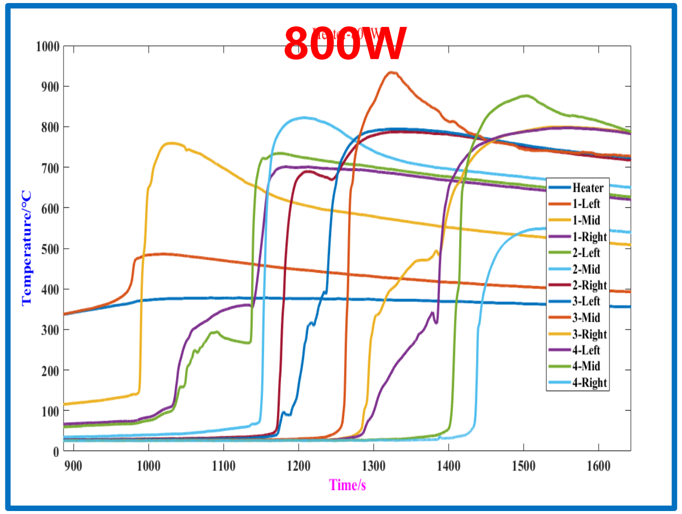
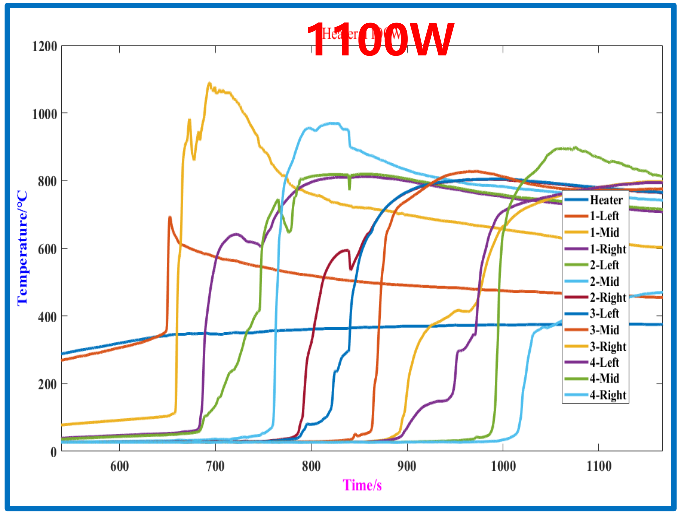
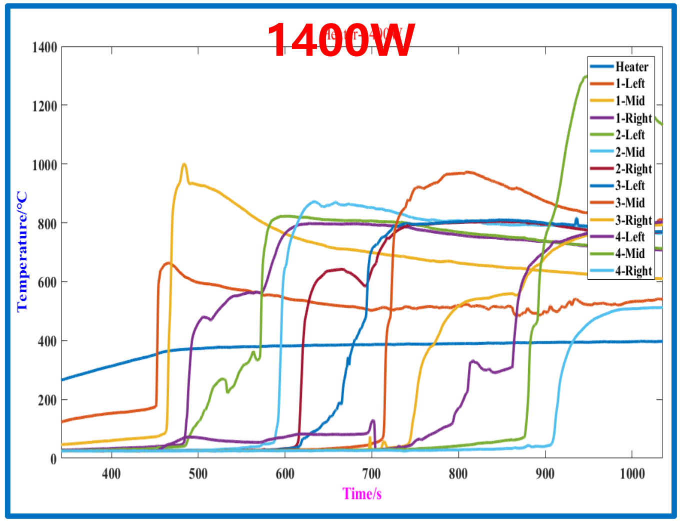
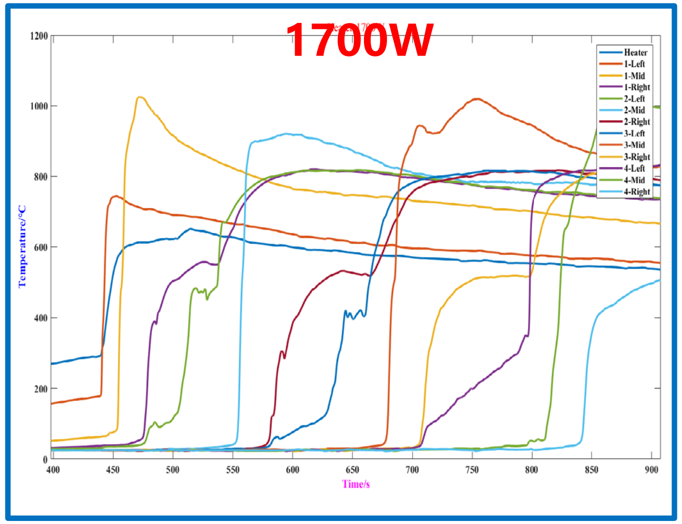
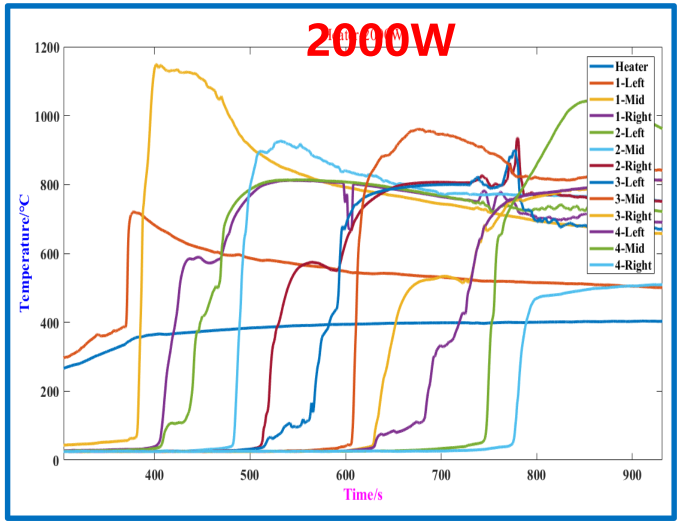


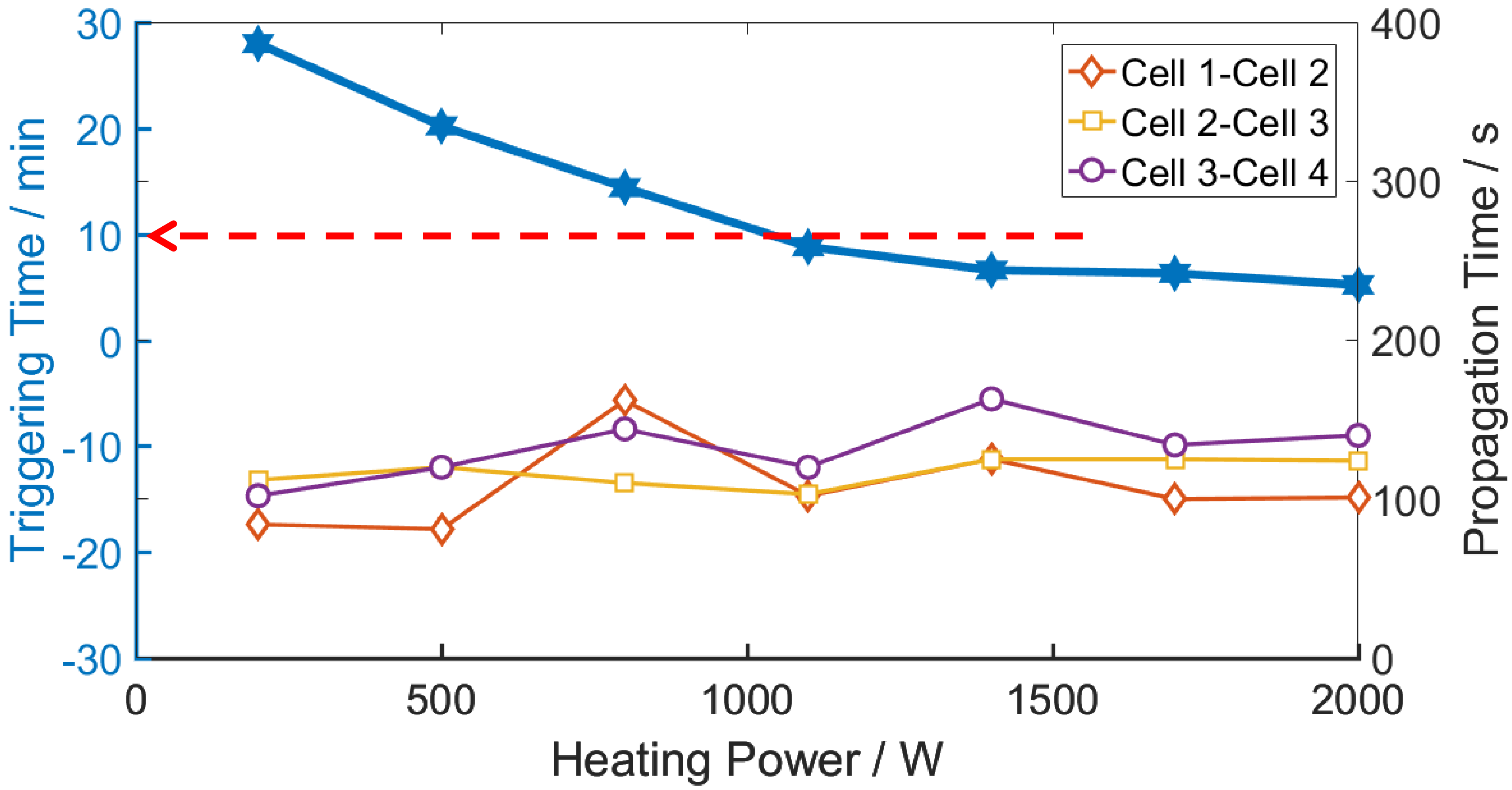



# The influence of heating power to the results of TP

- **Experimental research**



# The influence of heating power to the results of TP

- **The heating power in the test had limited influence on the results of TP.**
- **When the heating time is controlled within 10 min, the heating power has limited influence on the triggering time.**
- **So for a Prismatic cell, the recommended heating power is:**

$$P_{heat} = k\frac{C_{\mathrm{p}} \bullet m_{cell} \bullet \Delta T}{\Delta t}$$

$$k \geq 6$$

$$\Delta t \leq 600s$$

# Contents

# Self-Triggering Method Research Update

## ➢Background

- Name change, “Self-heating” method → “Self-Triggering” method
- The purpose of this method is to use the energy by the battery itself, heating a physical resistance to trigger the battery go to thermal runaway
- The remarkable feature of this method is that there is no additional energy compared to a fully charged cell
- Optimization of test set up and test condition, easy for assembling

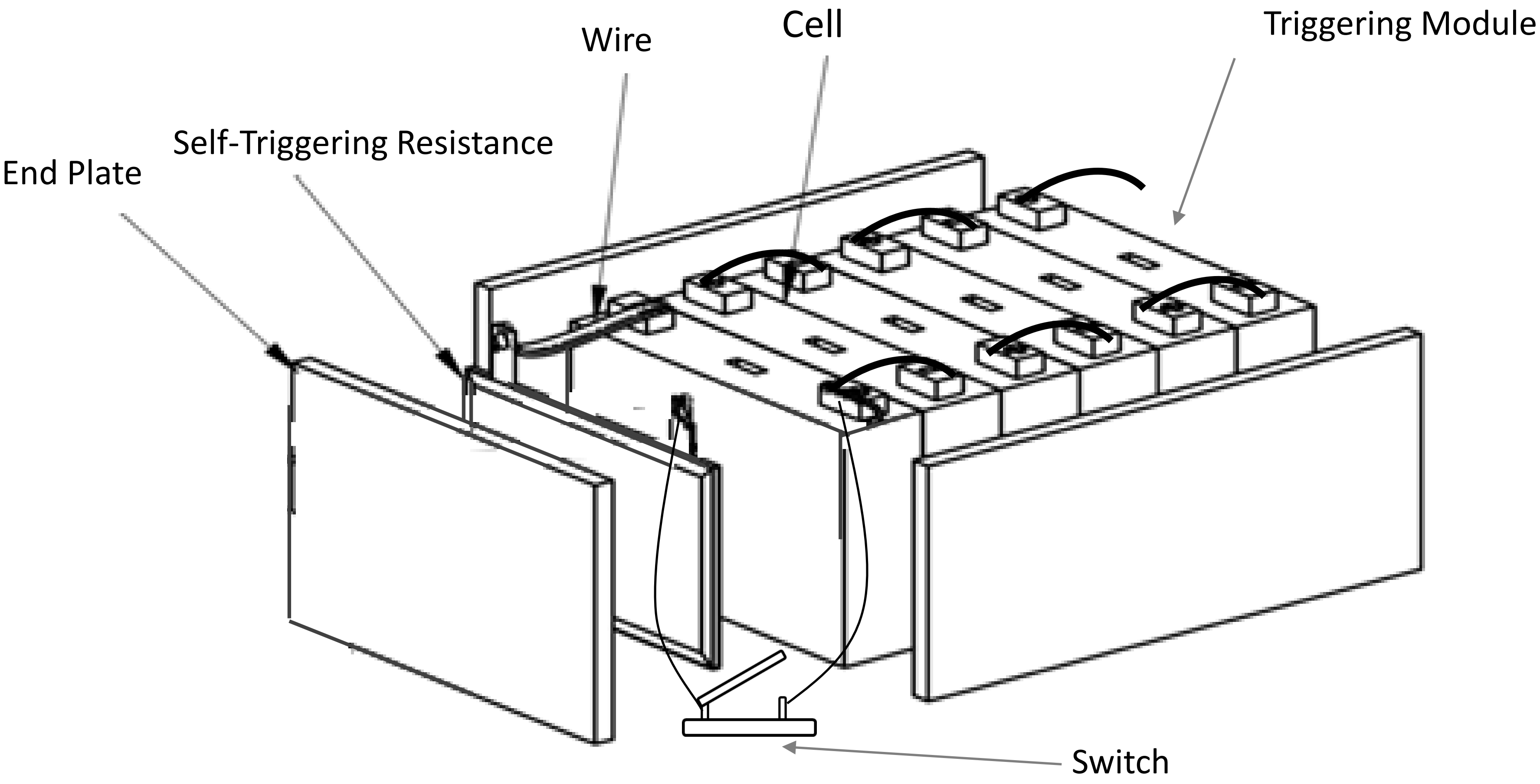
# Self-Triggering Method Research Update

## Chapter 1

Self-Triggering Method Update

# Self-Triggering Method Research Update

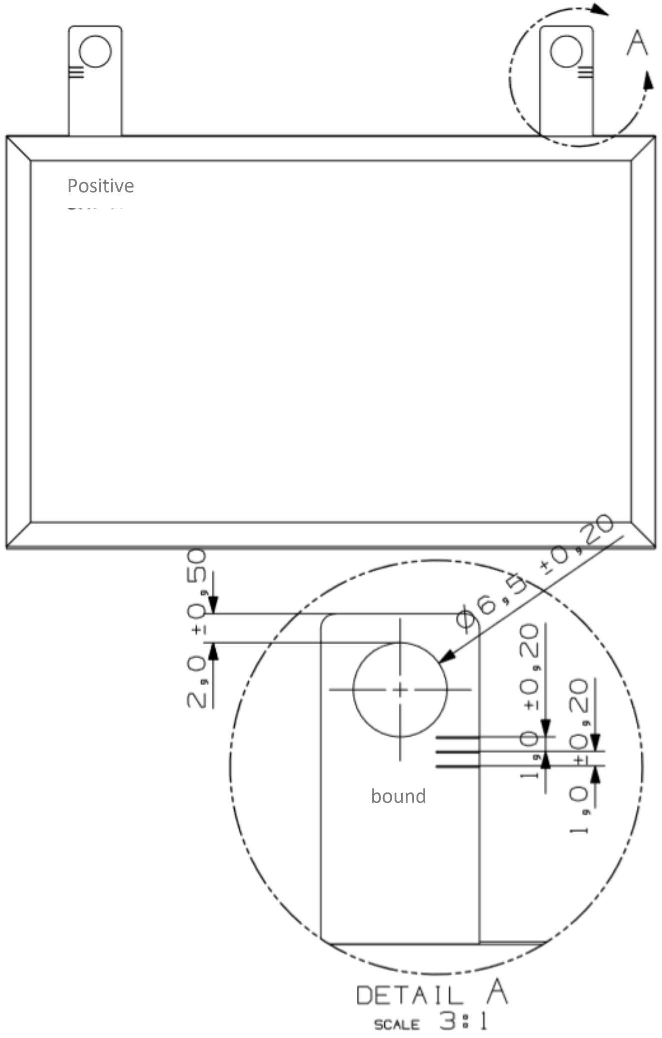
## ➢Self-Triggering Module Constructional Sketch




- Remark: trigger cell at the module telos.

# Self-Triggering Method Research Update

## ➢The Self-Trigger Device Resistance

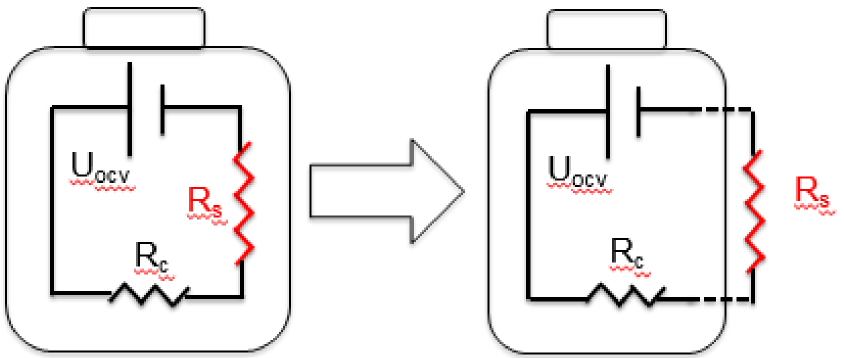


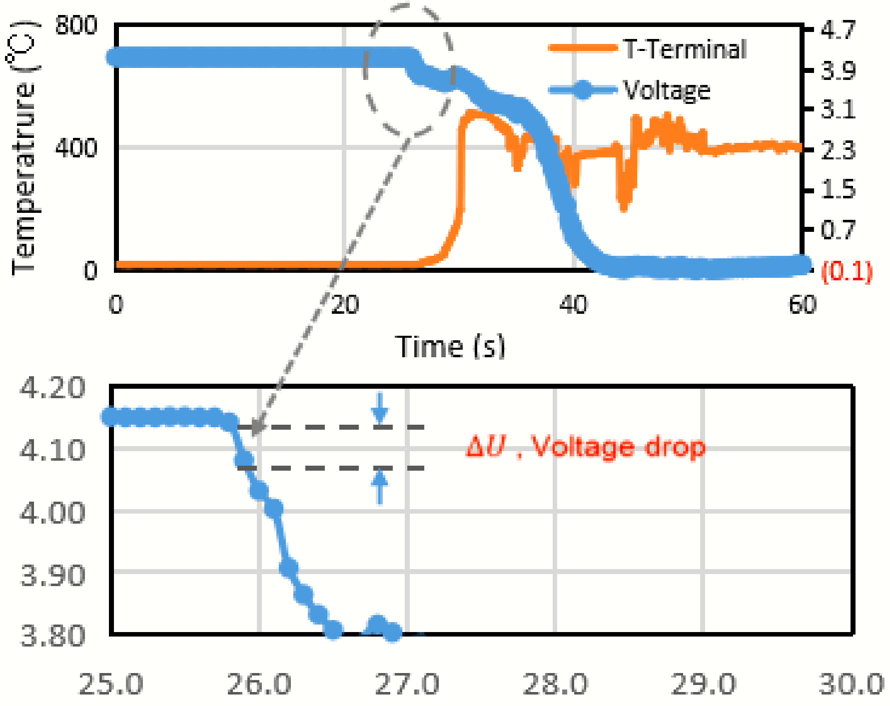

| | | Ideal Conditions | Reasoning |
|---|---|---|---|
| Material | | Metal | Such as $Fe_xCo_y$ alloy, $Ag_xCu_y$ alloy, $Ni_xCr_y$ alloy, et al. |
| heater | Thickness (mm) | ≤5 | Thickness contained sealed materials and metal |
| | Area | not be larger than area of cell surface | Not include the positive and negative terminals |
| Shape | | Planate or others | Covered with ceramics, metals or insulator |
| Heating Rate (℃/s) | | 1~10 | Depends on the voltage of the triggering cells and the resistance |
| Minimum heater temperature (℃) | | >300℃ | ↑ |
| Value of Resistance | | 30~100mΩ | Detail in Blow |
| Resistance acquisition accuracy | | ±2mΩ | / |
| Suitable Cell | | / | Pouch & Prismatic |

# Self-Triggering Method Research Update

## ➢ Value of Self-Triggering Resistance

– Calculate internal short resistance($R_s$) according to nail test




$$\Delta U = U_{t=0} - U_{t=\varepsilon} = U_{ocv} - U_{t=\varepsilon}$$

$$U_{t=\varepsilon} = (R_c + R_s) * I$$

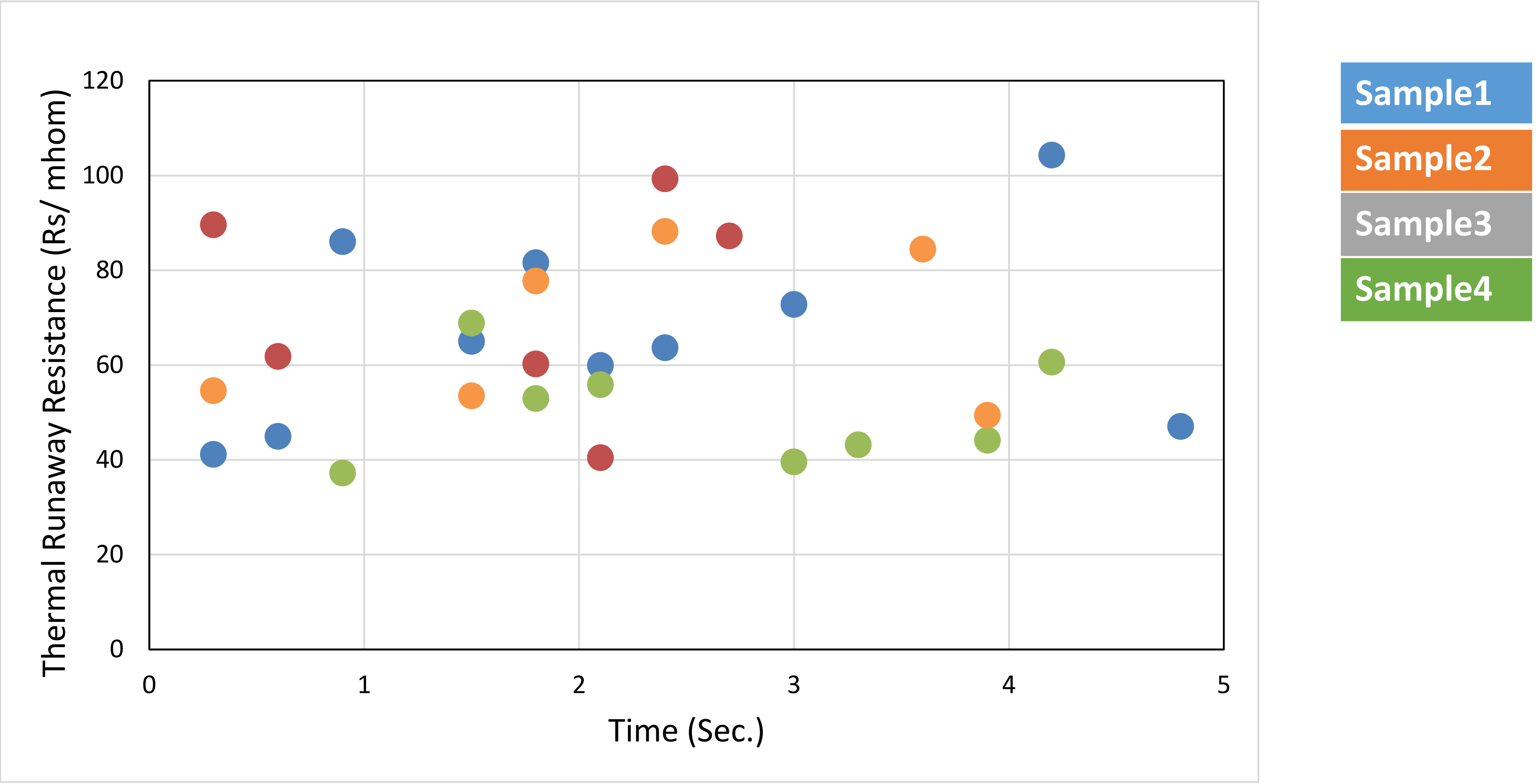
$$\Delta U = U_{t=\varepsilon} - (U_{t=\varepsilon} - R_c * I) = R_c * I$$

Simplified Equation: $R_s = R_c\left(\frac{U_{ocv}}{\Delta U t_0} - 1\right) = 0.5 * \left(\frac{4.15}{0.05} - 1\right) \approx 40\text{mhom}$

# Self-Triggering Method Research Update

## ➢ Short Resistance Analysis

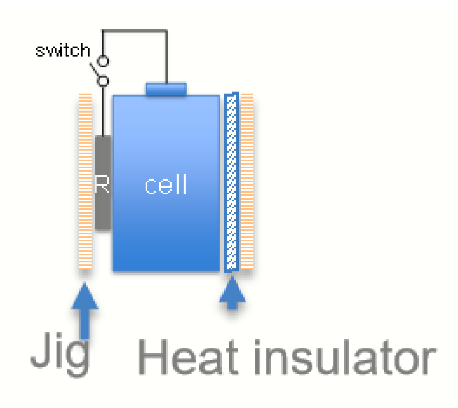
– Herein, we propose internal short resistance($R_s$) by nail test to be the self-triggering resistance

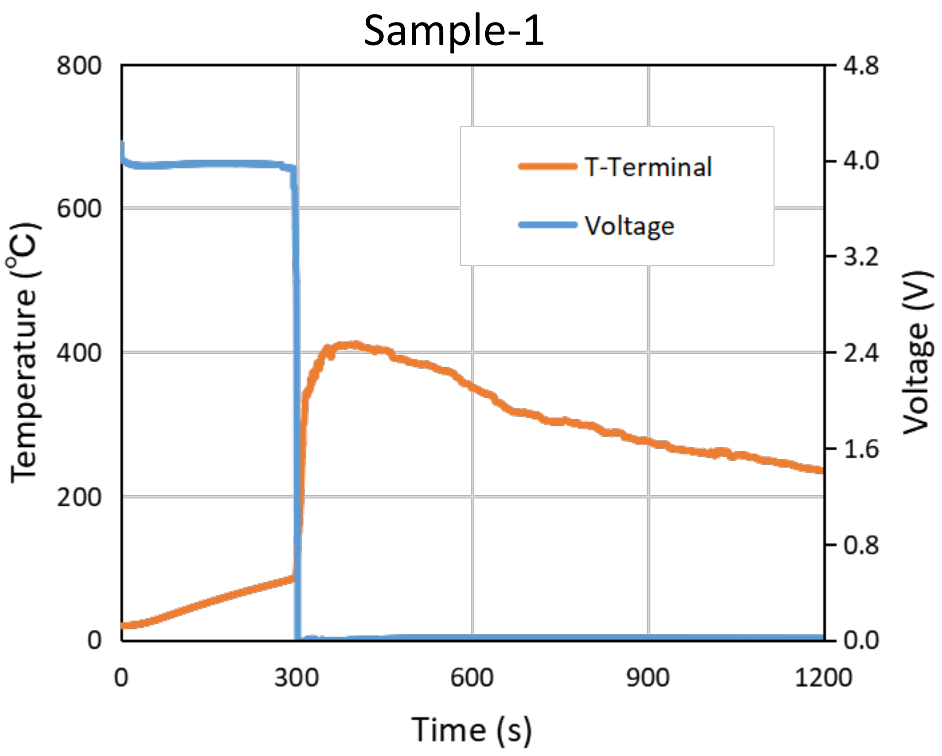


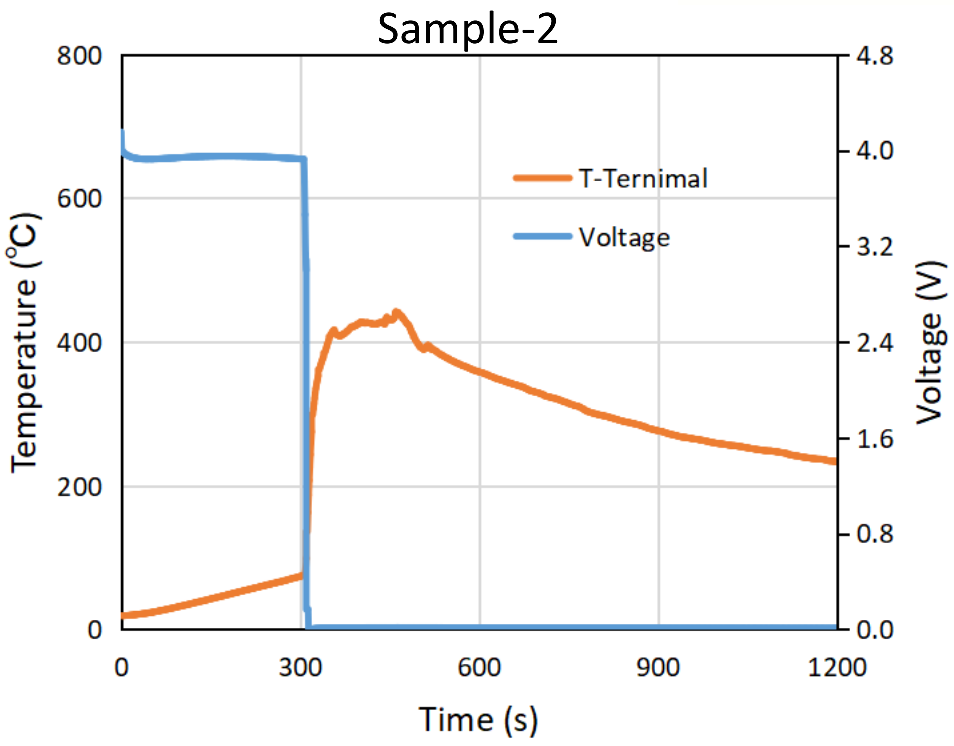
# Self-Triggering Method Research Update

## ➢Self-Triggering Resistance Validation

- Use **40mhom** as the typical Self-Triggering Resistance for the Lithium-ion battery.

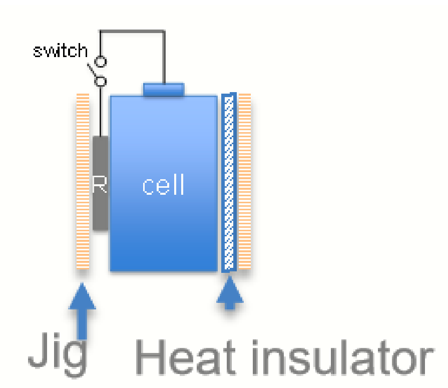


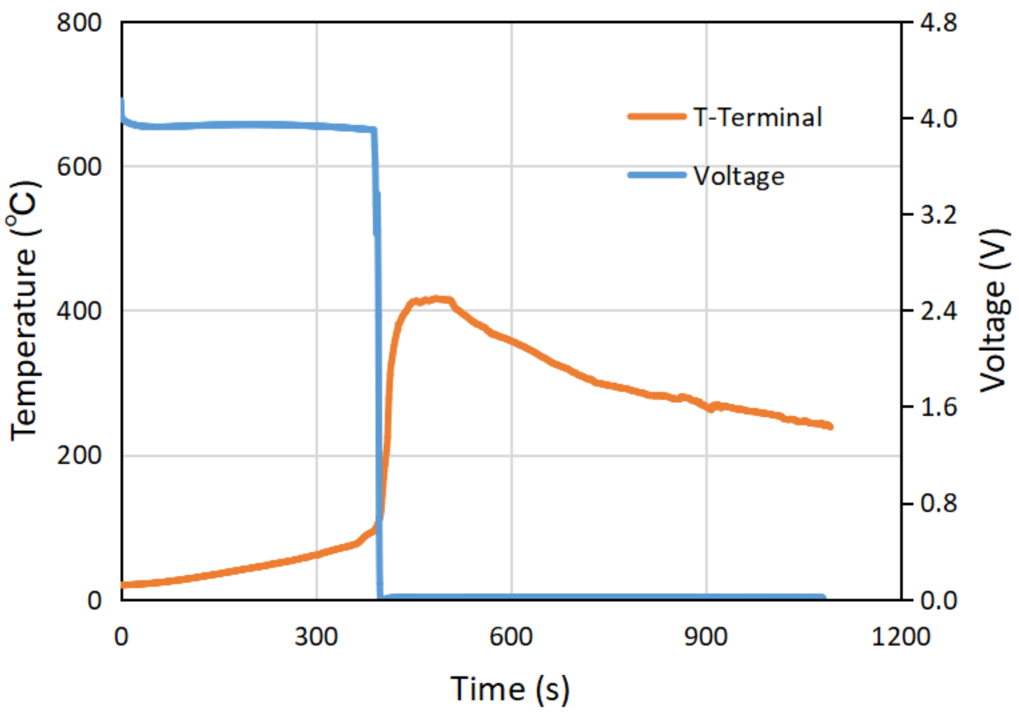



# Self-Triggering Method Research Update

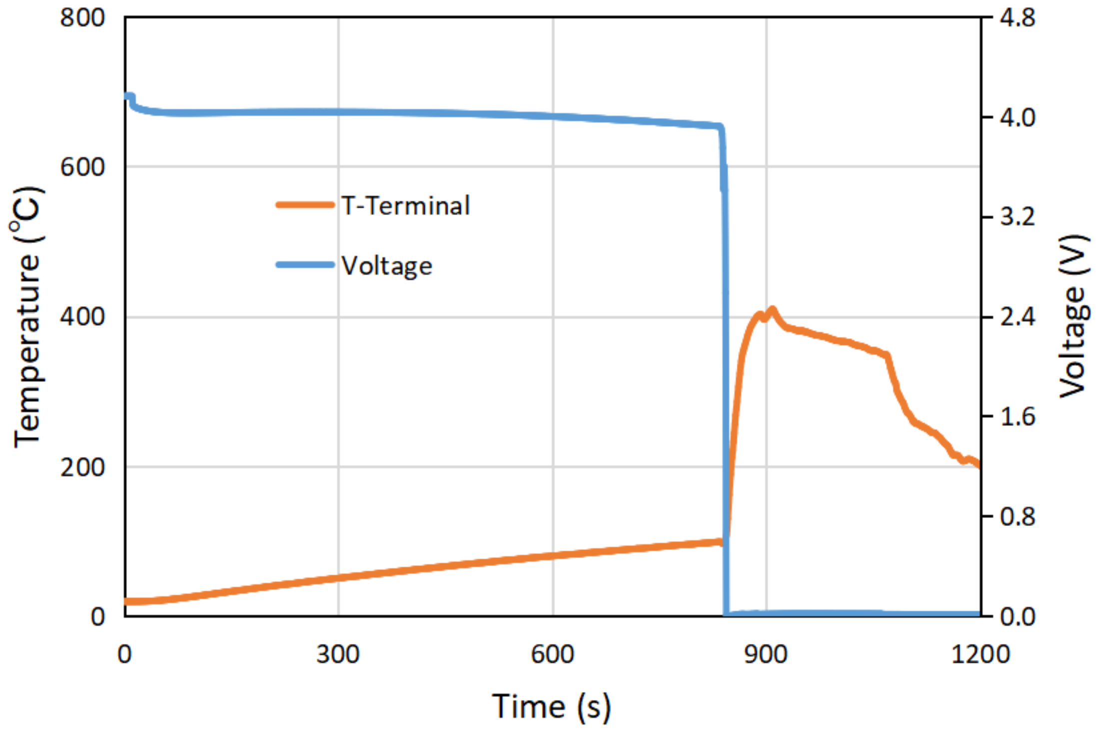
## ➢Self-Triggering Resistance Validation




50mhom_Self-Triggering Resistance




80mhom_Self-Triggering Resistance



# Chapter 2

Questions & Answers

# Self-Triggering Method Research Update

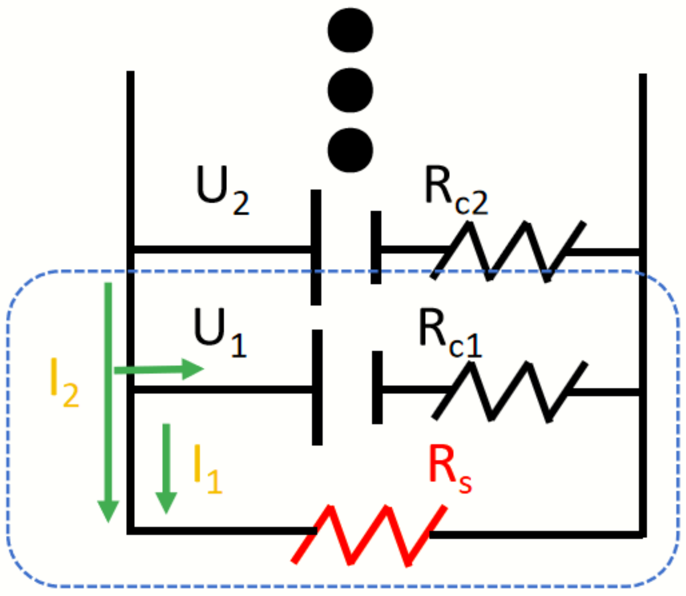
- Question1:
  - Is the Self-Triggering Method like the Discharge case which cause the cell into thermal runaway?
- Answer:
  - Discharge **without energy back** would not cause cell thermal runaway

| No. | Test Method | Rate | Initial SOC[a)] | ΔT_Cell Surface | Result |
|---|---|---|---|---|---|
| 1 | Discharge | 1C | 100% | ＜10℃ | HL2 |
| 2 | Self-Triggering | 1C | 100% | >200℃[b)] | ≥HL4 |

Remark:
a) The operate voltage area is 2.80~4.20V.
b) Temperature before thermal runaway.

# Self-Triggering Method Research Update

- Question1:
  - OICA also requested a clarification about the situation of parallel connection of cells (e.g. 4P connection).
- Answer:
  - in parallel cells, the heating energy results from all the parallel ones which is same with the internal short case.



Parallel Cells

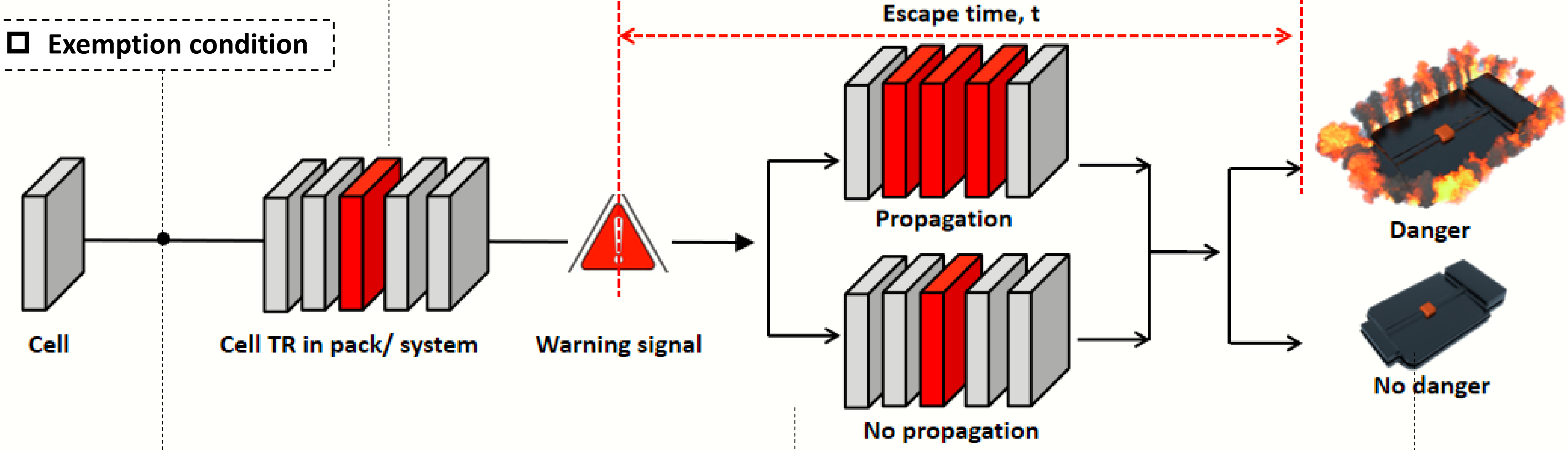
| No. | Energy (Wh) | Size | ΔT_Cell Surface | Result |
|---|---|---|---|---|
| 1 | >400 | 2P1S | ~200℃ | ≥HL4 |
| 2 | 200~400 | 3P1S | ~210℃ | ≥HL4 |
| 3 | <200 | 3P1S | ~204℃ | ≥HL4 |

# The following work

- **Escape time** EVSTF-08-57e by JP&KR&CN
  - How long is enough for different applications?

- **Trigger target and position**
  - Worst case & Operational, under research

- **Exemption condition**




- **Trigger method:**
  - Mechanism of TR, under research
  - Trigger method CA/JRC/JP/KR/CN
  - Repeatability of TR EVS1541-616 [CHN]
  - Influence to TP of trigger method

- **Repeatability of results of TP**
  - Same method for same sample
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  - Different method for same sample

- **Specific contents of the danger**
  - Fire or explosion, confirmed
  - Toxic and combustible smoke, under research.

# Thanks for your attention!