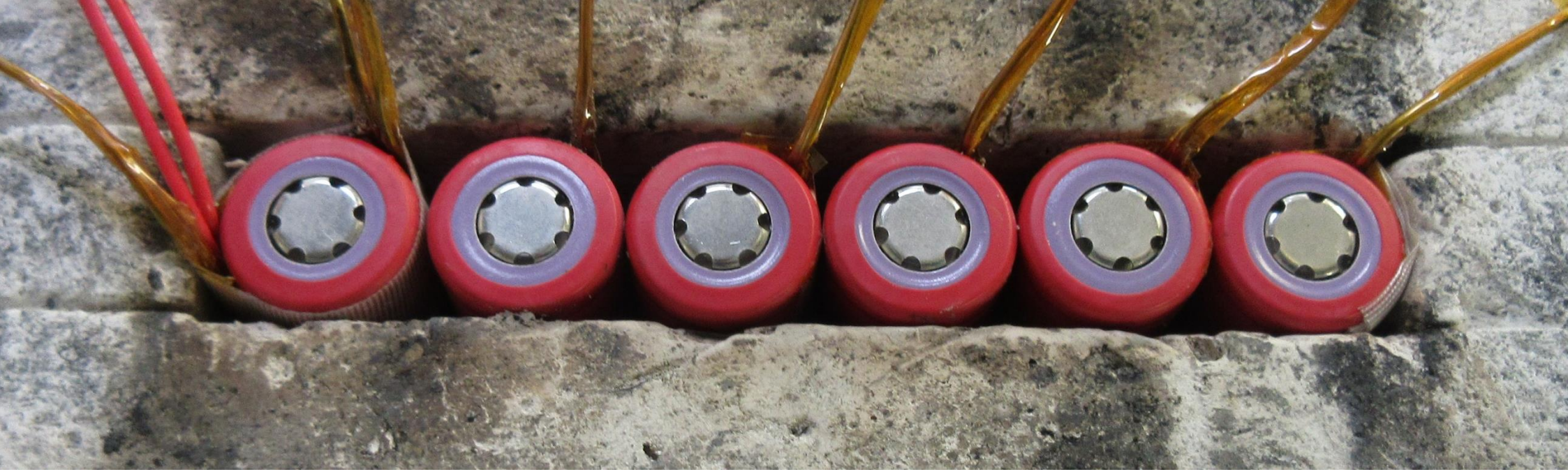

Testing good practices and reference protocol

IWG on hazard-based classification of Li batteries and cells

December 2020

RECHARGE

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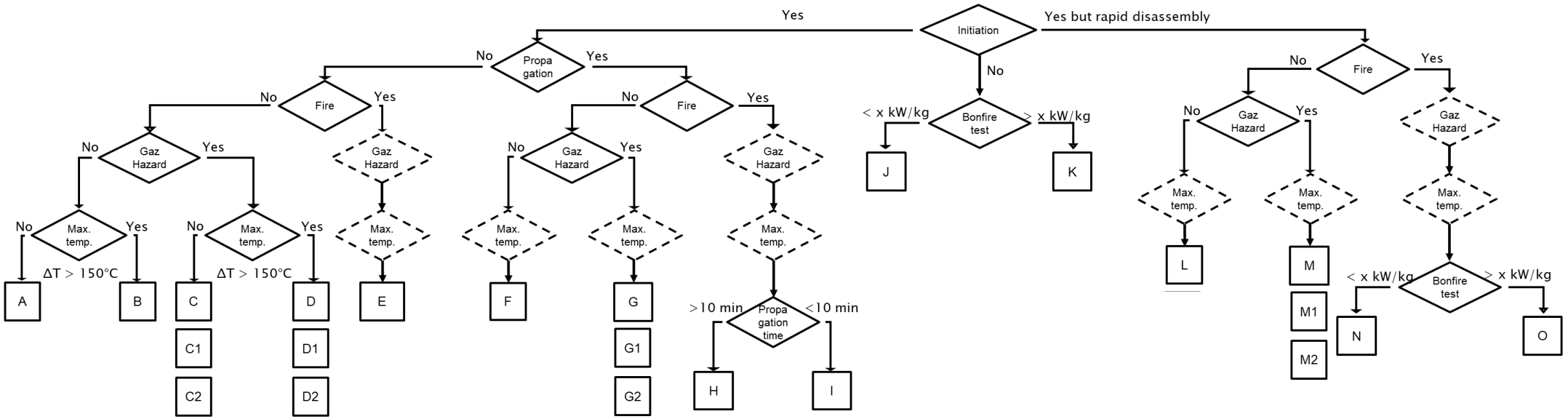
INERIS
controlling risks
for sustainable development

Last decision diagram (presented in Arlington)

- No mater the final decision diagram, classification will be based on testing
- Need to assess
  - Initiation
  - Propagation
  - Fire
  - Temperature
  - Gaz hazard
  - Thermal energy released (to be further discussed)



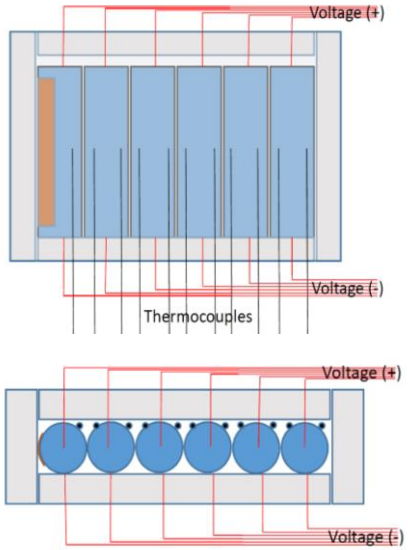
Hazard — Dashed box correspond to hazard that are assumed and are represented only to help understanding how the diagram was built and what are the hazards considered in each category

1 — Indicates that emitted gas is non-toxic

2 — Indicates that emitted gas is non-flammable

Proposed propagation test protocols (drafted by FAA and Boeing)

1. Cells with welded tabs are preferred, to allow easy connection of voltage-sensing wires.
2. Attach a thermocouple to each cell on the side. Avoid interfering with cell-to-cell contact.
3. Attach a patch heater to the side of the trigger cell. Heaters must be insulated and attached in a manner that will prevent separation during the test.
4. Attach wires to cell terminals to measure the voltages of all three cells.
5. Insulate and secure the wire ends for safe transportation to prevent accidental discharge of the cells.
6. Mount the six cells in the thermal housing and secure in place with a small amount of silicone glue.
7. Transport to the Test Building, Test Room.
8. Define the Data / Signal list to assign each measurement to a data acquisition channel and cable. Define the required resolution, range, and sample rates for each signal. Data may be acquired at a frequency of 1 Hz or higher.
9. Connect voltage sensing wires to the data collection system. If cell voltages are not at the correct SOC for the test, connect the wires to a charger and hold the test until the correct SOC has been reached for all cells.
10. Connect thermocouples to the data collection system (Cell, Housing, Enclosure Air, Room Ambient).
11. Connect the heater voltage and current signals to the data collection system.
12. Connect the power supply to the heater wires.
13. (Connect the pressure sensor to the data collection system.)
14. Verify data acquisition system is functional, and is monitoring and recording data.
15. Take documentation pictures of the test article and test apparatus.
16. Close and secure the Test Enclosure.
17. Arrange desired video coverage – angles, zoom, focus, lighting, etc.
18. Conduct a stand-up safety and test readiness review with personnel who are present in order to review the expected sequence of events, discuss appropriate actions in the event of unexpected behavior, and review roles and responsibilities of all present. Ask if there are any safety concerns at all from anyone and resolve them before proceeding.
19. Close and secure the access to the Test Room to assure no entry until the test room has been determined safe to enter. Flag the Room as Active Test (i.e., illuminate a red "TEST IN PROGRESS" light).
20. Declare test start, data collection start, video start.
21. Adjust power supply to provide wattage appropriate to heat the trigger cell at between 10 and 20 deg C / minute. Previous trials with a thermal surrogate of the cell are helpful to set the initial heating power.
22. Monitor cell voltages, cell temperatures on a real-time graphical display to observe temperature trends over a period of several minutes.
23. Adjust heater power as needed to maintain a steady temperature increase at the desired rate. There will be occasional temperature holds as components melt (absorbing heat of fusion) and as minor exo- and endo-thermic chemical reactions take place within the cell. Maintain the heater power setting during periods of melting i.e., do not chase the variations in cell temperature too closely).
24. Trigger cell is expected to enter thermal runaway when temperature approaches 180 - 190 degrees C. Thermal runaway is defined when cell temperature is increasing at a much faster rate than the heating device. *(This must account for minor internal reactions, venting, etc.)*
25. When cell has experienced thermal runaway stop the heating power.
26. When cell temperature reaches 200 deg C, reduce the heating power slightly to hold cell temperature constant. *(For consideration: maintain the thermal ramp until thermal runaway takes place – JCR)*
27. Observe remaining cells for propagating runaway.
28. 1h after all cell temperatures have dropped to 50°C stop acquisition.
29. Download and process the collected data and video.
30. After a cooling period, enter the test room and document the test outcome with still photography and written notes.
31. Perform analysis to generate the reportable data.
32. End of Test



- Six (6) 18650 cells touching each other
- Starting temperature of all cells: 20C +-5C
- Not electrically connected
- 1 type-K T/C on first cell and each remaining cell; attach at mid-height of cells at 1:30 position as shown in Figure 2.
- Insulation on bottom and all 4 sides; thermal conductivity less than .2W/mK. Insulation must not melt or decompose at temperatures below 800C. (superwool, kaowool)
- Cover on the top with allowable leakage for venting
- Temperature collection at 1Hz
- Heat 1st cell at 20C/min. (the temperature of the first cell rises 20C after every minute); Any size heater tape. Cartridge heaters must be less than .25" diameter and no longer than the cell.
- Turn heater off when first cell goes into thermal runaway (temperature jump above 200C)
- If a cell ejects its core, rerun the test and record event.
- If a cell has a sidewall rupture, rerun the test and record event.
- Cells oriented vertically

Objective of the test is to assess :

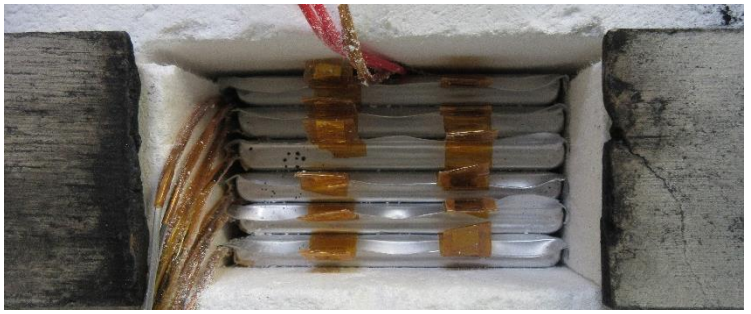
- **Initiation**
- **Propagation**
- **Fire**
- **Temperature**

Not to simulate any kind of abuse or internal short circuit

Key parameters

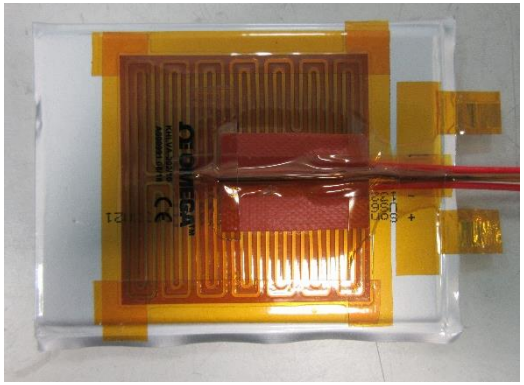
- **Cell positioning**
  - Cells oriented vertically
  - Cells touching each other
  - Cells slightly compressed (**important** especially for pouch cells)
  - Cells not electrically connected

- **Number of cells**
  - Currently performed with 6 cells
    → can we reduce it to 4 ?

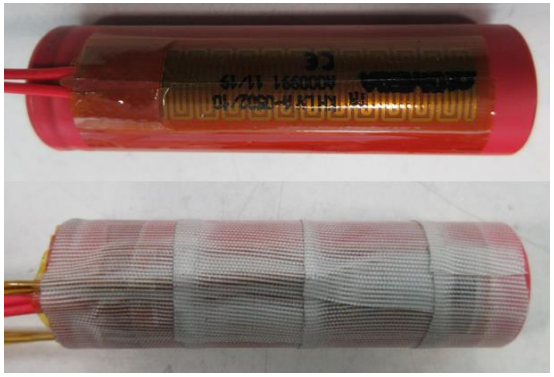


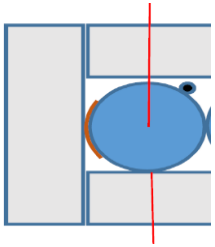
- **Insulation**
  - 4 sides + **1 lid** that allows venting
  - → **importance of the lid**
  - thermal conductivity less than .2W/mK
  - Rigid material (no fluffy wool)
  - Ensure compression of cell → **important**

Key parameters

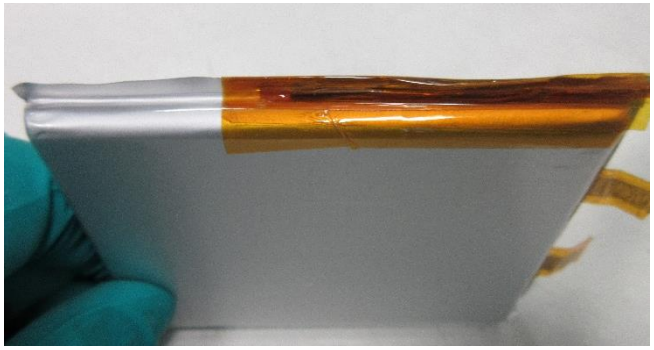


- **Heater**
  - Small enough to not excessively heat adjacent cell
    - must be less than .25" diameter (for cylindrical) and no longer than the cell
    - Must be thermally insulated
    - Can be cartridge, pad, micro mica, wire…



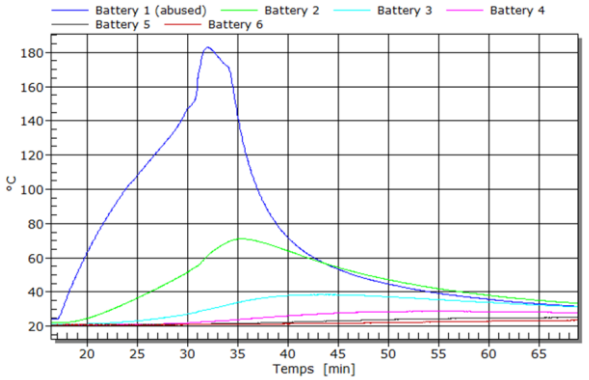


- **Heating protocol**
  - Start at 20+/- 5°C
  - Heating rate proven to be not crucial
    - A minimal and maximal rate should be fixed : **5°C to 40°C/min ?**
  - Heating temperature measured on the cell, not on the pad
  - Heating stopped when TR is reached

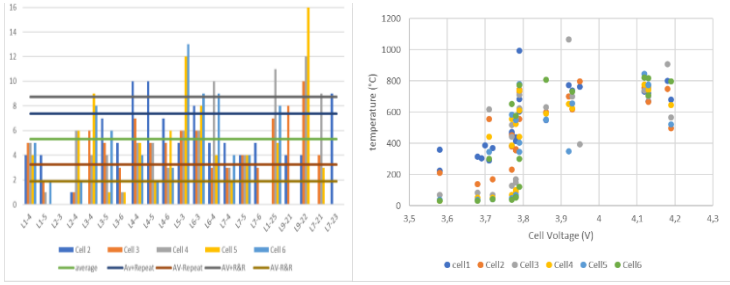


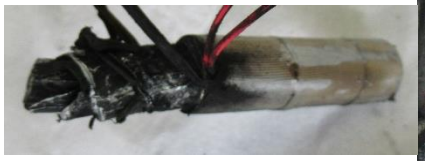
Key parameters

- **Data recording**
  - 1 T/C type K per cell→ **importance of positioning**
    - Avoid interfering with cell to cell contact
    - mid-height of cells at 1:30 position for cyclindrical
    - mid-height of cell on edge for pouch cells
  - No voltage measurement necessary
  - Collection at 1 Hz (at least)



- **Data reporting**
  - When a type-K thermocouple record temperature higher than 1200°K – temperatures recorded are no more representative
  - Need of a clear definition of thermal runaway to define
    - Onset temperature
    - Propagation time



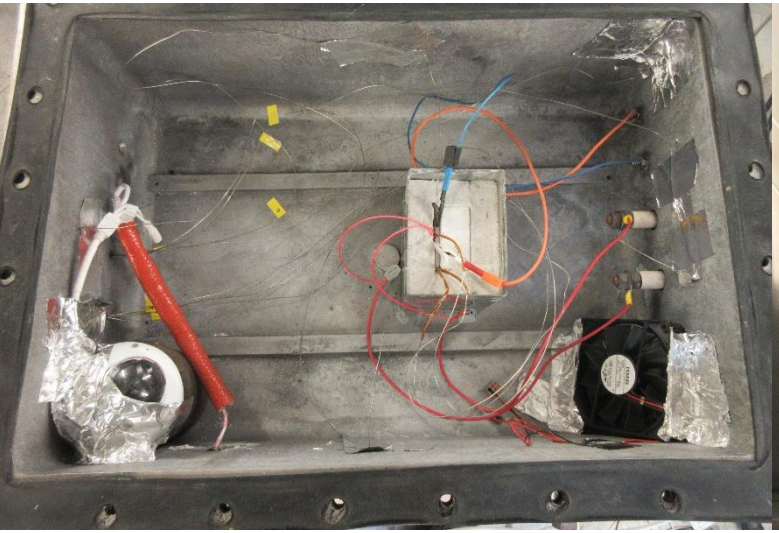
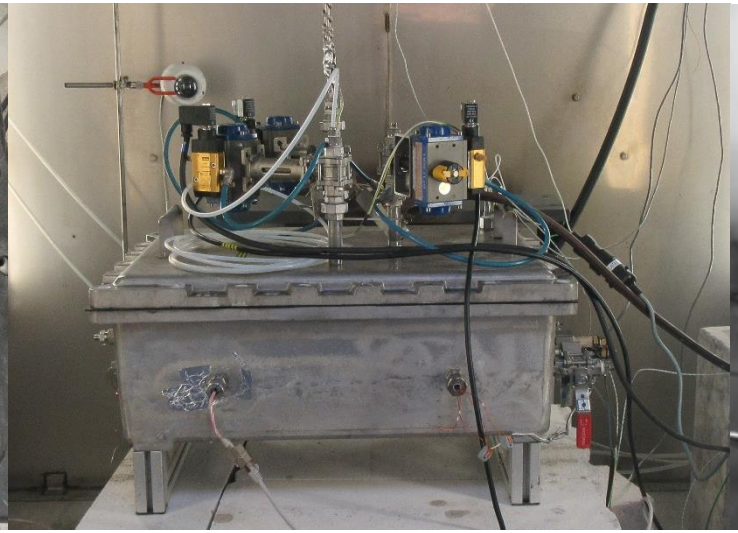
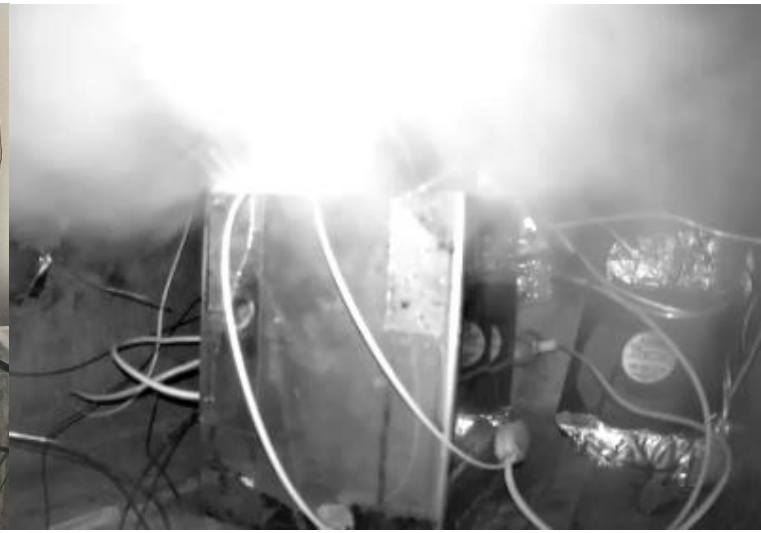


- **Test validity**
  - Reproduce test 3 times
  - If a cell ejects its core, rerun the test and record event
  - If a cell has a sidewall rupture, rerun the test and record event

Evaluation of gas hazard

- **Current protocol**
  - Done on one cell
  - With thermal insulation → is it necessary ?
  - Under argon → waiting for test results and discussions to statue
  - Emitted volume assessment by pressure measurement → easy and should be reproducible between labs
  - Composition of gas measurement → difficult for many labs and expected to be less reproducible between labs
    → interest of such measurement ?

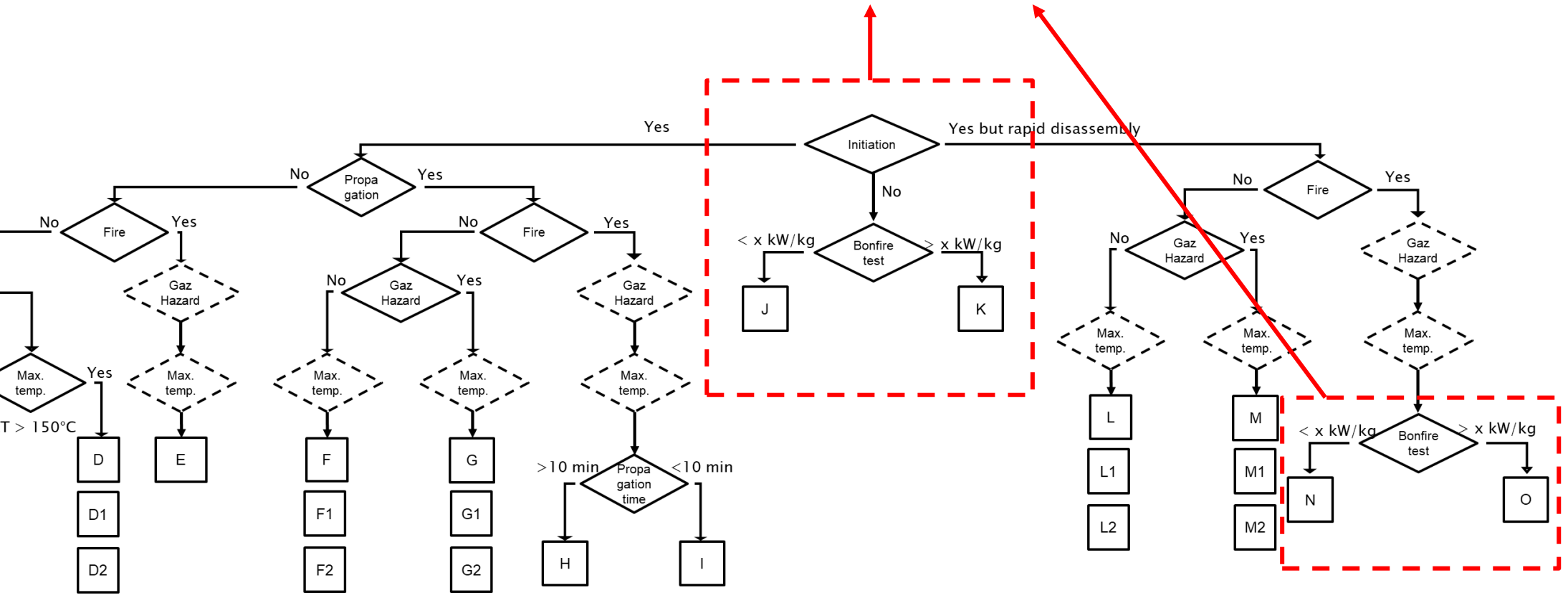
Need to analyze test results and discuss to define a protocol in coherence with the need of a hazard-based classification

Evaluation of thermal energy released

Keep in mind :

How to assess the hazard in this case ?
Need to define a different test protocol ?



Hazard

Dashed box correspond to hazard that are assumed and are represented only to help understanding how the diagram was built and what are the hazards considered in each category

Principle for cells and batteries classification

1-Non classified raw materials, substances and components:

Test of intrinsic properties

2-Classified materials based on Intrinsic properties (UN classes):

Specific combination and design per cell

3-Non classified Lithium cells

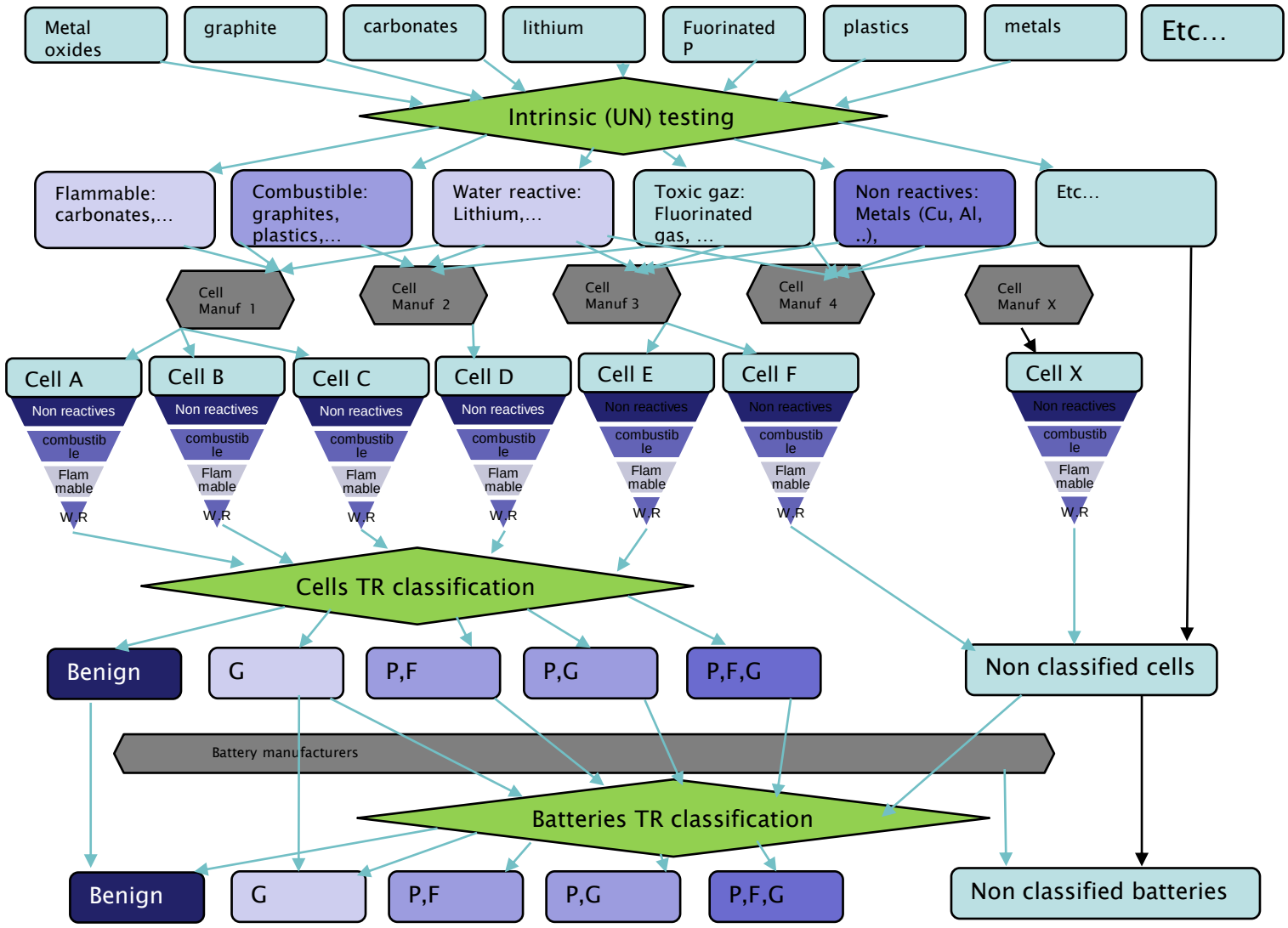
Test of cell design properties

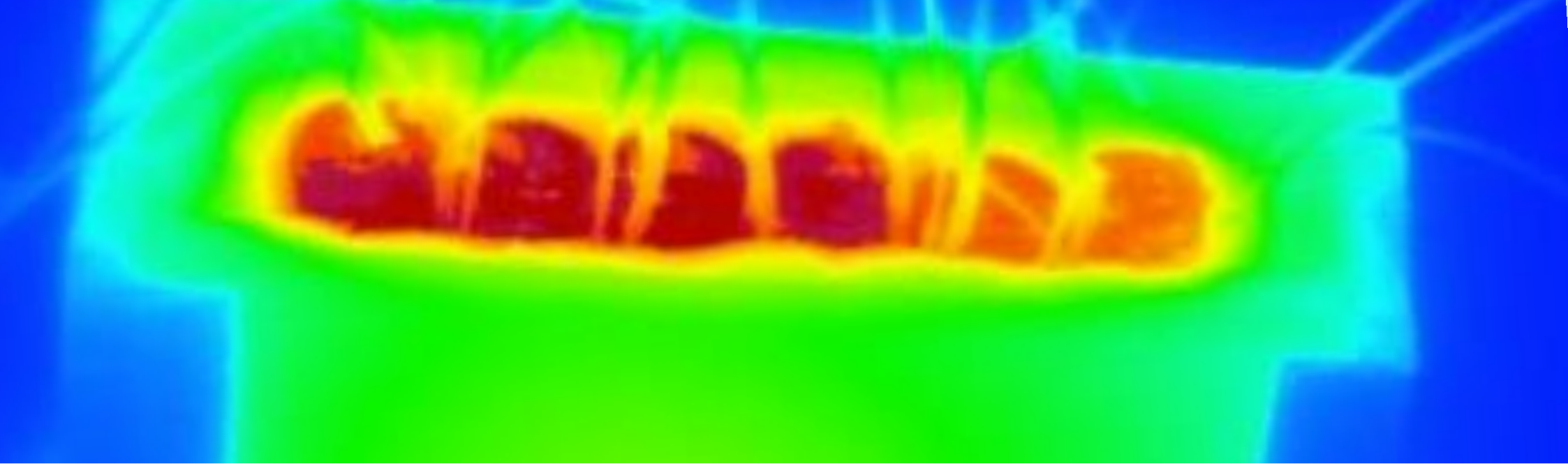
4-Classified li cells: P- propagation, F- flame G- toxic gas, B benign, …

Cells assembly (no cell classes mix!)

Test of battery design properties

5-Classified batteries





Thank you for your attention

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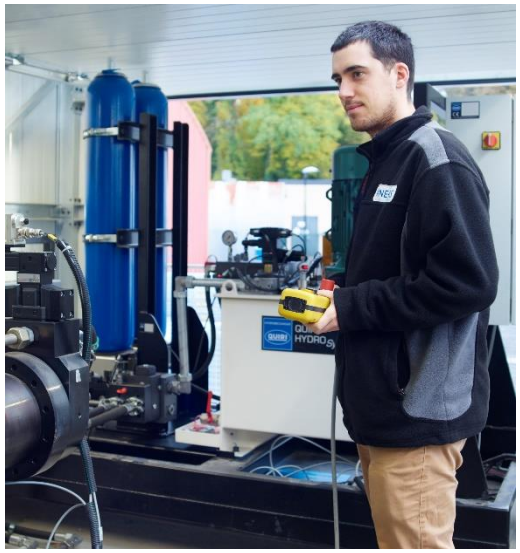

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