TESLA

# Mitigation of Risk of Propagation from Single Cell Runaway

Electric Vehicle Safety
Informal Working Group
Session 25

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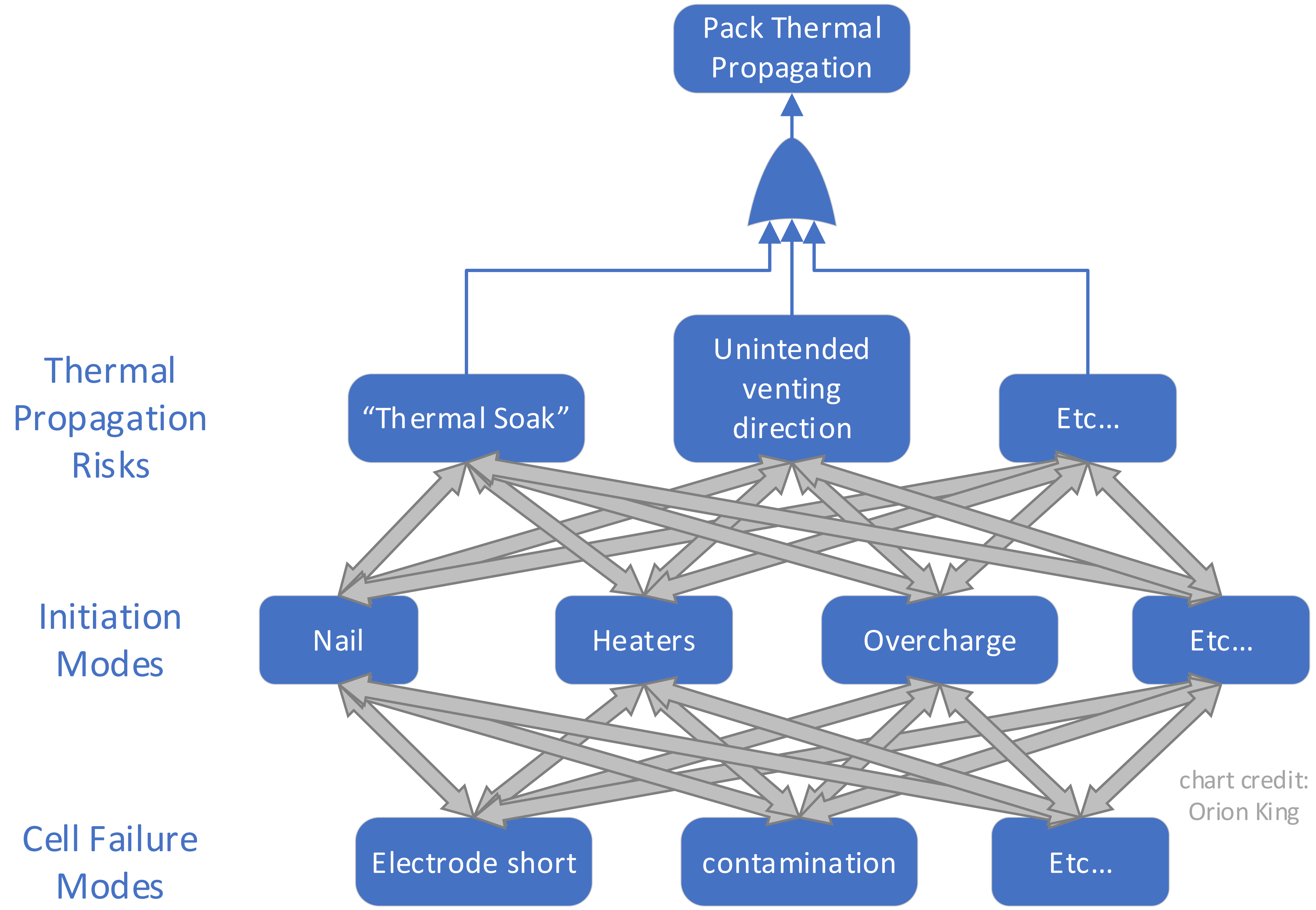
# The Goal of Mitigating the Risk of Propagation from a Cell Runaway

1. Pretending that battery cells “don’t go into runaway” shows a lack of experience.
2. Making many millions of lithium-ion batteries with tight tolerances is very challenging, and there are several ways that errors can lead to thermal runaway.
3. I have heard often that a specific cell design will not go into runaway, but I have never found a lithium-ion design that could not be sent into a thermal runaway somehow.
4. The electric vehicle industry is at risk of battery packs being perceived to be unsafe. Meanwhile, there are cost-effective engineering solutions to help provide a layer of protection from a single cell runaway that not only make products safer for customers, but also allow more margin to learn about and fix issues.
5. Tesla’s mission is to accelerate the transition to sustainable energy, and we are willing to share information we think can enable the industry to make all electric vehicles even safer.
6. The intent of this presentation is to give a brief summary of our understanding of strategies to eliminate the risk of single cell thermal runaway causing a hazard.

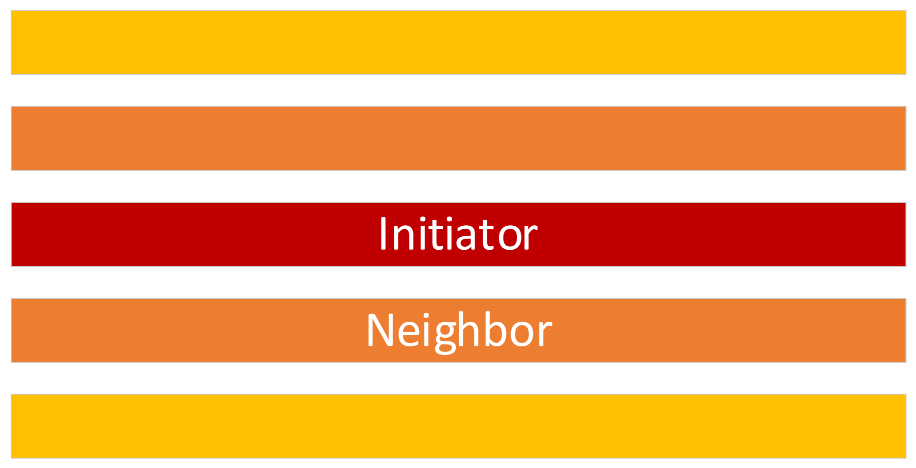
# Runaway Initiation

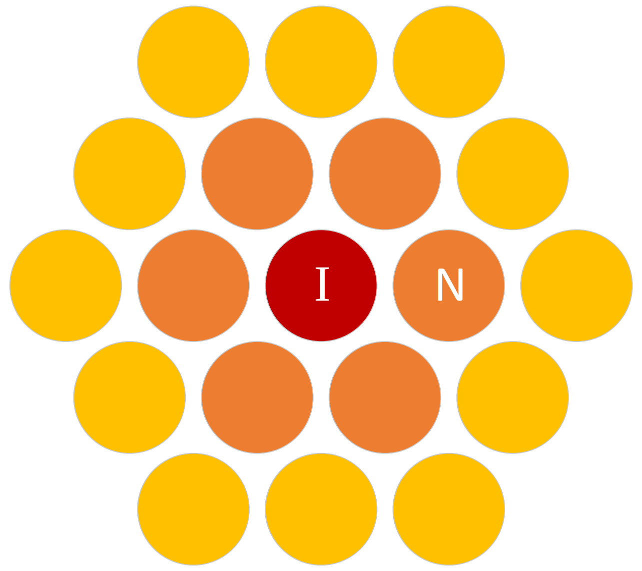
1. In the best designed and manufactured cells, often several things must go wrong to allow runaway. However, if enough batteries are made soon enough to meet the industry's needs, it will happen.
2. It's hard to predict what the failure will be and thus what artificial conditions to use to initiate thermal runaway in the ways truest to the field, but the industry is always gaining experience on this.
3. The best thing is to understand what are the worst initiation options for each of several "thermal propagation risks" for a pack and to look for those weaknesses
    1. For instance: we define "Thermal Soak" as a condition where too much thermal energy is held in the cell after runaway for the module to spread that energy preventing the neighboring cells from overheating
4. Specific initiation modes can have many implementations / tradeoffs
5. Running only a small number of initiation types does not cover the risk of propagation, but <u>careful selection of modes can help gain the best coverage for given resources</u>

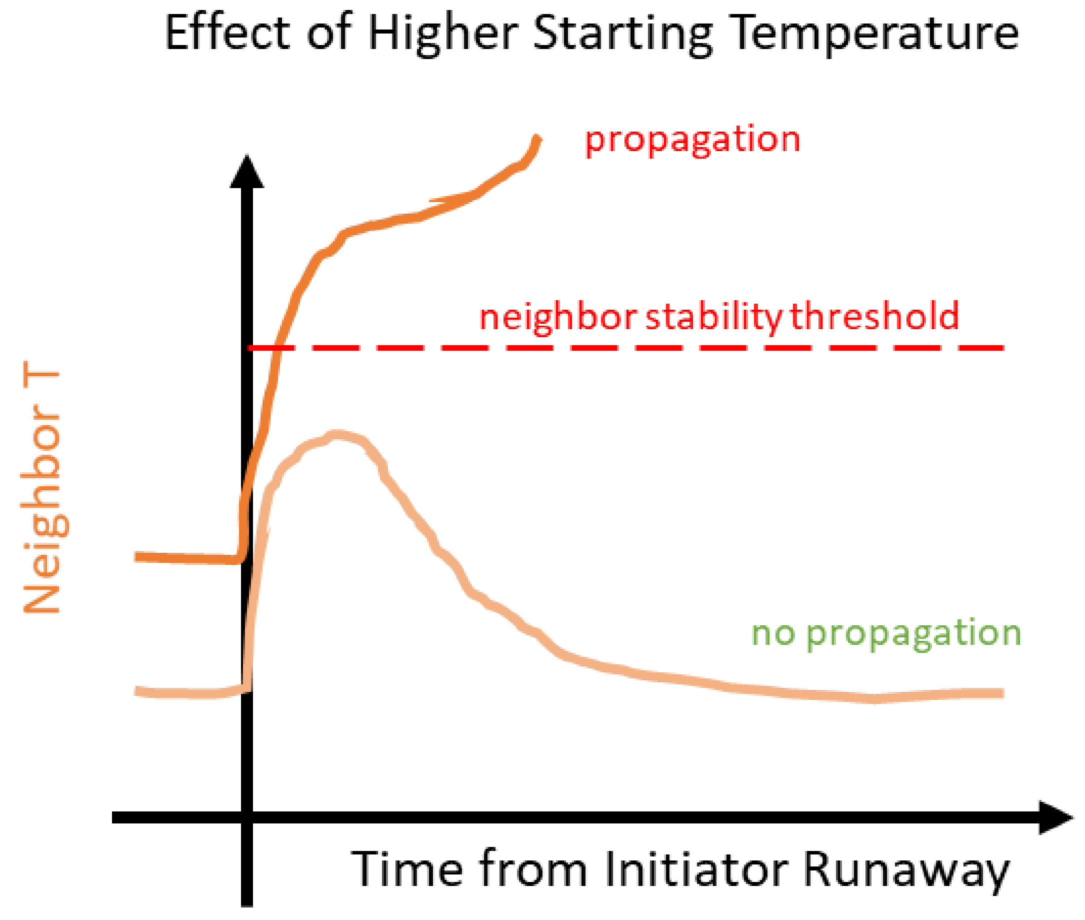


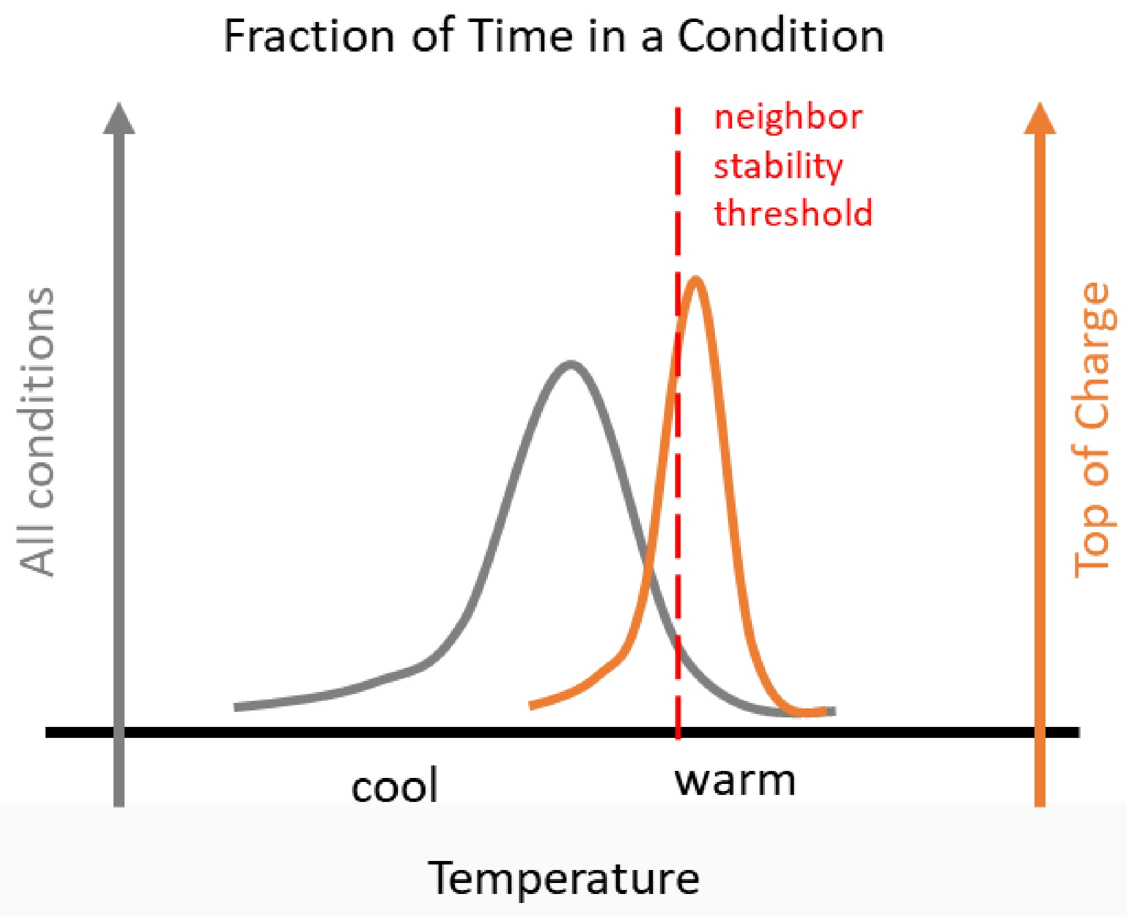
# Temperature

1. Clearly, the temperature conditions matter for the risk of “Thermal Soak” (too much thermal energy in the cells neighboring a runaway cell)
2. There is a distribution of product operating temperatures, but that might not be as hot as the temperature distribution of conditions when there is a cell runaway.  For example:
    1. “Industry lore” suggests that many issues are stressed most at the top of charge
    2. Top of charge can be one of the hottest conditions – this should be considered
3. Some types of cell failure modes might also heat before runaway, pre-heating neighbor cells and further reducing the margin
4. Running only cooler temperature tests does not cover the risk of propagation but <u>testing at elevated temperature can help give coverage</u>



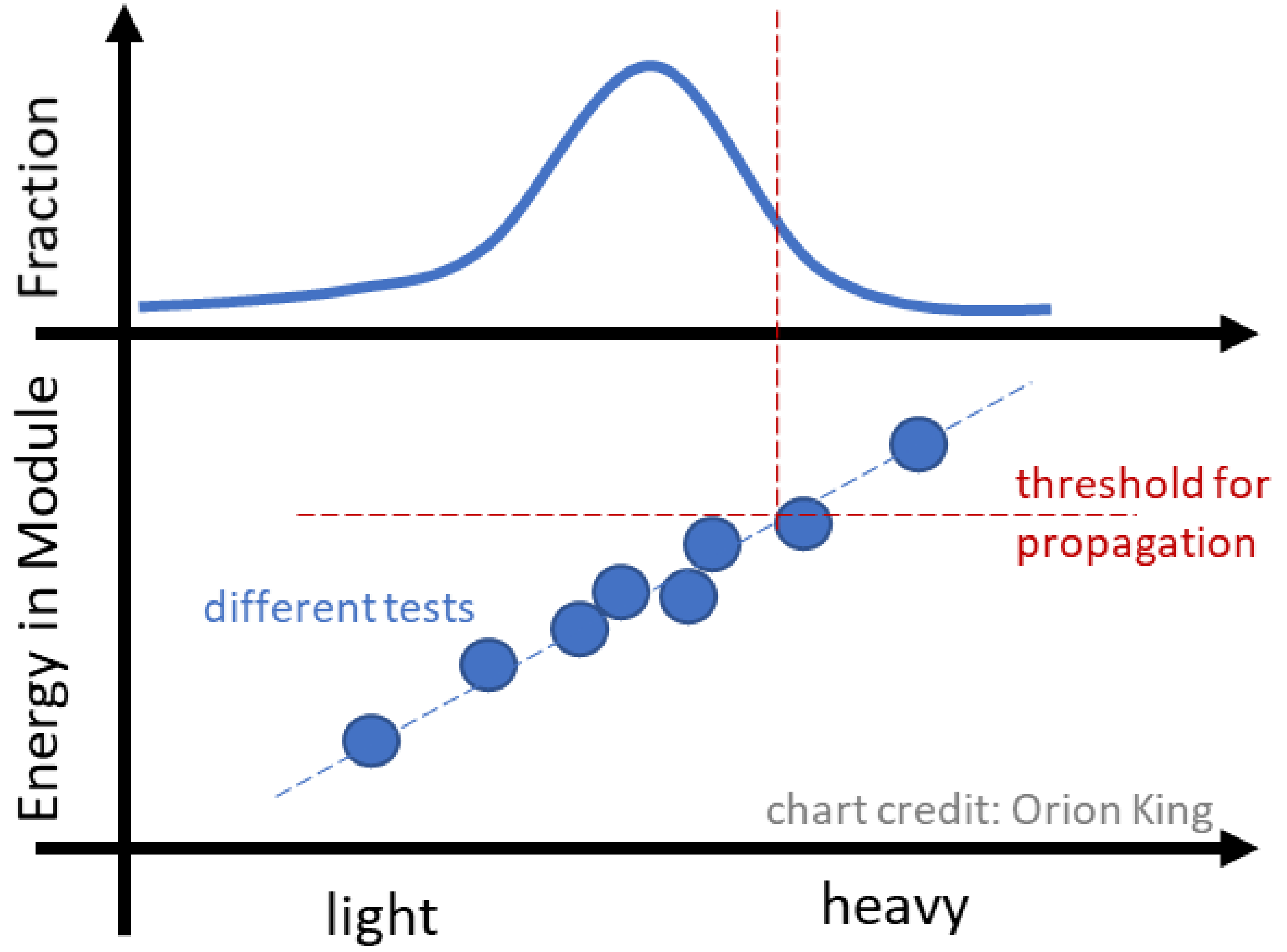



# Number of Tests

1. Cell runaway is chaotic, and sometimes the same design and same test conditions can result in propagation or no propagation.
2. Example numbers:
    1. 300 cells in 1 battery pack,
    2. Cell failure rate: 1 cell runaway in the lifetime of 1,000,000 cells
    3. 1,000,000 vehicles have 300M cells
    4. 300 vehicles will have 1 cell runaway over the life of the product
    5. Even being 10x better than these assumptions in cell quality or pack propagation resistance would result in **30 propagation cases**
3. To have confidence of less than one propagation in a product, binary statistics suggests that many tests should be run
    1. From the example, 60% confidence of an event happening less than 10% of the time **needs 8 test results without failure** (assuming binary test)
    2. See table on the right
4. This is even more important if test conditions are not conservative, which can be hard to achieve.
5. Running a small number of tests gives a chance of missing a propagation risk, and <u>many tests should be run to help give coverage for the risk of cell runaway</u>

Effect of Post-Runaway Mass on Energy in Thermal Soak



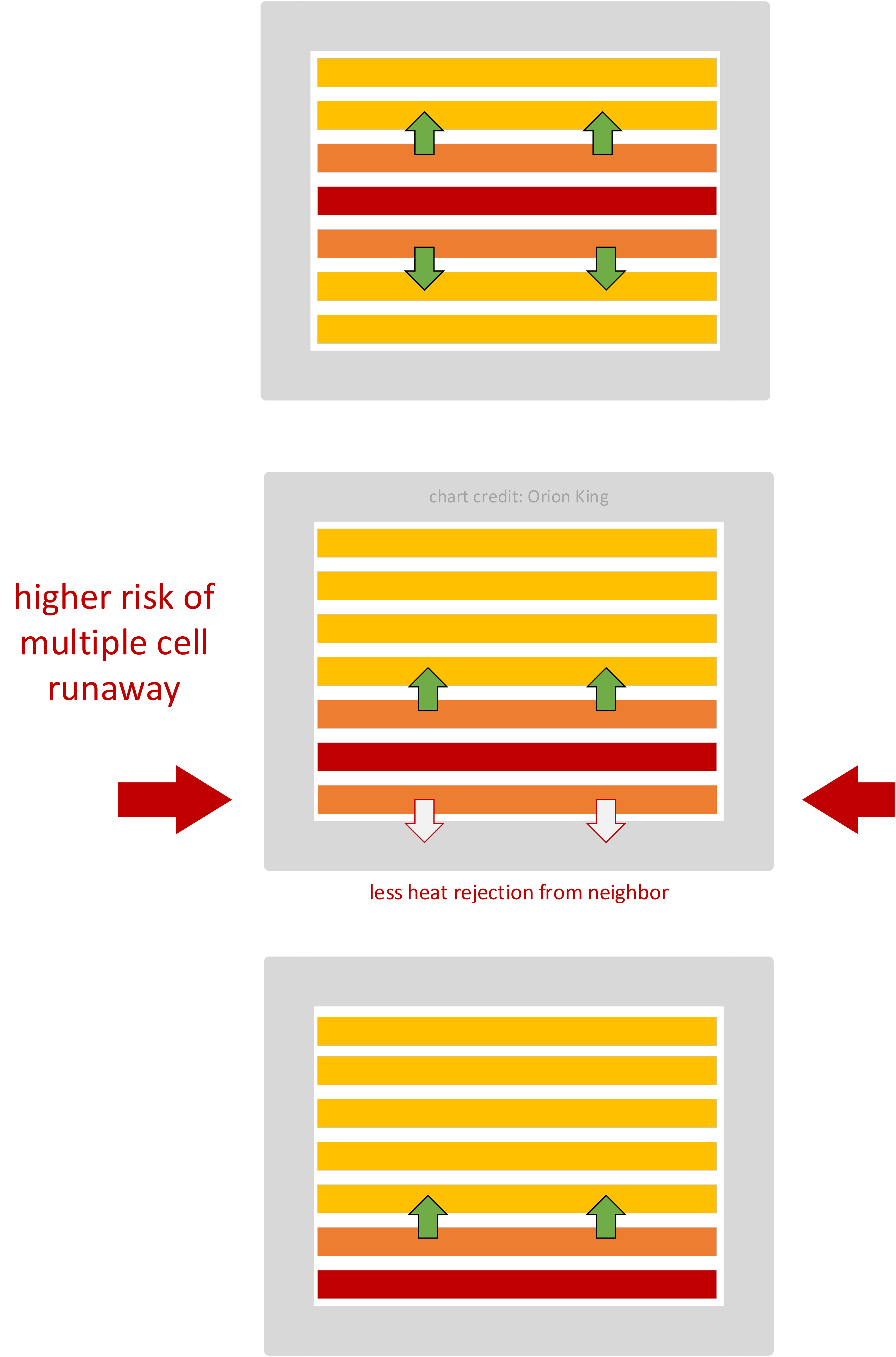

Post Runaway Mass of Initiator

Number of Tests Necessary for a Given Binary Confidence of a % Chance of an Event

| | Statistical Confidence | | |
|---|---|---|---|
| Chance of Event: | 60% | 90% | 95% |
| <10% | 8 | 21 | 28 |
| <1% | 91 | 231 | 299 |

# Different Pack Locations

1. Different cell locations in the battery pack will have different conditions relevant for understanding the risk to propagation
2. Some example special considerations: geometry of pack, venting paths, presence of different voltages, cooling system layout, etc.
3. It can be challenging to know the worst case. For example, “Thermal Soak” can be the most challenging for the next-to-last initiator in an array when the neighbor on the end can not reject heat (see figure to the right)
4. Full product level tests can be challenging, but small tests can sometimes be unrepresentative of a pack thermally, mechanically, or electrically.
5. Sampling an appropriate distribution of different pack locations can help mitigate the risk of propagation.
6. Testing some amount at a full product level can help mitigate the risk that something was oversimplified in subscale propagation testing.



# Situational Criteria

1. Vehicles can exist in a variety of different situations, where the needs of the user or the state of the vehicle's electronics can vary
2. Sometimes the vehicle might be in a situation where slow propagation to a vehicle fire does not result in hazard, but it's important to consider cases where the vehicle is within or nearby a structure where fire from the pack could put people at risk
3. Sometimes there might be an active cooling system operating or ready to operate, but unless it is always running with reliability appropriate for a safety criteria, the case that the cooling system is inoperable should be considered
4. It can be possible to detect and react to a cell runaway, but with the variety of initiation modes, temperatures, runaway behaviors, states, etc. the case of a false-negative detection should be considered.
5. Sometimes different exposed voltages can be "turned off," but the case of a runaway while they are powered should be considered if it exists in the product.
6. There are a variety of different situations to consider, but <u>holding a requirement of no thermal hazard even without detection or cooling present can help cover risk from cell runaway.</u>

# Summary

The following practices can help protect against the risk of a cell runaway leading to a hazard and can help ensure a future of safe, sustainable transportation:

1. Careful selection of cell runaway initiation modes can help gain the best coverage for a variety of different cell failure modes
2. Testing at elevated temperature
3. Running many tests to help give coverage for the variability of cell runaway conditions
4. Testing a variety of different pack locations to cover different sensitivities
5. Testing at a full product level helps make sure nothing is oversimplified in smaller scale testing
6. Holding a requirement of no thermal hazard even without detection or cooling present

# Thank You

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