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How to design and implement an Internal Short Circuit (ISC) test within a regulatory environment and is it the best approach?

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Outline

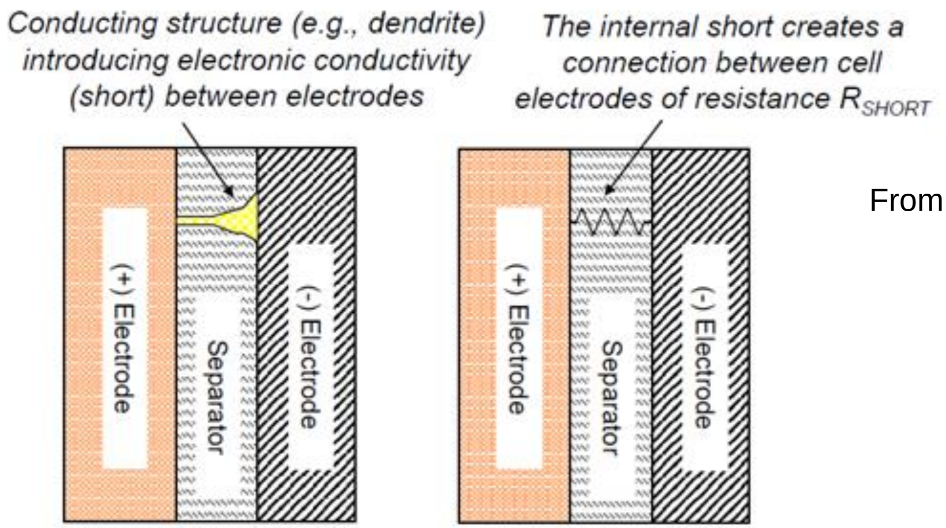
- Objectives
- What is an ISC?
- ISC detection and testing
- How to implement in regulatory environment and how does it reproduce the ISC event
- Is reproduction of an ISC the best approach?
- Path Forward Discussion

Objective

Internal Short Circuit (ISC) – How to develop a safety test method that embodies the characteristics of an ideal compliance test:

- **Representative** of a realistic abuse event
- Minimally invasive to the REESS design
  (minimal addition of foreign **holes, material** or **energy**)
- Reliable and repeatable
- Adaptable to all cell and pack designs

What is an ISC?



From B. Barnett, CamX Power

- The severity of the short circuit (resistance of the short) varies and is a critical parameter. This resistance **can** create a local hot spot that can initiate self propagating exothermic reactions at the electrodes. Without proper heat dissipation methods, this can lead to thermal runaway. Thermal runaway in one cell may propagate to other cells depending on the design of the module/pack.

What is an ISC?

- Unfortunately, as a internal short initially develops within a cell, its resistance is nearly invisible, when compared to the resistance of the cell and other ambient effects (Temp, SOH/SOC).

- So how can a manufacturer guarantee that it can be detected before initiating side reactions? Especially if one is not monitoring these changes quickly enough and with enough precision for **all cells** in the battery pack.

- There is no question; industry is working on solutions, but will they be sufficient? Will these rigorous solutions be applied unilaterally across all the various industry suppliers?

What is an ISC?

- For example,
  - Detecting ISC by comparing the measured voltage or temperature value of the battery with the value predicted by a model;
  - Detecting ISC by identifying the unusual voltage drop within the battery;
  - Detecting ISC by inspecting the one off voltage or capacity of the battery;
  - Detecting ISC by comparing the battery capacities calculated using different algorithms;
  - Detecting ISC by battery pack consistency
  - And more
- Again, Is this sufficient? Are these equivalent?

ISC - “they have never been recorded in the field, so why do we care about this”

- In theory, ISC are detected and removed before they are an issue. These cells **may or may not** have led to a thermal event.

- Are post-mortem analyses of field thermal events capable of identifying that an ISC was specifically the cause of failure? Some recorded reports indicate “the battery” was the source and others will be left as “unspecified”.

- Conclusion: Will we ever have **recorded evidence** of ISC events that lead to TR in the field? Will it be provided to regulators?

Can an ISC be replicated?

- Proposed internally activated ISC methods (Cu disk separator, implantable thermal heaters, particle insertion) are not “true” ISCs since they are engineered short circuits. The resistance and power of the ISC is chosen **by design** and these values have not been validated against true ISCs that could occur naturally in the field.

- They are also not a viable option within the various regulatory frameworks. They are engineered test methods, using specialized cells, and packs/vehicles containing them need to be carefully separated from standard packs/vehicles.

- Regardless of chosen ISC testing method, “real” world data is required to validate the chosen method(s). How do we get this data?

How to implement ISC Test in a regulatory environment?

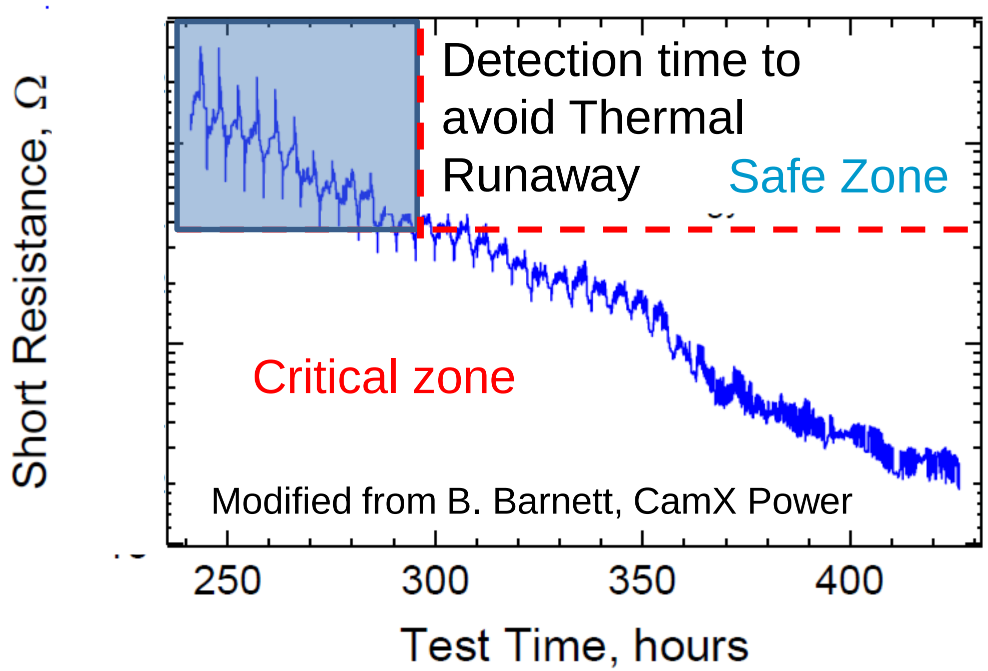
- Any ISC test (internally or externally activated) requires ISC data to emulate. Can sometimes perform external short circuit tests on individual cells, but is this realistic of a true internal short?

- Can we choose what is a realistic reproduction of an internal short circuit? Need to define the Contact areas, Resistances and Power **for every cell.**

- Results from literature, **using engineered cells**, show numerous types of short circuits and only some result in thermal runaway.

ISC Literature

An Internal Short Circuit (**from engineered embedded particle**) as it develops over time within an 18650 cell



The ISC-induced Joule heating will not develop into thermal runaway until the ISC resistance decreases to a low level, which varies for every cell/chemistry/design/etc etc.

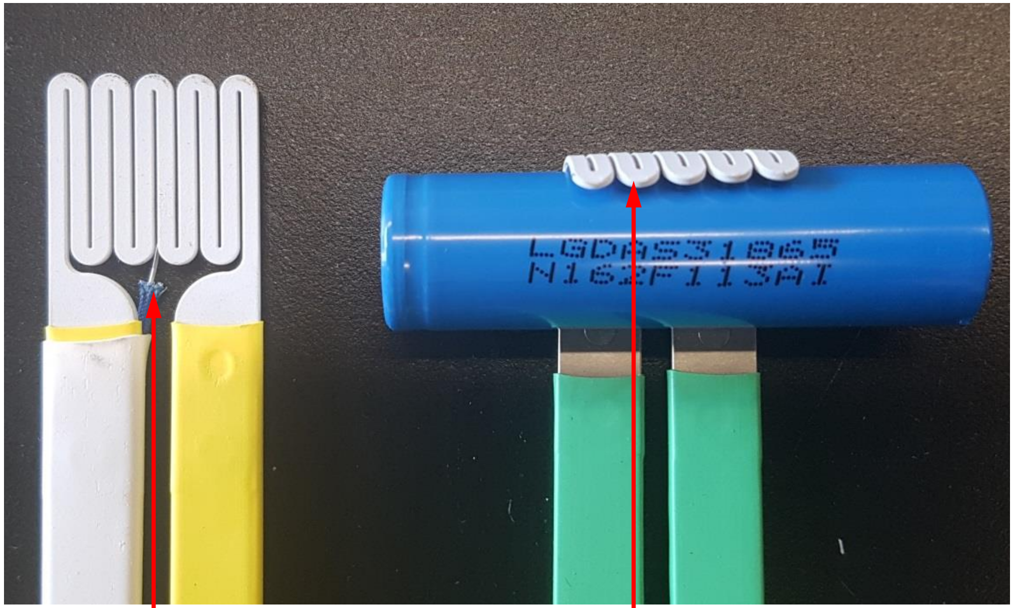
How to implement ISC Test in a regulatory environment?

Our Proposed Method

- To ensure that the battery pack/vehicle design can mitigate the most severe effects of an ISC. That is, the generation of a local hot spot that provides sufficient heat to initiate internal self-propagating exothermic decomposition of active material. This will lead to cell thermal runaway within a single cell when heat transfer from the cell to the environment is not sufficient. Test can not bias neighboring cells or system.

Latest Method Development

Newest TRIM design – WIPO WO 2018/132911



Key Parameters	Value
Thickness (mm)	1.0
Active Surface Area (cm^2)	5.6
Mass (g)	5.4
Peak Applied Power (W)	2000
Heat Flux (W/m^2)	$> 1 \times 10^6$
Applied Energy compared to Type A cell capacity (%)	< 10

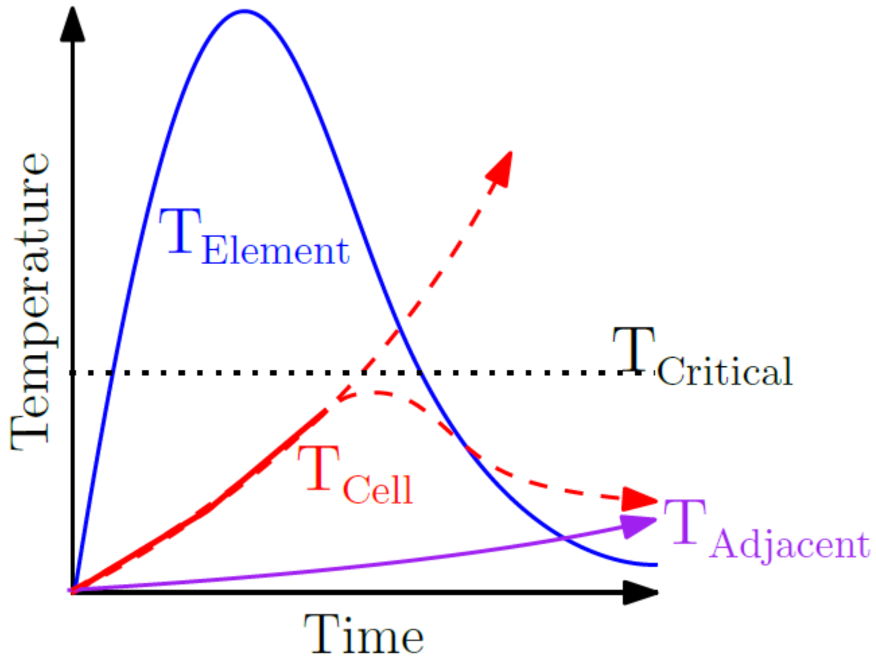
Formable to any cell (18650 shown)

Temperature feedback for optimized TR and element failure prevention

Internal Short Circuit Testing

How to Reproduce a "Realistic" event

$$T_{Cell} = f\ (P_{Element}\ ,\ k_{Cell})$$



Requires $P_{Element}$ input function for each and every EV cell type.

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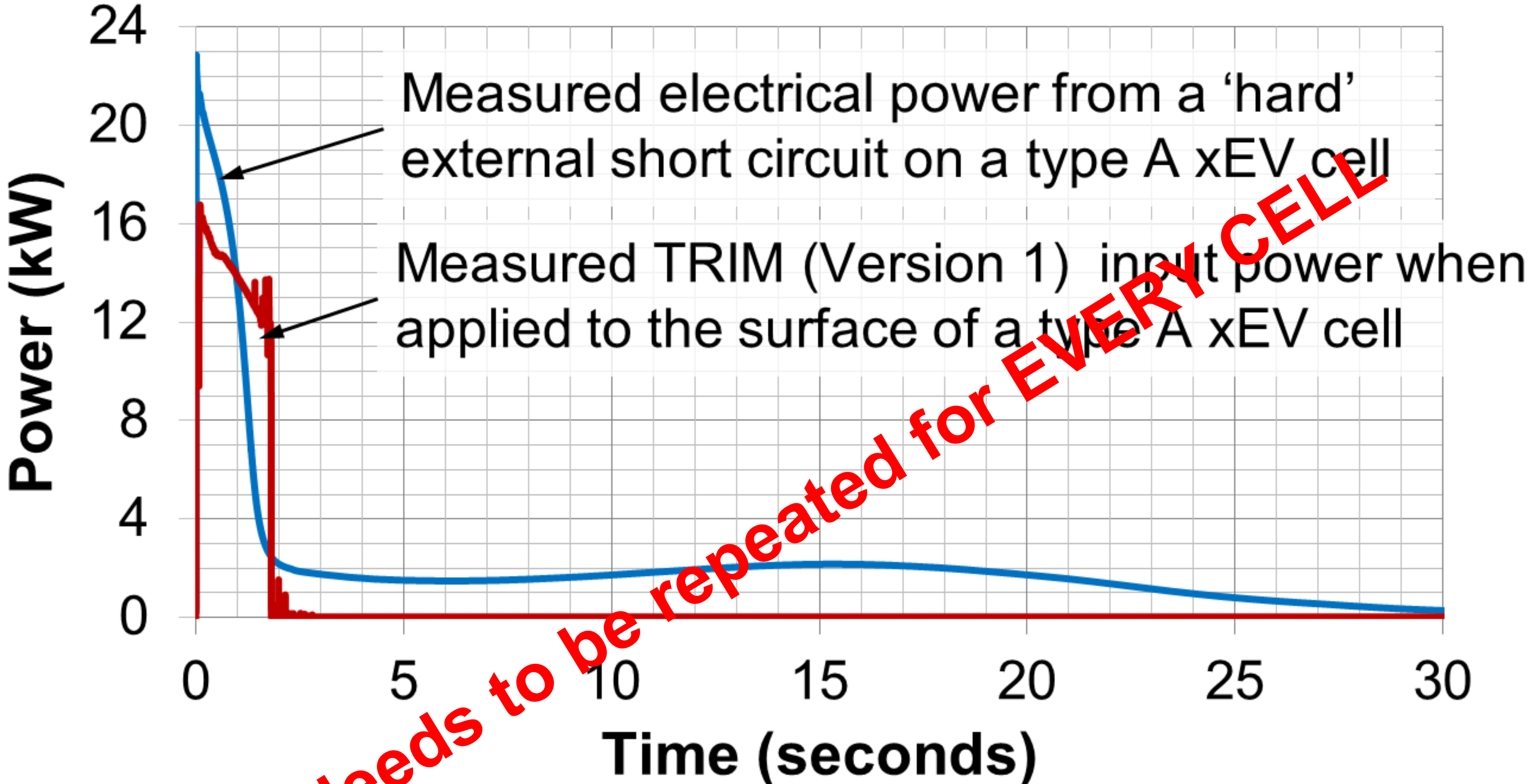
Option #1 - External Short Circuit Testing (where possible)



Comparison of TRIM input power applied to a type A xEV cell to the measured power during a 2.2mΩ external short circuit on an identical cell.

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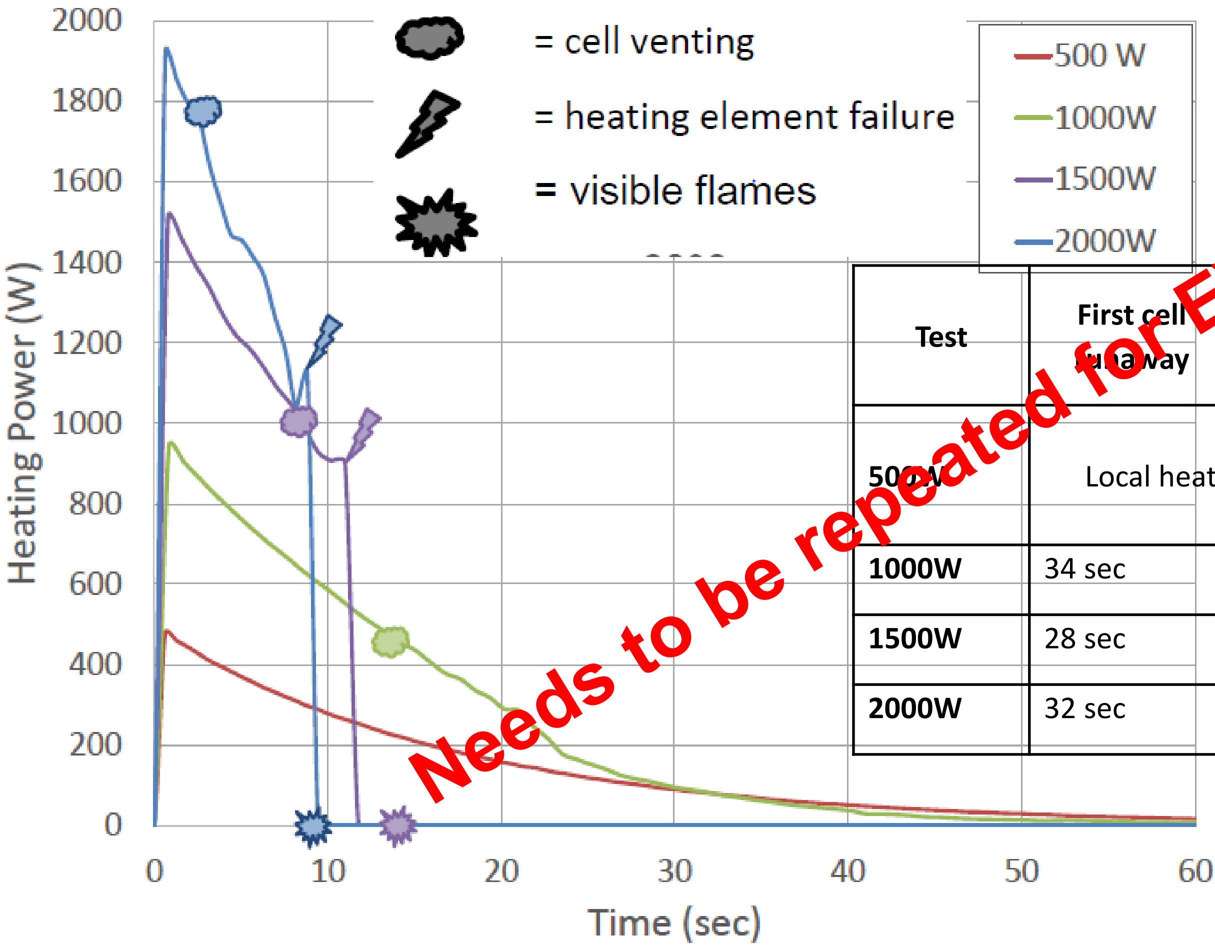
Option #2 - Determining power requirement for TR by trial and error



Total applied energy to heater for all tests is **<10%** of one cell's stored energy

Test	First cell runaway	Time to peak cell temp	Fire?	Last cell runaway
500W	Local heating only, no thermal runaway, no propagation			
1000W	34 sec	80 sec	NO	110 sec
1500W	28 sec	83 sec	YES (14 sec)	76 sec
2000W	32 sec	80 sec	YES (9 sec)	80 sec

Option #3 – Thermal Runaway Testing (ARC or Hot Box) or other

- Thermal Runaway data from hot box testing or ARC testing for every chosen EV cell
- Thermal Runaway profile is then converted to a power profile and applied to one cell in the pack
- If ARC/Hot Box testing shows no TR, is it “safe” and no further testing?

- Chose a short resistance for every cell based on some factor X
- Other?

Will manufacturers provide this information? Can we select and get acceptance by all contracting parties?

Again, Needs to be repeated for EVERY CELL

Is a “Realistic” reproduction of an ISC the Best Approach?

What are we trying to simulate?

- An ISC for which no data is available to validate?
- The response of the pack/vehicle design to a major ISC event?
- What is the critical concern? To ensure a thermal event does not result in a major safety issue for the occupants?
- In our opinion, any generated thermal event inside a cell should be mitigated at the pack/vehicle level. Thus, we need to validate that upon cell thermal runaway (the end of result of all major thermal events), the chosen packs/vehicle designs present no safety issue.

Is a "Realistic" reproduction of an ISC the Best Approach?

What are we trying to simulate?

- Thus, we need to design a test to determine the response of the pack/vehicle towards thermal runaway initiated from an ~~unspecified thermal event~~. Single cell thermal event caused by an unspecified internal short circuit.
- This will guarantee that the most critical end result of a single cell (thermal runaway) is tested and regulated.
- It is key that this testing occurs without biasing any pack or vehicle level safety system, any neighboring cells and without the additional of significant energy to the system.

Is a "Realistic" reproduction of an ISC the Best Approach?

What are we trying to simulate?

- Current GTR draft:

  "5.4.12: Thermal Propagation: For the vehicles equipped with a REESS containing flammable electrolyte, the vehicle occupants shall not be exposed to any hazardous environment **caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway**…"

May occur and **can potentially** lead to thermal runaway
No mechanism to identify, characterize or validate from field data

The real concern
Can be characterized, defined and replicated

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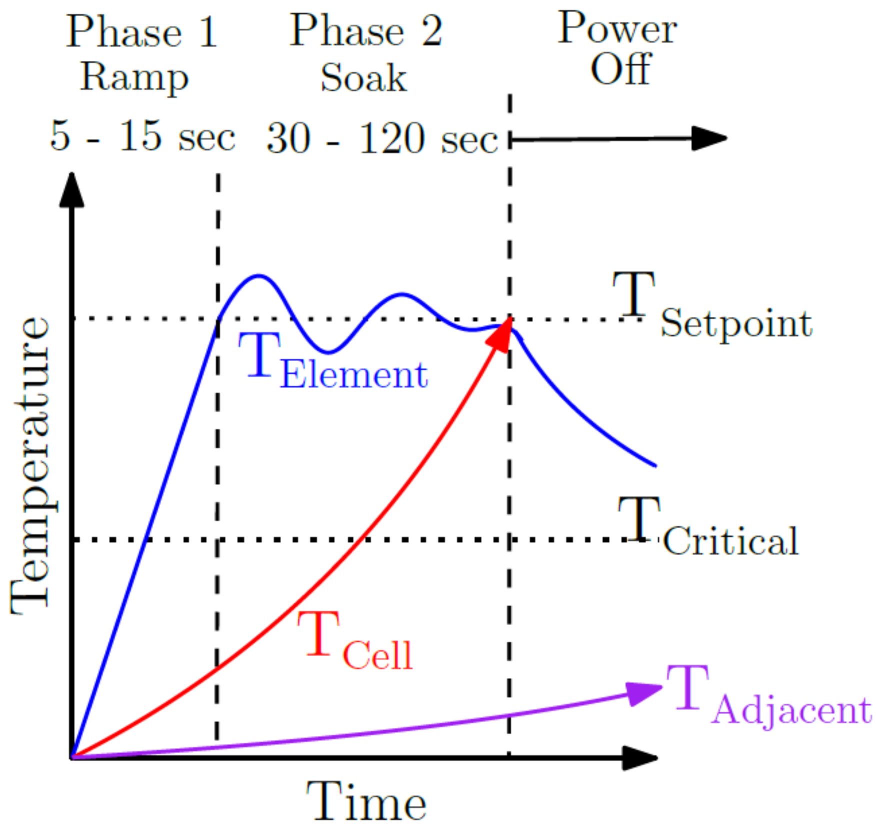
OUR APPROACH - Visual Implementation

Optimized for Runaway



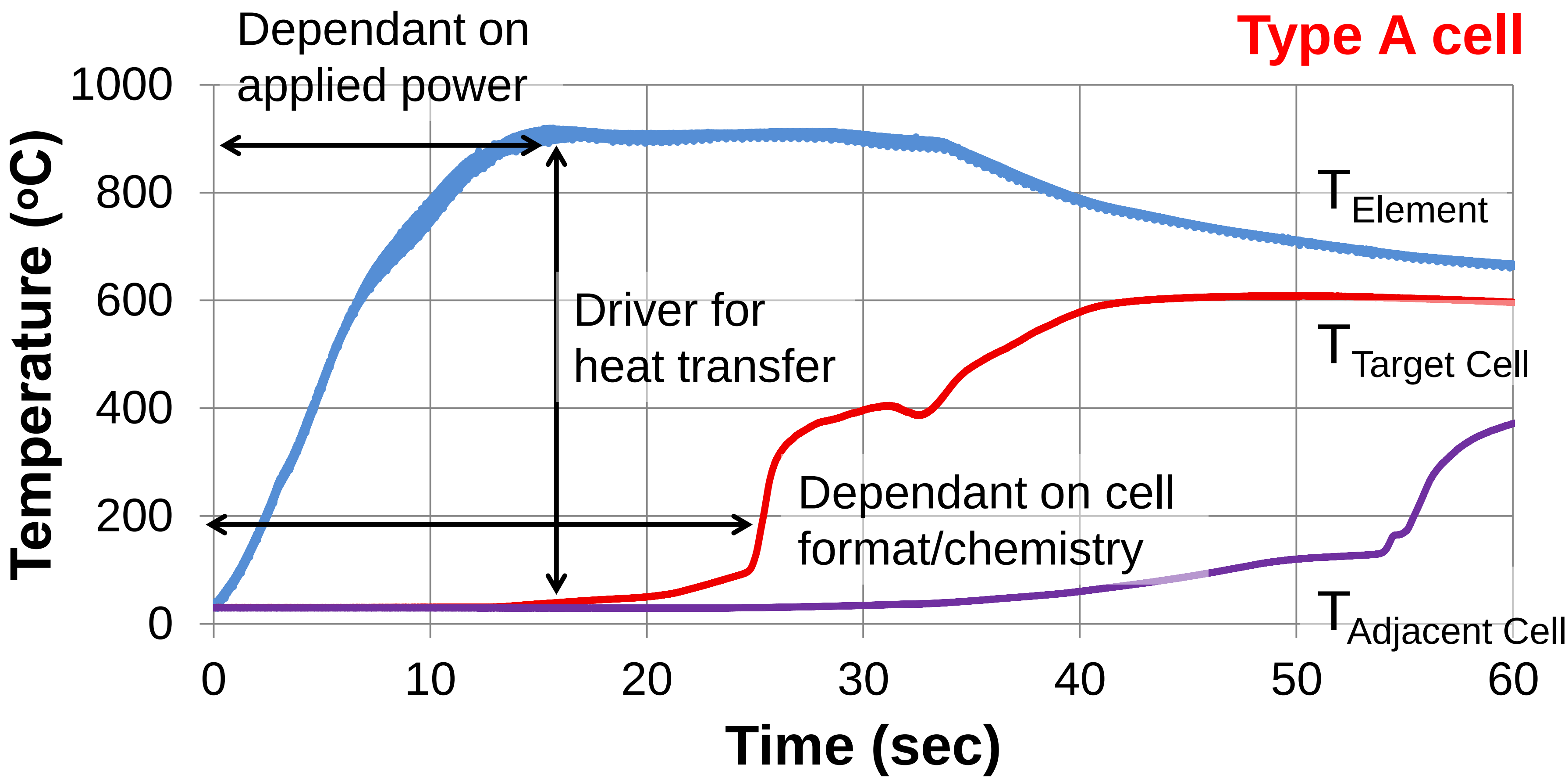
Requires $T_{Setpoint}$ and Ramp/Soak time definitions within test method.

$T_{setpoint}$ – dependent on cell chemistry, but likely some X° above the thermal stability of the battery materials

Ramp/Soak – dependent on thermal conductivity of chosen cell design/chemistry. Could be a value for pouch/prismatic/cylindrical

OUR APPROACH – Actual Implementation

Optimized for Runaway



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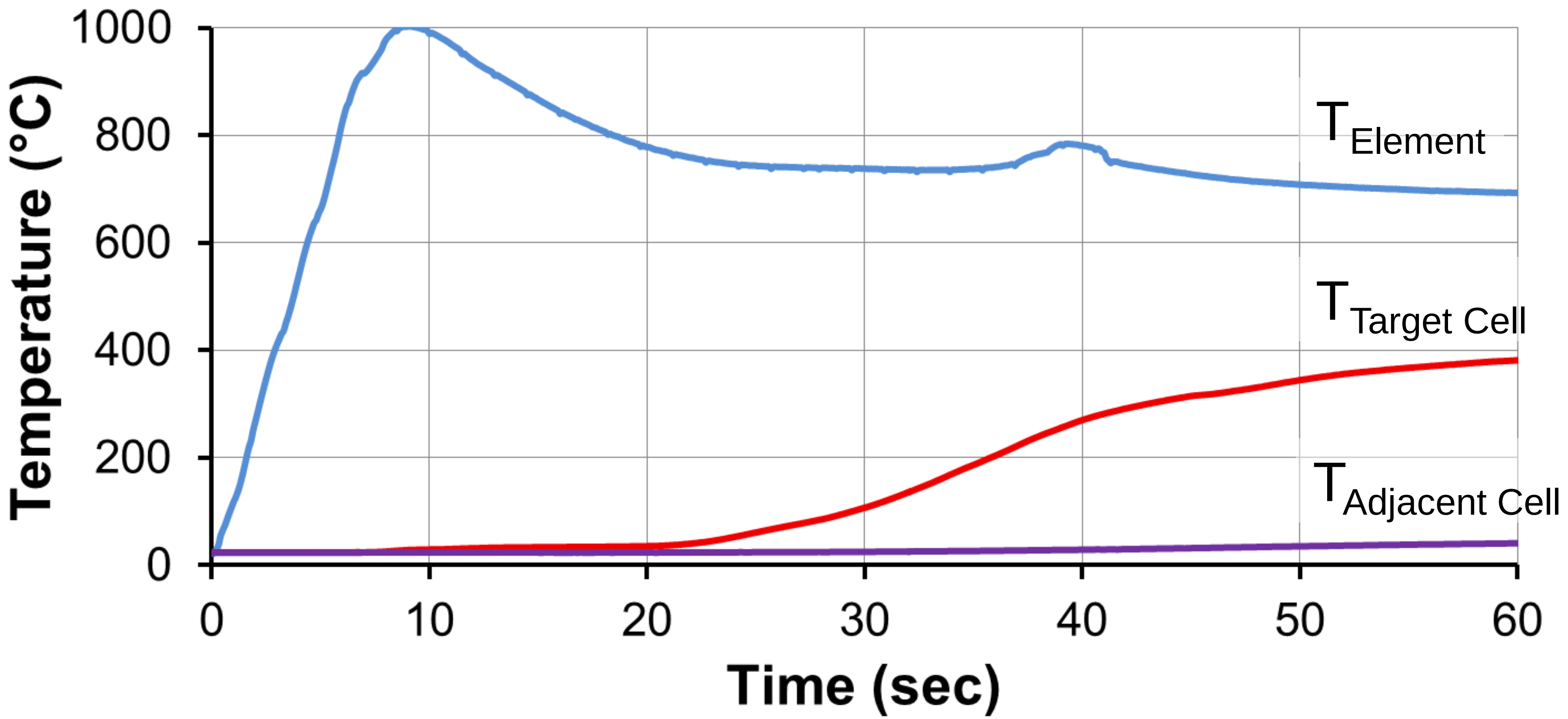
OUR APPROACH – Actual Implementation

Optimized for Runaway

Type D cell



The Path Forward

We need a consensus on what to simulate?

- An ISC or Thermal event leading to thermal runaway
- What are your Thoughts? We need to work through this JOINTLY

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Thank you for your kind attention!

Any Questions or Comments

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