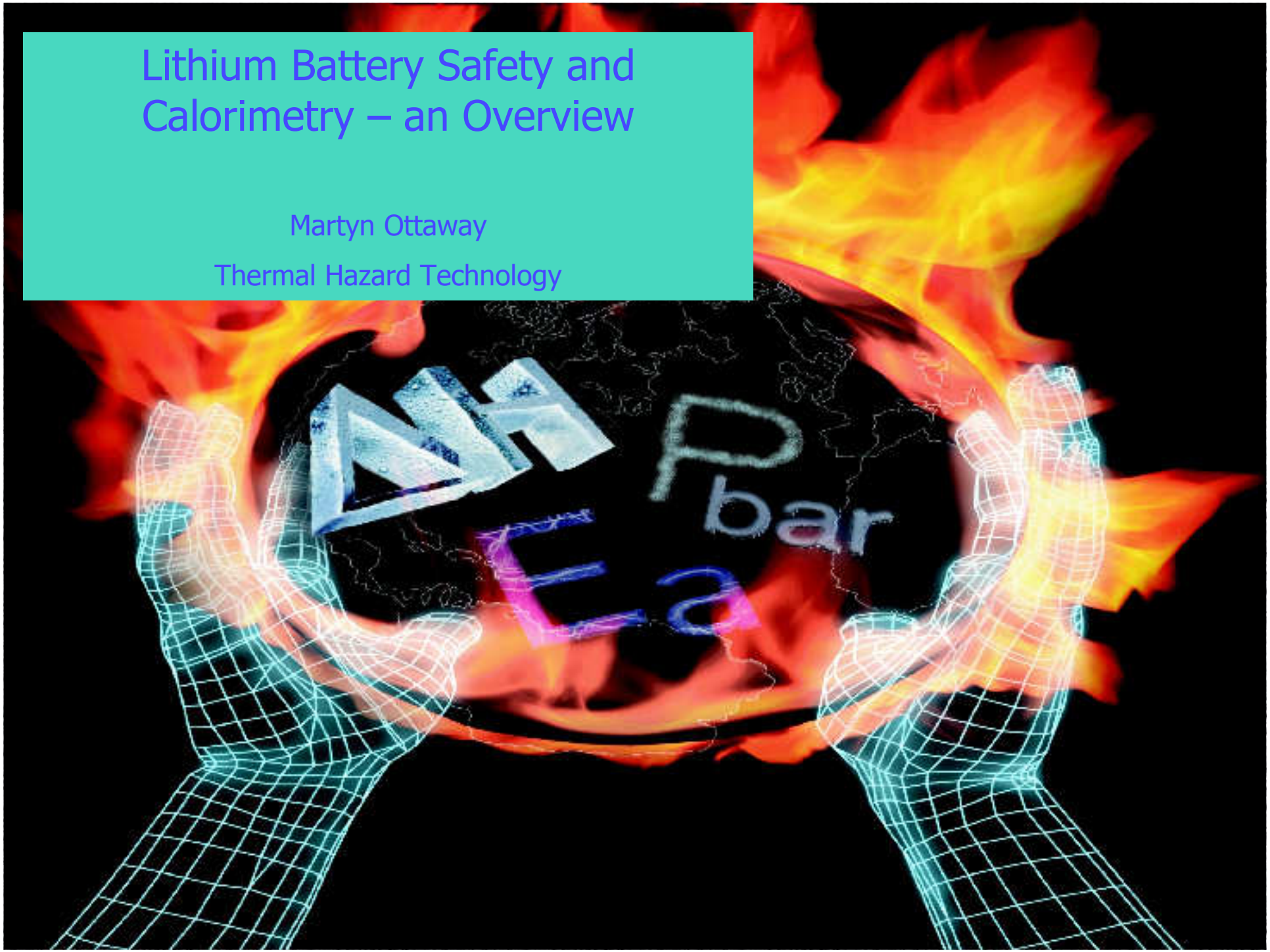
Lithium Battery Safety and Calorimetry – an Overview

Martyn Ottaway

Thermal Hazard Technology



Apple

Dell

HP

?

Next

Why use Lithium Batteries?

Maximum power density
Large temperature working range
Lifetime performance
Cost
Availability

Safety Issues with Li Batteries

Thermal properties are the…

- effect of heat on batteries – not much needed
- effect of heat produced by batteries – much produced!

Well known hazards: temperature exposure, over-voltage charging and over-discharge, shorting, crush, nail penetration…

Lithium battery hazards are due to:

(1) Maximum charge in minimum size & mass – greatest charge density…

(2) Dangerous chemistry - lithium is spontaneously flammable in air (and exists on a carbon matrix, carbon is a nice fuel) de-lithiated oxide (cathode) is unstable and reacts with oxidants (eg the electrolyte); electrolyte may be flammable

If the battery heats up and bursts as it will pressurise the internal materials will shoot out and burn like a Roman Candle (or worse)

To see more go to YouTube.com and in the Search box, type 'lithium battery explosion' and hit return…. Enjoy!

- 10 minutes Test Setup
- Latest Hardware and Software for operations and analysis
- Unparalleled adiabaticity
- Exceptional sensitivity; from 0.005DegC/min
- Very wide Battery Range
- Addition of Options for battery testing

Why the ARC with Li Batteries

- Quantifies the thermal and pressure
- Gives a 'worst case' assessment
- Tests components or batteries of 'any size'
- Very Many Labs using ARC... worldwide
- Different labs anywhere can compare data

Options & Modifications to allow

- Abuse tests in situ; Nail Penetration, Crush
- Shorting, Over-voltage charging / discharging
- In situ Cycling of batteries

- And extra-large volume calorimeters (for large batteries as used in HEV, PHEV, EV, bicycle, plane, space, military...

Why the ARC with Li Batteries

- Evaluates reactions in any type of battery component, for stability and safety
- Evaluates batteries under any state of charge and age, for their stability and safety
- Evaluates effect of abuse on battery safety, shorting, over-voltage, crush, nail
- Evaluates batteries when cycled from thermal properties, life cycle and electro-thermal efficiency information is determined
- Evaluates Battery performance and spatial temperature distribution over a wide temperature range

ARC is an Adiabatic Safety Calorimeter

…what is ADIABATIC?

Conditions of **NO HEAT LOSS** or gain… therefore –
the sample temperature is ALWAYS followed by calorimeter

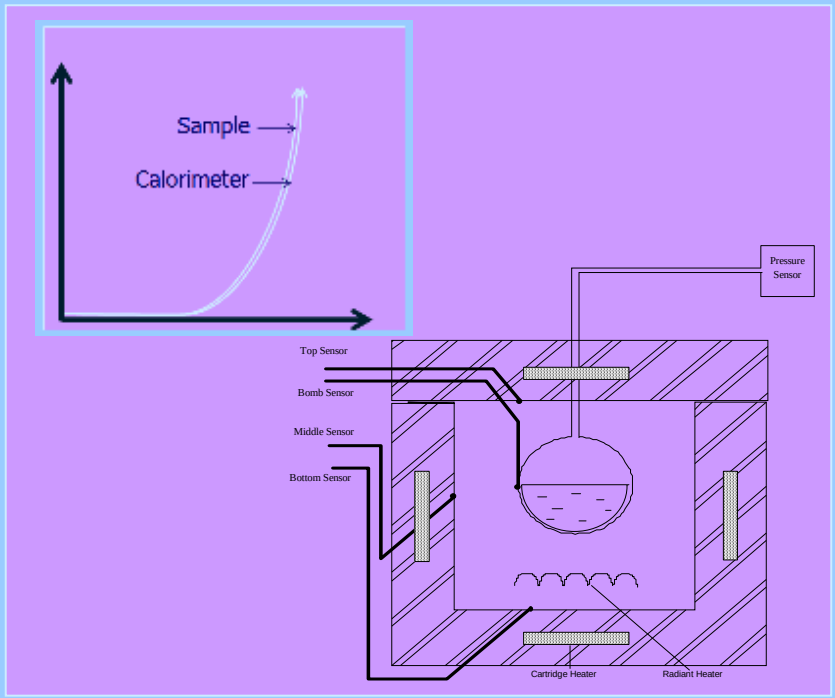
If the sample gives out heat….
its temperature increases
So …..
the ARC makes the
Calorimeter temperature rise

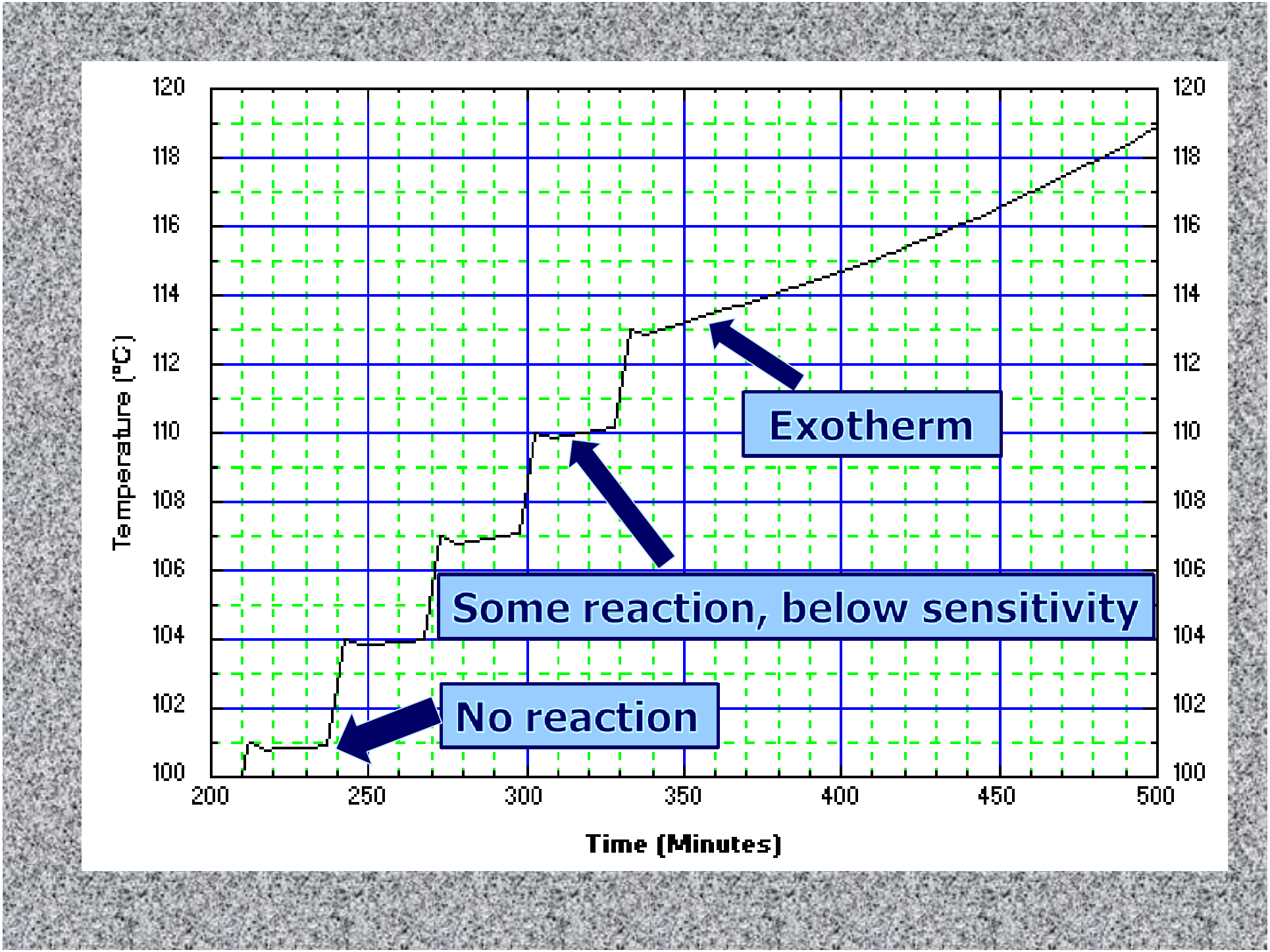
With conditions of NO HEAT LOSS or gain
…data showing exotherm reaction is 'WORST CASE' DATA

Therefore the ARC gives a SIMULATION of what may happen

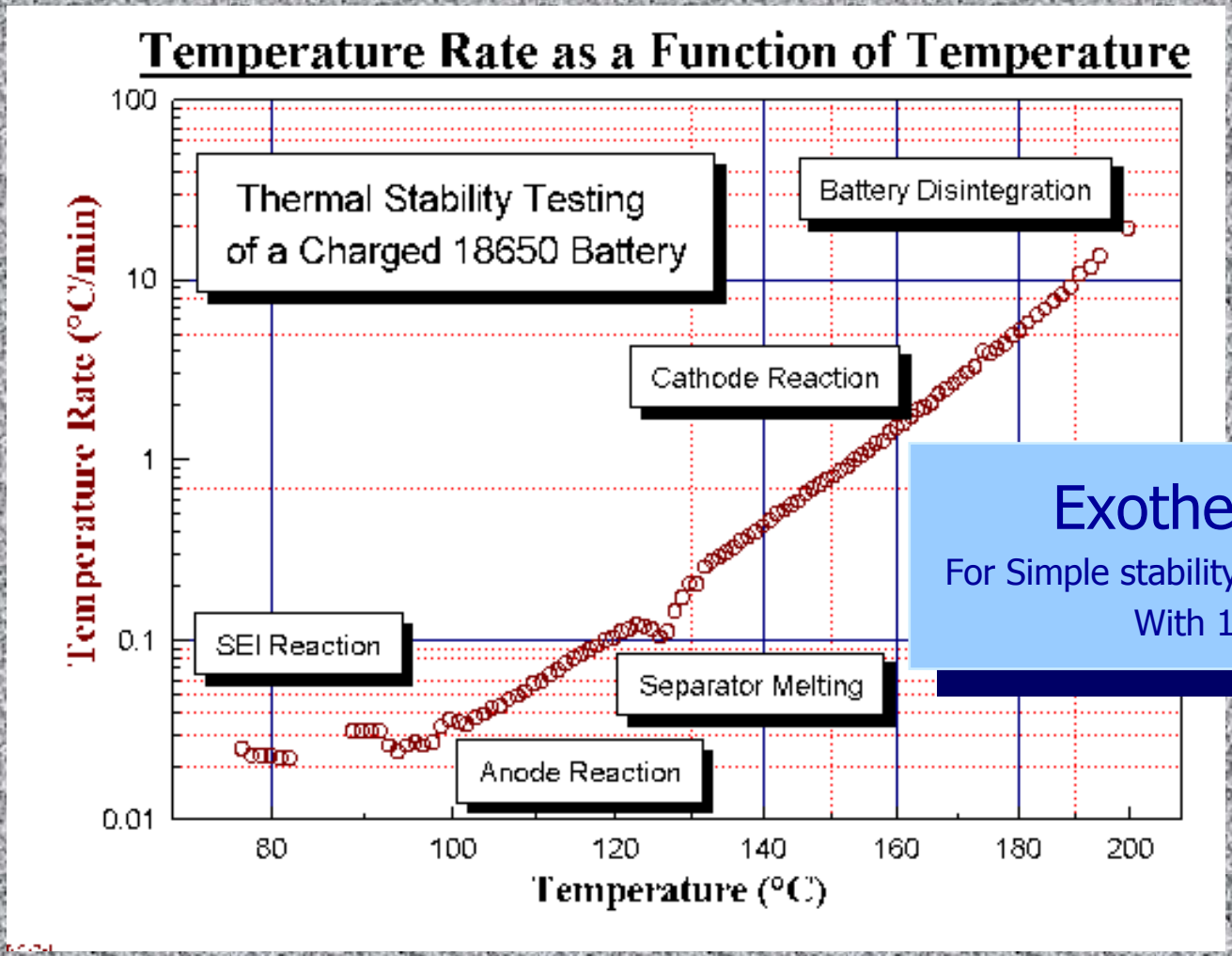
This WORST CASE data may be extrapolated to LARGER scale

As there is no heat loss, the data can be treated to simulate what will happen for any heat loss scenario




Temperature (°C)
120
118
116
114
112
110
108
106
104
102
100
200
250
300
350
400
450
500
Time (Minutes)
Exotherm
Some reaction, below sensitivity
No reaction

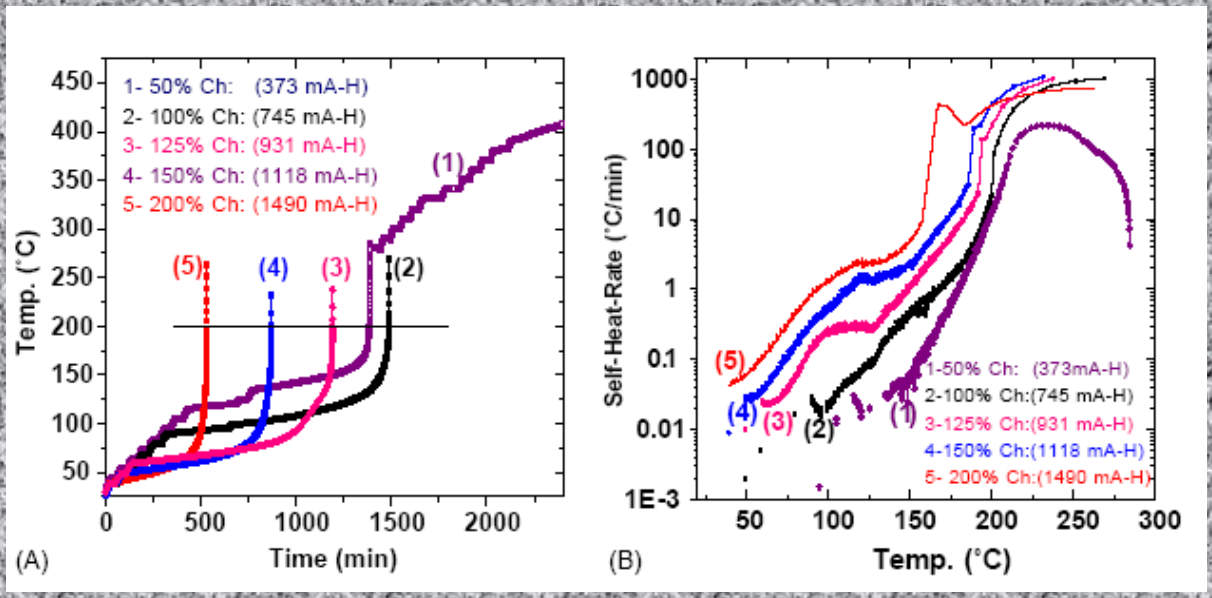
First test might be a THERMAL STABILITY, safety test.
To determine onset of heat release and 'runaway'



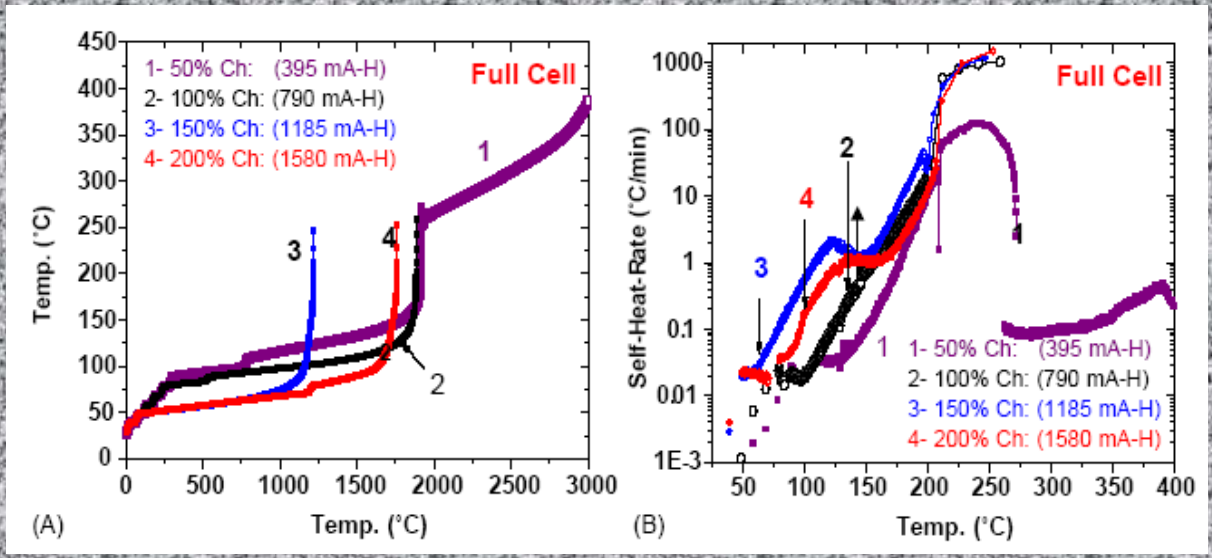
Exotherm only data

For Simple stability ARC heat-wait-seek test
With 18650 battery

Data varies with charge / age. Three regions of exothermicity, interface, anode and cathode reactions – but an 18650 may progress to explosion



Temperature vs. time and self-heat-rate vs. temperature for full cell at 50-200% SOC. All batteries went to thermal runaway except the one at 50% SOC.

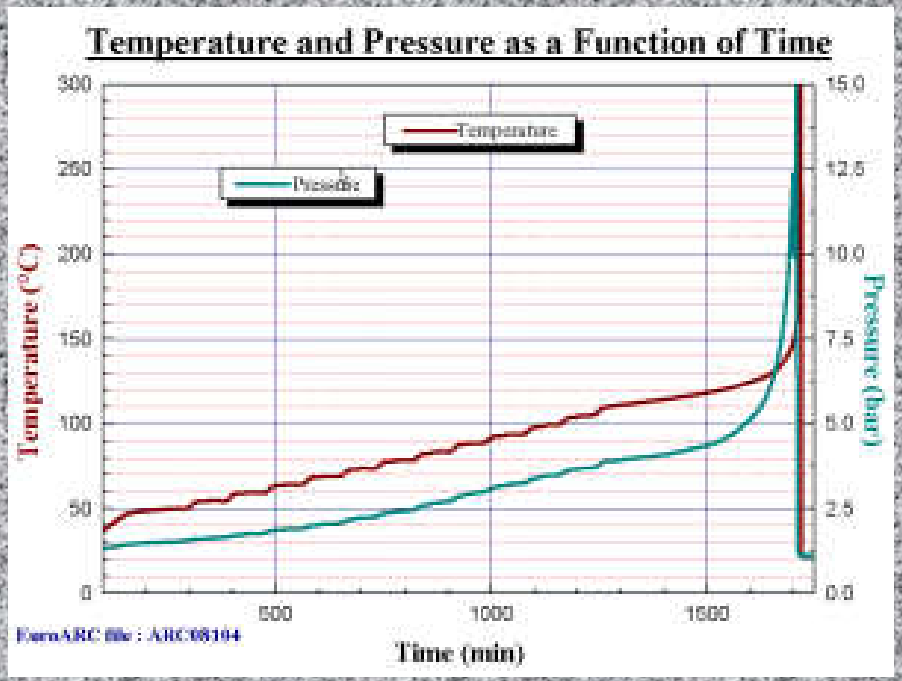


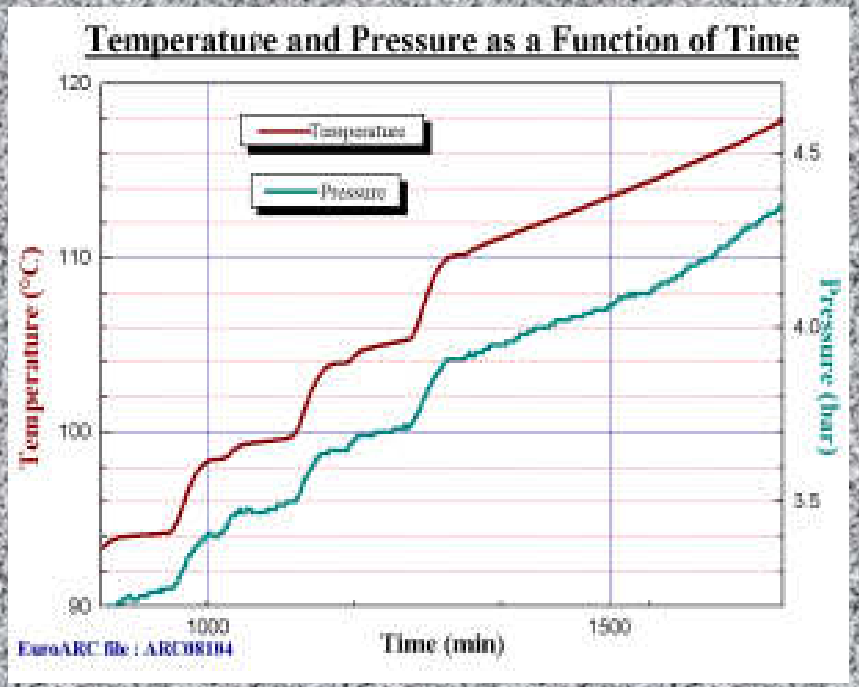
Battery A: Sn-LCO/ MCMF

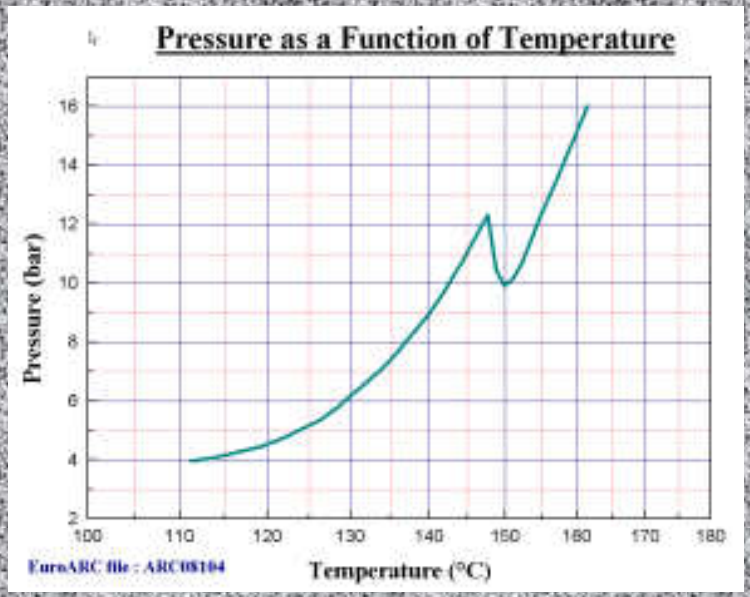
Battery B: LCO/ Graphite

J Power Sources 137 (2004) 117-127

Measurement of Internal Pressure

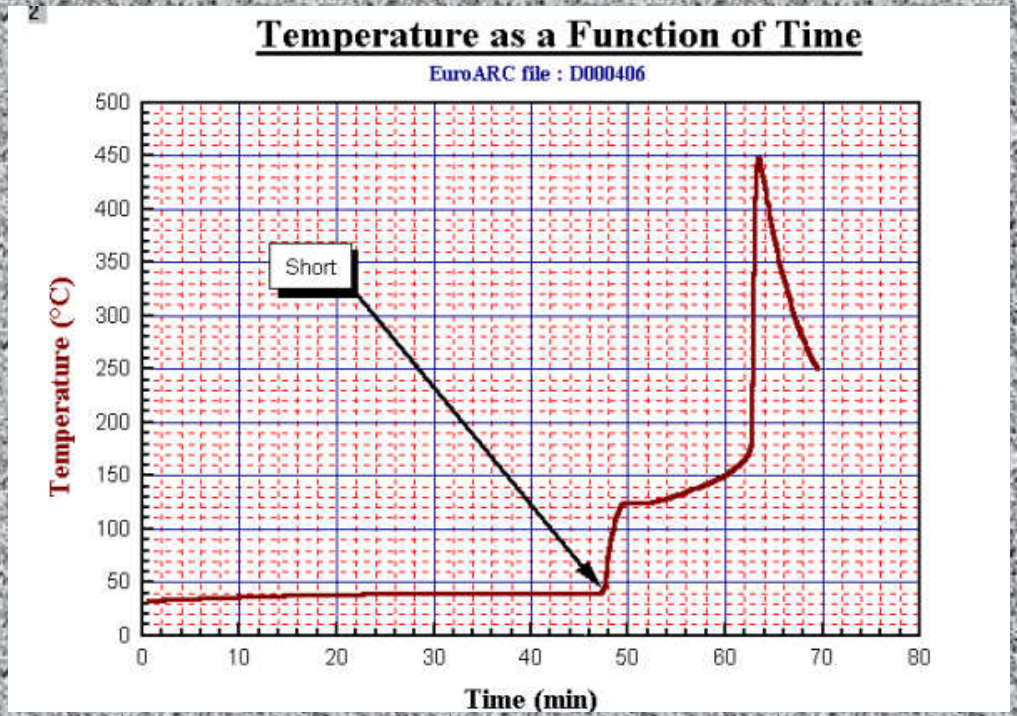


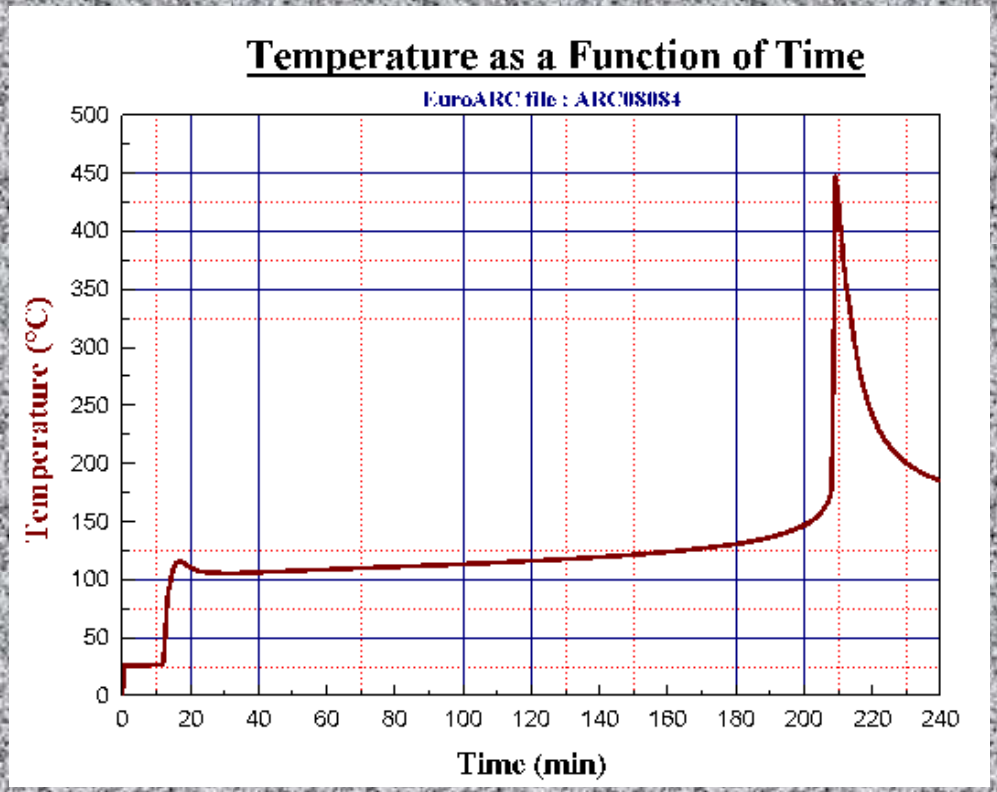




Abuse tests

- Over-voltage
- Shorting
- Heating
- Nail Penetration
- Crush
- Water Immersion

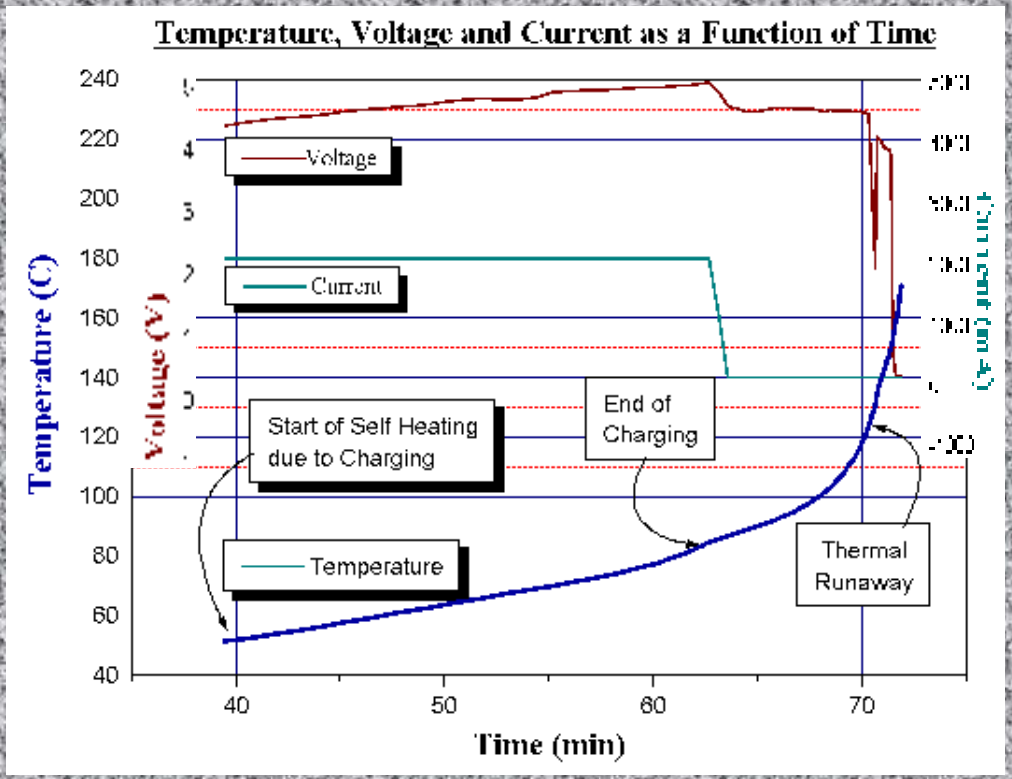


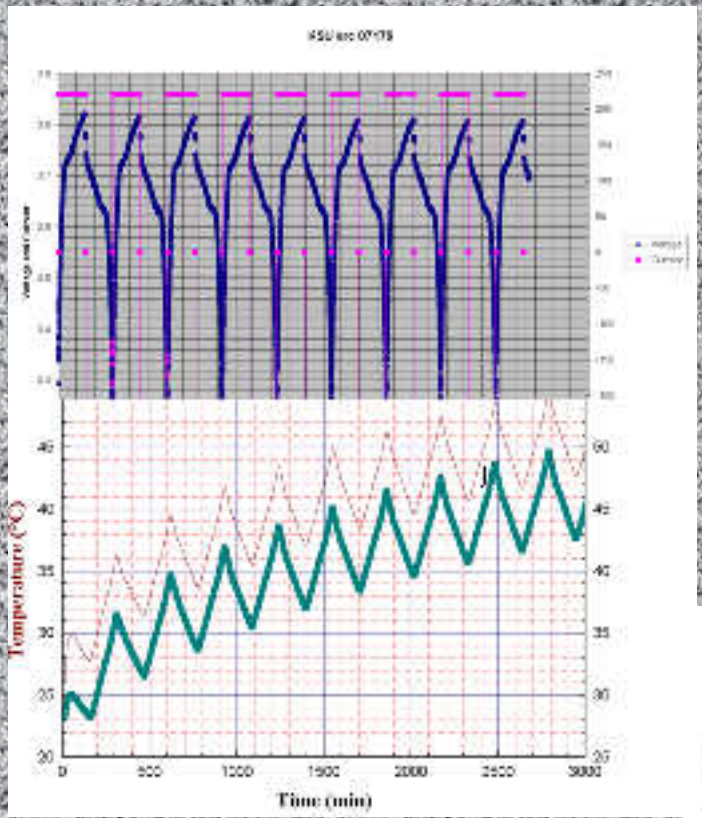


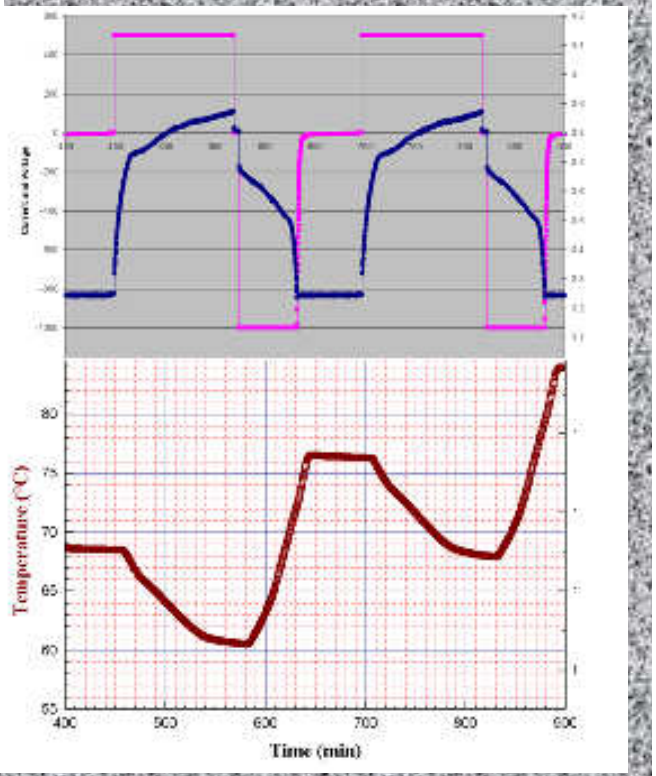
Shorting leads to explosion

Overcharging

Li-Polymer Battery

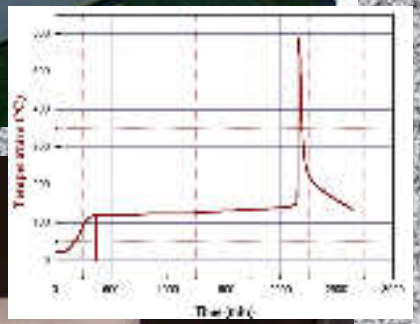


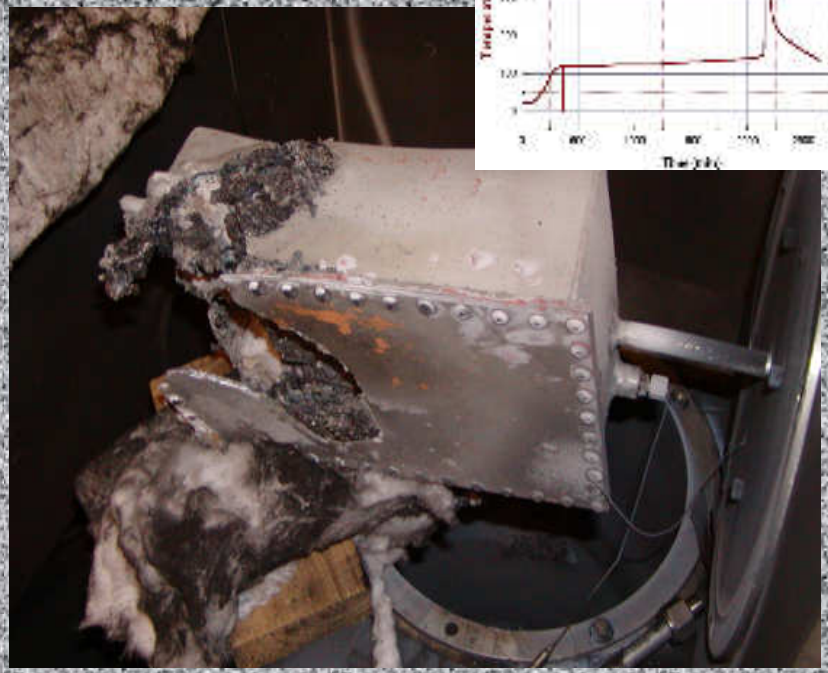




- Application of the ARC – not for Safety – but to
- DETERMINE BATTERY
- EFFICIENCY AND LIFECYCLE

- Electrothermal Dynamics
  - Discharging
  - Charging
  - Cycling





Electric vehicles- and one major future application

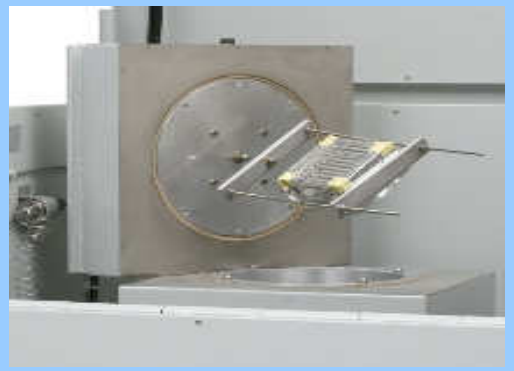
Fast discharge – Automotive (and Power Tools)

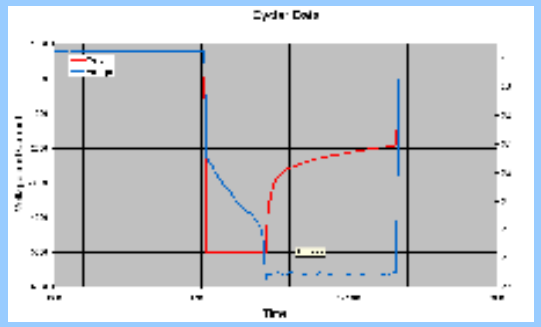
Battery Performance Calorimetry

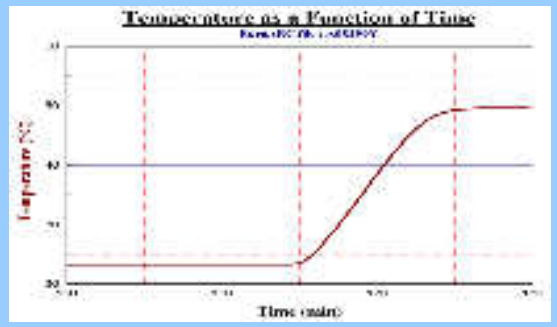
The latest application of the ARC within this area is for Automotive use where there is the need to determine heat output from EV batteries under conditions of fast discharge… to determine battery performance to aid design of thermal management.

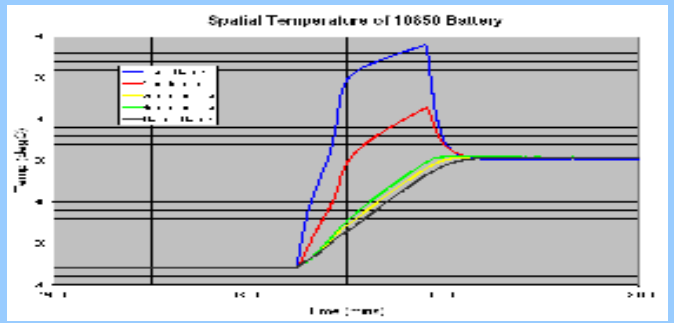
Such automotive batteries are of much different design to (eg) PC or cellphone batteries due to fast discharge requirements – they are also larger! There is the need to determine the variation of temperature rise on the surface if not with in the battery. Testing is using the ARC at ambient isothermal temperatures -20 to +40C, with discharge at tens of kW over short times

MultiPoint with CryoCool









MultiPoint in action – with the BPC (Battery Performance Calorimeter) –
recording temperatures around battery – note the most rapid rise at the anode

Summary

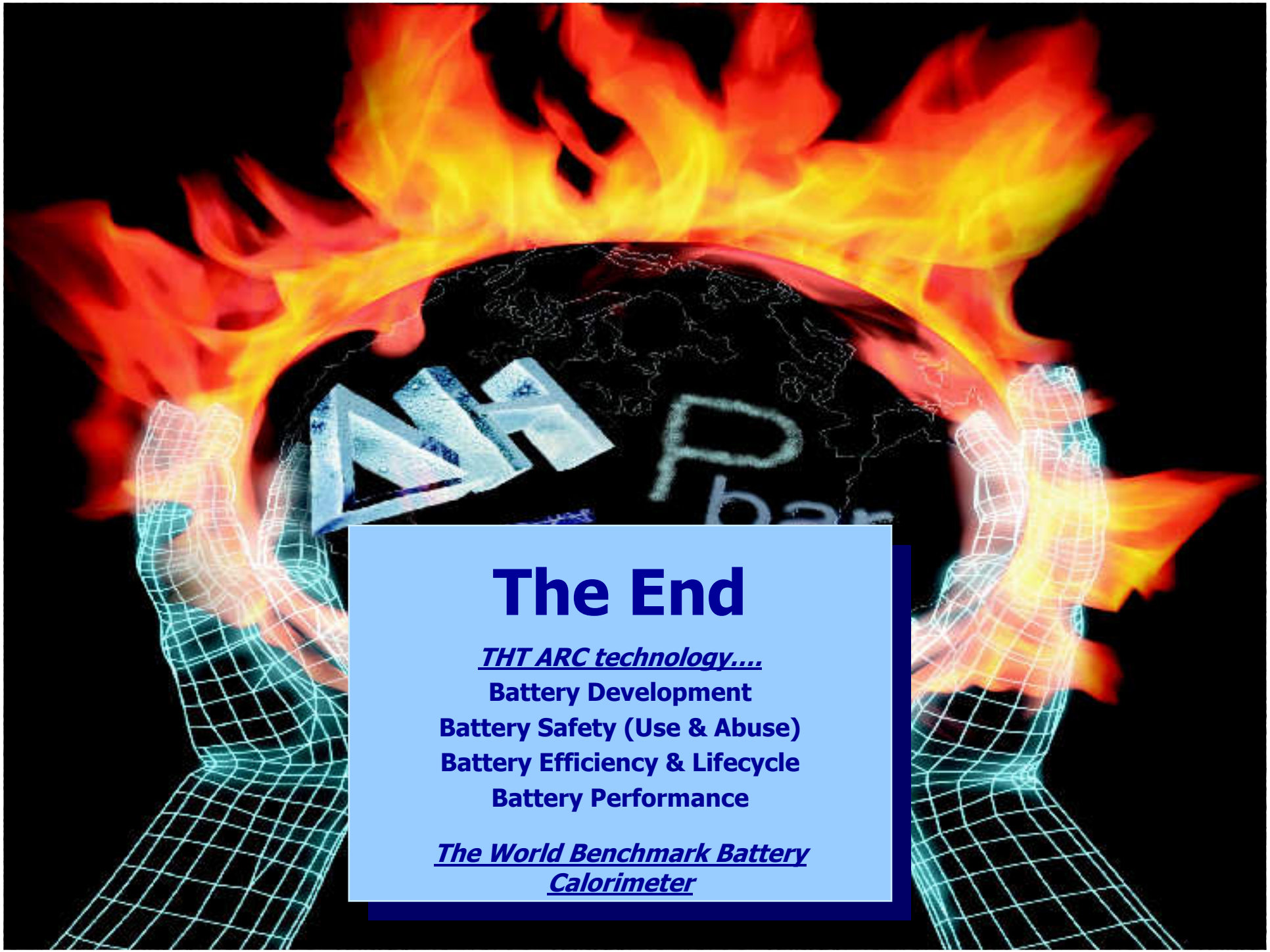
With Battery Safety and Cycler Options… the THT esARC, EV –ARC and BPC are Battery Safety Calorimeters,

All may be used to study;

BATTERY R&D, SAFETY, EFFICIENCY, PERFORMANCE…

- battery components (anode, cathode, electrolyte, SEI)
- batteries (at various age or State of Charge)
- batteries of 'any' size, battery packs
- batteries when shorted (internal or external), crushed
- batteries when over-voltage charging and over-discharging
- batteries when cycled to define their lifecycle and efficiency
- battery performance under fast discharge, MultiPoint and Cryocool

Uniquely the THT ARC gives quantitative, worst case, adiabatic data to fully quantify all potential thermal & pressure hazards associated with the battery and determines efficiency, performance and lifetime



The End

THT ARC technology….

Battery Development

Battery Safety (Use & Abuse)

Battery Efficiency & Lifecycle

Battery Performance

The World Benchmark Battery Calorimeter