# Safety of Li-Ion Batteries; Abuse Tests; Nail Penetration and Calorimetry.

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Calorimetric studies assessing the safety and thermal runaway potential of Lithium batteries have focussed on the heat release. Much work has been presented from ARC testing. The ARC has been used to evaluate thermal stability and has been seen to be a suitable calorimeter in which to do combined thermal (and pressure) and electrical measurements. These have included cycling, shorting and overvoltage. There are many other abuse tests that safety procedures and regulations request – one of these is Nail Penetration; internal shorting. The prescribed methods detail varied nail sizes and penetration speeds and the result is typically… are flames seen or not. Carrying out such a test within a calorimeter will give an extra dimension on the result. It will quantify the heat released in terms of temperature rise and will determine if the heat released on shorting leads in to other catastrophic reactions causing battery disintegration. It is illustrated here how the ARC can be used with simple modification to allow nail penetration tests to be performed. In the tests described the nail penetration has been achieved manually. An automated option is available from THT and there is also (not reported here) the possibility of simultaneously measuring battery voltage.

## Introduction

For simplicity the result from just one battery test is illustrated here where the test is commenced isothermally and nail penetration (internal shorting) is achieved. The surface temperature of the battery is measured against time. The test is with a ‘standard battery’ and is designed to illustrate the method and what data may be achieved.

## Battery

A commercial 18650 battery was used for these tests. The battery used was fresh and prior to testing was charged to 4.1V at C/5 (440mA). Charging then continued until the current was below 100mA.

## ARC Modification and Nail Penetration Protocol

A flat metal plate type battery holder was constructed. This had a thin insulting sheet on its upper surface and had height adjustment. On the base of this holder was a short metal rod that would go into the ‘plug hole’ in the base of the calorimeter. This allowed this holder to be securely fixed in place. The battery was placed on the plate and held in place with two high temperature straps. The battery position was near the centre of the Radiant Heater. The ‘nail’ itself was fixed to a rod being connected via a ceramic insulting join. (See photographs). This rod was of length to pass freely through the calorimeter lid. The dimensions were such that after passing through the calorimeter lid and replacing the lid onto the calorimeter base and with the nail resting on the battery, the rod came out of the calorimeter lid to a length suitable for nail penetration. There could be no pressure measurement during the test. The photographs illustrate the method, the battery and its position in the calorimeter.

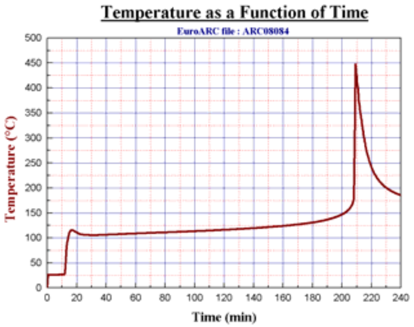



## Test Protocol

The test was set up in the manual mode. The calorimeter was heated to the starting temperature (25°C) A wait mode allowed for isothermal equilibrium and then the Seek mode commenced. Manual override of this mode forced the test to the Exotherm Mode and the Hold mode was implemented. The containment vessel door was opened. Using a heavy hammer, by hitting the protruding top of the rod, nail penetration was effected. The door was then closed. Data was collected, the Hold mode was switched off manually. The test time was short and the data observed. When it was clear that all exothermicity had been recorded the test was manually terminated.

## Results

Within one minute of nail penetration, 10 minutes into the test, rapid temperature rise was seen. It can be seen that over a time period of 3 minutes the temperature rose by 90 °C to 115 °C. The results show that during a further 2-3 hours the temperature continued to rise slowly, but then more rapidly, the temperature rising as a major reaction occurs that leads to battery disintegration

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## Conclusions

The data illustrates the ability of the ARC to carry out this abuse test and to produce data of value to an understanding of safety of lithium batteries. Of specific interest in this result is that after temperature rise due to the internal shorting there was lead in to further chemical decomposition that caused complete disintegration of the . Though not reported here, other tests have been carried out with this battery in a discharged state (and with batteries of different chemistries). These tests have shown lower temperature rises. And this lower final temperature has been too low to trigger further disintegration reaction; Heat-Wait-Seek steps occur. The conclusion would be that such a battery is inherently safer.

## Reference

For further information on this type of test protocol, data and other related scientific reprints, please contact the author at martyn.ottaway@thermalhazardtechnology.com