EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Imaging Dynamic Failure in Lithium Batteries	**Experiment number**: MA2768
Beamline: ID19	**Date of experiment**: from: 17/02/16 to: 20/02/16	**Date of report**: 08/09/16
Shifts: 12	**Local contact(s)**: Alexander Rack	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Paul Shearing – PI - (University College London)

Donal Finegan (University College London)

Dan Brett (University College London)

Gareth Hinds (National Physical Laboratory)

Report:

The purpose of the experiment conducted at ID19 in February 2016 was to capture the rapid failure mechanisms of commercial lithium-ion battery designs using high speed X-ray radiography. Lithium ion batteries can fail in particularly catestrophic ways, which can bypass integrated safety devices and containment strategies. The mechanism of battery failure is not well understood and therefore the magnitude of catestrophic failure is neither easily predicted nor controlled. We aim to elucidate key failure mechanisms that cause catestrophic failure and the efficacy of integrated safety devices for improving battery safety.

Our experimental setup consisted of a customised battery nail penetration system (Figure 1) that clamped the tested cells in line with the X-ray beam. The clamped batteries could then be subject to mechanical abuse (in the form of nail penetrations or crushing), thermal abuse (through application of high resistance heating wires), or electrical abuse (by connecting the battery terminals to a power source) (Figure 1c). A thermal camera located at the rear of the nail penetration system simultaneously recorded a live feed of the surface temperature of the batteries being tested (Figure 1b). A high flow-rate air pump was connected to the chamber in which the batteries were failed (Figure 1a) that extracted the generated gases outside. An additional vent cover was placed above the nail penetraion system to help capture any other escaping gases. The thermal camera, nail penetration system, electrical power, clamps, heating and ventilation were controlled from outside the hutch.

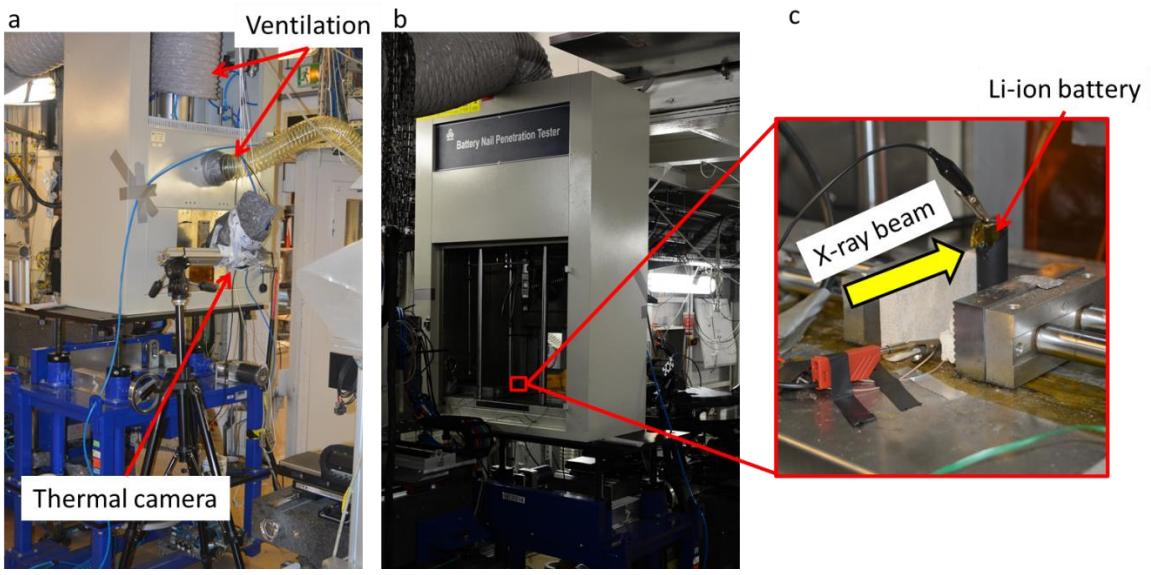

Figure 1(a) Rear view of the nail penetration system showing placement of the thermal camera. (b) Front view of the nail penetration system showing the location of the battery placement. (c) Battery placement within the nail penetration system showing a battery being clamped in place and electrically connected.

Over the duration of the 4 day experiment over 100 batteries were safely and successfully failed during various different abuse tests and studies. The beamline was very simple to operate and there were no setbacks experienced. The high energy and high flux of ID19 allowed us to capture even faster phenomena than what was expected at more than 10,000 frames per second – this allowed us to capture the most rapid failure mechanims; Figure 2 shows the an example where vent clogging was seen to cause the rupture of a commercial 18650 cell (captured at 18,000 Hz). We completed all of our proposed tests during the allocated beamtime and are currently disseminating the results. Certain causes of catestrophic failure have been identified and we aim to disseminate this research through high impact publications over the coming months.

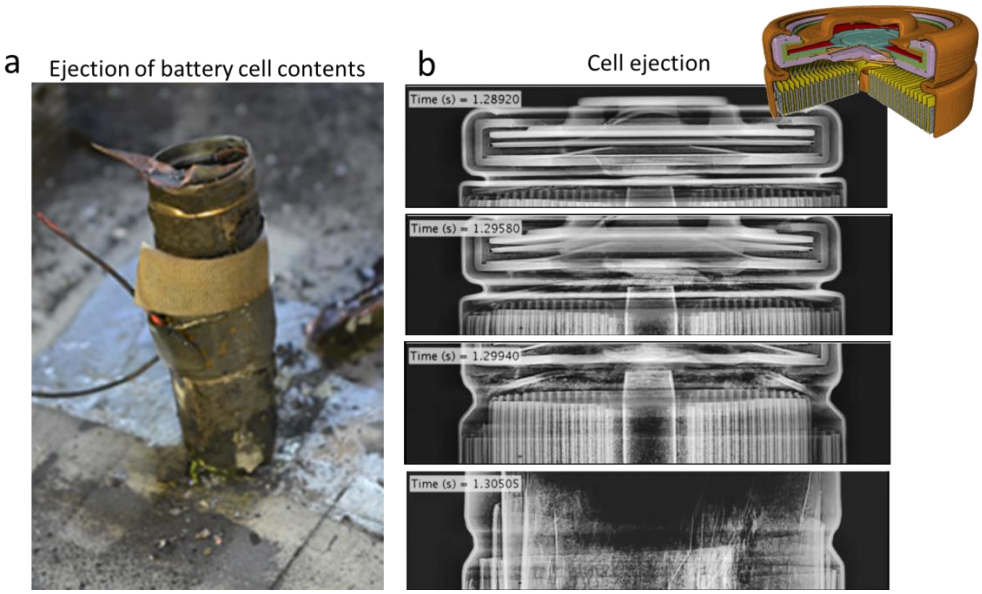

Figure 2. (a) Post-mortem photograph of a lithium-ion 18650 battery after ejecting its contents during thermal runaway. (b) Radiograph series captured at 18,000 Hz showing the progression of vent clogging leading up to an explosion. Inset: 3D reconstruction of the vent region showing integrated safety devices.

This was a highly technologically and logistically challenging experiment that has shown very promising results. We thank the ESRF, as well as Alexander Rack and Marco DiMichiel who were exceptionally helpful during and leading up to this experiment.