SABATAIR
Deliverable 2b:
Assessment of the effectiveness of the packaging performance tests

Task	**2**	Identification of packaging solutions and assessment of their effectiveness

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[1] Dissemination level: **PU** = Public, **PP** = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium (including the JU), **CO** = Confidential, only for members of the consortium (including the JU)

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Introduction

The purpose of Task 2 was to determine key variables within the SAE AS6413 G27 draft standard (Nov 2018 version) which materially affected the outcome of a test and the severity of the thermal runaway event. In addition, Task 2 was designed to gather data to feed the development of a thermal model to predict the performance of a given packaging scenario. The November 2018 draft of SAE AS6413 was used throughout this Task, however any changes to the base setup were taken into account. The detailed description of the test rig and of the test equipment used in the tests conducted in the context of Task 2 can be found in deliverable D2a.

The testing activities conducted in the context of Task 2 were distributed in four consecutive phases. At the end of each phase, the outcome generated therein was analysed to determine if there was any need to adjust and refine the plan and scope of the subsequent phase.

Having identified key variables in Phase I, Phase II, which included a subphase identified as Phase IIb, was dedicated to the identification of methodologies for the improvement of heating rate control, heater type and position, and determining which thermocouple location was best for heat transfer control purposes. Phase III was a follow on of Phase IIb which focused on the effect of differing rates of heating. Phase IV then ran tests using the “Reduced Cell Configuration” layout within UN certified fibreboard boxes in order to compare physical results with those of the thermal modelling, with the results discussed in deliverable D3b.

Chapter I: Phase I

I.1 Introduction

In Phase I, the objective was to trial testing in accordance to the proposed SAE AS6413 draft standard (November 2018 version). The key activity was to identify problems encountered during the testing as well as recording any inconsistency between the results of tests conducted following the same protocol on test articles having the same configuration. The results from this phase were used to determine the key variables that affect the reproducibility of the tests.

It's important to note that the heating rate during this phase was not linear as required in the SAE AS6413. This is because, the initial phase of Task 2 had the objective to identify the challenges in the test set-up and the control of the heater cartridge was one of the major difficulties.

I.2 Phase I Testing

Phase I is dedicated to evaluate the reproducibility of the 'Test VII: Reduced cell configuration' with pouch cells, cylindrical cells and using two different SOC level (SOC 30% & SOC 100%). The Phase I test was not designed to evaluate the performance of the package in the event of a thermal runaway.

I.3 Set-up and Material

There are two set-ups used during Phase I, illustrated in Figure 1, one for cylindrical cells and another one for pouch cells. During this phase, the set-up did not follow SAE AS6413 exactly (i.e. the thermal runway was not initiated on the cell on the center of the lateral row as described in the standard) but the focus of the tests was to investigate the repeatability of the thermal runaway initiation.

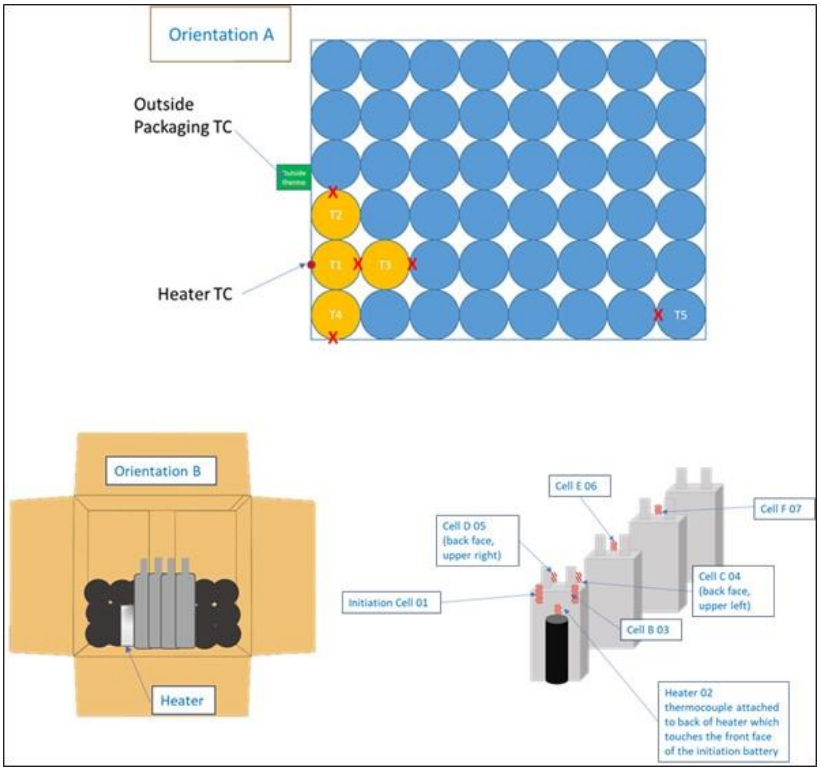

Figure 1: Test set-up in Phase I (orientation A & orientation B)

The heater cartridge used in this phase is 8mm thick and 40mm long, as shown in Figure 2. It is capable of reaching temperatures above 750°C and is rated at 200W running at 230V. This is wired to a PID (a proportional–integral–derivative) controller which is a control loop feedback mechanism which regulates the heater temperature based on the thermal response of a thermocouple.

Figure 2: Heater cartridge used in Phase I

In order to comply with the SAE AS6413 draft standard, thermocouple TC01 (placed between the initiation cell and a periphery cell on the far side from the heater cartridge) was assigned as the control thermocouple, which would control the heater cartridge to raise TC03 by between 5°C and 20°C a minute. Additionally, the outer packaging used in this phase was a UN fiberboard 4G box.

***Table 1**: Phase I Testing Parameters*

Parameter	Setting
Chemistry	NMC
Capacity	3.2Ah
Test configuration	SAE AS6413 Test VIII: Reduced Cell configuration
State of charge (SOC)	30% or 100% (based on recorded voltages)
Dividers	No dividers – cells and dummy cells touching (where possible)
Layers	One layer
# of cells	4
Repeats	3

I.4 Test Summary

Test 01-06 follows orientation A shown in Figure 1, using the 18650 cylindrical cells. Test 07 and 08 follows orientation B and pouch cells were used. An individual report of each test carried out in this phase can be found in Appendix I.

I.4.1 Highlight of Test ID 01

In this test the cells used were at a state of charge (SOC) of 100%. The heater cartridge was set to increase its temperature to 800°C. Nevertheless, due to the difficulties in controlling the heater's temperature, the temperature rise to 800°C was increased at a varying rate. This means that the heating rate was not consistent. In three minutes, smoke was observed and followed by an explosion.

Cells were dislodged from the test set-up, leading to debris shooting out of the test chamber. This indicates the aggressiveness of the thermal event when heater was set to a high temperature with no control of the ramp rate. Eventually, all cells entered thermal runaway and flame was observed.

Additionally, the outer packaging has localized damage (burnt), where the initiation cell was positioned. The highest temperature observed on the outer packaging is around 250°C.

I.4.2 Highlight of Test ID 02

Following the violent thermal event of Test 01, the initial temperature of the heater cartridge has been reduced to 300°C. The SOC of the cells was reduced to 30%. All cells entered thermal runaway at the same time which is around nine minutes into the test. The peak temperature observed was 420°C in the initiation cell. The aggressiveness of the test is clearly lower than Test 01, where the outer packaging was not damaged and no debris or flame was observed.

I.4.3 Highlight of Test ID 03

Test 03 aimed to simulate Test 01 and check its repeatability, result of Test 03 is shown in Figure 3. Therefore, the set-up was the same and heater cartridge was set to 800°C from the beginning and SOC remained at 100%. Smoke was observed three minutes into the test, follow by an explosion a minute after. Both flame and debris were observed and at the outer packaging a peak temperature of 150°C was recorded. The peak temperature observed overall was 1300°C (see Figure 3).

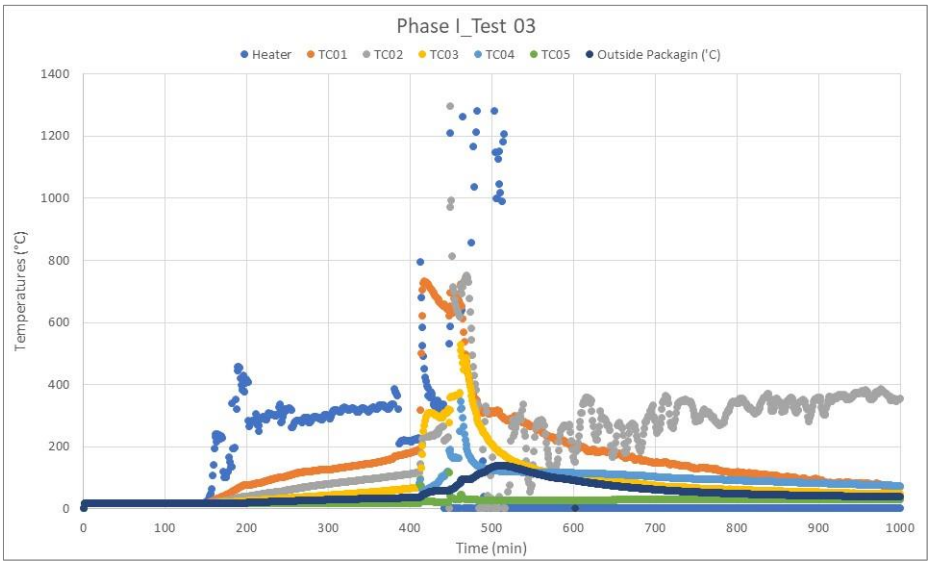

Figure 3: Result of Test 03

I.4.4 Highlight of Test ID 04, 05 & 06

Three additional tests (Test ID04-ID06) were performed to assess the reproducibility of Test 02. The results (see Figure 4 and Figure 5) show similarity in the aforementioned tests where thermal event occurred in the same way. No flame or debris were observed, no damage to the outer packaging and only slight temperature increase in the packaging. The peak temperature observed in this test was between 600°C-750°C.

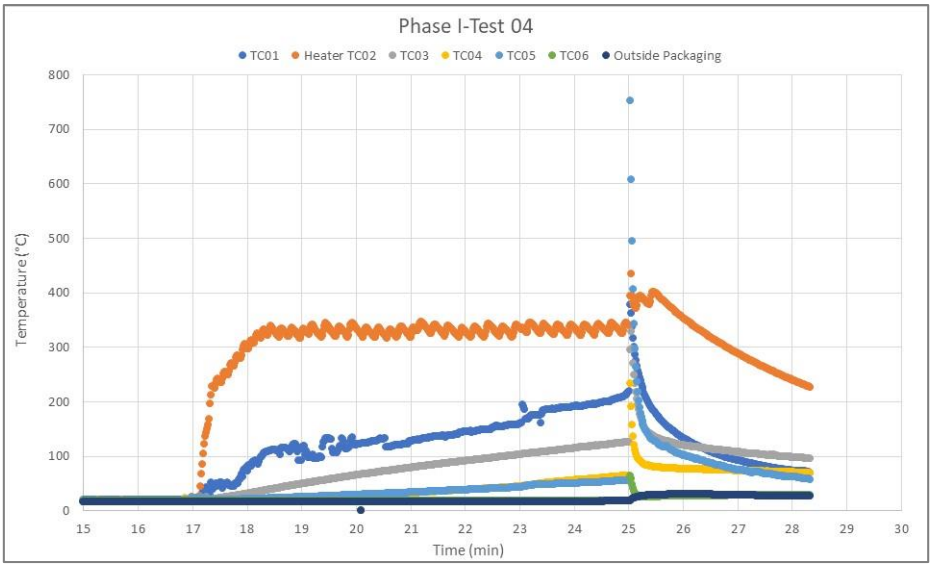

Figure 4: Result of Test 04. The cells were at 30%SOC.

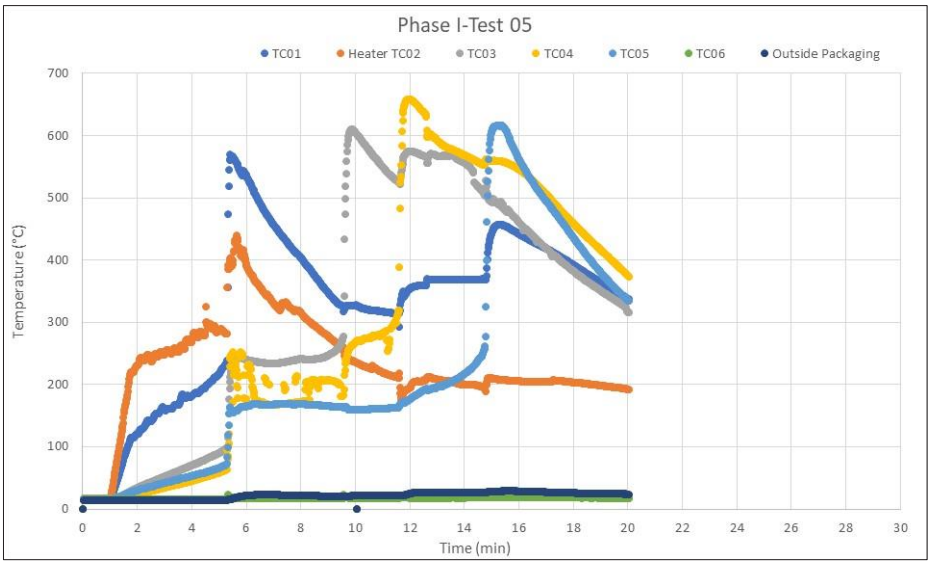

Figure 5: Result of Test 05. The cells were at 30%SOC.

I.4.5 Highlight of Test ID 07

The aim of Test 07 was to investigate the effect of the cell shape on the outcome of the test. Here prismatic pouch cells (Kokam 3.5Ah) were used. Therefore Test 07 followed test set-up Orientation B, as shown in Figure 6.

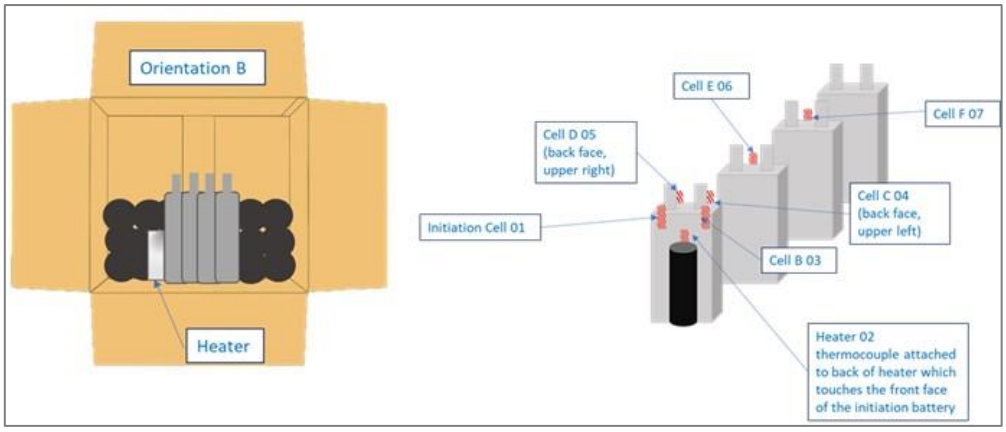

Figure 6: Description of the test setup using pouch cells

During this test, the pouch cells were tested at 30% SOC and the heater cartridge was initially set to 300°C. Some thermocouples recorded after 66 minutes a temperature increase to a maximum of 130°C. There was no violent thermal event or visible damage to the outer packaging. Although the packaging showed an increase in temperature (below 50°C) (see Figure 7).

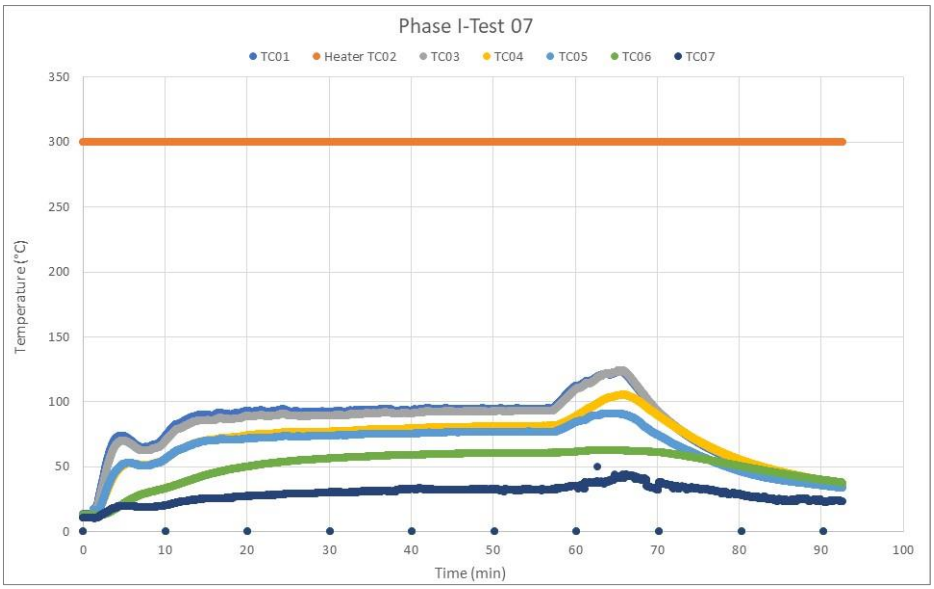

Figure 7: Result of Test 07 where 3.5Ah pouch cells were used.

I.4.6 Highlight of Test ID 08

Test 08 also followed the test set-up orientation B (refer to Figure 6) where the heater source was set to 500°C initially. This test is to repeat Test 07 but with a higher initial temperature at the heater source to investigate the effects of providing the initiation cell with more energy at the start of a test. This test set-up using pouch cells, entered thermal runaway after a prolonged period in comparison to orientation A set up (Test 01-06) and all cells entered thermal runaway and the outer packaging was clearly damaged (see temperature measurements in Figure 8). The duration of the test was around 140 minutes and the first thermal event occurred around 130 minutes into the test. Figure 9 highlights the result of the aggressive thermal event.

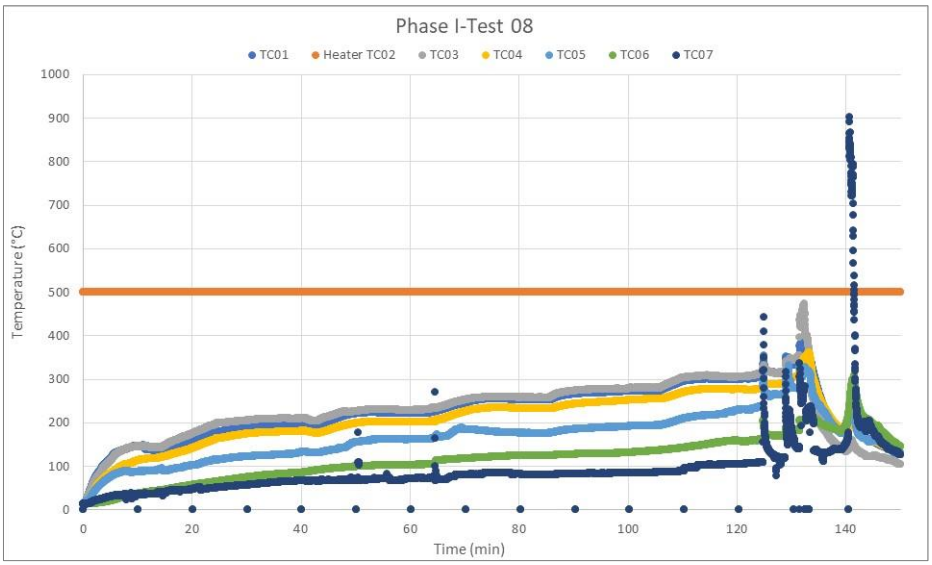

Figure 8: Aggressive thermal runaway in Test 08

Figure 9: Picture of the packaging at the end of the test.

Chapter II: Phase II

II.1 Introduction

Phase I testing highlighted that the test setup and procedure proposed in the SAE AS6413 draft standard could lead to lack of repeatability of the obtained test results. The key variables to improve repeatability were identified as the position of the heater, type of the heater and control of the heater. Therefore, Phase II focused on defining and controlling these variables to allow meaningful further testing, in particular on the type of heater used.

II.2 Problems encountered in Phase I testing

Phase I testing was intended to identify reoccurring problems proposed in the SAE AS6413 draft standard. The problems are identified as follows:

- Difficulty in locating the heater cartridge so that heat is transferred mainly to the initiation cell, without affecting also other adjacent cells, or even the inner side of the box.
- The geometry and shape of the cell and of the heater make actual surface contact difficult and imprecise.
- Control of the heater band based on the signal given by the thermocouple located on the rear side of the initiation cell leads to little control.
- Attaching thermocouples in tight space and ensuring a firm touch on the side of cells/heaters is challenging. Even a couple of millimeters gap between conductive area of thermocouple leads to erroneous readings.

II.3 Phase II testing

The purpose of the Phase II is to:

- define type of heater, and position of a heater for both 18650 and pouch cells (type, shape, power rating etc.).
- Determine the optimal method of controlling the heater to get a linear temperature ramp.
- Define how to prevent thermal energy being transferred to items (other cells, packaging) other than the initiation cell, for example by using suitable insulation methods.
- Define how to ensure that optimal amount of thermal energy is transferred to the initiation cells to cause thermal runaway.

II.4 Setup and Materials

There are four different set-ups in Phase II (refer to figure 10 and to individual test reports), which have the following common elements:

- One initiation cell at 30%SOC
- Heater placed on base of dummy box
- Insulation under heater
- Insulation above heater. 15mm hole cut to allow heat to initiation cell
- Thermocouples on base of 3 dummy cells to measure energy lost to dummy cells (not absorbed by initiation cell)
- Three thermocouples on initiation cell (base – control), 10mm from base, 20mm from base

- One thermocouple outside the packaging where the heater is located (to establish if a significant amount of energy is transferred to the packaging before thermal runaway occurs)
- Aim will be to demonstrate a consistent thermal runaway over three tests.

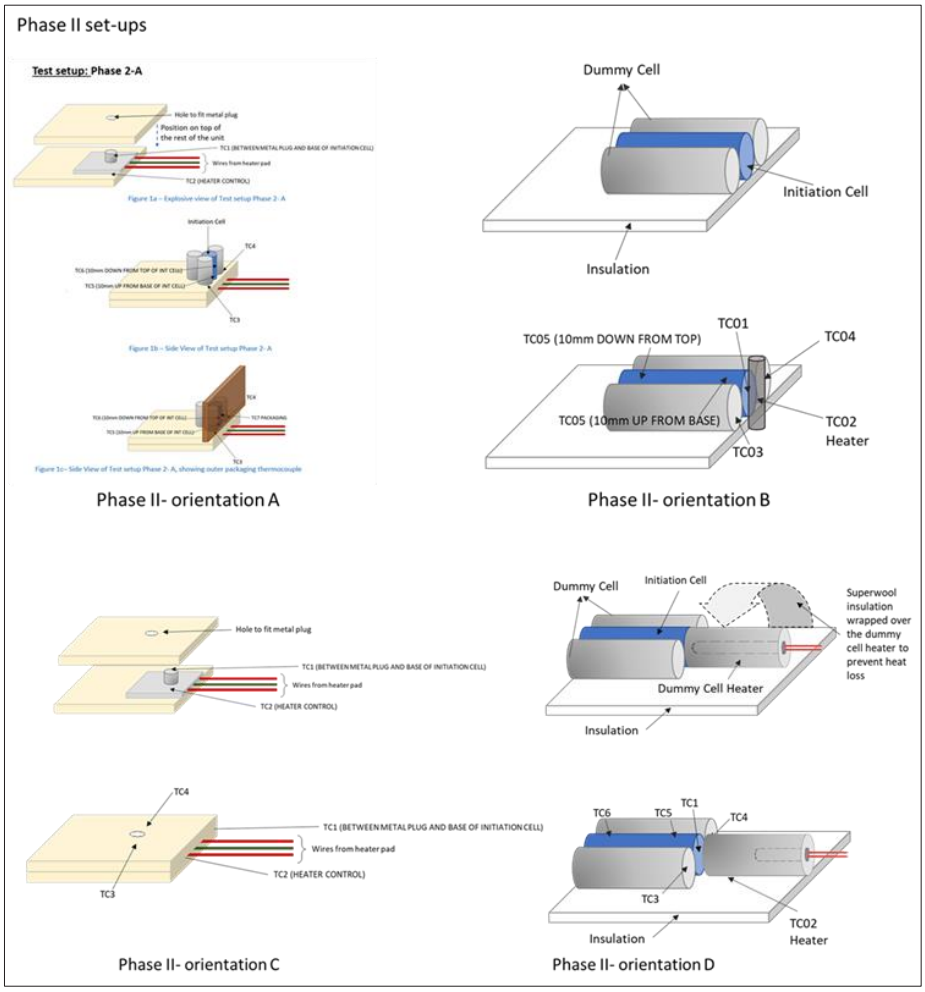

Figure 10: Phase II set-up summary

II.5 Heater Specification

The heater used in the set-up shown in Figure 10 (Phase II orientation A-C) is a Mica Flat heater (Figure 11). The heater is constructed by winding resistance wire and it is insulated with terminal connections fitted. Zintec sheet is used to encase the heater to provide good mechanical strength and protection. The heater can heat up to 300 °C. Moreover, the heater cartridge used in Phase II- orientation D is the same as the Phase I set-up.

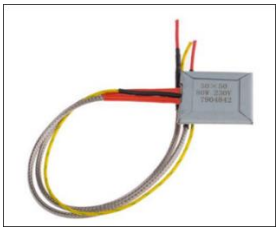

Figure 11: Mica Flat heater

II.6 Insulation Specification

A "Superwool 607 HT Blanket" insulation of 6mm thick was used for the testing. This was layered in three layers and compressed to create a blanket approximately 15mm thick. The insulation material made of Superwool 607 HT long fiber. It is a flexible blanket with excellent thermal insulating performance and thermal stability. It is also important that the Superwool is flexible with a good resistance to tearing and easy to cut, so it is easy to wrap around hot equipment. Additionally, It does not contain binder or lubricant that can cause fumes and has high resistance to chemicals and solvents. It is efficient for insulating temperatures up to 1300°C.

II.7 Test Plan

The Phase II test plan is shown as in Table 2, it shows that tests in this phase follows multiple test set-up. The different orientations allow further identifications of other key parameters and optimization method to increase the repeatability of tests.

Table 2: Phase II Test Plan

Phase	Test ID	SOC	Geometry	Chemistry	Capacity	Test Type	Comment	orientation
2	10	30	cyc	NCA	3.2	300C	9mm contact	P2A
	11	no cell					check on insulation	P2C
	12	30	cyc	NCA	3.2	300C	9mm contact	P2A
	13	30	cyc	NCA	3.2	300C	9mm contact	P2A
	14	30	cyc	NCA	3.2	500C	500C heater	P2B
	15	30	cyc	NCA	3.2	500C	500C heater	P2B
	16	30	cyc	NCA	3.2	500C	500C heater	P2B
	17	30	cyc	NCA	3.2	300C	18mm contact	P2D
	18	30	cyc	NCA	3.2	300C	18mm contact	P2D
	19	30	cyc	NCA	3.2	300C	18mm contact	P2D

II.8 Test Summary

The findings made in Phase I led to the test program definition as proposed in test runs 10 through 18. The tests during this phase were carried out without packaging. In some tests the heating source was not removed once the temperature reached 200°C as required by the SAE AS6413. The purpose of not removing the heating source was to force the cell into thermal runaway in order to record meaningful data to aid the development of the heating system.

During this phase of testing different set temperatures were selected depending on the type of heater used. This was to attempt to keep a consistent temperature increase rate of the initiation cell given the variability of the way the heat was transferred from the heater to the initiation cell.

II.8.1 Highlights of Test ID 10, 12 and 13

Test runs 10,12,13 were carried out using a cylindrical heater, with a 9mm diameter(65mm height), and initially set at 300°C. The test set-up of the aforementioned tests is shown in Figure 12. In these tests, the heater source was not removed once TC03 has reached 200°C as described in SAE AS6413 November 2018 version. Results were considered consistent, with similar times to thermal runaway and peak temperatures. However following Test 13 it was discovered that the heater had burned through and was no longer operable. Some pictures of Test 10 are shown in Figure 13.

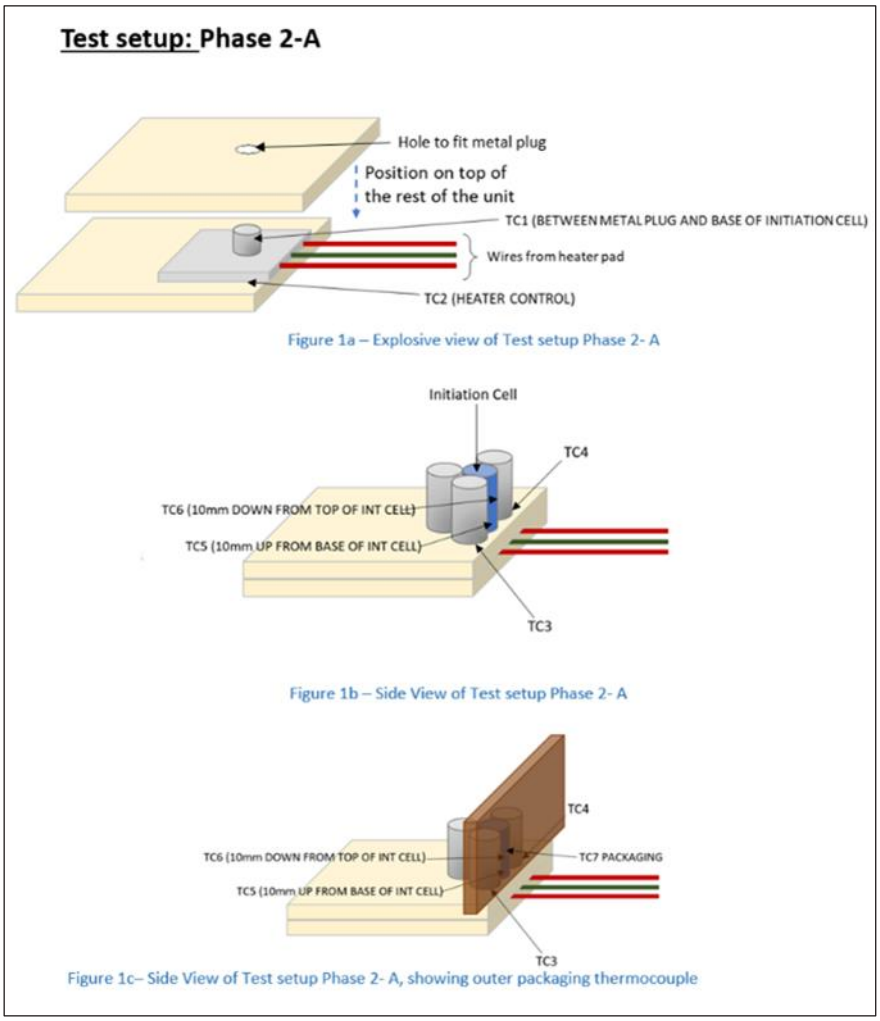

Figure 12: Phase II test set-up - A

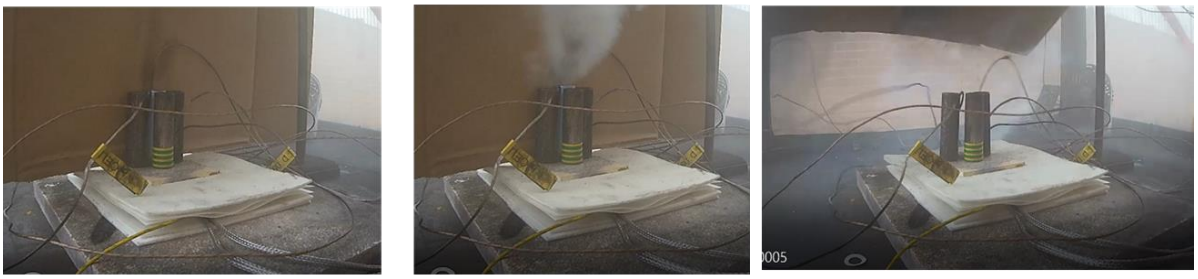

Figure 13: Pictures of Test 10 - (left) Beginning of the Test; (right) Beginning of Thermal Runaway; (centre) Experienced Thermal Runaway

II.8.2 Highlights of Test ID 11

Given the high temperatures on the dummy cells, a test without any cells was conducted. No rise in temperature was seen on thermocouples placed immediately above the insulation. This confirmed the test setup was working as intended and that the temperature rise in the dummy cells was due to transmission of heat from the ignition cell to the dummy cells.

It is highly likely that this would be representative of heat transfer to other cells outside the ignition cell.

II.8.3 Highlights of Test ID 14 and15

Due to the low rate of temperature increase observed in Test 10, 12 and 13, and the limitations of the flat heater, it was decided to revert to the cylindrical heater. Nonetheless, the cell was subjected to a faster rate of increase in temperature. In order to feasibly undertake the testing a new test setup was devised as shown in Figure 14. The set point of the heater was increased to 450°C as a result.

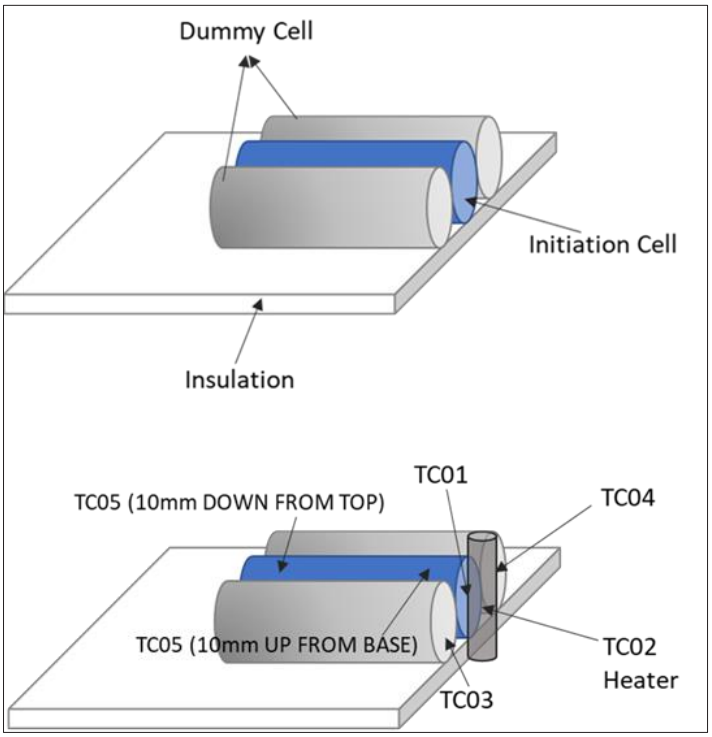

Figure 14: Phase II - orientation B set-up

In Tests 14 (Figure 15) and Test 15 the heating rate was between 12.5°C and 15°C, with thermal runaway starting in around 15 minutes. No peak temperatures could be recorded due to the severity of the explosion which dislodged the thermocouples.

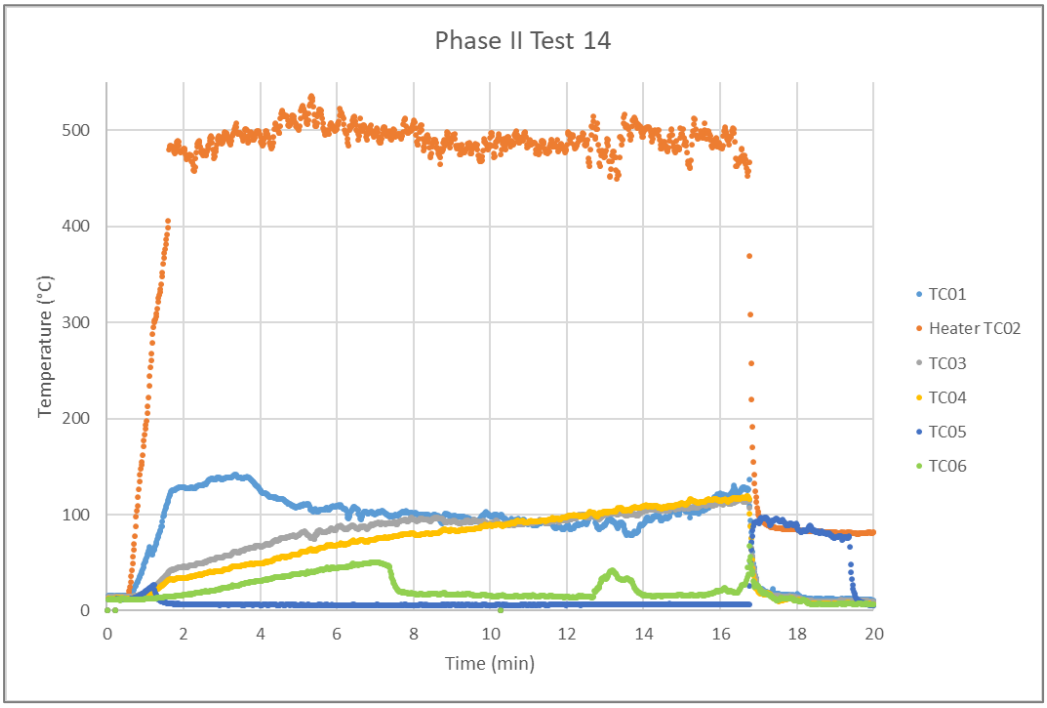

Figure 15: Test 14 results

II.8.4 Highlights of Test ID 16

Test 16 followed Phase II- orientation D set-up, despite sustained temperatures of above 300°C on the ignition cell, no thermal runaway was observed. The ignition source was removed after 3 hours and the ignition cell left for a further 12 hours, without any runway being observed.

As can be observed in Figure 16 during the test the heater cartridge had moved and become decoupled from the initiation cell. This is likely the cause of no thermal runaway.

Figure 16: Test 16 - (top) setup; (bottom) during testing showing the heater cartridge becoming detached from the initiation cell.

II.8.5 Test ID17 and 18 – 18mm contact area

Test 17 and Test 18 followed the same test set-up and parameters as in Tests 10 through 13. However, the only change is the heater cartridge used, which has a width (diameter) of 18mm instead of a 9mm diameter. The 18mm diameter of the heater cartridge is the same as the diameter of the cell, this will simulate a damaged cell causing heat in the package.

Chapter III: Phase IIb

III.1 Introduction

Phase IIb focused on resolving the issues arising in Phase II testing. The rate of temperature ramp was identified as a key parameter in the previous phase with small differences causing differing test results. Furthermore, it was concluded in Phase II that the heater should distribute heat in as a confined space (pin point) as possible, rather than spread evenly over the cell. Therefore, one of the novel ideas in Phase IIb was to design a bespoke heater contact to maximise the contact area of the heater and the cell. This design is shown in Figure 17 and Figure 18.

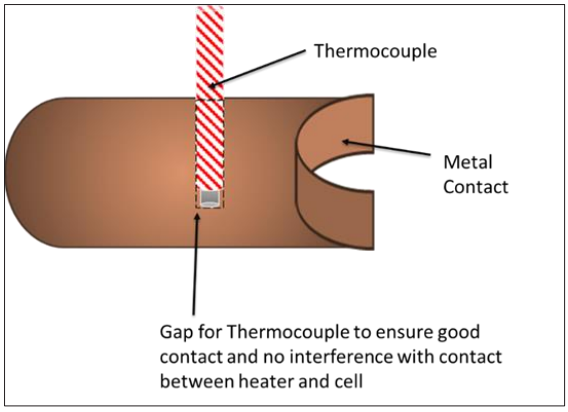

Figure 17: Heater contact design

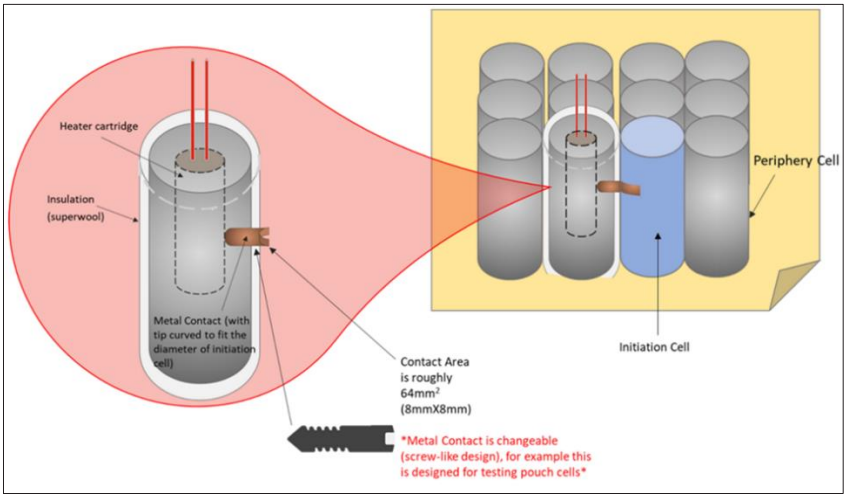

Figure 18: Phase IIb – orientation A with bespoke heater contact

III.2 Phase IIb Overview

The focus of Phase IIb was to investigate the consistency in thermal runaway by applying heat to the lateral surface of a cell and monitoring the temperature of different points on the external surface of the cell. This will allow the determination of the optimal rate of temperature rise which is critical to

the test. Furthermore, the data obtained will indicate the most suitable position to place the control thermocouple.

III.3 Problems encountered in Phase II testing

It should be highlighted that the problems mentioned in this section is related to the method of testing and not to the specifications of the standard. The purpose of Phase IIb was to provide greater clarify to test houses to ensure consistency of testing.

Problems encountered were:

- The temperature recorded at the point of contact between the heater and the initiation cell is not as consistent and linear as expected
- An observation was made that the heater cartridge and the cylindrical cell were not touching. This means the heater does not have full contact with the initiation cell.

III.4 Setup and Materials

Full setups for each test are shown in the individual test reports. Figure 19 shows the thermocouple set-up of orientation A and Figure 20 show orientation B set-up. One initiation cell at 30%SOC has direct contact with thermal conductive contact. The exposed area of the heater unit is insulated with Superwool. The initiation cell and the heater unit are surrounded by dummy cells.

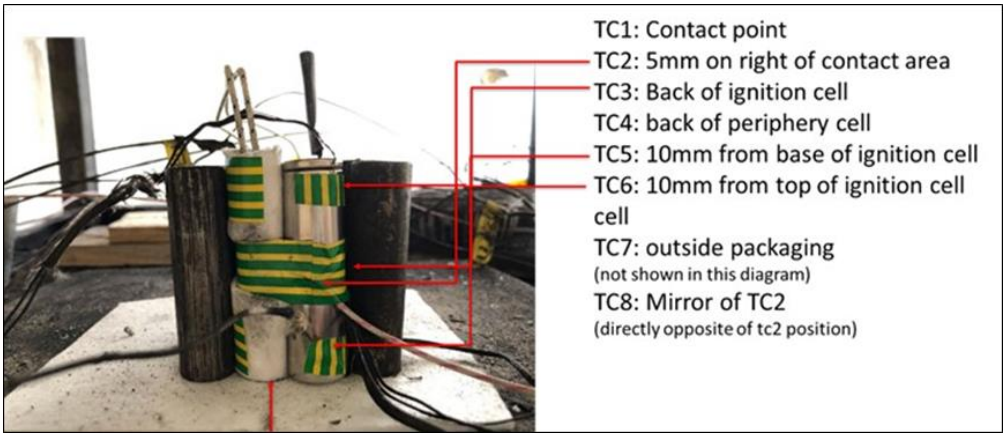

Figure 19: Phase IIb setup -A

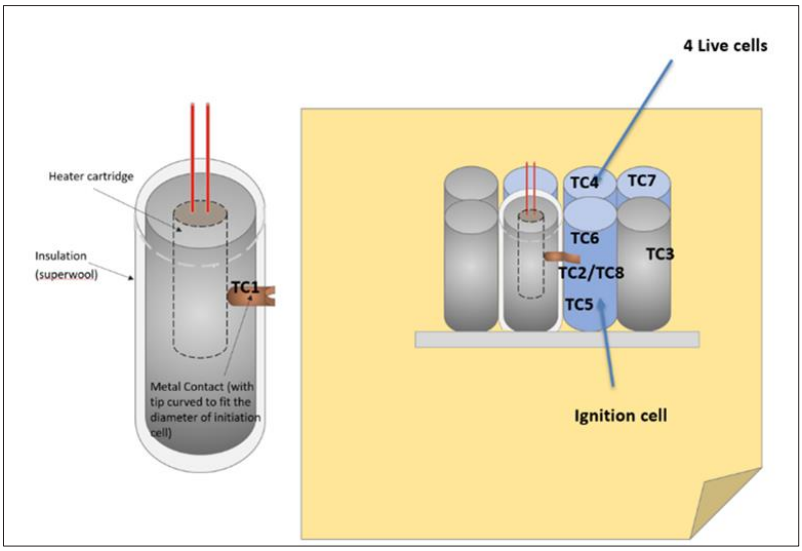

Figure 20: Phase IIb set-up -B

III.5 Heater & thermal conductive contact specification

The heater used in Phase IIb is the same heater cartridge as the one used in Phase I, however the thermal conductive contact is made bespoke to this project. It is designed with a contact surface area that is compatible to the radii of the cylindrical 18650 cells (see Figure 21). While bespoke, the part is machinable by any competent machinist and can be made for a variety of cell types. It is believed that the more contact the heater source has with the cell, the more consistent and linear the cell will heat.

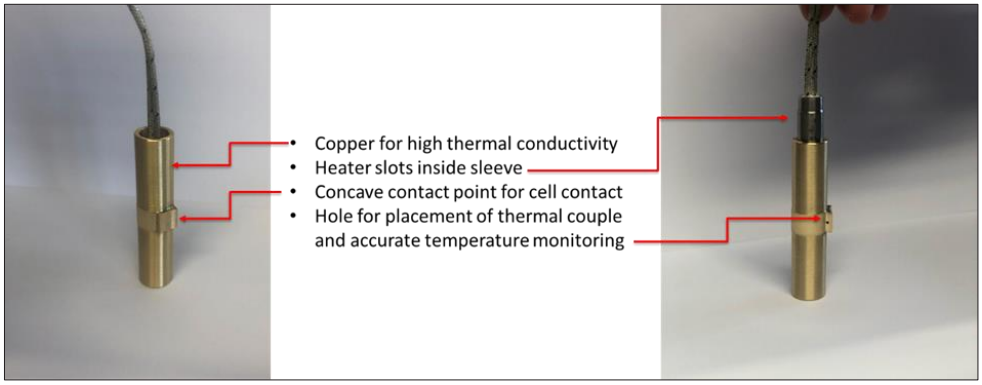

Figure 21: Bespoke thermal conductive heater

III.6 Test Summary

The individual reports of the performed tests are shown in Appendix II, where Test 24 is not included on purpose. This is because Test 24 was a foul test and the data is not meaningful.

Phase IIb demonstrates the repeatability of the test setup where consistent thermal runaway was achieved. The bespoke heater unit design (incl. thermal conductor & heater cartridge) can fit into typical box layout. It is concluded that the 18650 30% SOC cells will enter thermal runaway and lead to failure of a fiberboard box. The ramp rate of 5°C-20°C of the heater was achieved although only as the average throughout the duration of the test. Nevertheless, the rate is not as linear as desired.

III.6.1 Highlight of Test ID 19, 22, 23

The cells used in these tests were at 30% SOC, with the heater initially set at 300°C, however the actual temperature of the heater exceeded the set temperature (reaching 400°C as can be seen in Figure 22), highlighting the challenge in controlling temperatures in different setups/environments. This could be improved by using more accurate temperature controllers (more advanced PID controllers). In these tests, the temperature control was also performed on the heater cartridge itself in order to try and make the test control easier.

Thermal runaway occurred around 25 minutes into each test. No observation of any sudden temperature spikes, but cells were visibly destroyed. Additionally, large amount of smoke was observed.

Figure 22: Test 19 results

III.6.2 Highlight of Test ID 20, 21

The cells used in test 20 and 21 were charged to 100% SOC. Both tests experienced a peak temperature around 600°C. There was a violent 'bang' which indicates thermal runaway with flame and smoke observed (see Figure 23 showing the cells damages at the end of the test). Overall, the temperature rises were relatively consistent.

Figure 23: Result of test ID20

III.6.3 Highlight of Test ID 25

In test 25, five live cells at 30% SOC were used. Heater was initially set to 300°C and was ramped at 5°C/min (see Figure 24). Thermal runaway was recorded around 50 minutes into the test, when smoke was observed. A small flame was observed soon after the thermal event. The outer packaging was visibly damaged (Figure 25).

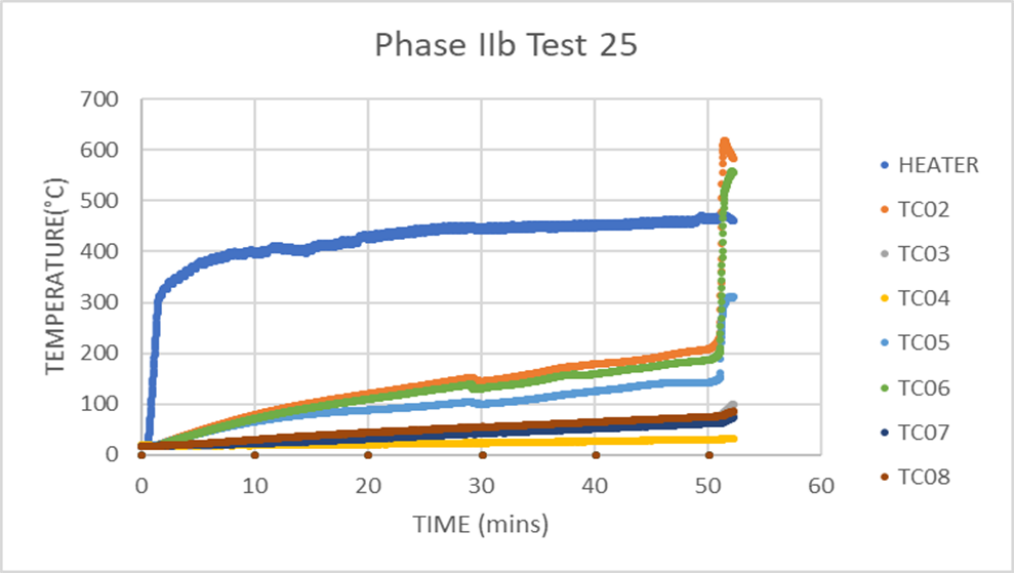

Figure 24: Test ID25 results

Figure 25: Visible damage during Test 25

Chapter IV: Phase III

IV.1 Introduction

Phase III repeats the test set-up from Phase IIb, but the objective of this phase is to achieve a more linear temperature ramp rate with the heater. This phase aims to understand the effect of a linear heating rate on the severity and position of the thermocouple. Moreover, the repeatability of the test set-up is also a key focus.

IV.2 Problems encountered in Phase IIb testing

Overall, phase IIb showed that the test set-up is appropriate and the repeatability is achievable. Nevertheless, the ramp rate is not as linear as expected therefore the heater temperature should be more controlled.

IV.3 Setup and Materials

The first setup of this phase and material used in this phase is the same as the Phase IIb – orientation A (Figure 12), but with the inclusion of an outer packaging. In some tests there is an additional use of a voltmeter, where crocodile clip is connected to the Squirrel 2020 data logger. This provides a live reading of the voltage change of the cell. The first voltage trial in this phase started in Test 30.

As Phase III progressed, a variation to the set-up was introduced because the data obtained from the initial test runs indicated opportunity for improvements. The improvements mainly surrounds the change in thermocouple positioning to obtain more accurate results. These changes improved the rate of temperature rise in the initiation cell (TC03) which better aligned with the thermal modelling (see deliverable D3b). This second set-up is illustrated in Figure 26, which shows the use of real cells and the set-up includes the use of an outer packaging.

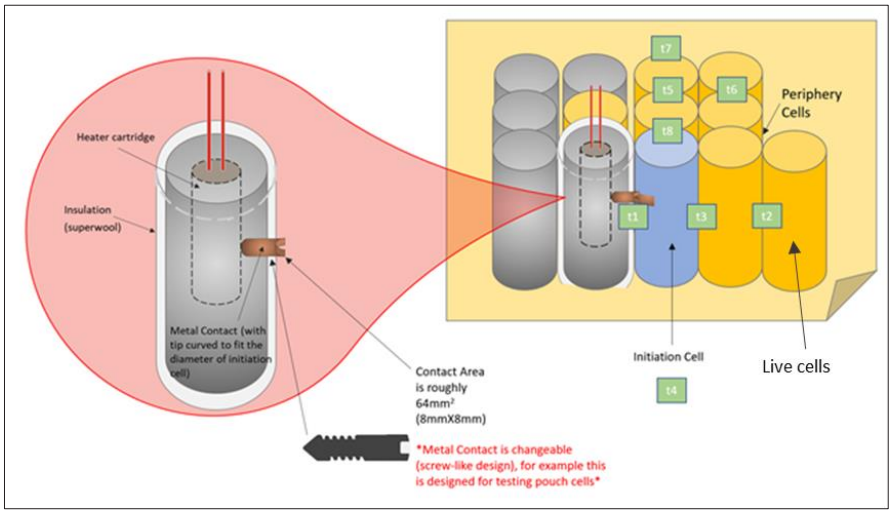

Figure 26: Phase III - 2nd set-up

IV.4 Test Summary

The test results are shown in separate report, where Test 31 is not included on purpose. This is because Test 31 was a foul test and the data is not meaningful. Test 33 and 34 are the tests which use the Phase III second set-up.

IV.4.1 Highlight of Test ID 28

The initial temperature of the heater was set at 50°C and the temperature is slowly ramped at 2°C/min. However, this led to a high initial temperature spike (between 1-3 mins) which affected the overall linearity of the heater temperature. The slow ramp rate also led to a prolonged test and thermal runaway did not occur until 220 minutes into the test.

IV.4.2 Highlight of Test ID 29

The cells used in Test 29 were charged to 30% SOC. The initial temperature of the heater was set to 50°C and remained at this temperature for the first 5 min to allow cells to reduce the initial temperature spike (see Figure 27). The temperature is then increased to 100°C which is when the heater control started. From 100°C, the heat transfer was increased slowly by 2°C/min until TC03 has reached 200°C then the temperature is retained for one hour. A small pop was heard 58 minutes into the test and it was closely followed by a thermal runaway.

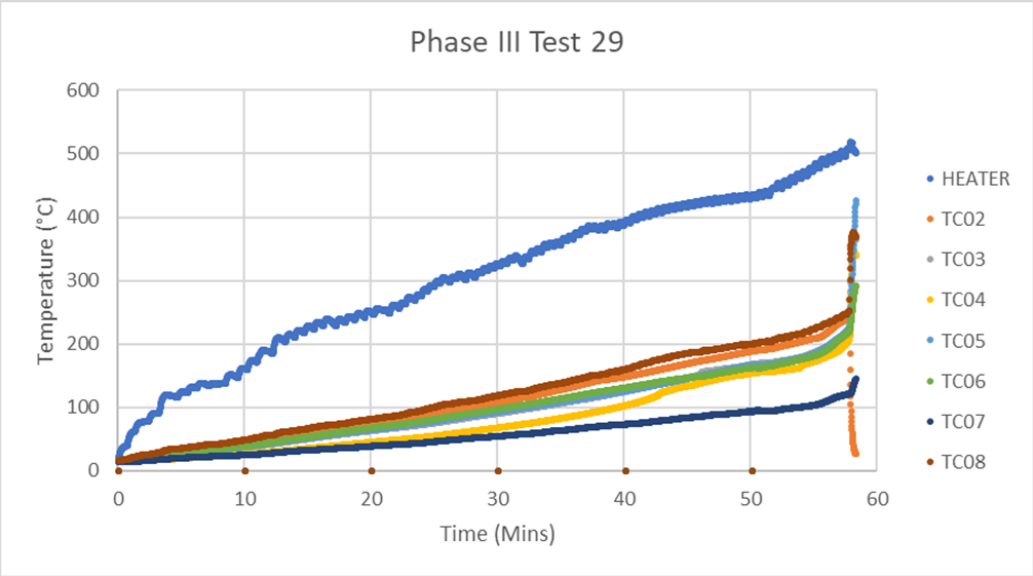

Figure 27: Result of Test 29

IV.4.3 Highlight of Test ID 30 & 32

Test 30 and 32 also used cells charged to 30% SOC and the starting temperature was set at 50°C. The heater temperature was slowly raised by 6°C/min. A live reading of the initiation test voltage was introduced for the first time in this test. Where the voltage reading shows a fluctuation immediately before the thermal runaway. After the thermal runaway, the voltage reading shows 0V. During this test, the heater temperature was relatively linear and TC03 reading shows linearity also, shown in Figure 28 and Figure 29. Both test result shows consistency and similar trends.

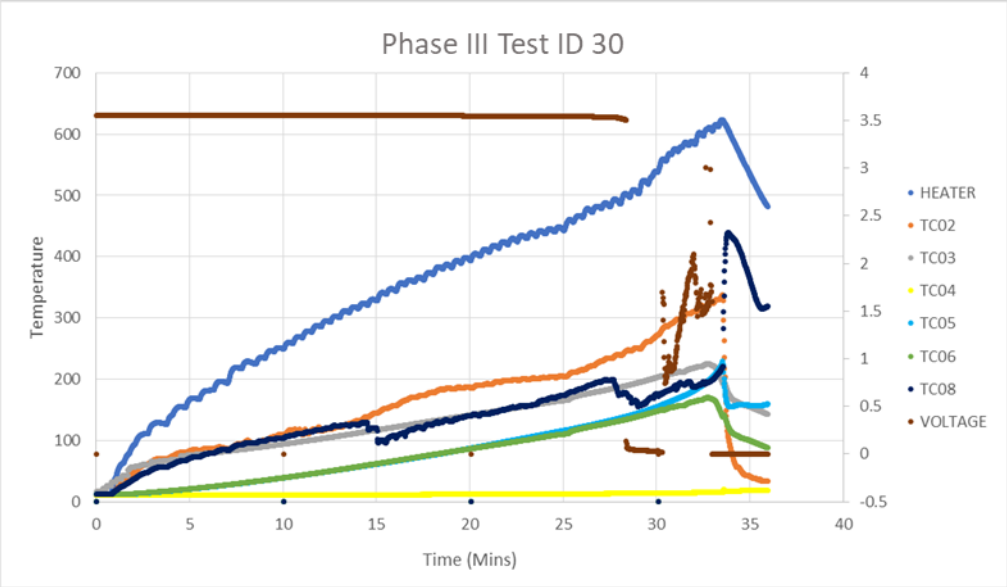

Figure 28: Test 30 Results

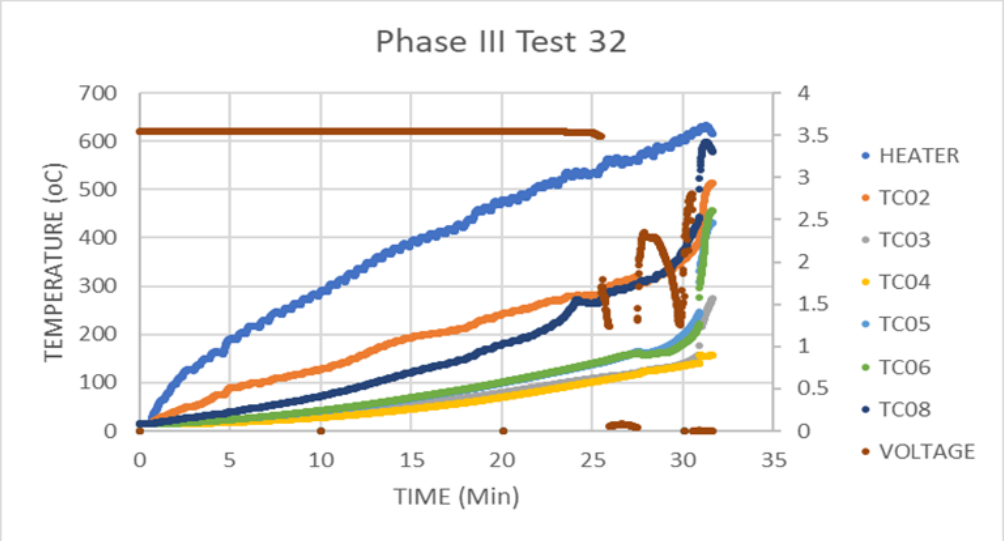

Figure 29: Test 32 Results

IV.4.4 Highlight of Test ID 33

Test 33 follows the second test set-up with eight cells at 30% SOC were used. The initial heater temperature was also set at 50°C and the heater control increased at a rate of 6°C/min, nevertheless TC03 rate of increase was only at around 3°C/min. A small pop was heard 42 minutes into the test, this indicate the venting of a cell, closely followed by an explosion at 48 minutes into the test where heater source was removed. The overall readings of all thermocouples were relatively linear (see Figure 30), however this test reveals that the temperature control of the heater is not significant. The heater temperature should be controlled according to the rate of temperature increase of TC03.

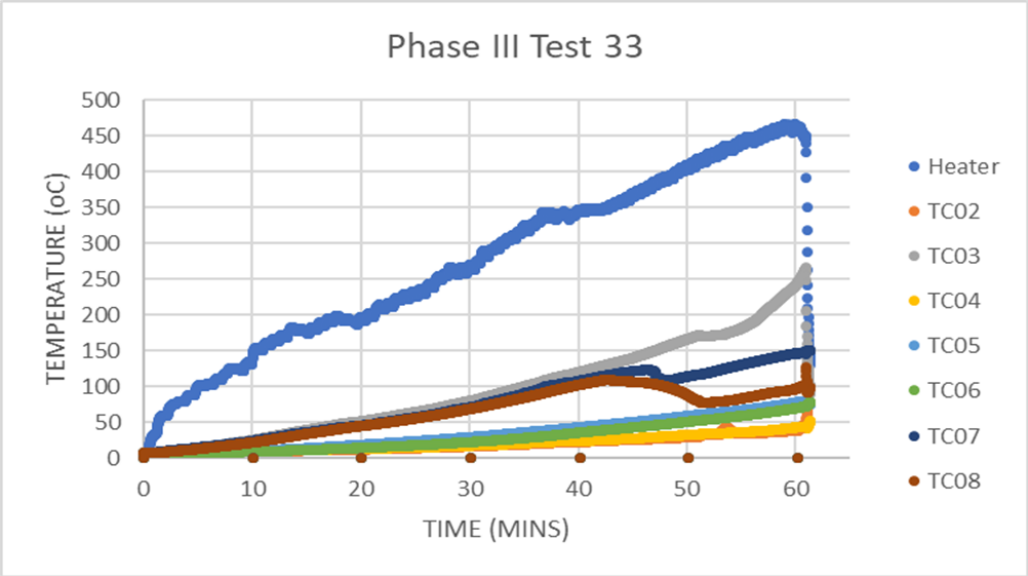

Figure 30: Result of Test 33

IV.4.5 Highlight of Test ID 34

Test 34 shares the same test set-up as Test 33, nevertheless the focus of this test is to control the rate of temperature increase of TC03 (positioned in the back of initiation cell). The rate of temperature increased in TC03 was 7.7°C/min, slight above the minimum requirement. As a result, thermal runaway of the initiation cell was observed at around 17 minutes into the test. There were a sign of smoke and outer packaging is visibly damaged as shown in Figure 31.

Figure 31: Damage caused to packaging in Test34

Conclusion

During Task 2 the following conclusions have been reached;

- The SAE G27 proposed test standard can be carried out consistently, if appropriate test setup improvements are introduced to enhance control of the heat transfer from the heater to the initiation cell.
- The test setup developed in Task 2 is based on the tight control of the contact area between the heater and the initiation cell, combined with the installation of insulation material to prevent heat transfer to the adjacent cell and the package itself.
- The hardware used in Task 2 allowed to meet the specification given in SAE AS6413 for the rate of temperature increase. However, using the thermocouple on the rear side of the cell to drive the heater results in a significant temperature gradient between the contact area and the rear side of the cell.
- It is important that test houses that carry out the testing understand the variables which affect the results. This may require clarifications within the standards to define the type of heater and tighter control around the ramp rate. In particular the test results seem to indicate that the ramp rate has a large effect on the outcome of the test, with a low ramp rate showing less severe thermal runaway when compared to higher ramp rates.
- The positioning of the control thermocouple is highly critical and requires great care in the installation phase. In approximately 10% of cases tests needed to be abandoned due to control thermocouples becoming detached or dislodged.

Appendix I

Phase I test reports.

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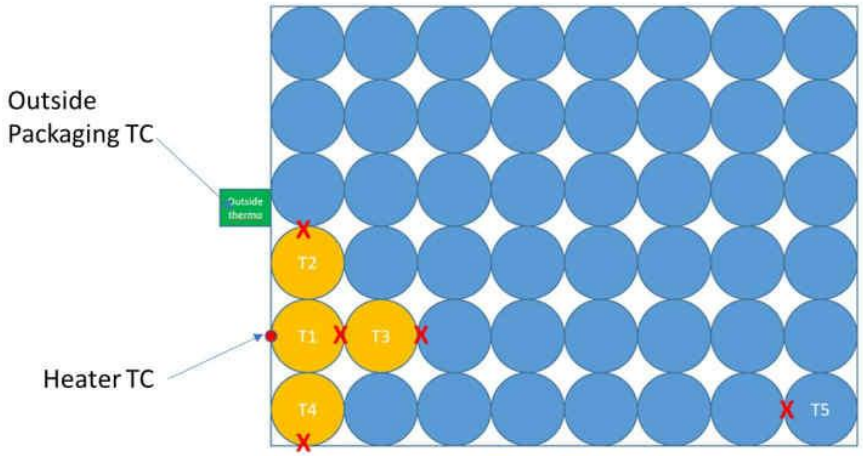
Sabatair Phase I evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase I Test 01

Test Date	12-11-2018
Test Location	Grangemouth
Outside air temp (C)	10°C
Cell(s) used	NCA 3.2AH 100% SOC
Test Setup	Phase I - orientation A
Test start time	10:45
Test duration	11mins
First thermal runaway observed	Around 4 mins into the test, First TR on initiation cell
First signs of smoke	3 mins into the test
Ignition source removed	Soon after the first initiation cell went into thermal runaway (around the 4 mins mark)
Peak temperature	1300°C observed in Initiation Cell (TC04)

Test Layout:



Photos

Figure 2- Start of Test ID 01

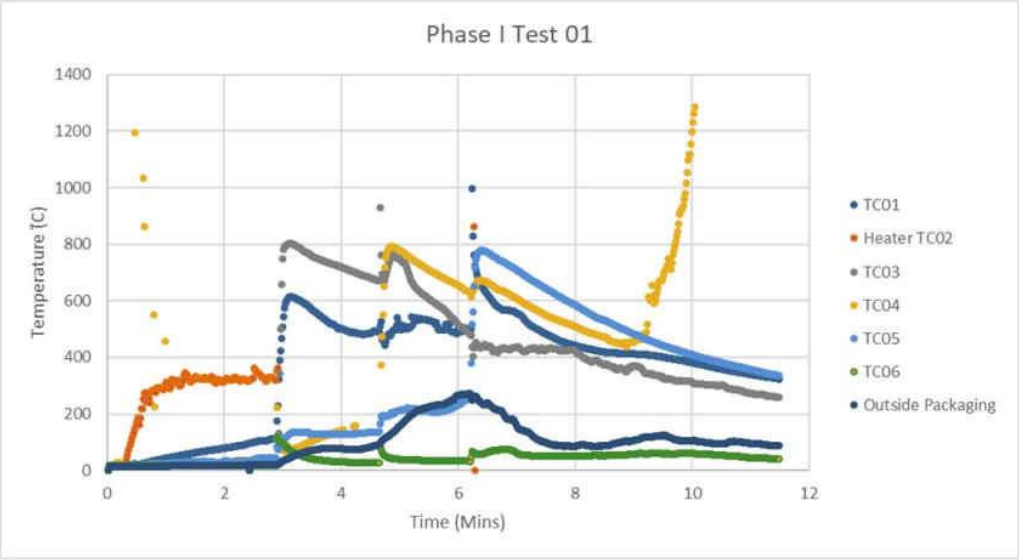
Figure 1- Test ID 01 first observed TR

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on (set at 300°C)
3 mins	Smoke observed
4 mins	Cell "pops" – temperatures rapidly decline. No shock seen in chamber.
4 mins 30 secs	Heater power off (continuing to observe for ~10 mins for other TR)
10 mins	TC04 entered thermal runaway
11 mins	Test ended

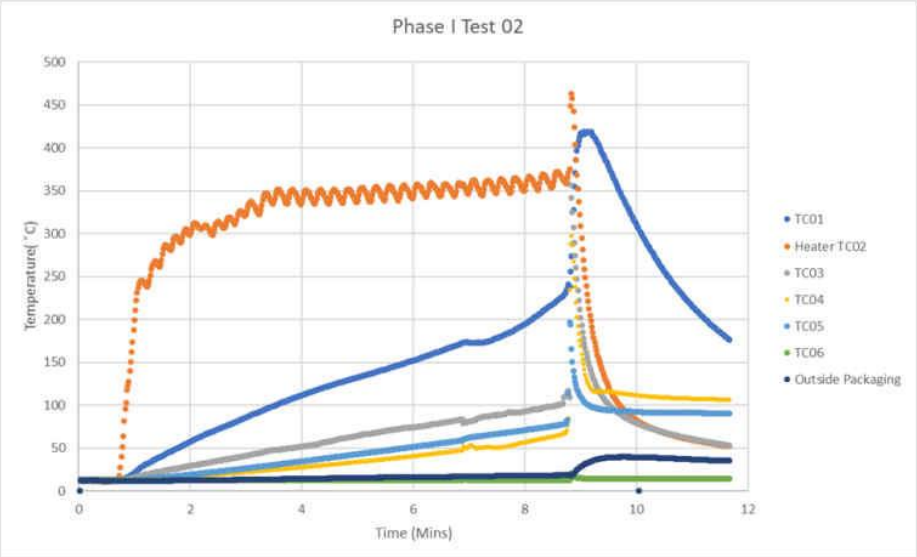
Test Results and Post-test Observations

- Thermal runaway occurred shortly after the test started, this is under a quick temperature ramp to 800°C.
- Visible damage to the outer packaging (localised at where the position where imitation cell is), highest temperature observed on outer packaging is around 250°C.
- Cells were completely destroyed and dislodged from test set-up.
- Cell 1 & Cell 4 were the first thermal runaway observed, followed by cell 2.
- Eventually, all cells entered a TR.
- Flame was observed during the test
- There were debris shooting out of the chamber during the test.



Test Results and Post-test Observations

- The heater control was set to 300°C at the beginning of the test.
- No damage to the outer packaging but its temperature did increase slightly to around 30°C.
- All Cells entered thermal runaway, according to the graph, it appears the TR occurred at the same time (around the 9 mins mark).
- Venting was evident not long before the "pop"
- No observations of any debris shooting out of the chamber during the test.



Photos

Figure 1- Beginning of Test ID 02

Figure 2- Gas release before TR

Photos

Figure 1- Beginning of Test ID 03

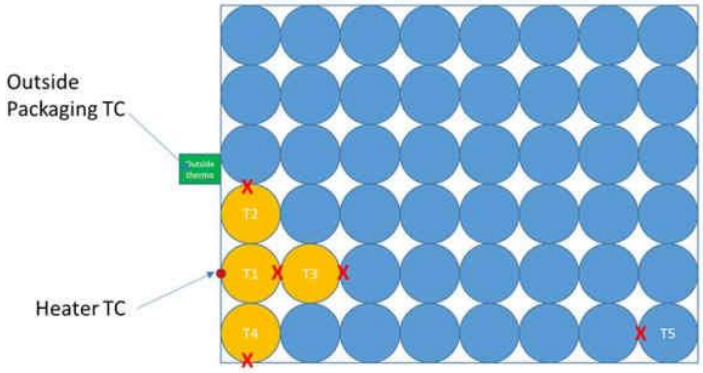
Figure 2- Initial Thermal Runaway observed

Sabatair Phase I evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase I Test 04

Test Date	15-11-2018
Test Location	Grangemouth
Outside air temp (C)	10°C
Cell(s) used	NCA 3.2AH 30% SOC
Test Setup	Phase I - orientation A
Test start time	0930
Test duration	27mins
First thermal runaway observed	Around 25mins into the test
First signs of smoke	20 mins into the test
Ignition source removed	As soon as the first TR occurred
Peak temperature	750°C observed in TC1

Test Layout:



Observations:

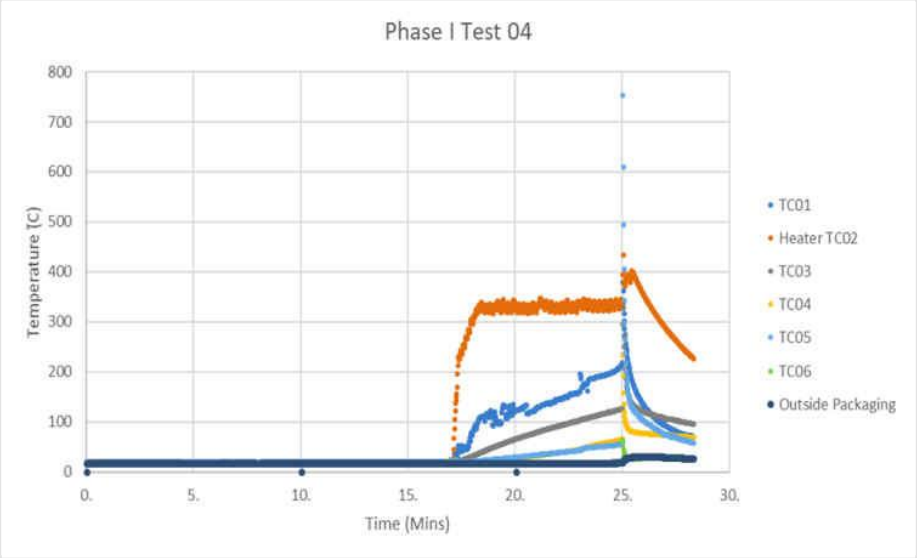
Elapsed time	Observation
START	Test started with cartridge heater turned on (set at 300°C)
20 mins	Smoke observed
25mins	Cell "pops" – temperatures rapidly decline. No shock seen in chamber.
25 mins 30 secs	Heater power off
27mins	Test ended

Task 2 – Phase I – Interim Report – ANNEX I

TEST ID 04 |

Test Results and Post-test Observations

- The highest temperature observed was in TC1 at 750°C
- All thermal runaway seems to have occurred at around the same time (~25 mins into the test)
- No prominent damage to packaging, temperature observed on outer packaging is around 60°C.
- No flame or debris observed
- All cells entered thermal runaway
- Note that the heater recording is very inaccurate therefore its readings are omitted



Task 2 – Phase I – Interim Report – ANNEX I

TEST ID 04 |

Photos

Figure 2 - Beginning of Test ID 04

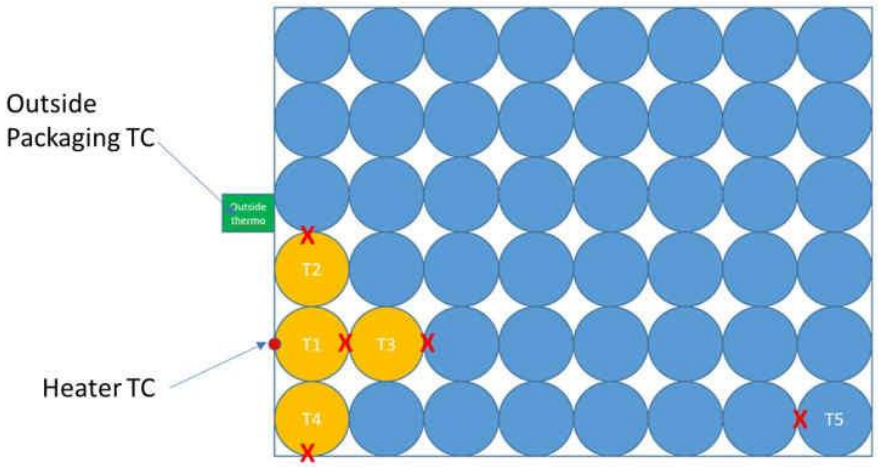
Figure 1- First Sign of Smoke

Sabatair Phase I evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase I Test 05

Test Date	16-11-2018
Test Location	Grangemouth
Outside air temp (C)	9°C
Cell(s) used	NCA 3.2AH 30% SOC
Test Setup	Phase I orientation A
Test start time	10:30
Test duration	20 mins
First thermal runaway observed	Around 5 mins into the test, First TR on initiation cell
First signs of smoke	3 mins into the test
Ignition source removed	Soon after the first initiation cell went into thermal runaway
Peak temperature	650°C observed in Heater thermocouple (TC2)

Test Layout:



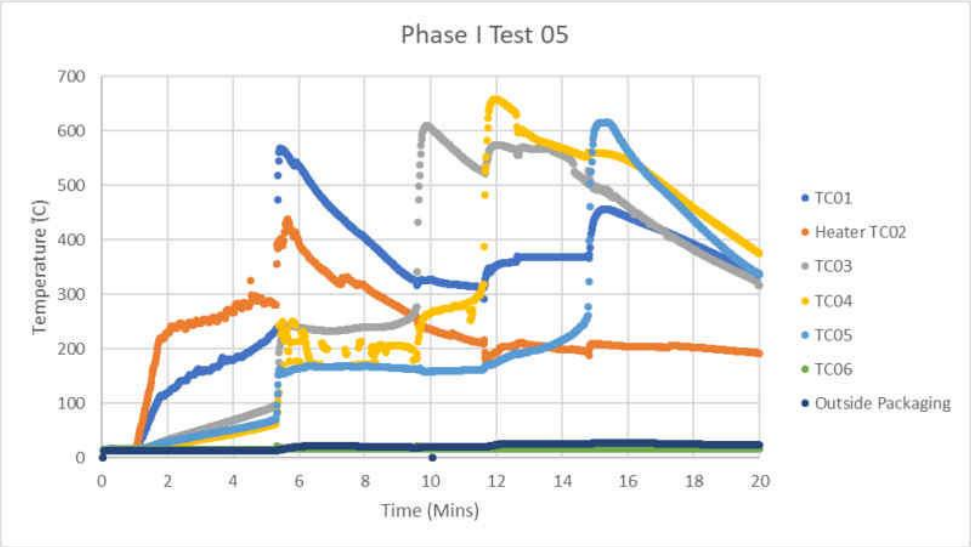
Task 2 – Phase I – Interim Report – ANNEX I

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on
4mins	Smoke observed
5mins	Cell "pops" – temperatures rapidly decline. No shock seen in chamber.
5 mins 30 secs	Heater power off as soon as first thermal runaway observed (continue to observe TR)
20 mins	Test ended

Test Results and Post-test Observations

- First thermal runaway occurred after 4 mins, it is believed that initiation cell was the first to enter TR.
- Both flame and debris were observed
- Heavy smoke (gas release) just before TR
- No prominent damage to the outer packaging
- All cells went into thermal runaway, all cells appeared to have entered TR at a similar temperature (~650°C)



Photos

Figure 1-Beginning of Test ID 05

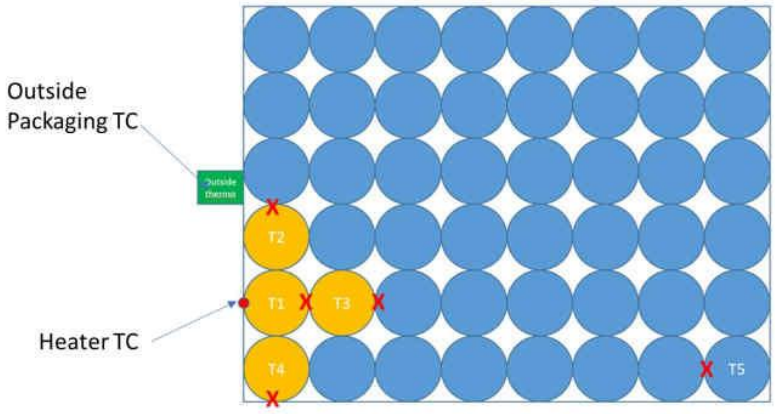
Figure 2- Initial Gas release

Sabatair Phase I evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase I Test 06

Test Date	19-11-2018
Test Location	Grangemouth
Outside air temp (C)	5°C
Cell(s) used	NCA 3.2AH 30% SOC
Test Setup	Phase I- orientation A
Test start time	10:00
Test duration	25 mins
First thermal runaway observed	Around 14 mins into the test, First TR on initiation cell
First signs of smoke	12 mins into the test
Ignition source removed	Soon after the first initiation cell went into thermal runaway
Peak temperature	600°C observed

Test Layout:

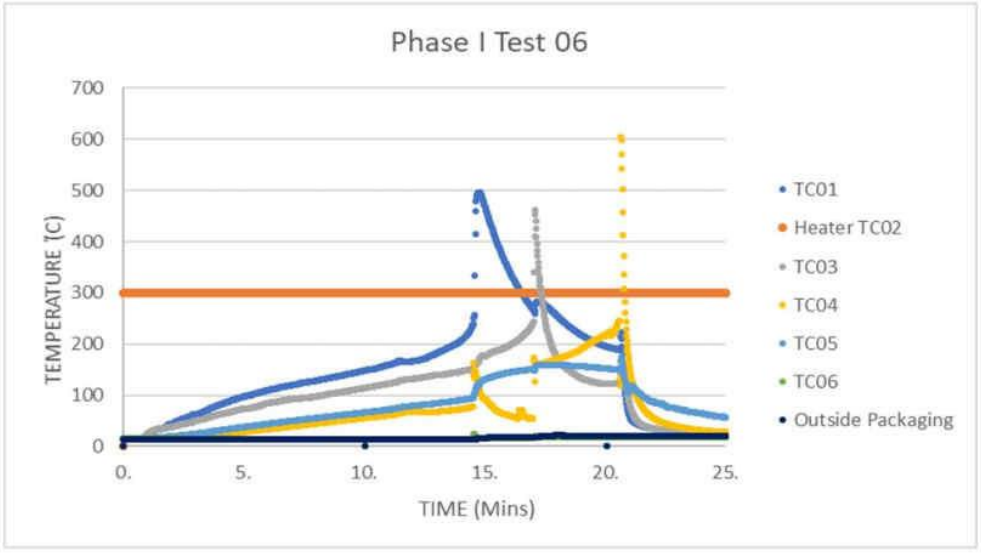


Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on (set at 800°C)
12 mins	Smoke observed
14 mins	Cell "pops" – temperatures rapidly decline. No shock seen in chamber.
14 mins 30 secs	Heater power off (continuing to observe for ~10 mins for other TR)
25 mins	Test ended

Test Results and Post-test Observations

- Thermal runaway occurred shortly after the test started, this is under a quick temperature ramp to 800°C.
- No prominent damage to outer packaging, only a slight temperature increases of 30°C was observed
- Both flame and debris were observed
- All cells entered thermal runaway



Photos

Figure 1- Beginning of Test ID 06

Figure 2- Smoke observed

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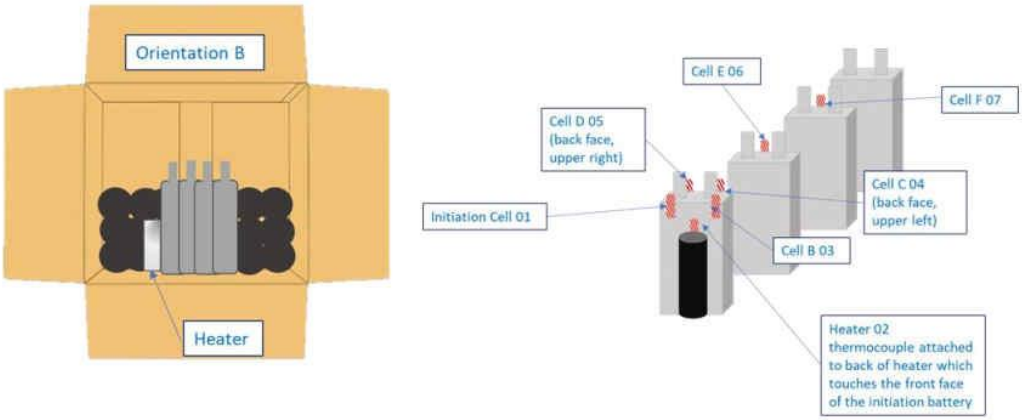
Sabatair Phase I evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase I Test 7

Test Date	20-11-2018
Test Location	Grangemouth
Outside air temp (C)	9°C
Cell(s) used	NCA 3.2AH 30% SOC POUCH
Test Setup	Phase I - Orientation B
Test start time	10:45
Test duration	80 mins
First thermal runaway observed	N/A
First signs of smoke	N/A
Ignition source removed	80 mins in to the test
Peak temperature	125°C observed in Initiation Cell (TC1)

Test Layout:



Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on
60 mins	No signs of thermal runaway
66 mins	Small Spike in temperature
80 mins	Heater power off (continuing to observe in case of TR)
80 mins	Test ended

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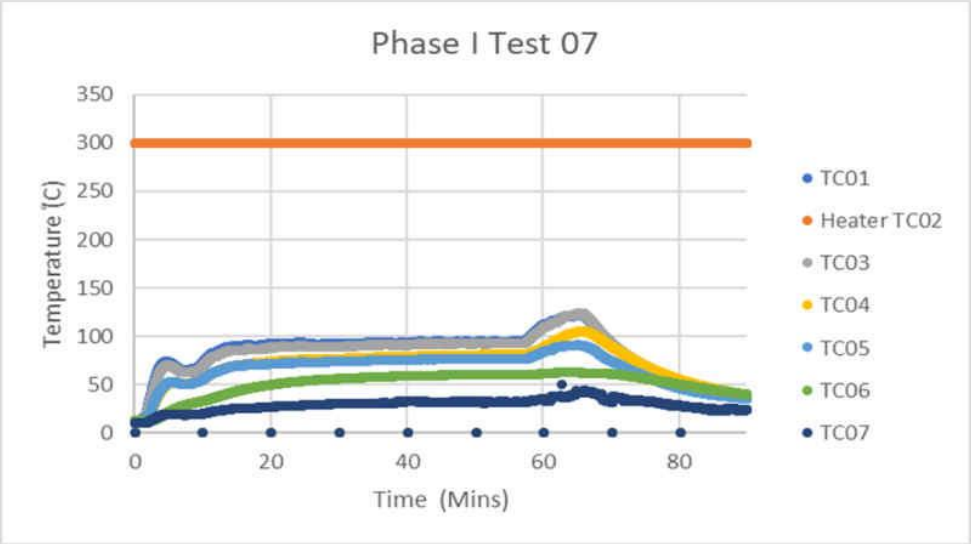
TEST ID 07|

Test Results and Post-test Observations

- No cells entered thermal runaway
- All cells experienced a spike in temperature at around 66 mins into the test
- No damage to the outer packaging but there was an increased in its temperature
- The heater power was cut after over 1 hr of heating and no TR occurred. But the test continued to record temperature of cells and to observe whether TR will occur as heat dissipates.
- All Cell temperature decreased gradually at a similar rate



Task 2 – Phase I– Interim Report – ANNEX I

TEST ID 07|

Photos

Figure 1- Beginning of Test ID 07

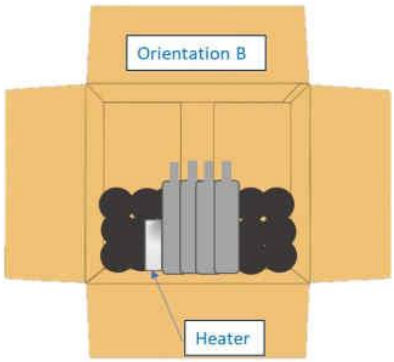
Figure 2- End of Test ID 07

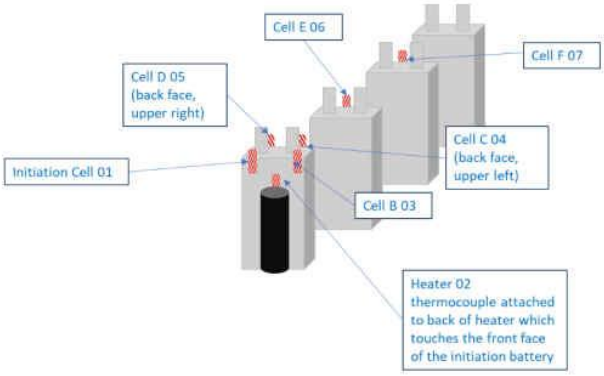
Sabatair Phase I evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase I Test 8

Test Date	23-12-2018
Test Location	Grangemouth
Outside air temp (C)	7°C
Cell(s) used	NCA 3.2AH 30% SOC POUCH
Test Setup	Phase I- orientation B
Test start time	10:00
Test duration	150mins
First thermal runaway observed	Around 130 mins into the test
First signs of smoke	125 mins into the test
Ignition source removed	Soon after the first TR
Peak temperature	900°C observed

Test Layout:





Observations:

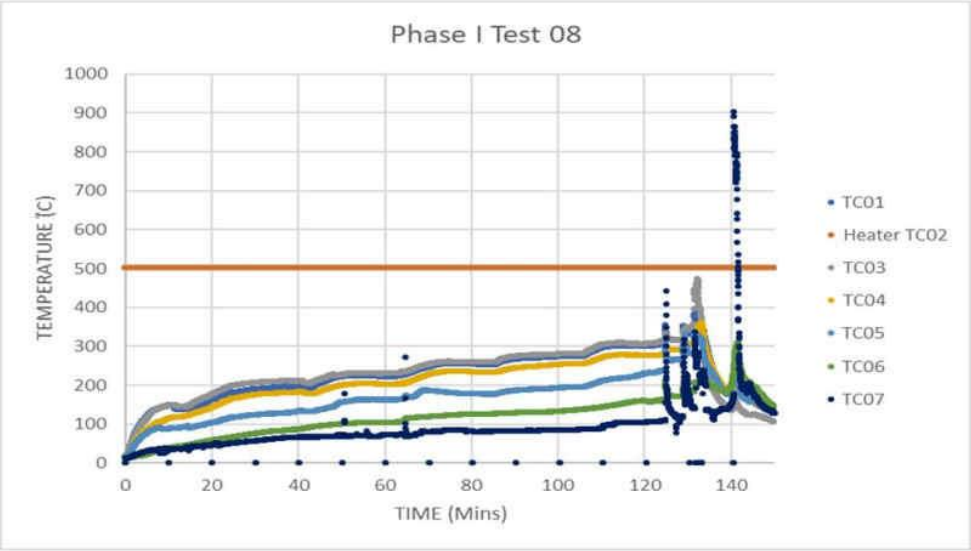
Elapsed time	Observation
START	Test started with cartridge heater turned on (set at 500°C)
125mins	Smoke observed
130 mins	Cell "pops" – temperatures rapidly decline. No shock seen in chamber.
130mins 30 secs	Heater power off
150 mins	Test ended

Task 2 – Phase I – Interim Report – ANNEX I

TEST ID 08 |

Test Results and Post-test Observations

- All cells entered TR, where the temperature of cell 4 experienced the highest spike.
- Clear damage to the outside packaging as well as the cell set-up
- Aggressive thermal runaway
- Thermal runaway occurred but only after a prolonged period of heating



Photos

Figure 1- Damage to Outside Packaging

Figure 2 - Damage to the Cells set-up

Task 2 – Phase I – Interim Report – ANNEX I

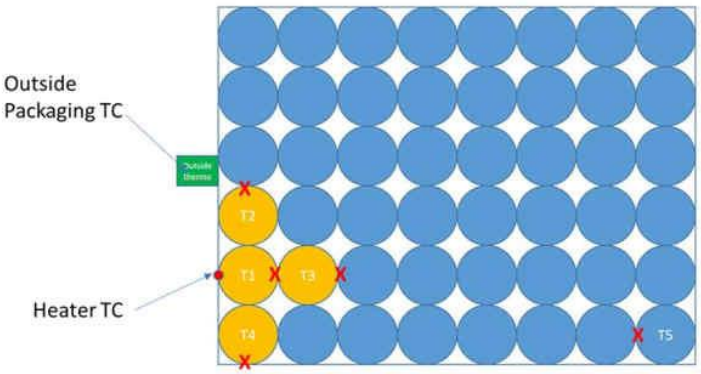
TEST ID 08 |

Sabatair Phase I evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase I Test 03

Test Date	14-11-2018
Test Location	Grangemouth
Outside air temp (C)	10°C
Cell(s) used	NCA 3.2AH 100% SOC
Test Setup	Phase I- orientation A
Test start time	10:00
Test duration	10 mins
First thermal runaway observed	Around 4 mins into the test, First TR on initiation cell
First signs of smoke	7 mins into the test
Ignition source removed	Soon after the first initiation cell went into TR
Peak temperature	1300°C observed

Test Layout:

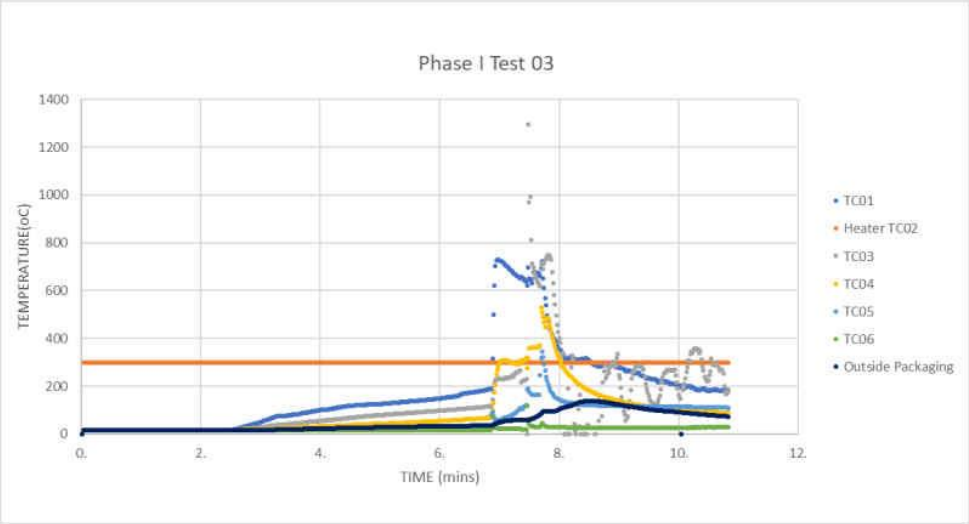


Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on (set at 300°C)
3 mins	Smoke observed
4 mins	Cell "pops" – temperatures rapidly decline. No shock seen in chamber.
4 mins 30 secs	Heater power off (continuing to observe for ~10 mins for another TR)
11 mins	Test ended

Test Results and Post-test Observations

- Thermal runaway occurred shortly after the test started, this is under a quick temperature ramp to 800°C.
- Visible damage to the outer packaging (localised at where the position where imitation cell is), highest temperature observed on outer packaging is around 150°C.
- All thermal runaway occurred at around the same time (~10 mins into test)
- The highest temperature observed was 1300°C.
- Flame was observed, it is believed that this is the reason why TC02 (heater) shows unexpected rise and fluctuation in temperature after TR. The flame has damaged the thermocouple, thus temperature recorded is not accurate.
- There were debris shooting out of the test chamber during the test.



Appendix II

Phase II and Phase IIB test reports.

Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: TEST ID10

Test Date	25-01-2019
Test Location	Grangemouth
Outside air temp (C)	4°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase II- orientation A
Test start time	11.50am
Test duration	51 minutes
First thermal runaway observed	49 minutes
First signs of smoke	31 minutes
Ignition source removed	49 minutes after start time
Peak temperature	265°C observed at 10mm from base of cell

Test Layout:

Test setup: Phase 2-A

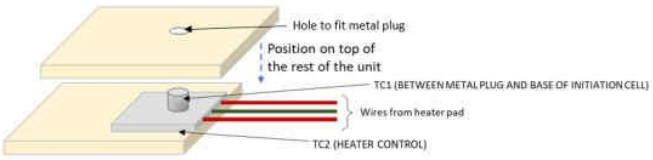


Figure 1a – Explosive view of Test setup Phase 2- A

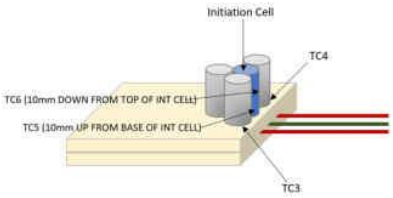


Figure 1b – Side View of Test setup Phase 2- A

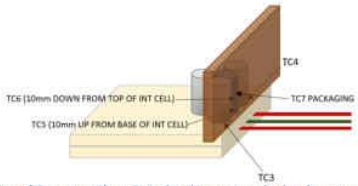


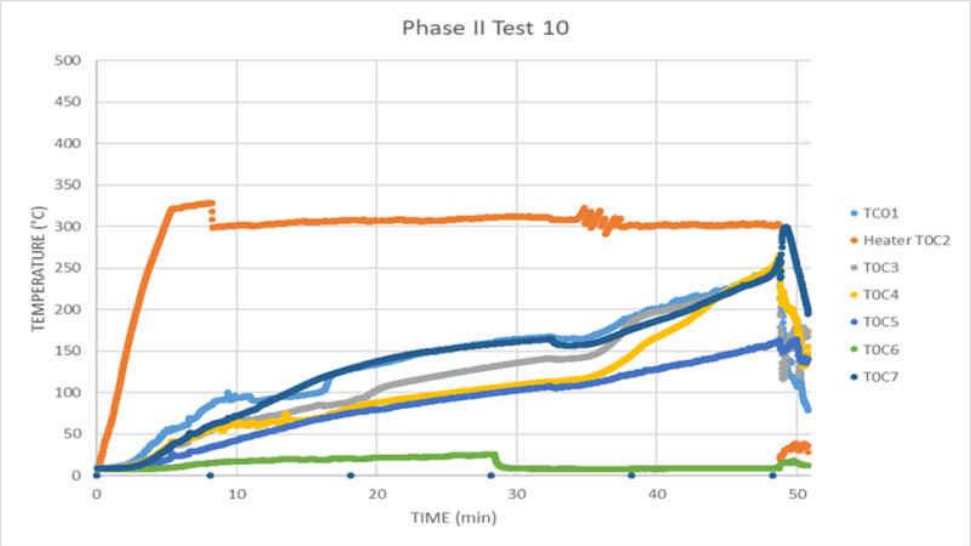
Figure 1c– Side View of Test setup Phase 2- A, showing outer packaging thermocouple

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on
31 mins	Smoke observed from ignition cell
49 mins	Cell "pops" – temperatures rapidly decline. No shock seen in chamber.
50 mins	Manual observation shows thermocouples blown off test setup
51 mins	Test ended

Test Results and Post-test Observations

- Cell took a long time to enter thermal runaway.
- Venting was evident for 18 minutes before the cell "popped"
- Rate of temperature increase 10mm from base of cell was 5.5°C/min with heater temperature controlled accurately at 300C ± 10°C
- Cell completely destroyed and dislodged from test set up
- Outer packaging temperature saw little rise
- Dummy cells increased in temperature at same rate as ignition cell, despite insulation used. This heat transfer is likely from transfer between ignition cell and dummy cell.



Photos

Figure 1- (left) Beginning of the Test; (right) Beginning of Thermal Runaway; (centre) Experienced Thermal Runaway

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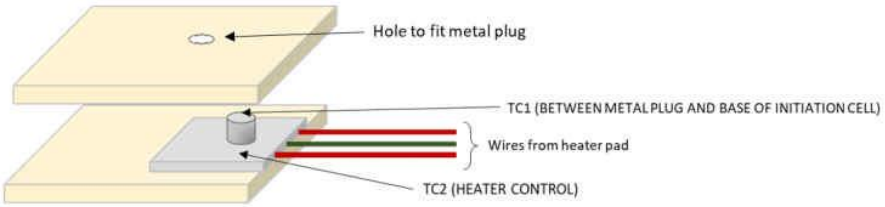
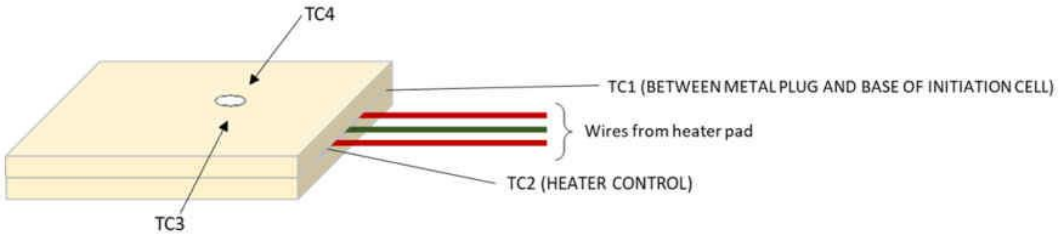
Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase II TEST ID11

Test Date	25-01-2019
Test Location	Grangemouth
Outside air temp (C)	5°C
Cell(s) used	none
Test Setup	Phase II – orientation C
Test start time	1517
Test duration	12 minutes
First thermal runaway observed	N/A
First signs of smoke	N/A
Ignition source removed	9 minutes
Peak temperature	273C from heater

Setup





Task 2 – Phase II – Interim Report – ANNEX II

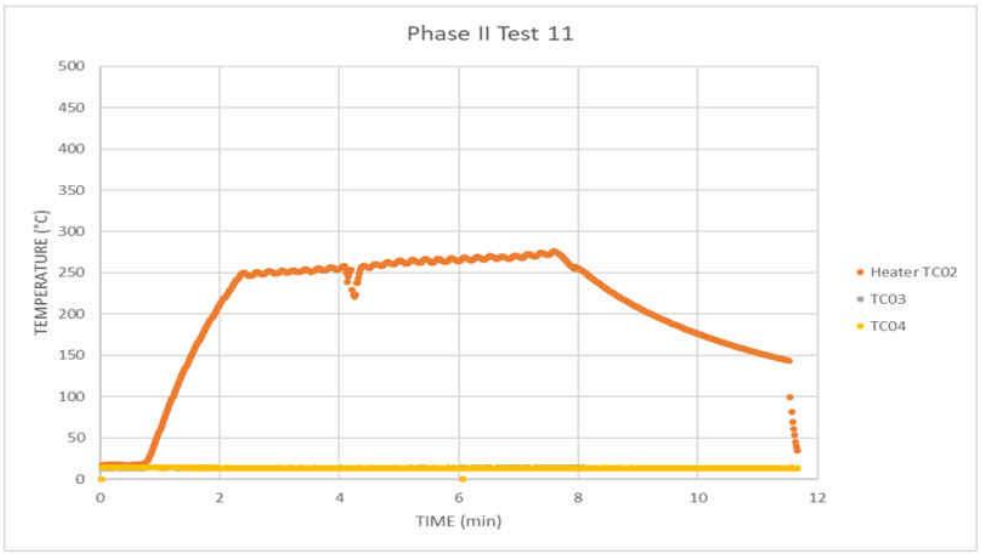
TEST ID#11 |

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on – no cells present
5 mins	No temperature rise on insulation. Heater constant temperature
12 mins	Test ended

Test Results and Post-test Observations

- Heater reached temperature in around 2 minutes.
- Temperature above/on insulation (TC4 and TC3) remained constant
- Ignition of heater removed after 9 minutes.
- Conclusion is insulation is preventing heat reaching dummy cells, and heat rise is transferred from ignition cell to dummy cell.



Photos

Figure 1- (left) insulating pad heater), (right) Showing the combination of the full module/heating unit; (centre) Top view of the heating unit

Task 2 – Phase II – Interim Report – ANNEX II

TEST ID#11 |

Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IITEST ID 12

Test Date	29-01-2019
Test Location	Grangemouth
Outside air temp (C)	5°C
Cell(s) used	NMC 3.2AH 30%SOC
Test Setup	Phase II- orientation A
Test start time	1359
Test duration	100 minutes
First thermal runaway observed	86 minutes
First signs of smoke	61 minutes
Ignition source removed	86 minutes
Peak temperature	251°C from ignition cell base

Setup

Test setup: Phase 2-A

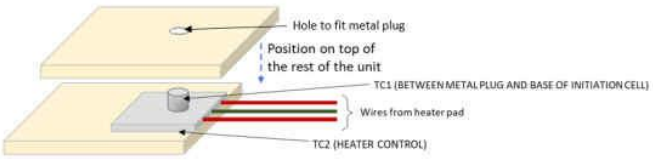


Figure 1a – Explosive view of Test setup Phase 2- A

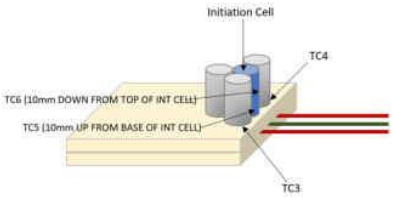


Figure 1b – Side View of Test setup Phase 2- A

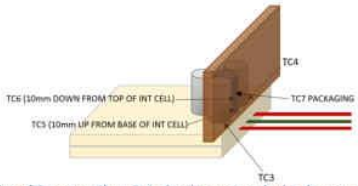


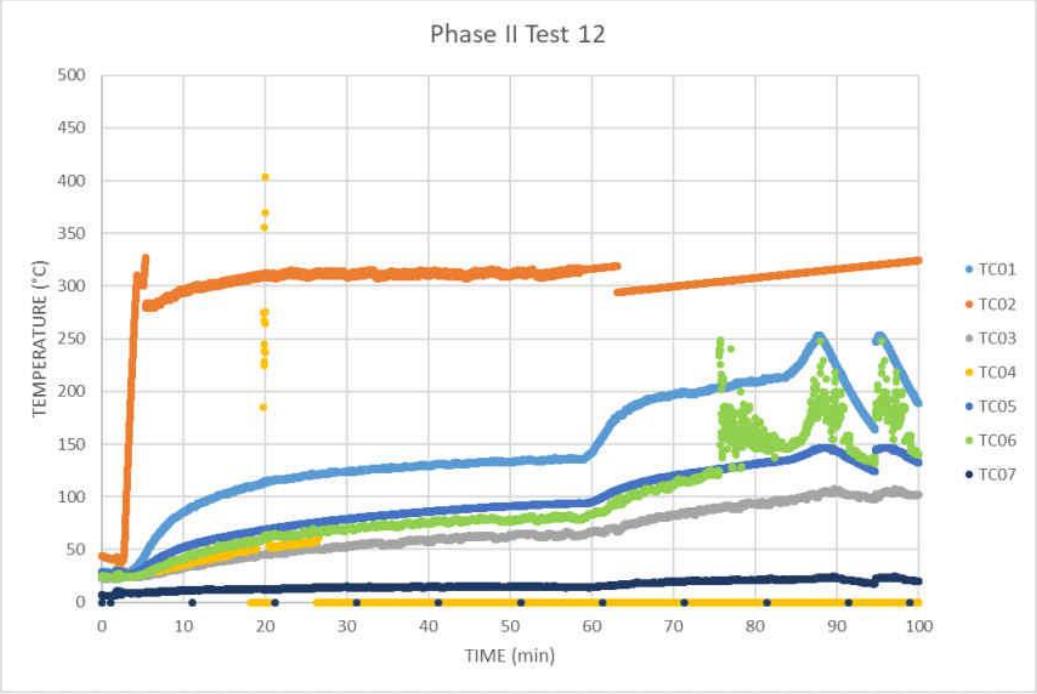
Figure 1c- Side View of Test setup Phase 2- A, showing outer packaging thermocouple

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on.
5 mins	Heater at temperature of 300°C and stable
53 mins	Temperatures stable
61 mins	Temperatures increasing. Smoke now visible.
86 mins	Thermal runaway evident. "Pop" heard.

Test Results and Post-test Observations

- Heater reached temperature in around 2 minutes.
- All thermocouple temperatures increased slowly.
- Temperatures appeared to have stabilised after 53 minutes, but then started increasing again, most notably on TC1.
- Smoke was observed after 61 minutes, with thermal runaway occurring about 25 minutes later.
- Maximum observed temperature was 251°C, with a small "pop" heard.



Photos

Figure 1- (left) Test setup; (right) initiation cell after thermal runway

Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase II TEST 13

Test Date	29-01-2019
Test Location	Grangemouth
Outside air temp (C)	5°C
Cell(s) used	NMC 3.2AH 30%SOC
Test Setup	Phase II- orientation A
Test start time	16.19
Test duration	53 minutes
First thermal runaway observed	51 minutes
First signs of smoke	32 minutes
Ignition source removed	51 minutes
Peak temperature	301°C from ignition cell base

Setup

Test setup: Phase 2-A

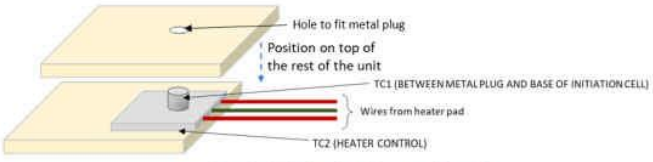


Figure 1a – Explosive view of Test setup Phase 2- A

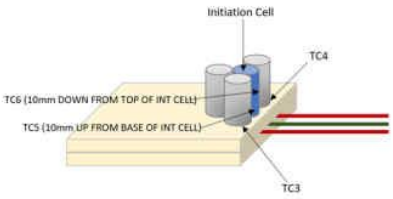


Figure 1b – Side View of Test setup Phase 2- A

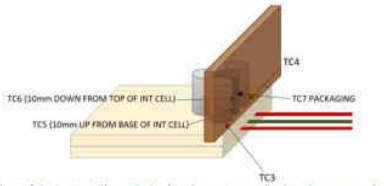


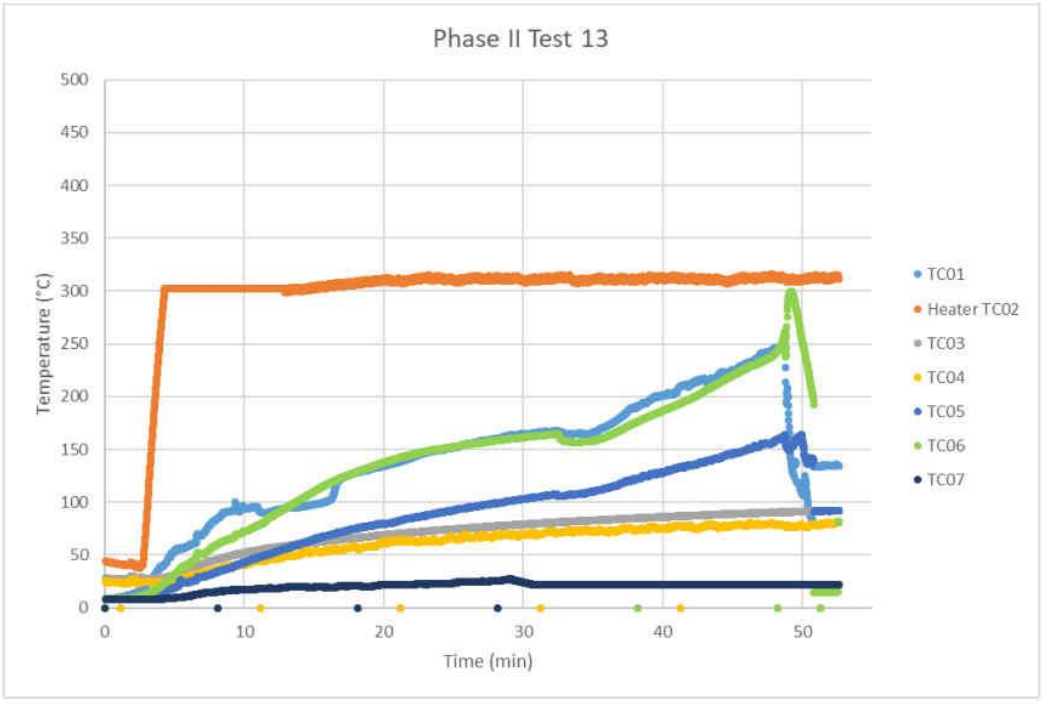
Figure 1c- Side View of Test setup Phase 2- A, showing outer packaging thermocouple

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on – no cells present
2 mins	Heater at 300°C
5 mins	Temperature rise on dummy cells lower than previously observed
39 mins	Smoke observed
40 mins	TC6 reading higher than TC5. TC5 possibly been dislodged by melting adhesive
51 mins	Thermal runaway observed – medium pop
51 mins	Ignition source removed
53 mins	End of test

Test Results and Post-test Observations

- Heater reached temperature of 300C and remained constant throughout
- Rate of heating on TC6 was around 5.5°C /min. TC5 had a lower temperature. Likely dislodged due to melting adhesive early in the test
- Temperature of base of cell and 10mm from top of cell were very similar throughout
- Thermal runaway observed shortly before TC6 reached 250°C, with peak temperature 300°C
- TC3 and TC4 did not absorb as much heat as previously.



Task 2 – Phase II – Interim Report – ANNEX II

TESTID13 |

Photos

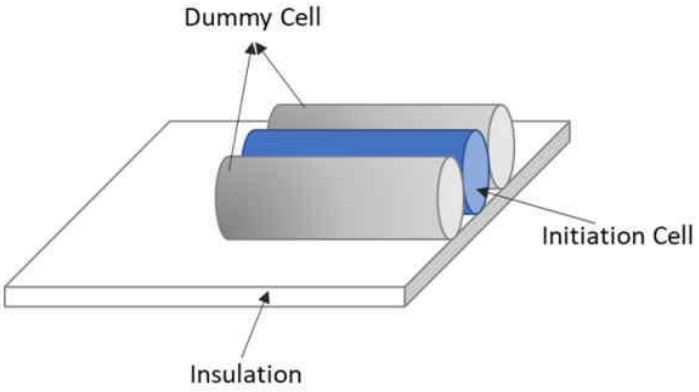
Figure 1- (left) close-up of setup, cells are wrapped tight with insulation tape once thermocouples are positioned; (right) start of test

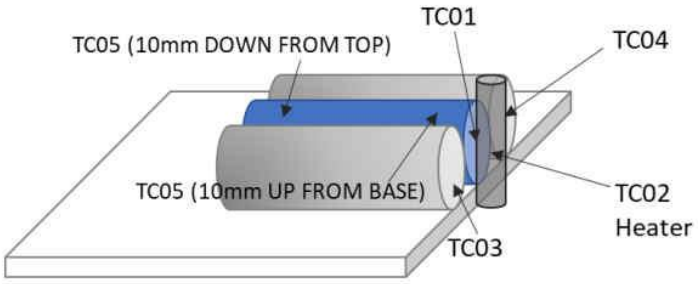
Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase II TEST 14

Test Date	5-02-2019
Test Location	Grangemouth
Outside air temp (C)	4°C
Cell(s) used	NMC 3.2AH 30%SOC
Test Setup	Phase II- orientationB
Test start time	11.58AM
Test duration	16 minutes
First thermal runaway observed	15 minutes
First signs of smoke	7 minutes
Ignition source removed	15 minutes
Peak temperature	150°C from ignition cell base

Setup





Task 2 – Phase II – Interim Report – ANNEX II

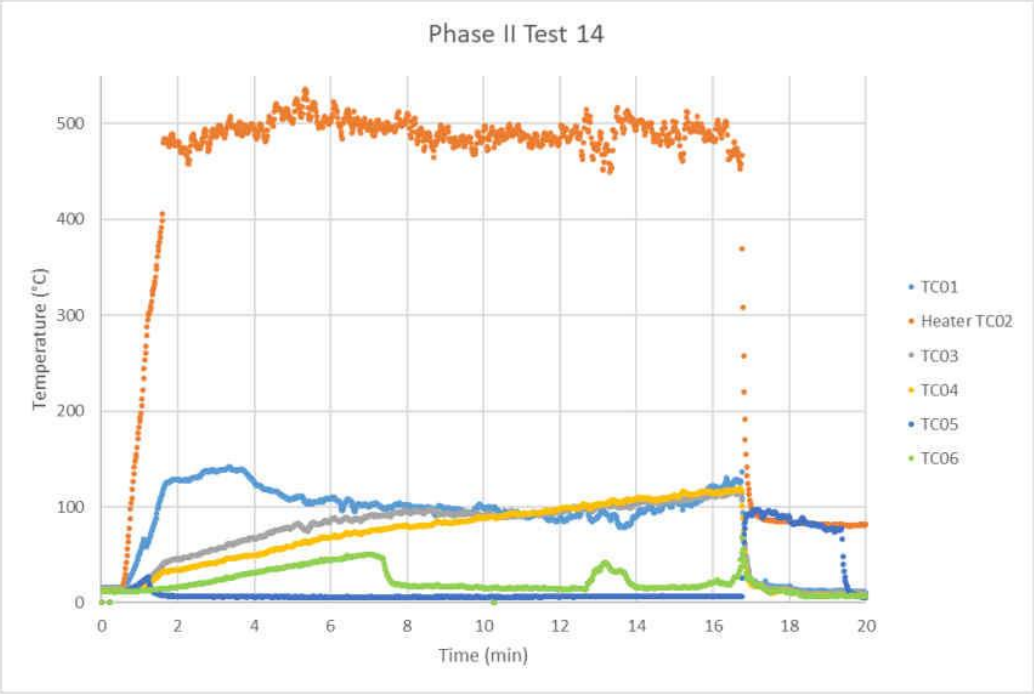
TESTID14 |

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on – no cells present
1 mins	Heater at 500°C
3 mins	Base of ignition cell nearing 150°C
7 mins	First sign of smoke
7 mins	Dummy cell temperatures overtaken ignition cell. Thermocouples observed to be in place from visual inspection
10 mins	Ignition cell temperature decreasing. Dummy cells increasing.
15 mins	Violent explosion. Shock wave visible on chamber wall. All cells displaced.
16 mins	End of test

Test Results and Post-test Observations

- Heater reached temperature of 500°C within 60 seconds
- Thermocouples dislodged during testing so peak temperature on cell not recorded
- Dummy cells quickly increased in temperature
- Smoke observed after just 7 minutes – much quicker than previously
- "Pop" from cell was much larger than usual. Enough to blow dummy cells across the test chamber. Ignition cell completely destroyed



Task 2 – Phase II – Interim Report – ANNEX II

TESTID14 |

Photos

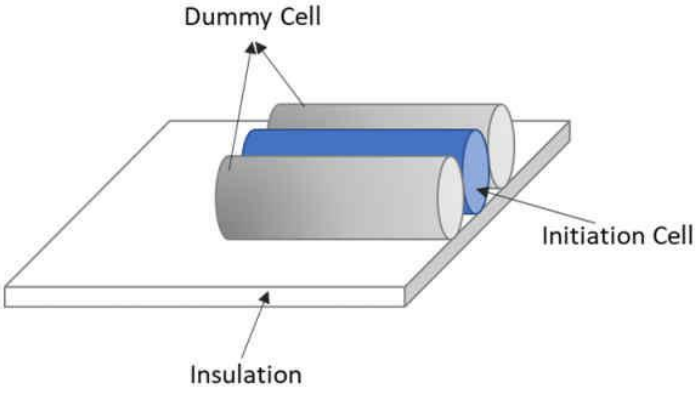
Figure 1- (left) test setup; (right) Beginning of thermal runaway; (centre) After violent thermal runaway

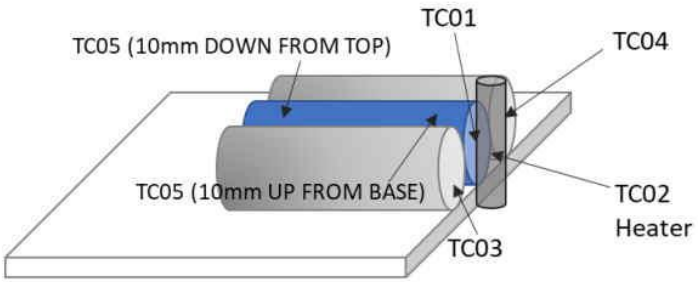
Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase II TEST 15

Test Date	05-02-2019
Test Location	Grangemouth
Outside air temp (C)	4°C
Cell(s) used	NMC 3.2AH 30%SOC
Test Setup	Phase II- orientation B
Test start time	1413
Test duration	18 minutes
First thermal runaway observed	17 minutes
First signs of smoke	3 minutes
Ignition source removed	17 minutes
Peak temperature	150°C from ignition cell base

Setup





Task 2 – Phase II – Interim Report – ANNEX II

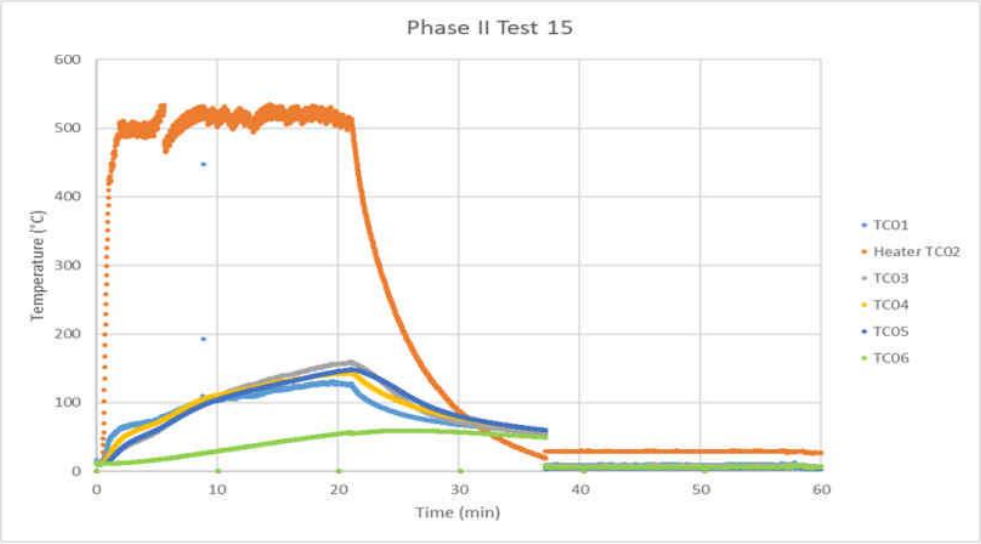
TESTID15 |

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on – no cells present
1 mins	Heater at 500°C
3 mins	Flame observed in test chamber. Base of box burning.
5 mins	Steady rate of temperature increase at 12.5°C /min. Temp on base of ignition cell constant with temperature of dummy cells.
17 mins	End of test

Test Results and Post-test Observations

- Heater reached temperature of 500°C within 60 seconds
- Rate of temperature rise is 12.5°C a minute at base of cell and 10mm from base of ignition cell.
- Flame observed within 3 minutes – heater had ignited the wooden base and fibreboard box. No effect on peak temperature for cell, however quickly raised dummy cells to ~300°C
- Large "pop", consistent with test 14. Probes blown off cells so no peak temperatures recorded



Task 2 – Phase II – Interim Report – ANNEX II

TESTID15 |

Photos

Figure 1- (left) Setup, (right) After Thermal Runaway

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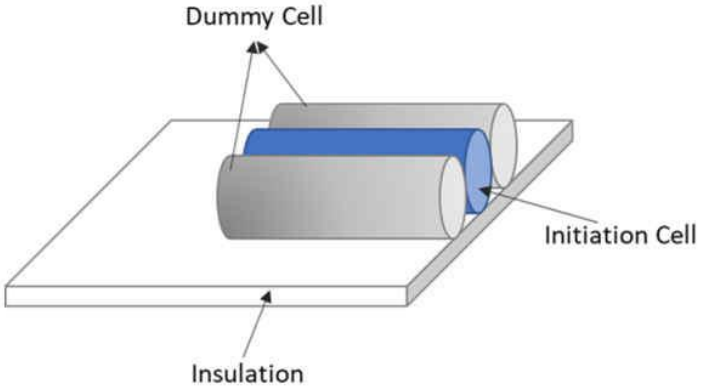
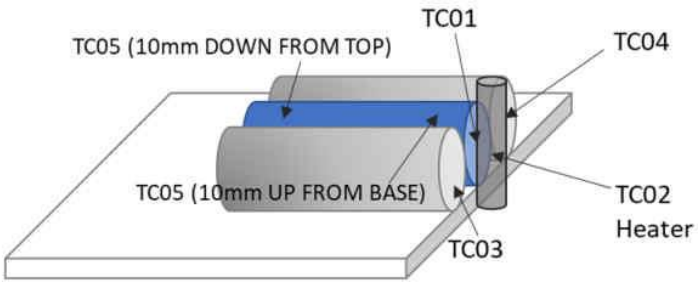
Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase II TEST 16

Test Date	05-02-2019
Test Location	Grangemouth
Outside air temp (C)	4°C
Cell(s) used	NMC 3.2AH 30%SOC
Test Setup	Phase II- Orientation B
Test start time	1540
Test duration	360 minutes
First thermal runaway observed	n/a
First signs of smoke	62 minutes
Ignition source removed	180 minutes
Peak temperature	450°C from ignition cell base

Setup





Task 2 – Phase II – Interim Report – ANNEX II

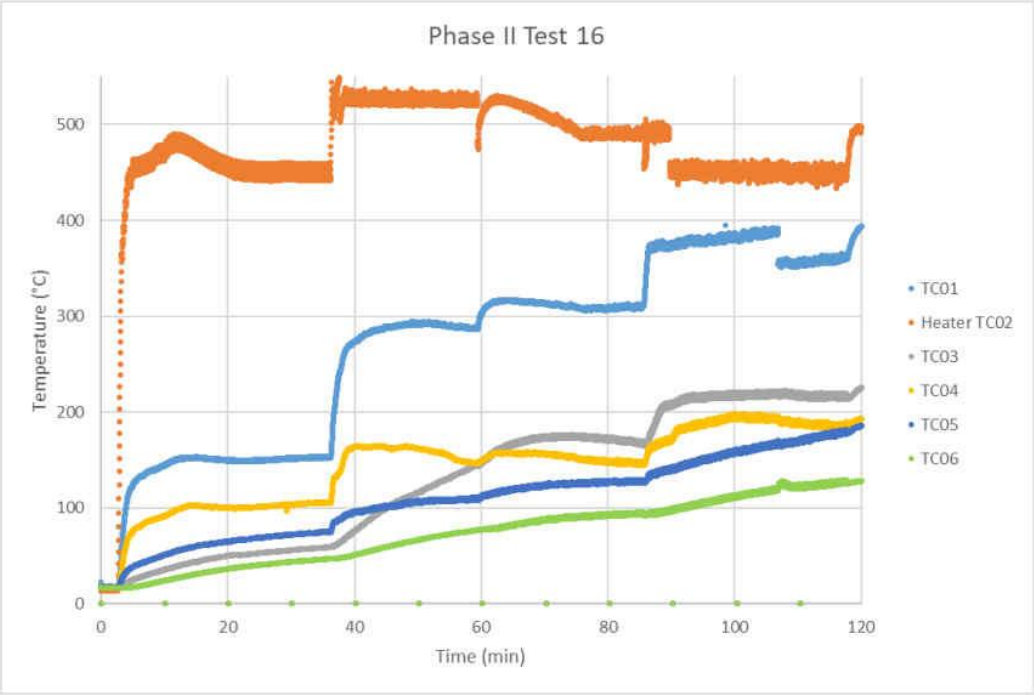
TESTID16 |

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on – no cells present
1 mins	Heater at 500°C
30 mins	No smoke observed
62 mins	First sign of smoke from cell
120 mins	Temperatures rising slowly. Little smoke. No sign of thermal runaway.
150 mins	Temperature on TC6 (top of ignition cell) stable
180 mins	End of test

Test Results and Post-test Observations

- Heater reached temperature of 500°C within 60 seconds
- Smoke took a long time to start, despite high cell temperatures
- TC6 remained low, despite rest of cell, and dummy cells, being high
- No thermal runaway observed after 180 minutes, so ignition source removed. Cell left overnight. No thermal runaway observed 12 hours later.



Task 2 – Phase II – Interim Report – ANNEX II

TESTID16 |

Photos

Figure 1- (top) setup; (bottom) during testing

Task 2 – Phase II – Interim Report – ANNEX II

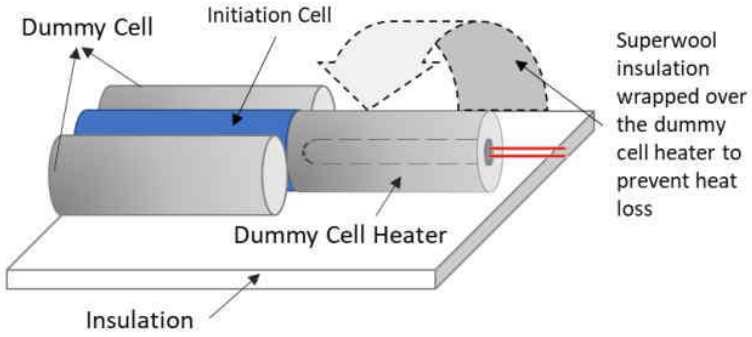
TESTID16 |

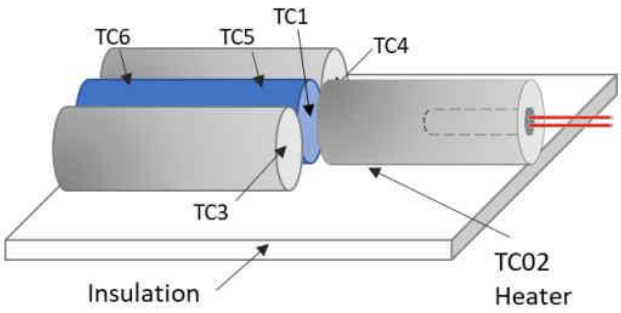
Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase II Test 17

Test Date	11-02-2019
Test Location	Grangemouth
Outside air temp (C)	6°C
Cell(s) used	NMC 3.2AH 30%SOC
Test Setup	Phase2-D with New Heater Dummy Cell instead
Test start time	1026
Test duration	80 minutes
First thermal runaway observed	n/a
First signs of smoke	n/a
Ignition source removed	Right after thermal runaway
Peak temperature	500°C

Setup





Task 2 – Phase II – Interim Report – ANNEX II

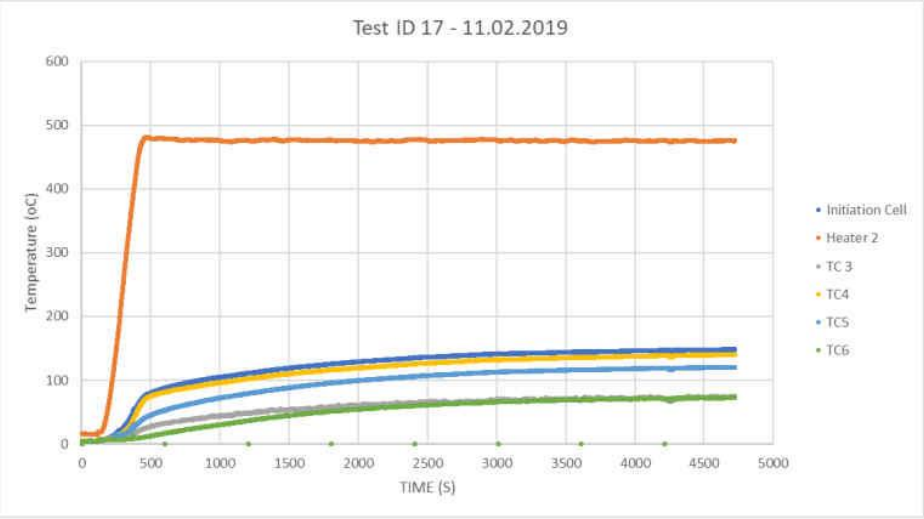
TESTID17 |

Observations:

Elapsed time	Observation
START	Heater is set to 400°C
20 min	Initiation Cell temp at 124°C
30 mins	No smoke observed, TC5 at 118°C & TC6 at 72°C
40 mins	All temp seems to have stabilised, no smoke observed
60 mins	Increased heater control temp to 500°C
70 mins	Only slight increase in temp but all temps are stabilised
80 mins	End of test

Test Results and Post-test Observations

- Within 20 mins TC1 temperature increased to around 124°C
- Nevertheless, TC5 was sitting at 95°C & TC6 was only at around 55°C
- Around 30 minutes later, slow rise in temp TC5 raised to around 118°C & TC6 read 72°C, whereas TC2 (heater) was recorded as 474.9°C
- The temperature overall seems to have stabilised at this point
- No gas/smoke was observed, but the smell of burnt insulation can be detected
- Temperature was increased to 500°C but all Thermocouples only detected a slight rise in temperature. Although the temperatures stabilised quickly.

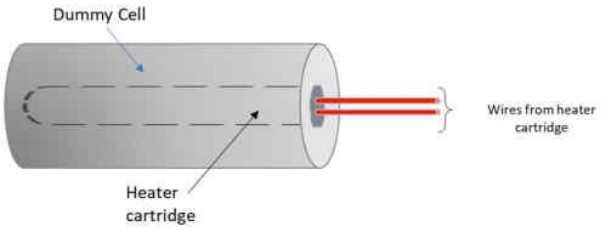


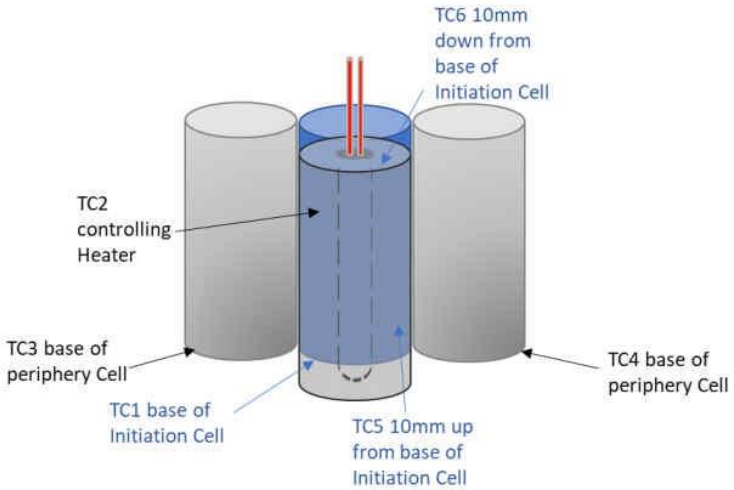
Sabatair Phase II evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase II TEST ID18

Test Date	13-02-2019
Test Location	Grangemouth
Outside air temp (C)	10°C
Cell(s) used	NMC 3.2AH 30%SOC
Test Setup	Phase II-E
Test start time	1128
Test duration	18 minutes
First thermal runaway observed	n/a
First signs of smoke	n/a
Ignition source removed	Right after thermal runaway
Peak temperature	1250°C

Setup





Task 2 – Phase II – Interim Report – ANNEX II

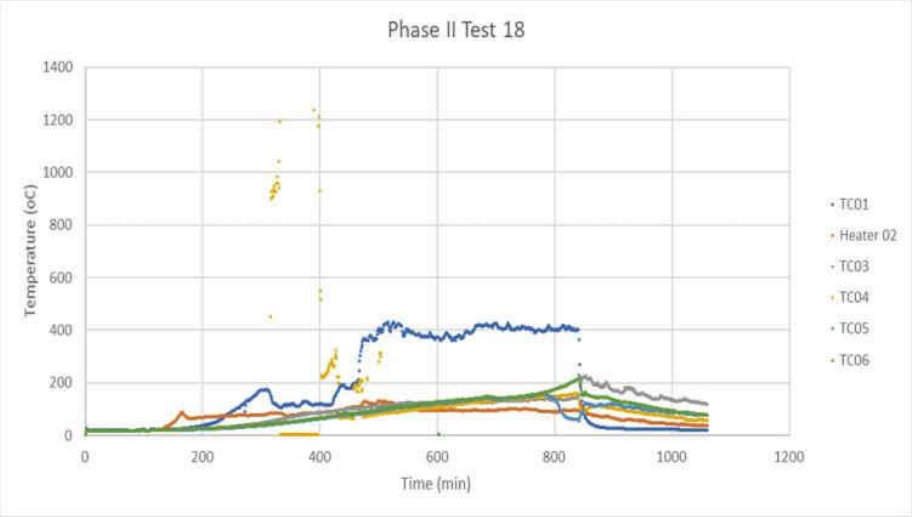
TESTID18 |

Observations:

Elapsed time	Observation
START	Heater is set to 400°C
1 min	Temperature increased consistently
5 mins	No smoke observed
10 mins	Temperature continues to rise steadily
13mins	First sign of gas release then 'bang'
17 mins	End of Test

Test Results and Post-test Observations

- Consistent rise in temperature throughout the test, although TC4 temperature varied dramatically.
- In the graph shown below, it indicates that thermal runaway may have occurred after 7 mins into the test.
- Nevertheless, in reality no signs of smoke or 'bang' noise occurred until around the 13 mins mark of the test.
- Gas release occurred for few seconds before the 'bang'

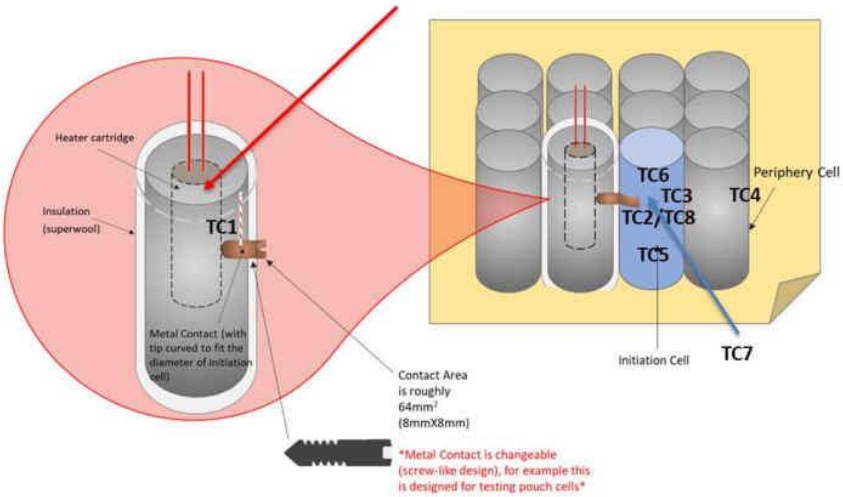


Sabatair Phase IIb evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IIb TEST 19

Test Date	11-04-2019
Test Location	Grangemouth
Outside air temp (C)	7°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase IIb
Test start time	0916
Test duration	30 minutes
First thermal runaway observed	29 minutes
First signs of smoke	27 minutes
Ignition source removed	Right After TR
Peak temperature	observed at TC2

Test Layout:

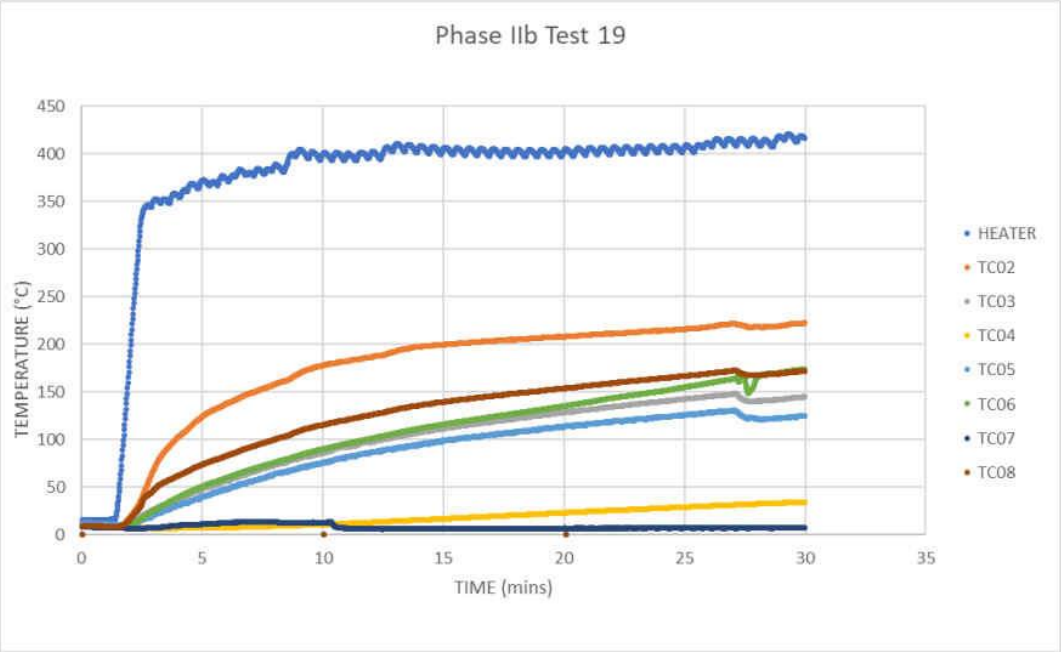


Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on
27 mins	Smoke observed from ignition cell
29 mins	Thermal runaway observed
30 mins	Test ended

Test Results and Post-test Observations

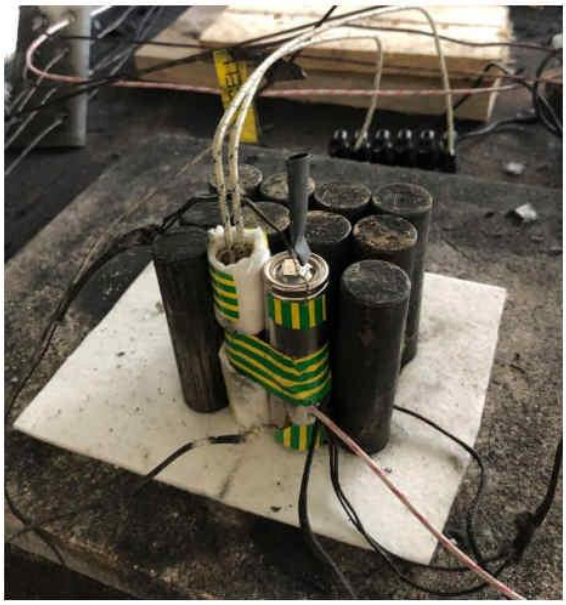
- Heating/ temperature rise of TC02 was relatively rapid following the Heater TC
- Heater control was initially set to 300°C and temperature was ramped at 5°C /min
- At there was a small "pop" sound but visually no signs of TR were observed
- No smoke observed
- Outer packaging temperature saw little rise
- Highest Temp observed in TC04 (periphery cell) was ~50°C, there was a temperature rise indicating heat dissipated to periphery cell but not significant.



Task 2 – Phase IIb – Interim Report – ANNEX III

TEST ID 19 |

Photos

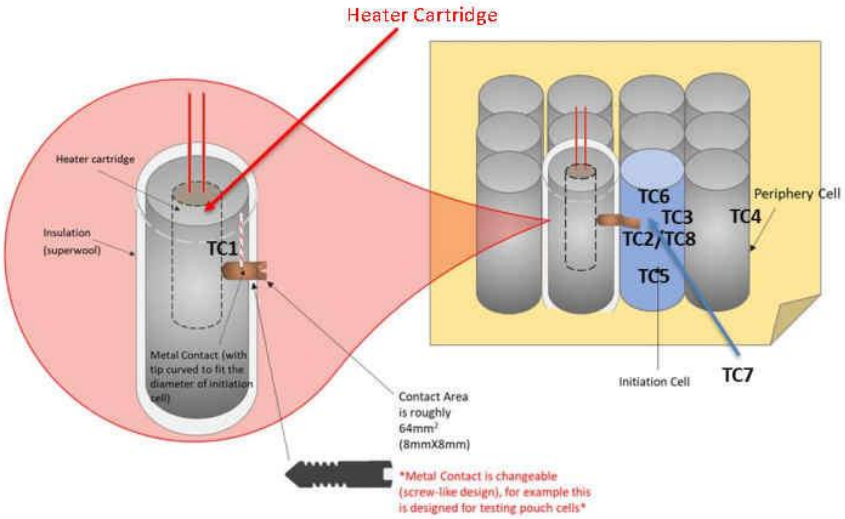


Sabatair Phase IIb evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IIb - TEST 20

Test Date	12-04-2019
Test Location	Grangemouth
Outside air temp (C)	6°C
Cell(s) used	NMC 3.2AH 100% SOC
Test Setup	Phase IIb
Test start time	0915
Test duration	40 minutes
First thermal runaway observed	35minutes
First signs of smoke	35minutes
Ignition source removed	35minutes after start time
Peak temperature	observed at back of cell

Test Layout:



Task 2 – Phase IIb – Interim Report – ANNEX III

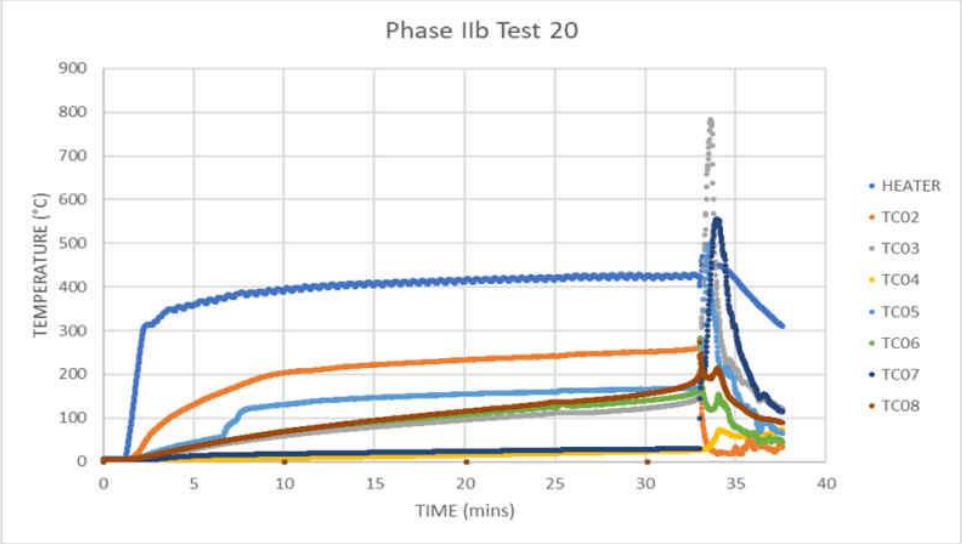
TEST ID20 |

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @300°C
31 mins	A small pop was heard
35 mins	There was a big bang and smoke & heater switched off
37 mins	Flame was observed
40mins	Test ended

Test Results and Post-test Observations

- Heating/ temperature rise of TC02 was relatively rapid following the Heater TC
- Heater control was initially set to 300C and temperature was ramped at 5°C /min
- At there was a small "pop" sound around 30 mins into the test
- No smoke was observed until the "big bang" occurred
- Soon after the bang, flame was observed
- The temperature rise between all TC were relatively consistent.



Task 2 – Phase IIb – Interim Report – ANNEX III

TEST ID20 |

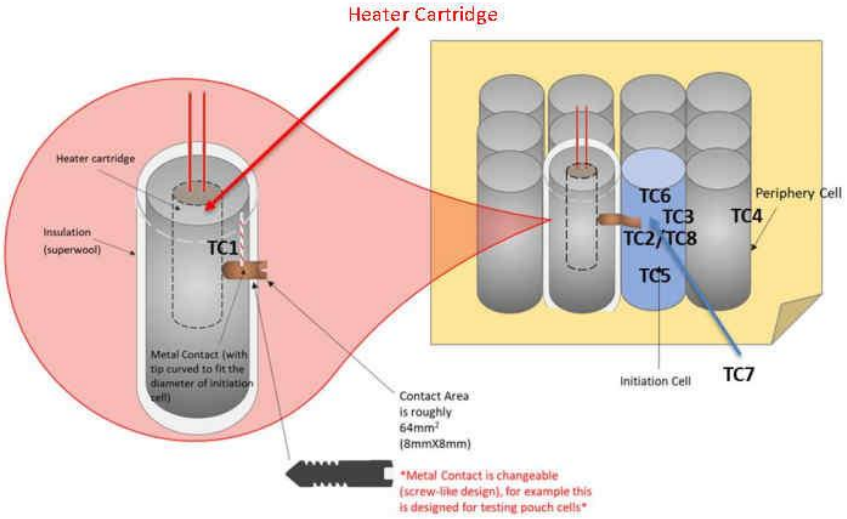
Photos

Sabatair Phase IIb evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IIb TEST ID 21

Test Date	12-04-2019
Test Location	Grangemouth
Outside air temp (C)	6°C
Cell(s) used	NMC 3.2AH 100% SOC
Test Setup	Phase IIb
Test start time	11:35
Test duration	45 minutes
First thermal runaway observed	45minutes
First signs of smoke	NO SIGN
Ignition source removed	45 minutes after start time
Peak temperature	observed at HEATER

Test Layout:



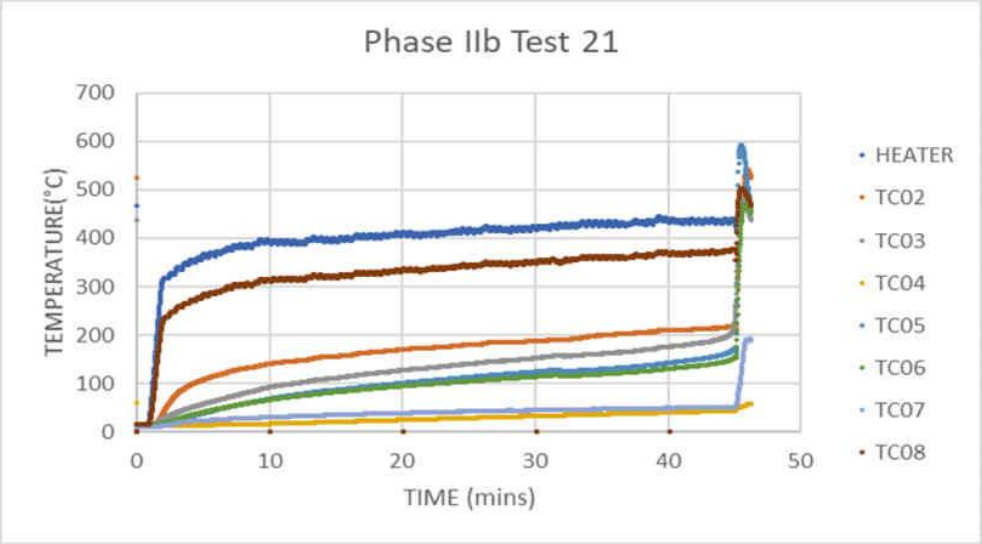
Task 2 – Phase IIb – Interim Report – ANNEX III

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @300°C
40 mins	A big bang was heard
41mins	TR observed. Removed heat source
45mins	Test ended

Test Results and Post-test Observations

- Heating/ temperature rise of TC02 was relatively rapid following the Heater TC
- Heater control was initially set to 300°C and temperature was ramped at 5°C /min
- A big band sound around 40 mins into the test
- Fame and smoke were observed in the duration of the test
- Temperature rise between all Tc were relatively consistent.



Photos

Task 2 – Phase IIb – Interim Report – ANNEX III

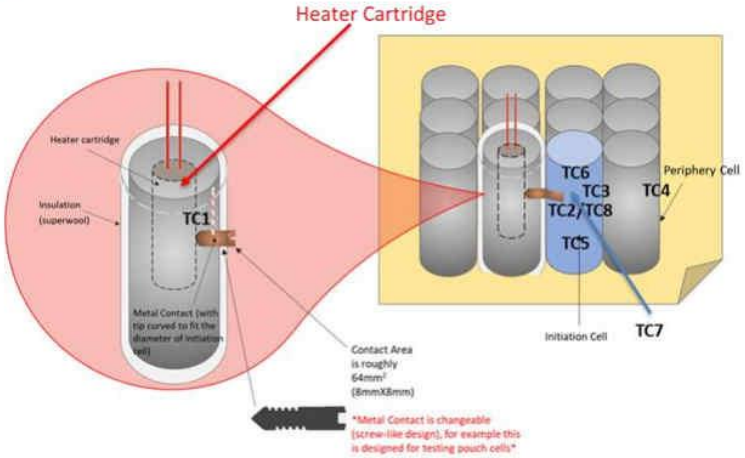
TEST ID21 |

Sabatair Phase IIb evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IIb Test 22

Test Date	15-04-2019
Test Location	Grangemouth
Outside air temp (C)	10°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase IIb
Test start time	11:00
Test duration	27minutes
First thermal runaway observed	24minutes
First signs of smoke	23 minutes
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:

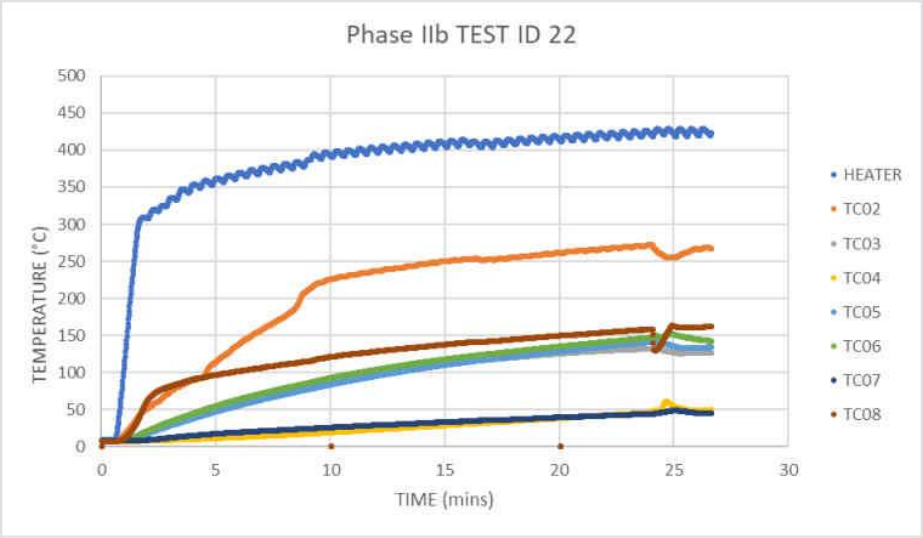


Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @300°C
22 mins	A small pop was heard
25mins	TR observed
28mins	Test ended

Test Results and Post-test Observations

- Heating/ temperature rise of TC02 was relatively rapid following the Heater TC
- Heater control was initially set to 300°C and temperature was ramped at 5°C /min
- At there was a small "pop" sound around 22 mins into the test
- Smoke was observed at around 23 minutes into the test
- Soon after the bang, flame was observed
- The temperature rise between all TC were relatively consistent.



Photos

Task 2 – Phase IIb – Interim Report – ANNEX III

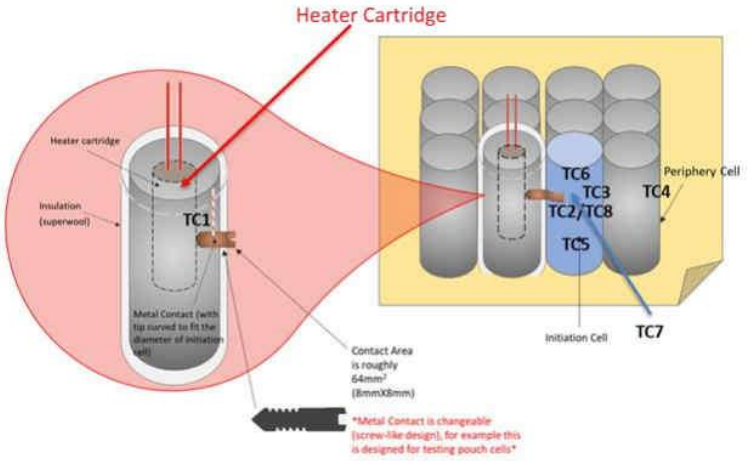
TEST ID01 |

Sabatair Phase IIb evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IIb Test 23

Test Date	15-04-2019
Test Location	Grangemouth
Outside air temp (C)	10°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase IIb
Test start time	1300
Test duration	33minutes
First thermal runaway observed	27minutes
First signs of smoke	25 minutes
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout



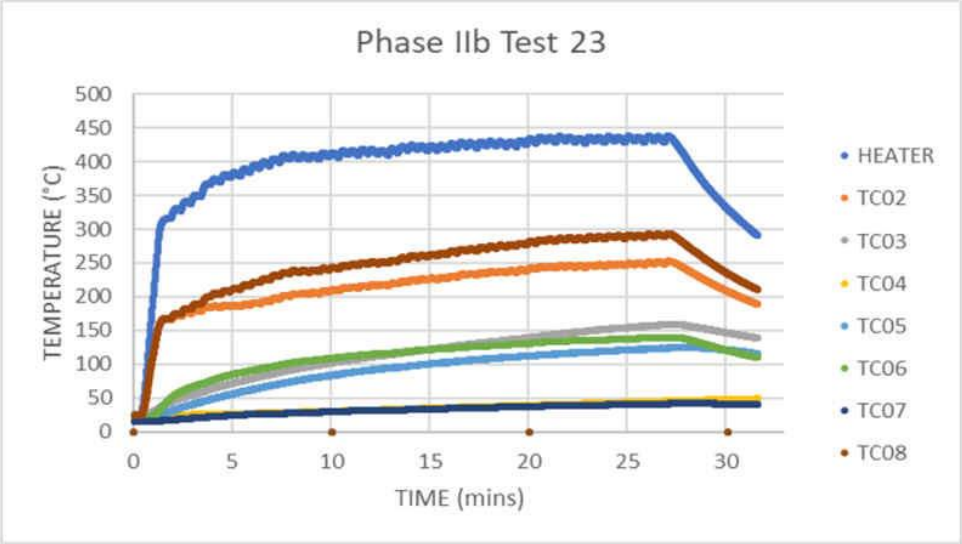
Task 2 – Phase IIb – Interim Report – ANNEX III

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @300°C
25 mins	Sign of smoke
27mins	TR observed
33mins	Test ended

Test Results and Post-test Observations

- Heating/ temperature rise of TC02 was relatively rapid following the Heater TC
- Heater control was initially set to 300°C and temperature was ramped at 5°C /min
- At there was a sign of smoke 25 mins into the test
- TR occurred 27 mins into test
- The temperature rise between all TC were relatively consistent.



Task 2 – Phase IIb – Interim Report – ANNEX III

TEST ID23 |

Photos

Task 2 – Phase IIb – Interim Report – ANNEX III

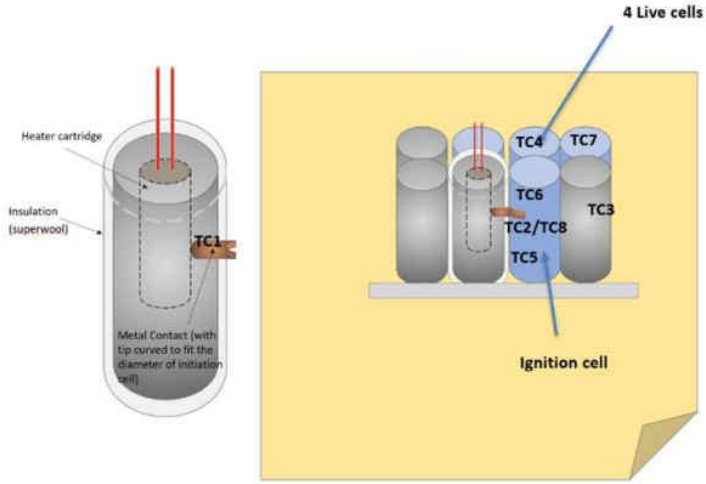
TEST ID23 |

Sabatair Phase IIb evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IIb Test 25

Test Date	23-04-2019
Test Location	Grangemouth
Outside air temp (C)	12°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase IIb in box with 5 cells
Test start time	15:00
Test duration	52minutes
First thermal runaway observed	50minutes
First signs of smoke	48 mins into test
Ignition source removed	Immediately after TR
Peak temperature	observed at TC02

Test Layout:

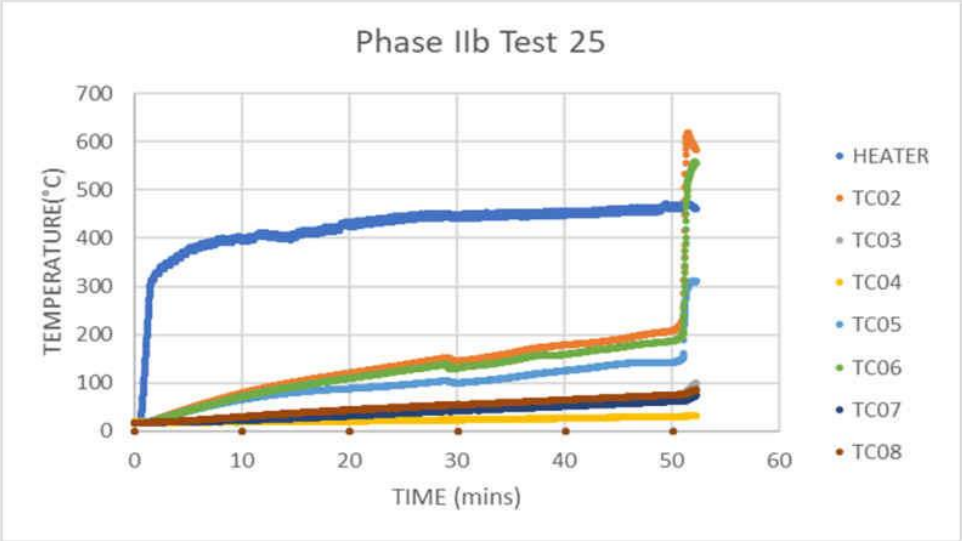


Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @300°C
46 mins	A small pop was heard
48mins	Signs of gas release
50mins	TR observed

Test Results and Post-test Observations

- Heating/ temperature rise of TC02 was relatively rapid following the Heater TC
- Heater control was initially set to 300°C and temperature was ramped at 5°C /min
- At there was a small "pop" sound around 34 mins into the test
- White smoke was observed in the duration of the test
- No flame or debris were observed
- The temperature rise between all TC were relatively consistent.



Task 2 – Phase IIb – Interim Report – ANNEX II

TEST ID25 |

Appendix III

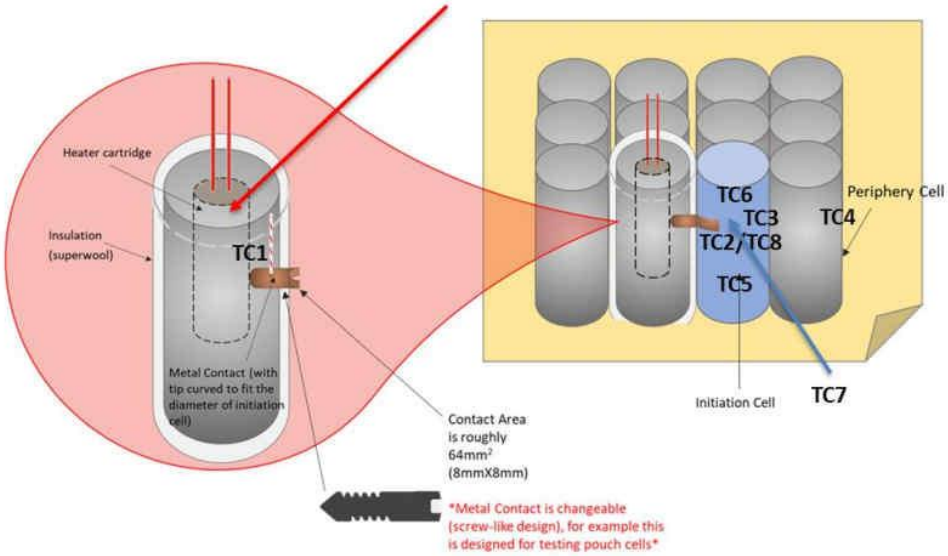
Phase III test reports.

Sabatair Phase III evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase III Test 28

Test Date	04-06-2019
Test Location	Grangemouth
Outside air temp (C)	15°C
Cell(s) used	NMC 3.2AH 30% SOC (in box)
Test Setup	Phase III same as IIb -A
Test start time	0900
Test duration	220 minutes
First thermal runaway observed	220 minutes
First signs of smoke	217 minutes
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:

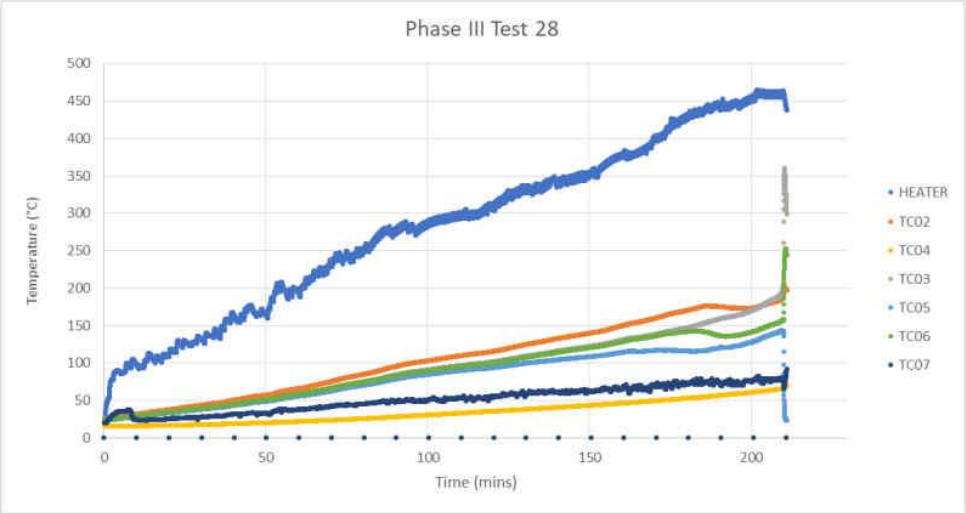


Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @50°C
217 mins	Smoke observed
218 mins	Small pop
220 mins	Thermal runaway occurred & Test ended

Test Results and Post-test Observations

- Heater control started at 50oC and slowly ram up by 2°C/min
- Until TC03 (back of initiation) is reading 200°C then hold for 1 hour or until TR observed
- TC03 temperature was reading much higher than other TC even TC02 (this is an unexpected result)
- The graph showed a very high initial spike in temperature which caused a kink in the initial phase; therefore, data is not as linear as expected.



Photos

Task 2 – Phase III – Interim Report – ANNEX IV

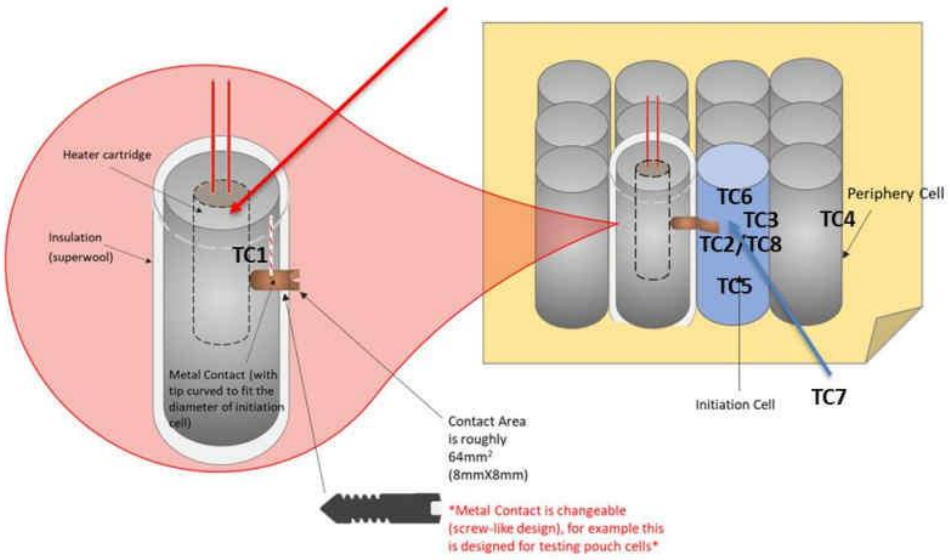
TEST ID28 |

Sabatair Phase III evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase III Test 29

Test Date	04-06-2019
Test Location	Grangemouth
Outside air temp (C)	17°C
Cell(s) used	NMC 3.2AH 30% SOC (in box)
Test Setup	Phase III
Test start time	1300
Test duration	60 minutes
First thermal runaway observed	59 minutes
First signs of smoke	55 minutes
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:

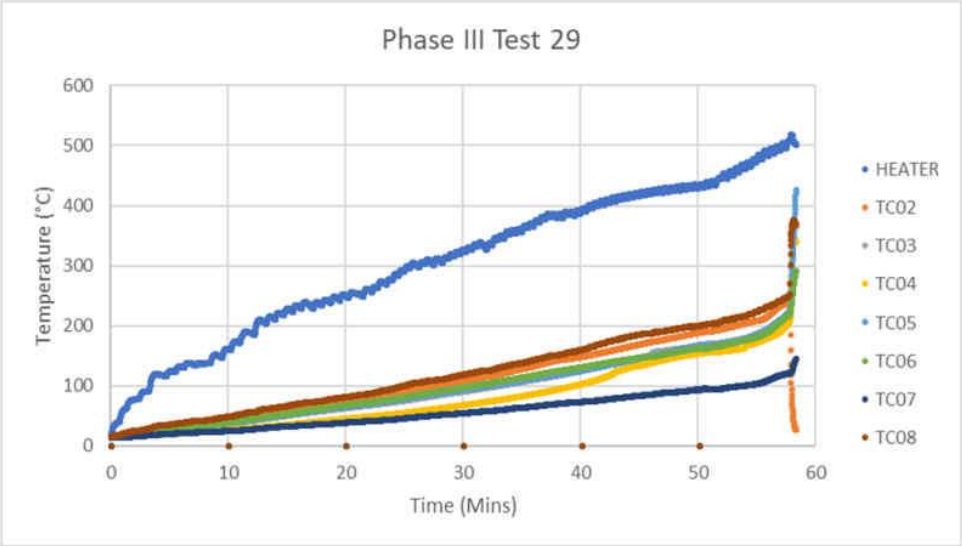


Observations:

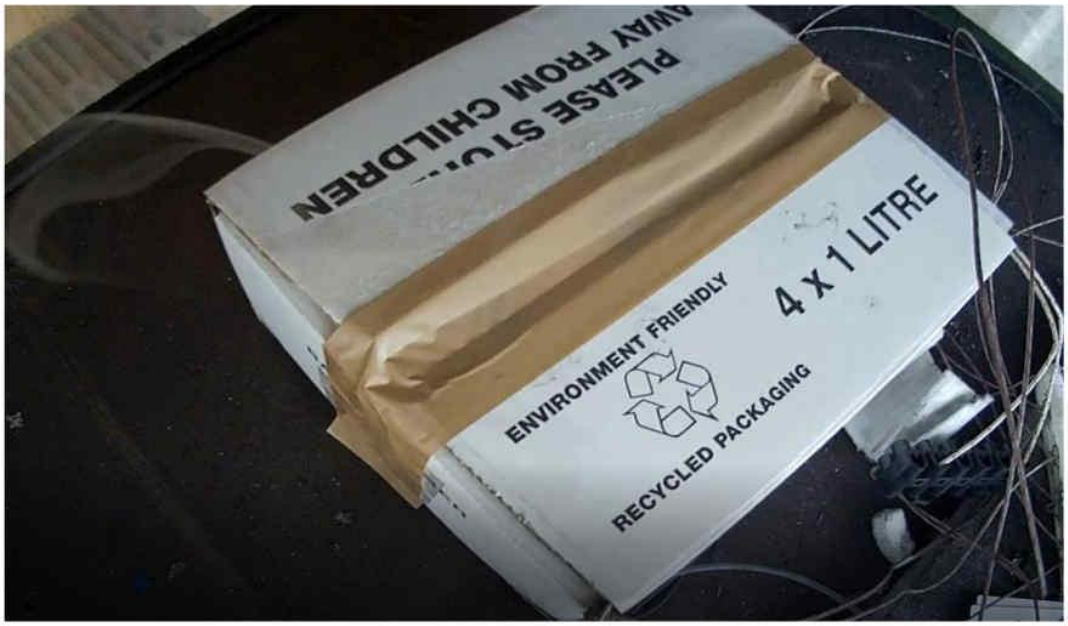
Elapsed time	Observation
START	Test started with cartridge heater turned on @50°C
58 mins	Small 'pop' was heard
59mins	TR was observed
60mins	Test ended

Test Results and Post-test Observations

- Heater control started at 100°C and slowly ram up by 2°C /min
- Until TC03 (back of initiation) is reading 200°C then hold for 1 hour or until TR observed
- TC03 temperature was reading much higher than other TC even TC02 (this is an unexpected result)
- The graph showed a very high initial spike in temperature which caused a kink in the initial phase; therefore, data is not as linear as expected.
- Initial temperature spike has been reduced compared to the previous test



Photos



Task 2 – Phase III – Interim Report – ANNEX IV

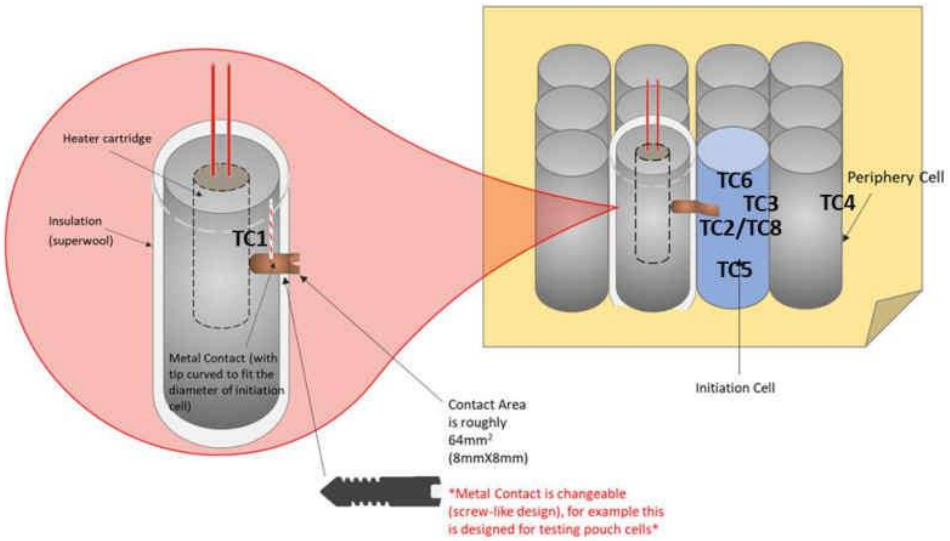
TEST ID29 |

Sabatair Phase III evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase III Test 30

Test Date	05-06-2019
Test Location	Grangemouth
Outside air temp (C)	16°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase III
Test start time	0900
Test duration	35 minutes
First thermal runaway observed	34 mins into test
First signs of smoke	28 mins into test
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:



Task 2 – Phase III – Interim Report – ANNEX IV

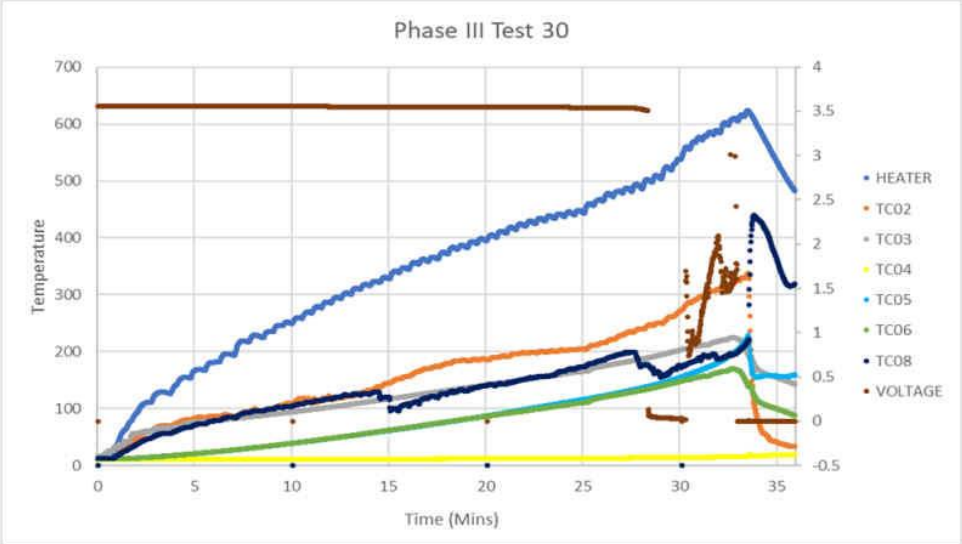
TEST ID30 |

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @50°C
28 mins	Gas release
34mins	TR observed
35 mins	Test ended

Test Results and Post-test Observations

- Heater control started at 50°C and slowly ram up by 6°C /min
- Until TC03 (back of initiation) is reading 200°C then hold for 1 hour or until TR observed
- Live voltage recording was introduced to the test
- Voltage fluctuation right before thermal event, 0V after TR
- Heater temperature is becoming more linear at this ramp rate.



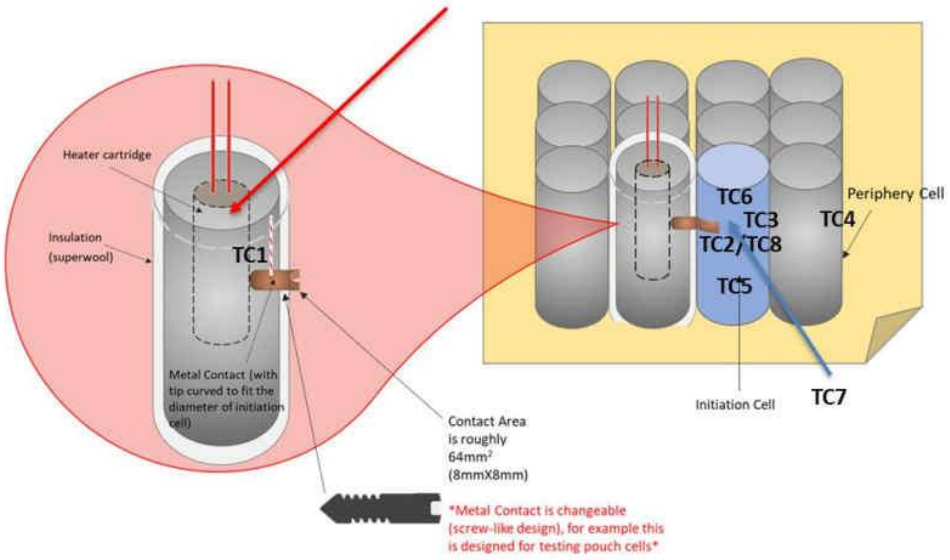
Photos

Sabatair Phase III evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase III Test 32

Test Date	06-06-2019
Test Location	Grangemouth
Outside air temp (C)	16°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase III
Test start time	0900
Test duration	32 minutes
First thermal runaway observed	30 minutes
First signs of smoke	29 minutes
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:



Task 2 – Phase III – Interim Report – ANNEX IV

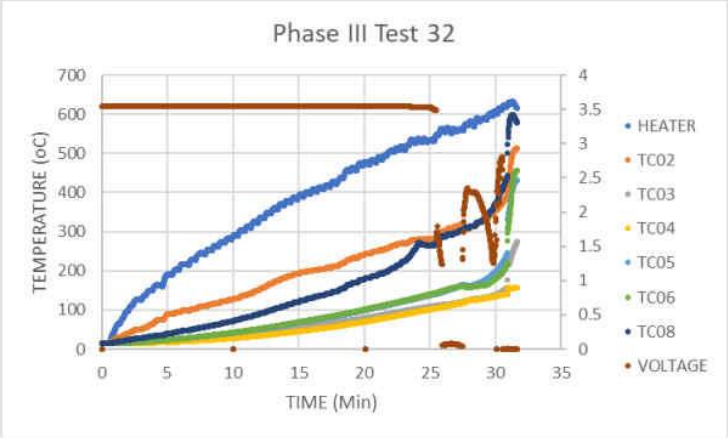
TEST ID32 |

Observations:

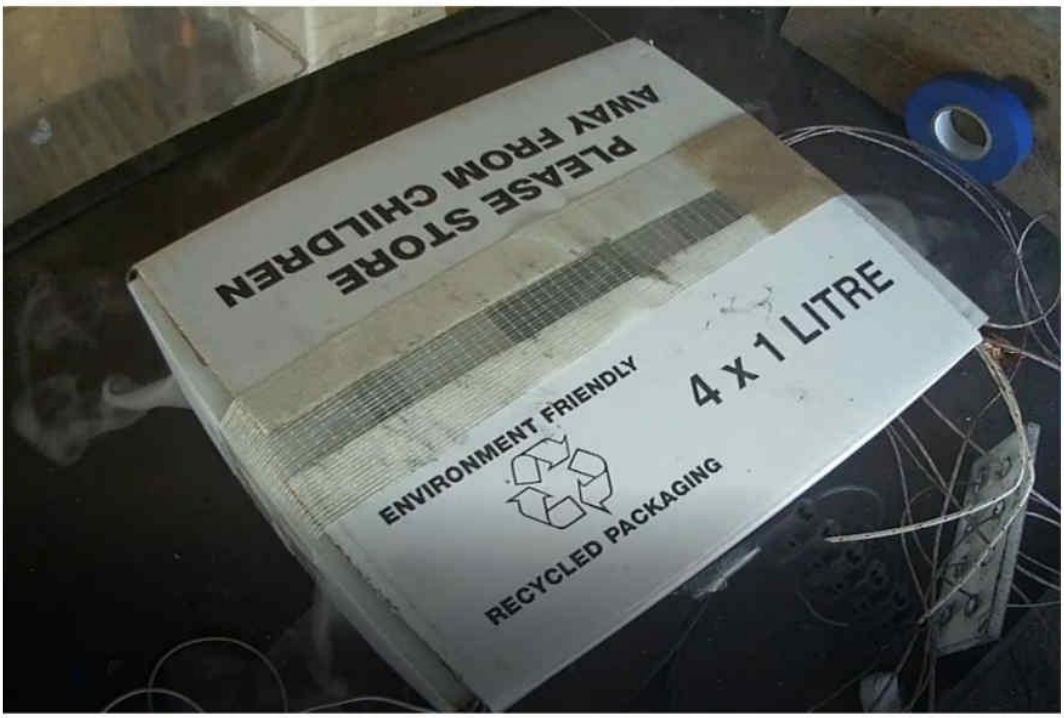
Elapsed time	Observation
START	Test started with cartridge heater turned on @50°C
29 mins	Gas release
30 mins	TR observed
33 mins	Test ended

Test Results and Post-test Observations

- Heater control started at 50°C and remained at 50°C for the first 10 minutes then slowly ramp up by 6°C /min
- Until TC03 (back of initiation) is reading 200°C then hold for 1 hour or until TR observed
- Voltage fluctuation right before thermal event, 0V after TR
- Initiation cell entered thermal runaway at around 31 minutes into the test and heater source was removed immediately.
- The voltage reading doesn't show any valuable data, therefore a reading of voltage before and after test is adequate.



Photos



Task 2 – Phase III – Interim Report – ANNEX IV

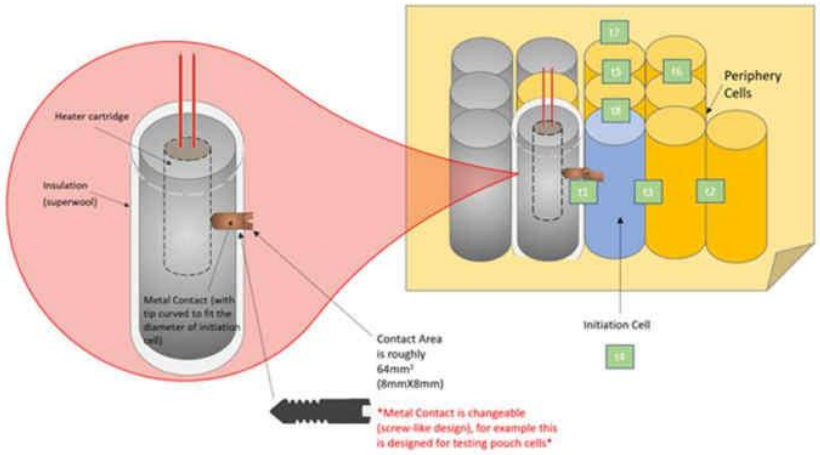
TEST ID32 |

Sabatair Phase III evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase III TEST 33

Test Date	28-11-2019
Test Location	Grangemouth
Outside air temp (C)	8°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase III – 2nd set-up
Test start time	1000
Test duration	50 mins
First thermal runaway observed	48 mins
First signs of smoke	48 mins
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:



Task 2 – Phase III – Interim Report – ANNEX IV

TEST ID33|

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @50°C
42 mins	Small pop
48 mins	Sign of smoke
48 mins	Thermal runaway occurred & heater source removed

Test Results and Post-test Observations

- This test is the first test in Phase III to use a new layout where 8 live cells are used with new thermocouple positioning. All cells used in this test are charged to 30% SOC.
- Heater control started at 50°C and slowly ramped up by 6°C /min
- Until TC03 (back of initiation) is reading 200°C then hold for 1 hour or until TR observed
- TC03 result shows that thermal runaway occurred at 48 mins
- Heating rate of TC03 is only at 3°C/min
- Result shows that the temperature ramp rate should be done according to TC03 temperature increase and not a consistent ramp rate at the heater. This means, the linearity of the heater TC is not significant and the heater would increase/decrease according to TC03 temperature.

Photos

Task 2 – Phase III – Interim Report – ANNEX IV

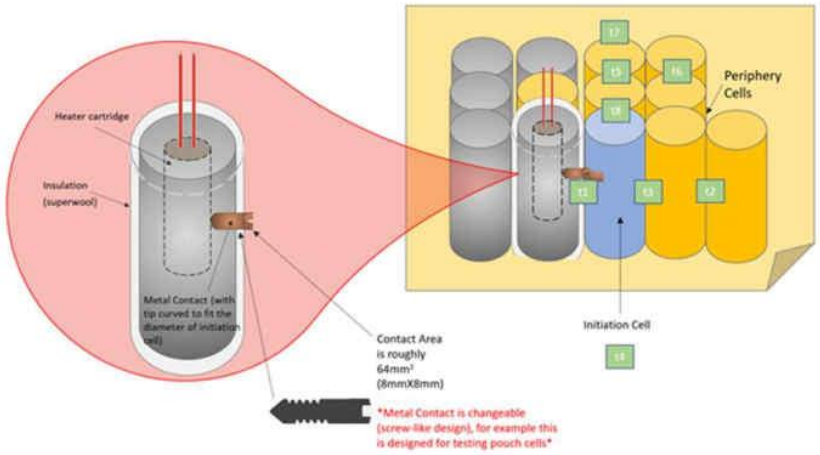
TEST ID33|

Sabatair Phase III evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase III Test 34

Test Date	29-11-2019
Test Location	Grangemouth
Outside air temp (C)	6°C
Cell(s) used	NMC 3.2AH 30% SOC
Test Setup	Phase III – 2nd set up
Test start time	0900
Test duration	20 mins
First thermal runaway observed	20 mins
First signs of smoke	20 mins
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:



Task 2 – Phase III – Interim Report – ANNEX IV

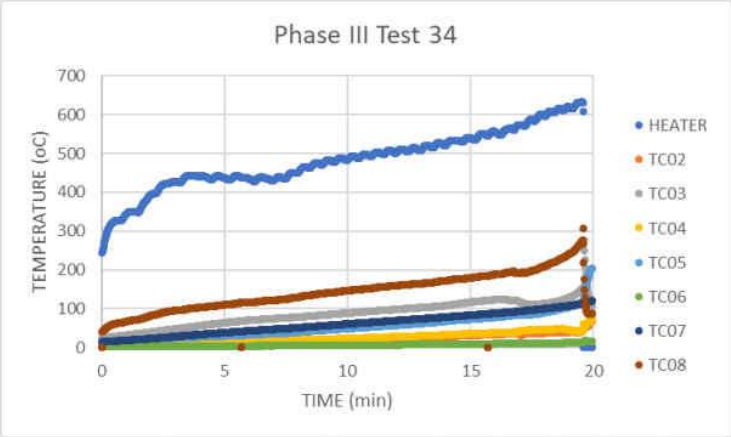
TEST ID34|

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @200°C
15 mins	Small pop
20 mins	Sign of smoke
20 mins	Thermal runaway occurred & heater source removed

Test Results and Post-test Observations

- Cells used in this test are at 30% SOC. There were 8 live cells.
- Heater control is dependent on the temperature rise of TC03 to try achieve a rate of increase at 6°C/min
- Therefore, heater is controlled accordingly at varying temperature setting to achieve a minimum 6°C/min rise at TC03
- Thermal runaway occurred (shown by TC03 results) at around 17 minutes
- The graph shows that all thermocouples except from Heater TC has a linear temperature rise.
- Heating rate of TC03 is at 7.7°C/min



Photos

Task 2 – Phase III – Interim Report – ANNEX IV

TEST ID34|

Appendix IV

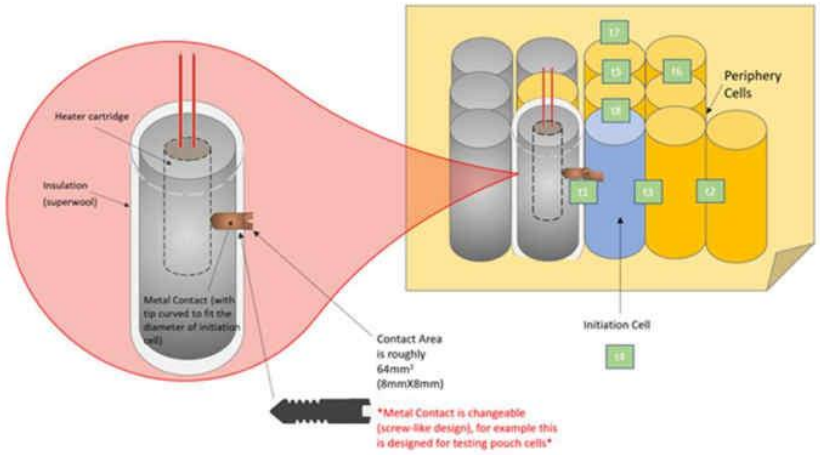
Phase IV test reports.

Sabatair Phase IV evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IV Test 35

Test Date	16-12-2019
Test Location	Grangemouth
Outside air temp (C)	6°C
Cell(s) used	NMC 3.2AH 100% SOC
Test Setup	Phase III – 2nd set up
Test start time	1000
Test duration	20 mins
First thermal runaway observed	20 mins
First signs of smoke	20 mins
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:



Task 2 – Phase IV – Interim Report – ANNEX V

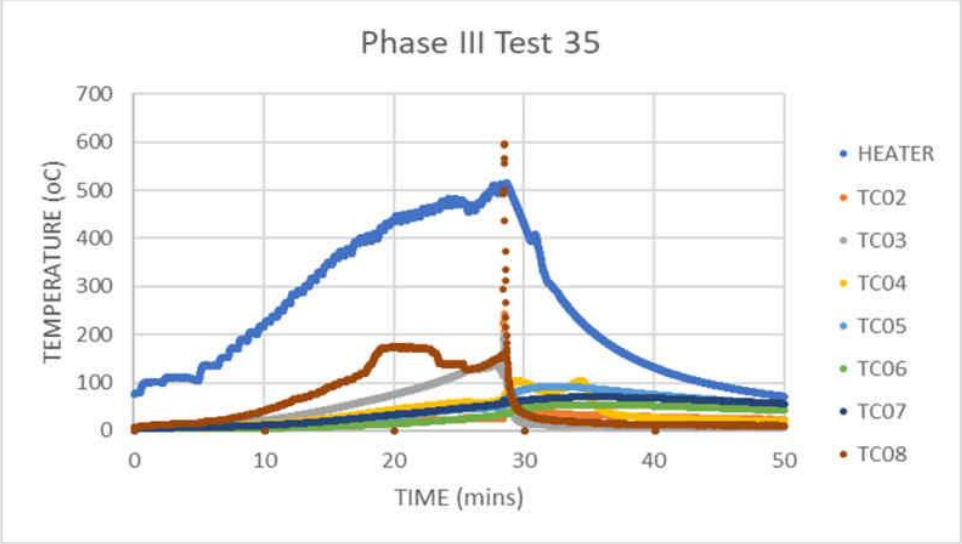
TEST ID35|

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @175°C
20 mins	Small pop
27 mins	Sign of smoke
27 mins	explosion & flame observed & heater source removed

Test Results and Post-test Observations

- Cells used in this test are at 100% SOC. There were 8 live cells.
- Heater control is dependent on the temperature rise of TC03 to try achieve a rate of increase at 6°C/min
- Therefore, heater is controlled accordingly at varying temperature setting to achieve a minimum 6°C/min rise at TC03
- Thermal runaway occurred (shown by TC03 results) at around 27 minutes
- The graph shows that all thermocouples except from Heater TC has a linear temperature rise.
- Heating rate of TC03 is at 4°C/min which is slightly slower than expected but relatively linear, shows that temperature control via heater is still a challenge
- Result of TC08 (north of initiation cell) the cell vented at around 20 mins into the test, followed by an explosion around 27 minutes.
- Outer packaging is visibly damaged



Photos

Task 2 – Phase IV – Interim Report – ANNEX V

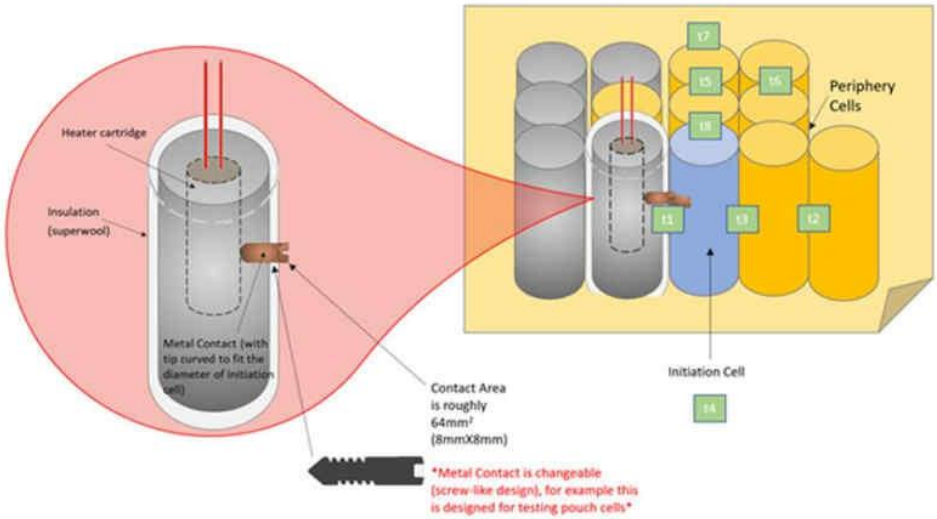
TEST ID35|

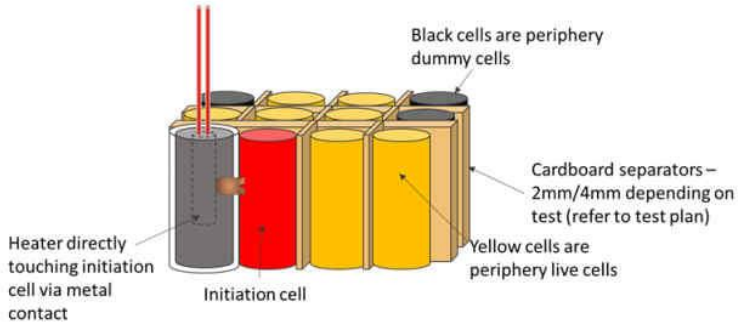
Sabatair Phase IV evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IV Test 36

Test Date	17-12-2019
Test Location	Grangemouth
Outside air temp (C)	3°C
Cell(s) used	NMC 3.2AH 100% SOC
Test Setup	Phase III – 2nd set up with 2mm cardboard separators
Test start time	0900
Test duration	70 mins
First thermal runaway observed	15 mins
First signs of smoke	15 mins
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:





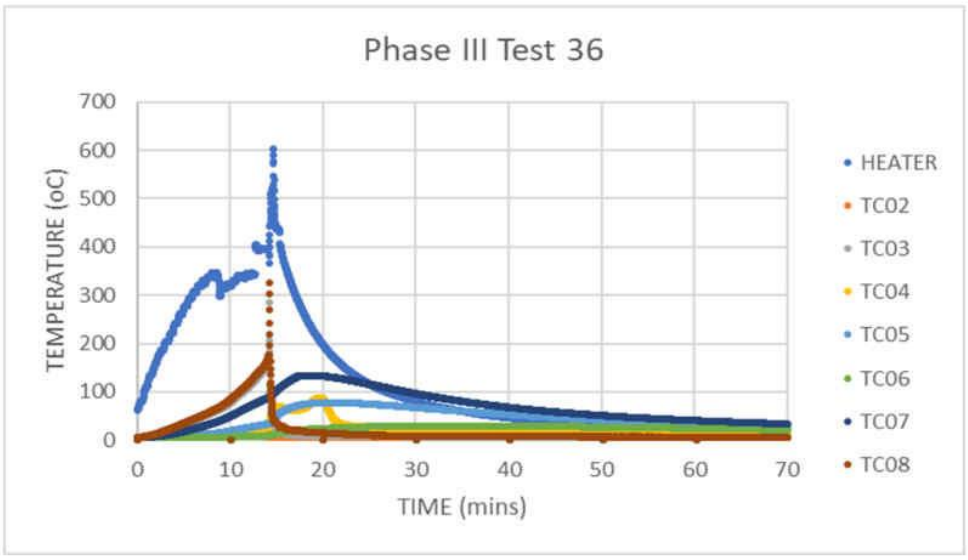
Thermocouple set-up is the same as Phase III 2nd set-up. This diagram illustrate the layout with additional cardboard separators

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @175°C
14 mins	Small pop
15 mins	Sign of smoke
15 mins	explosion & flame observed & heater source removed

Test Results and Post-test Observations

- Cells used in this test are at 100% SOC. There were 8 live cells.
- Heater control is dependent on the temperature rise of TC03 to try achieve a rate of increase at 6°C/min
- Therefore, heater is controlled accordingly at varying temperature setting to achieve a minimum 6°C/min rise at TC03
- After thermal runaway, the heater source is removed immediately, but the data logger continues to log for 1hr after this. This is to observe another other thermal runaway during the hour. TC07 which is placed on the cell north of the heater, went into thermal runaway 3 minutes after the initiation cell TR according to the result.
- Voltage reading showed that initiation cell has 0V post-test (cell ruptured) and cell north of heater dropped voltage to 1V (cell vented) which confirms thermal runaway.
- Thermal runaway occurred (shown by TC03 results) at around 15 minutes
- Heating rate of TC03 is at 9°C/min which is slightly higher than the minimum requirement and it is relatively linear.
- Result of TC08 (north at initiation cell) aligns with TC03 (back at initiation cell) almost completely. This is a very good sign to show that heat is distributed evenly across the whole cell
- Outer packaging is visibly damaged



Photos

Task 2 – Phase IV – Interim Report – ANNEX V

TEST ID36|

Task 2 – Phase IV – Interim Report – ANNEX V

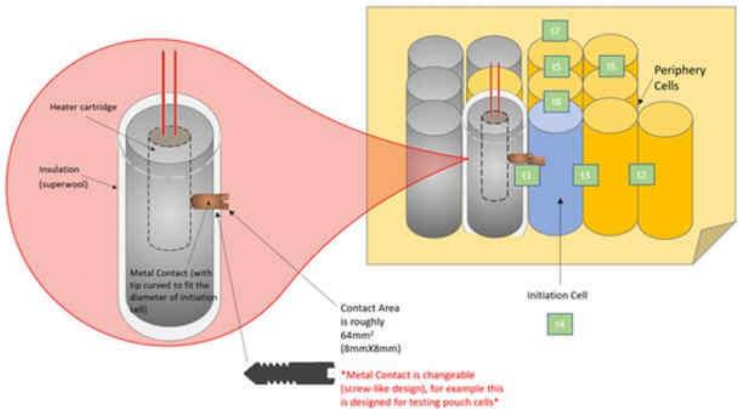
TEST ID36|

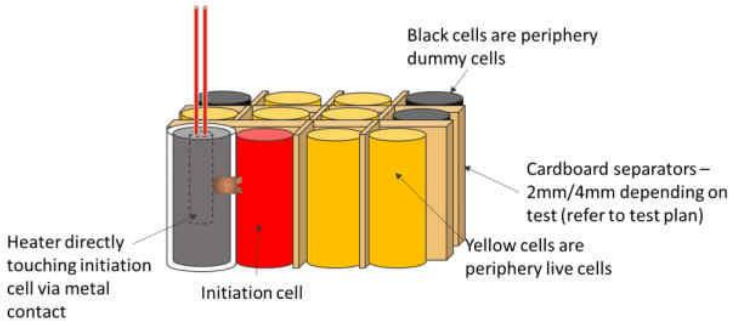
Sabatair Phase IV evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IV TEST 37

Test Date	17-12-2019
Test Location	Grangemouth
Outside air temp (C)	3°C
Cell(s) used	NMC 3.2AH 100% SOC
Test Setup	Phase III – 2nd set up with 4mm separators
Test start time	0900
Test duration	70 mins
First thermal runaway observed	15 mins
First signs of smoke	15 mins
Ignition source removed	Right after TR
Peak temperature	observed at HEATER

Test Layout:





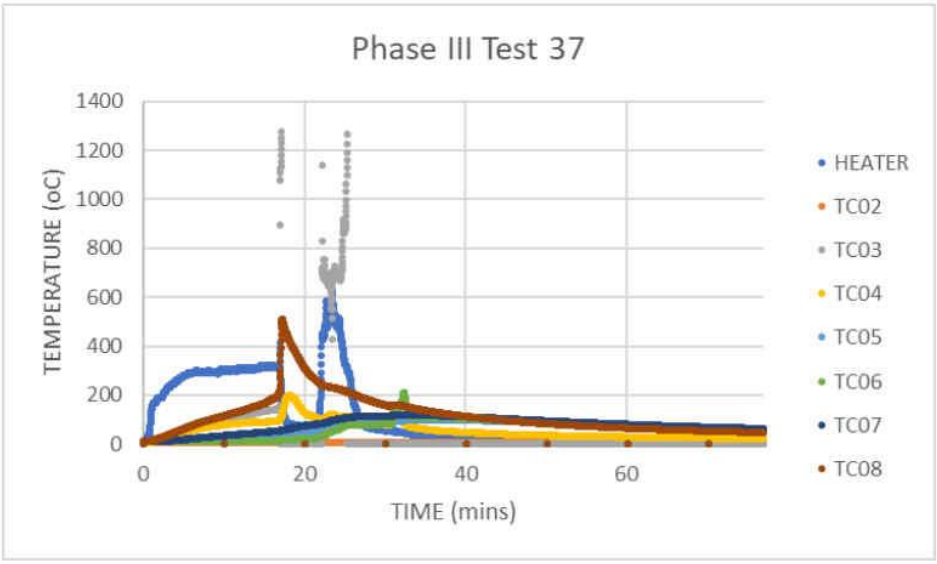
Thermocouple set-up is the same as Phase III 2nd set-up. This diagram illustrate the layout with additional cardboard separators

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @175°C
16 mins	Small pop
17 mins	Sign of smoke
17 mins	explosion & flame observed & heater source removed

Test Results and Post-test Observations

- Cells used in this test are at 100% SOC. There were 8 live cells with 4mm carboard separators between the cells (refer to test layout).
- Heater control is dependent on the temperature rise of TC03 to try achieve a rate of increase at 6°C/min
- Therefore, heater is controlled accordingly at varying temperature setting to achieve a minimum 6°C/min rise at TC03
- Results show that the initiation cell entered thermal runaway (shown by TC03 results) at around 17 minutes into the test.
- After thermal runaway, the heater source is removed immediately, but the data logger continues to log for 1hr after this. This is to observe another other thermal runaway during the hour. TC02 which is placed directly on the right of the initiation cell vented (0V post-test) but no rupture.
- The second cell on the right-hand side of the initiation cell also entered thermal runaway as the cell was ruptured but the time of this occurrence is uncertain as this cell did not have a thermocouple attached.
- The cell north of heater dropped voltage to 1V (cell vented) which confirms thermal runaway. TC07 indicates that this may have happened just over 20 minutes into the test.
- The cell at the far-right corner (diagonal to cell with TC5) also lost voltage
- Heating rate of TC03 is at 9°C/min which is higher than the minimum requirement and it is relatively linear.
- After the first big bang, flame was observed for around a minute and it stopped. However, a few minutes after that the flame restarted.
- Outer packaging is visibly damaged, visual observation shows that this test was very violent



Photos

Task 2 – Phase IV – Interim Report – ANNEX V

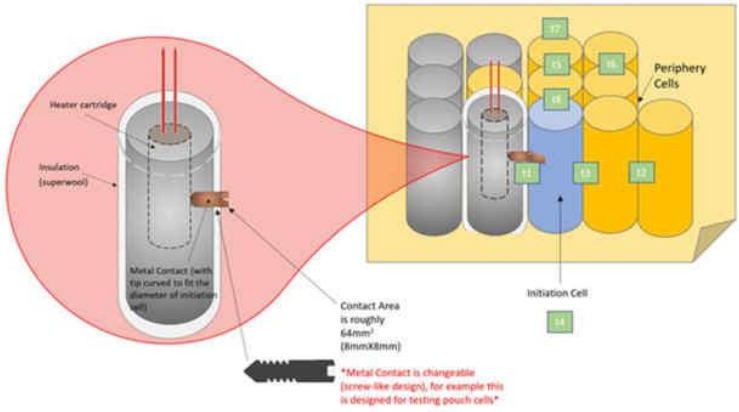
TEST ID37|

Sabatair Phase IV evaluation of heater for initiation cells using NMC 3.2AH cells

Test Summary: Phase IV Test 38

Test Date	17-12-2019
Test Location	Grangemouth
Outside air temp (C)	5°C
Cell(s) used	NMC 3.2AH 100% SOC
Test Setup	Phase III – 2nd set up with 2mm separator and sand
Test start time	1300
Test duration	80 mins
First thermal runaway observed	20 mins
First signs of smoke	No Smoke
Ignition source removed	Right after TR
Peak temperature	observed at TC08

Test Layout:



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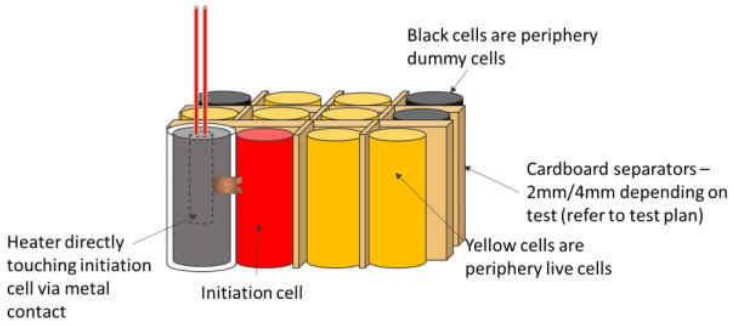


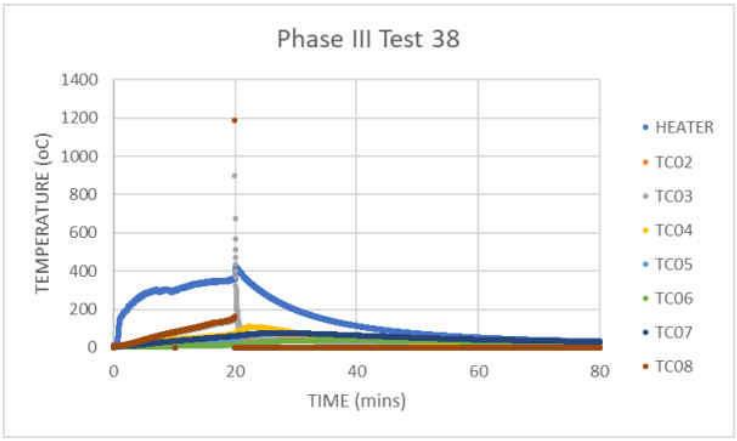
Thermocouple set-up is the same as Phase III 2nd set-up. This diagram illustrate the layout with additional cardboard separators

Observations:

Elapsed time	Observation
START	Test started with cartridge heater turned on @175°C
18 mins	Small pop
20 mins	Bang was heard
20 mins	heater source removed no flame observed

Test Results and Post-test Observations

- Cells used in this test are at 100% SOC. There were 8 live cells with 2mm carboard separators between the cells (refer to test layout) and sand to fill up the inside on the packaging.
- Heater control is dependent on the temperature rise of TC03 to try achieve a rate of increase at 6°C/min
- Therefore, heater is controlled accordingly at varying temperature setting to achieve a minimum 6°C/min rise at TC03
- Results show that the initiation cell entered thermal runaway (shown by TC03 results) at around 20 minutes into the test.
- After thermal runaway, the heater source is removed immediately, but the data logger continues to log for 1hr after this. This is to observe another other thermal runaway during the hour.
- Only initiation cell entered thermal runaway and no flame or smoke observed when TR occurred
- No visible damage to outer packaging


Phase III Test 38
TEMPERATURE (oC)
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
TIME (mins)
HEATER
TC02
TC03
TC04
TC05
TC06
TC07
TC08

Photos

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TEST ID38|