Custom Test Report

TIS Report: 80152896
Date: February 13, 2023

CLIENT: CellBlock FCS LLC
234 Northeast Road
Standish, ME 04084
USA

Attention: Dylan Vandemark [Click here and type customer title]

Issued by: Joshua Dinaburg

SUBJECT: CellBlock XL Cabinet Custom Testing

APPLICABLE REQUIREMENTS:

Custom Test: See Below

ASSESSMENT:
Testing was conducted to evaluate the ability of the CellBlock XL Cabinet to contain a thermal runaway event to a single level of a shelf. A custom test plan was developed to initiate thermal runaway in a single 18650 cell surrounded by other cells charged to 100% SOC (state-of-charge) on the middle shelf of the cabinet. Target cell packs were placed on shelves above and below the initiating level. Thermocouples were used to measure propagation of thermal runaway and peak temperatures on target cells and cabinet surfaces. The tests were conducted beneath the 1 MW calorimeter hood at the CSA Distributed Energy Resources Laboratory at 8801 East Pleasant Valley Road in Cleveland, OH. Two tests were conducted on January 19 and January 20, 2023 with the initiating and surrounding cells in unique geometric arrangements. Test data included visual observations, measurements of gas, smoke, and heat release, and temperatures throughout and on the exterior of the XL Cabinet.

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Summary of Results

The table below identify an overview for the outcome of testing.

Initiating Fire Source		
Energy Storage	300 18650 Lithium Ion Cells – 3.62 V and 3350 mAh 100 Cells per shelf in assembled packs of 25	
Heat Source	Thin film heater on a single cell	
	Test 1	**Test 2**
Arrangement	1.407 kWh per shelf Initiating cell pointed vertically at CellBlockEX shelf	1.407 kWh per shelf Two initiating cells surrounded by target cells oriented horizontally
Time to Thermal Runaway	22:51	13:21
Peak Cell Temperature (°C)	549	670
Peak Air Temperature above cell (°C)	76	434
Release of CellBlockEX Beads	22:52	14:21
Propagation of Thermal Runaway	None	~7 additional cells
Peak Temperatures of Targets		
	Test 1	**Test 2**
Adjacent Cells (°C)	247 (east of initiating cell)	843 (above initiating cells)
Adjacent Packs (°C)	104 (north of initiating pack)	886 (west of initiating pack)
Upper Shelf Target Cells (°C)	25	133
Lower Shelf Air Temperature (°C)	22	25
Exterior Surface (°C)	24	31
Offset from cabinet 11 inches (°C)	22	29

Sample Description

Testing was conducted using the CellBlock XL cabinet. The cabinet consists of three shelves each containing CellBlockEX glass granulates stored within thermally sealed chambers above the shelf. The cabinet measured 61.25 inch width by 35.37 inch depth and 65.53 inch height. The construction and assembly of the rack unit was not observed, and the test unit was provided directly by CellBlock for testing. The specifications of the CellBlockEX (e.g. granule size and composition) was also not provided. The CellBlock XL Cabinet is shown in Figure 1.

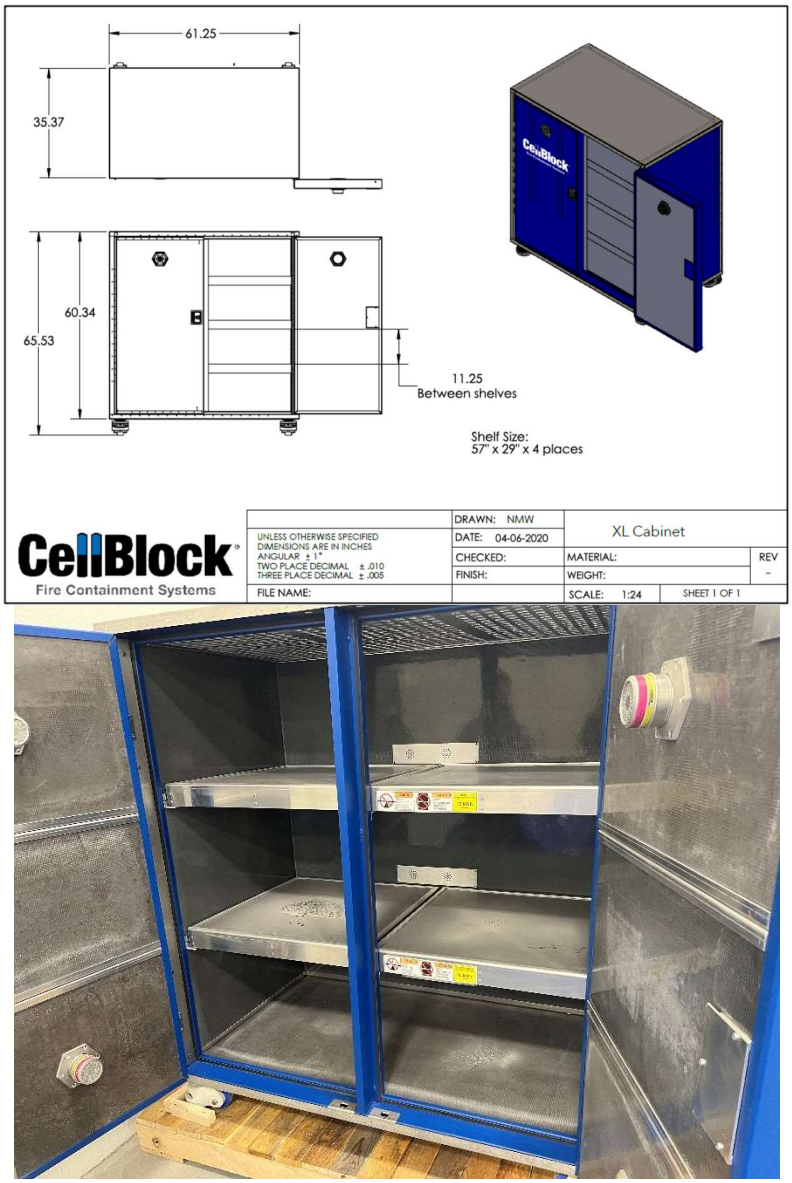


Figure 1 – CellBlock XL Cabinet

The test was conducted by initiating thermal runaway within an 18650 battery cell placed in a simulated pack of twenty-five (25) cells placed on the middle shelf level. The cells were 3.62 V, 3350 mAh rechargeable Lithium Ion 18650 cells. The cells were selected and provided to CSA by CellBlock. Each cell was charged prior to testing by CSA Group at a constant voltage of 4.2 V and constant current of 0.3C (975 mA) to a cutoff current of 50 mA. A total of 300 cells were charged and placed within the XL cabinet for both tests, with a total of 100 cells on each of the three shelves. Each shelf held a total energy of 1.407 kWh. Cells were assembled into simulated packs of 25 cells using modular plastic sleeves on the top of bottom of the cells. The center cell was heated to thermal runaway using a thin film heater with temperature control. A simulated pack of 25 cells (without the top sleeves) is shown in Figure 2.

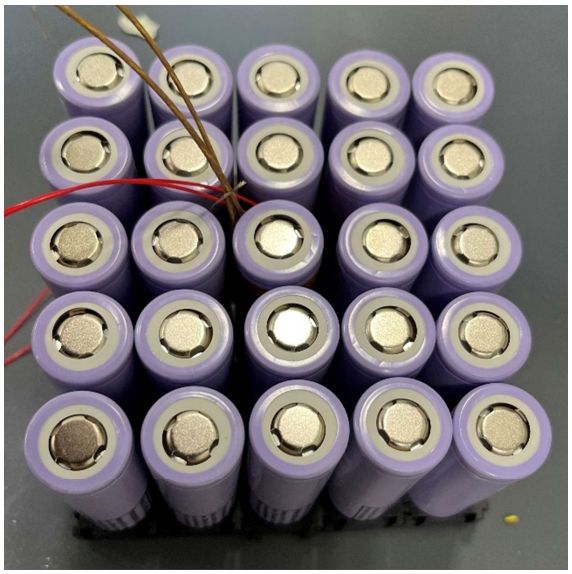


Figure 2 – Test cells and simulated cell packs

The center cell was heated in the initiating pack in Test 1. Thermocouples (type K, 30 gauge, fiber glass sheath) were placed on the four surrounding cells. One additional thermocouple was placed on a cell in the outside corner of the pack.
The initiating cell pack arrangement for Test 1 is shown in Figure 3 (Test 1) and Figure 4 (Test 2).

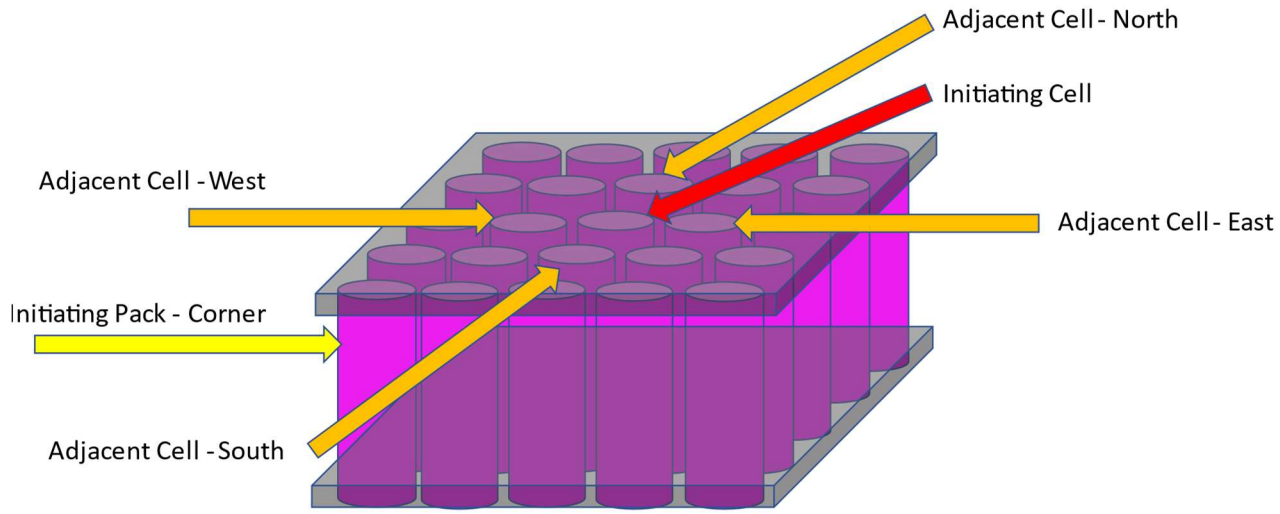


Figure 3 – Arrangement and placement of thermocouples in the initiating cell pack for Test 1

A second test was conducted with a different arrangement of cell packs on the initiating shelf. The initiating pack was turned horizontally, such that the cell vent was not directed at the CellBlockEX shelf. Two cells were heated in parallel using two thermocouples wired in parallel,

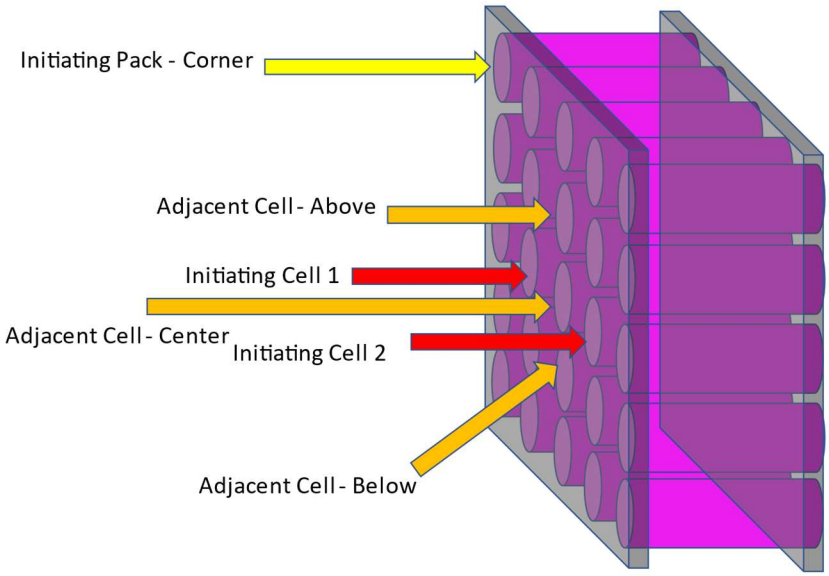


Figure 4 – Arrangement and placement of thermocouples in the initiating cell pack for Test 2

The first test was conducted to evaluate the potential for cell-to-cell propagation. The second arrangement was selected to increase the propensity for propagation and create a worse case thermal condition. In the first test, the cells were oriented vertically, and the packs were placed together in a square, with the initiating pack placed in the southeast quadrant (toward the cabinet door on the right side) as shown in Figure 5. In the second test, the cells were oriented horizontally, and target packs were placed to the west (left) and north (back of cabinet) and east (right) as shown in Figure 6. The air temperature was also measured directly above the initiating pack in both tests.

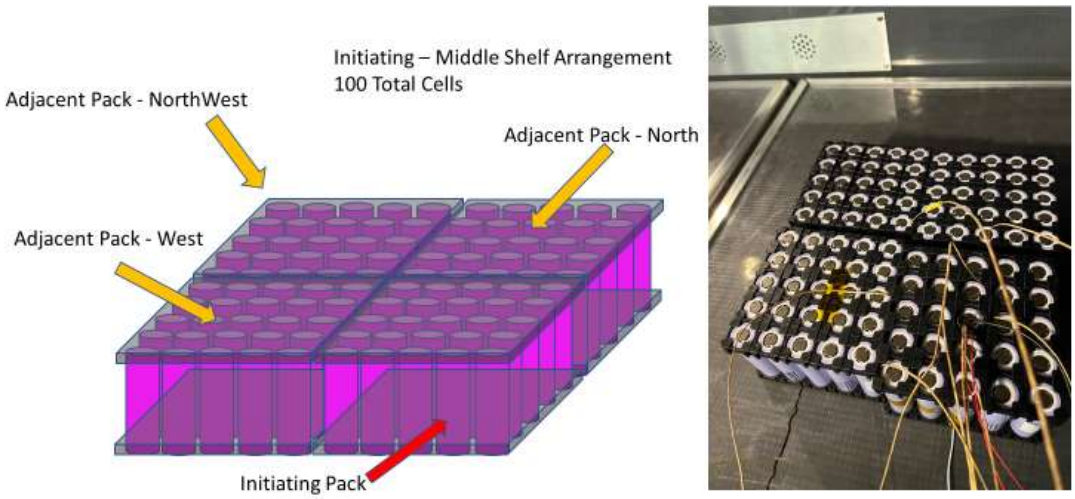


Figure 5 – Arrangement of the target packs used for Test 1

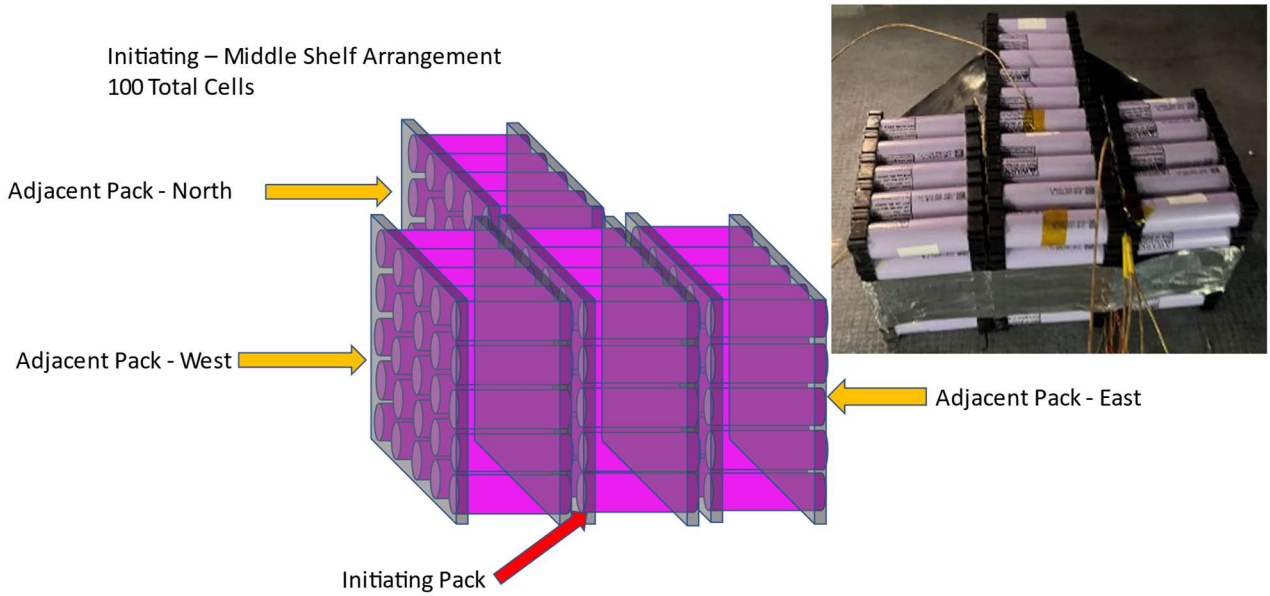


Figure 6 - Arrangement of the target packs used for Test 2

Four packs of cells were placed on the upper and lower shelves uniformly spaced in each of four quadrants as shown in Figure 7. A thermocouple was placed on a cell in each of the target packs on the upper shelf. In the lower shelf, only the air temperature in the center of the shelf was measured.

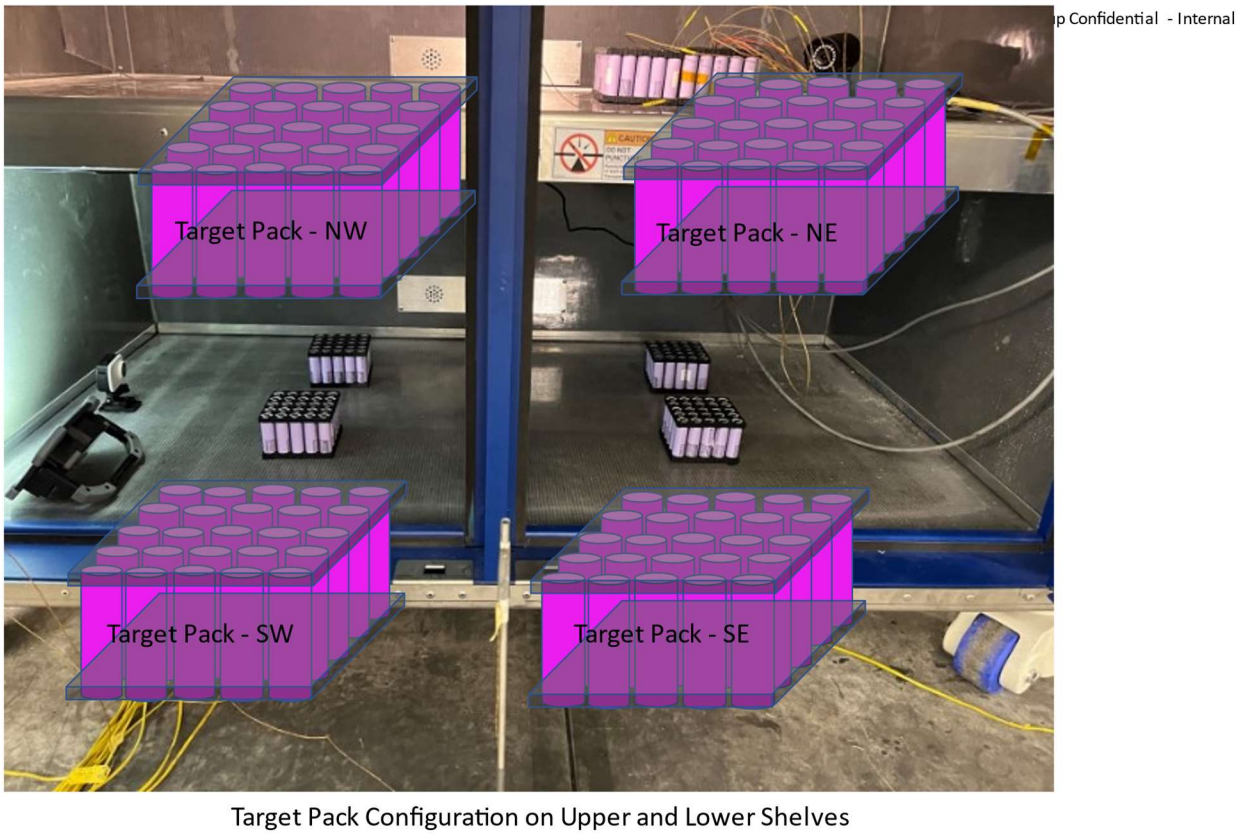


Figure 7 – Arrangement of target packs on the upper and lower shelves of the XL Cabinet

Instrumentation

The test setup included video of the exterior of the XL cabinet and a video of the interior of the cabinet focused on the initiating cell pack.

A total of twenty-four (24) 30 AWG, Type K, fiber glass sheathed welded thermocouples were placed on target cells and on the exterior of the XL Cabinet to monitor exposure temperatures. The thermocouples were recorded at a rate of 1 Hz. The thermocouple locations are summarized in Table 1.

Table 1 – Test thermocouple locations

Shelf/Height	Identifier	Location / Description
Middle	Initiating Cell	On the heater and the initiating cell (x2 one for control and one for monitoring)
Middle	Adjacent Cell – North	On a cell directly adjacent to the initiating cell toward the back of the cabinet
Middle	Adjacent Cell – South	On a cell directly adjacent to the initiating cell toward the front of the cabinet
Middle	Adjacent Cell – East (Test 1) Adjacent Cell – Above (Test 2)	On a cell directly adjacent to the initiating cell toward the right (Test 1) or directly above (Test 2)
Middle	Adjacent Cell – West (Test 1) Adjacent Cell – Below (Test 2)	On a cell directly adjacent to the initiating cell toward the left (Test 1) or directly below (Test 2)
Middle	Initiating Pack – Corner	On a cell on the exterior corner of the initiating pack
Middle	Adjacent Pack - West	On a cell in the center of the pack to the left of the initiating pack, placed on surface oriented toward initiating pack
Middle	Adjacent Pack - Northwest	On a cell in the corner of the pack to the back left of the initiating pack, placed on surface oriented toward initiating pack
Middle	Adjacent Pack - North	On a cell in the center of the pack behind the initiating pack, placed on surface oriented toward initiating pack
Middle	Initiating Shelf - Air Temp	Placed just below the CellBlockEX ejection vents at the top of the middle shelf
Top	Upper Shelf - NW Pack	On a cell in the center of the pack in the back left corner of the top shelf
Top	Upper Shelf - NE Pack	On a cell in the center of the pack in the back right corner of the top shelf
Top	Upper Shelf - SE Pack	On a cell in the center of the pack in the front right corner of the top shelf
Top	Upper Shelf - SW Pack	On a cell in the center of the pack in the front left corner of the top shelf
Bottom	Lower Shelf Air Temp	Placed just below the CellBlockEX ejection vents at the top of the middle shelf
Top	Exterior - Left Door Vent	Emitted gas temperature at the filtered gas vent on the left door of the cabinet
Top	Exterior - Right Door Vent	Emitted gas temperature at the filtered gas vent on the right door of the cabinet
Middle	Exterior - Door	Surface Temperature on the right face of the cabinet door, aligned at the height and position of the initiating cell
Middle	Exterior - Right Wall	Surface Temperature on the right face of the cabinet, aligned at the height and position of the initiating cell
Top	Exterior - Top	Surface Temperature on the top surface in the center of the cabinet
Bottom	Offset front	Air temperature 11 inches away from the center of the door gap, 12 inch height
Bottom	Offset back	Air temperature 11 inches away from the back center of the cabinet, 12 inch height

Several exterior temperature measurements were also recorded. Each door of the cabinet is provided with a filtered gas vent. A thermocouple was placed to measure the gas temperature from each of these vents. Exterior surface temperatures were also measured on the front cabinet door and right wall, aligned with the position of the initiating cell. The temperature at the center of top cabinet surface was also measured. Two remote thermocouples were also placed at a height of 1 ft and a distance of 11

inches at the center of the front (doors) and rear of the cabinet. The positioning of the exterior thermocouples on the CellBlock XL Cabinet are shown in Figure 8.

Figure 8 – Location of exterior thermocouples on CellBlock XL Cabinet

The test was conducted below a 10 x 10 x 8 ft high exhaust hood. The hood is instrumented with a thermocouples to measure the gas temperature and a bidirectional probe to measure the velocity of air flow. A broad-spectrum quartz tungsten white light source with a photopic photocell and a red 630 nm laser with silicon photodiode was used to measure the optical density of smoke in the exhaust. The concentrations of gases in the exhaust were also measured, including the total hydrocarbon (flame ionization detection), the oxygen concentration (paramagnetic analyzer), the carbon monoxide and carbon dioxide concentrations (non-dispersive infrared) and the hydrogen concentration (nickel-palladium). The rate and total amount of gas and smoke produced were measured along with the total chemical heat release rate through oxygen consumption calorimetry.

Thermal Runaway in Initiating Pack

Thermal runaway was initiated in the initiating pack by placing a thin film heater on a cell in the center of the initiating pack. The heater temperature was measured by a thermocouple and the heating rate was controlled by a PID temperature controller. The cell was heated until achieving thermal runaway, and then the external heater was removed. The cell in Test 1 was heated at an average rate of 5.94 °C per minute and reached thermal runaway in 22.93 minutes at a surface temperature of 206.2 °C. The cell in Test 2 was heated at an average of 7.32 °C per minute and achieved thermal runaway in 13.4 minutes at a temperature of 215.8 °C. The initiating cell heating ramps until thermal runaway are shown in Figure 9.

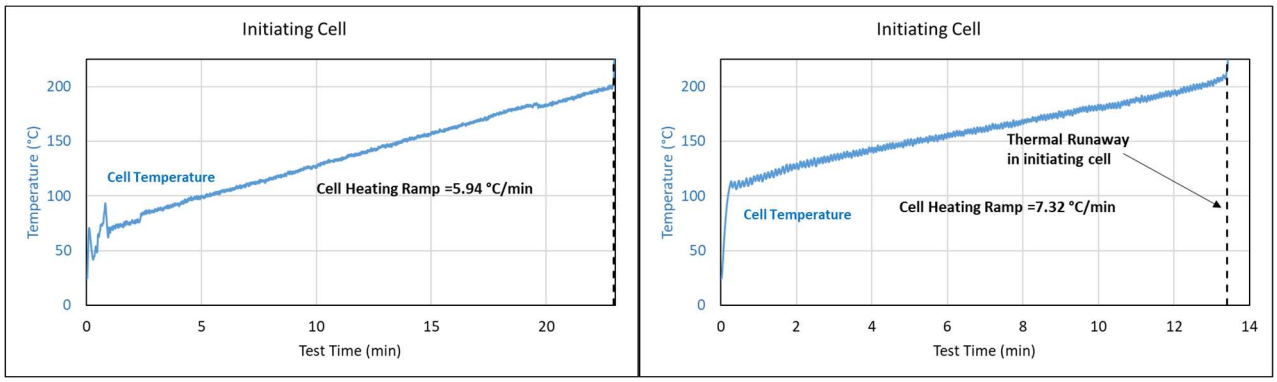


Figure 9 – Temperature ramp rate of initiating cell in Test 1 (left) and Test 2 (right)

Results

As intended, there was significantly more propagation of thermal runaway in Test 2 compared to Test 1 due to the horizontal orientation of cells. This is because there were cells directly above the initiating cell being subjected to significantly more heat. In Test 1, the initiating cell vented directly upward into the CellBlockEX shelf, and no cell-to-cell propagation was observed. In both tests, the CellBlockEX was released onto the cells in thermal runaway and there was no damage to cells on the upper and lower shelves. The peak temperatures, smoke, gas, and heat release rates measured in the two tests are summarized in Table 2.

Table 2 – Summary of data from two CellBlock XL Cabinet tests

Peak Temperatures (°C)				
Test 1			**Test 2**	
Initiating Cell	549		Initiating Cells x2	670/982
Adjacent Cell – North	78		Adjacent Cell – Above	CBD
Adjacent Cell – East	247		Adjacent Cell – Center	CBD
Adjacent Cell – South	98		Adjacent Cell – Below	843
Adjacent Cell – West	29			
Initiating Pack – Corner	157		Initiating Pack – Corner	342
Adjacent Pack – West	31		Adjacent Pack – Above	856
Adjacent Pack – Northwest	23		Adjacent Pack – West	886
Adjacent Pack – North	104		Adjacent Pack – North	451
Initiating Shelf – Air Temp	76		Initiating Shelf – Air Temp	434
Upper Shelf – NW Pack	24		Upper Shelf – NW Pack	57
Upper Shelf – NE Pack	25		Upper Shelf – NE Pack	77
Upper Shelf – SE Pack	24		Upper Shelf – SE Pack	54
Upper Shelf – SW Pack	23		Upper Shelf – SW Pack	133
Lower Shelf Air Temp	22		Lower Shelf Air Temp	25
Exterior – Left Door Vent	24		Exterior – Left Door Vent	29
Exterior – Right Door Vent	23		Exterior – Right Door Vent	31
Exterior – Door	23		Exterior – Door	25
Exterior – Right Wall	23		Exterior – Right Wall	22
Exterior – Top	22		Exterior – Top	21
1ft in front of cabinet	22		1ft in front of cabinet	29
1ft in rear of cabinet	22		1ft in rear of cabinet	27

Heat Release Rate - Calorimetry		
	Test 1	**Test 2**
Peak Heat Release Rate (kw)	Below Detectable Limits	23.6
Total Heat Release Rate (MW)	Below Detectable Limits	5.2

Gas Release		
	Test 1	**Test 2**
Peak Release of Hydrocarbon Gases (LPM)	0.1	5.7
Total Release of Hydrocarbon Gases (L)	0.8	19.9
Peak Release of Hydrogen Gas (LPM)	Below Detectable Limits	Below Detectable Limits
Total Release of Hydrogen Gas (L)	Below Detectable Limits	Below Detectable Limits
Peak Release of Carbon Monoxide (LPM)	0.3	21.5
Total Release of Carbon Monoxide (L)	1.4	67.4
Peak Release of Carbon Dioxide (LPM)	Below Detectable Limits	69.8
Total Release of Carbon Dioxide (L)	Below Detectable Limits	393.7
Total Flammable Gas Produced	2.3	87.4
Total Gas Produced	2.3	481.4

Smoke Release		
	Test 1	**Test 2**
White Light – Peak Smoke Release (m^2/s)	Below Detectable Limits	0.03
White Light – Total Smoke Release (m^2)	Below Detectable Limits	0.01
Laser – Peak Smoke Release (m^2/s)	Below Detectable Limits	0.22
Laser – Total Smoke Release (m^2)	Below Detectable Limits	30.99

CBD – Cannot be determined

Both fire tests caused he CellBlockEX granules to release within the initiating shelf and cover the initiating cells. Release of the CellBlockEX occurred within 1 second of thermal runaway in Test 1. The cell vent was directed straight up with no obstructions and the granules were released rapidly. No other cells entered thermal runaway and the test was over with no visible smoke in the cabinet in less than 20 minutes from the thermal runaway. A summary of observed test events is provided in Table 3. Images of selected test events are shown in Figure 10.

Table 3 – Test 1 Observations

Time	Test Time (HH:MM:SS)	Description
4:52:22 PM	00:00:00.0	Start of Heating
5:15:07 PM	00:22:45.0	First visible smoke
5:15:14 PM	00:22:51.9	Thermal runaway in initiating cell Release of CellBlockEX
5:15:15 PM	00:22:53.4	Release of CellBlockEX
5:15:20 PM	00:22:57.6	End of runaway, residual smoking
5:33:46 PM	00:41:24.0	End of visible smoke in cabinet

Figure 10 – Select video images from Test 1

First visible smoke – 22:46 after heating

Thermal runaway in initiating cell – 22:51 after heating

	
Release of CellBlockEX 00:01 after thermal runaway	Visible sparking from thermal runaway – 22:53 after heating
	
Residual smoking only after thermal runaway of primary cell – 00:05 after thermal runaway	No residual smoke in cabinet – 18:26 after thermal runaway

The geometry and heating of two cells in Test 2 resulted in far greater propagation of the fire event. The venting of the initiating cell was oriented away from the CellBlockEx shelf and was obstructed by other cells. Some visible CellBlockEX was released on the opposite side of the packs away from the camera view after the third thermal runaway event, approximately 2 minutes after the initial runaway.

A total of 5 thermal runaway events were observed until the internal camera view was lost about 3.5 minutes after the first runaway event. Over the next 4 minutes, smoke was visibly released from the top of the cabinet and at least three thermal runaway events were observed through visible sparks in the door frame. No more smoke was visible 11 minutes after the first thermal runaway event. When the cabinet was opened, CellBlockEX granules had been released, but a time of release could not be determined. A summary of observed test events is provided in Table 4. Images of selected test events are shown in Table 4.

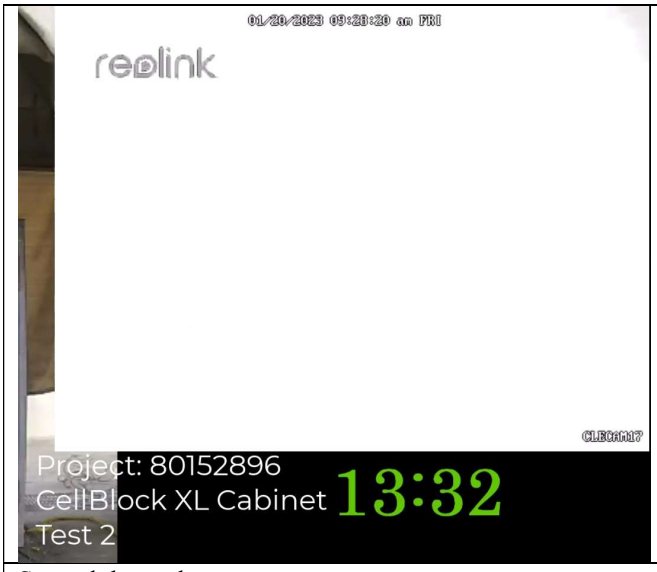
Table 4 – Test 2 Observations

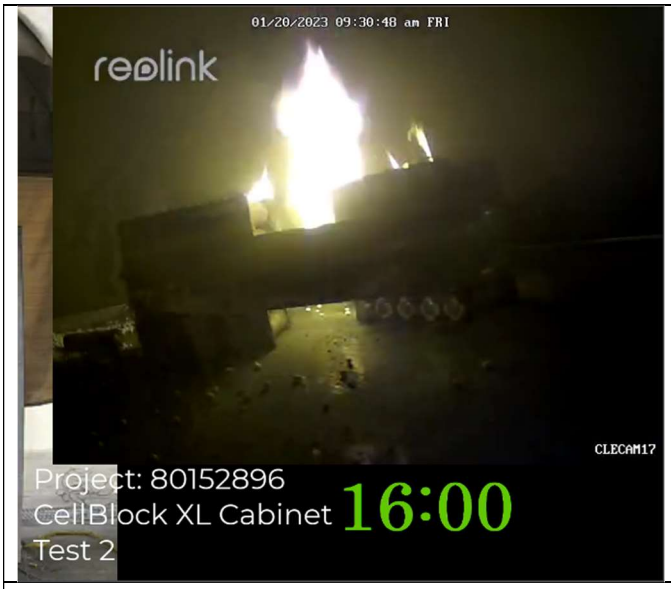
Time	Test Time (HH:MM:SS)	Description
9:14:48 AM	00:00:00.0	Start of Heating
9:28:09 AM	00:13:21.0	Thermal Runaway of Initiating Cell - packs pushed apart
9:28:17 AM	00:13:28.8	Flaming of cell
9:28:20 AM	00:13:31.8	Second runaway event – 2nd initiating cell
9:29:06 AM	00:14:18.0	Third runaway event
9:29:09 AM	00:14:21.0	First visible CellBlockEX released around packs
9:30:18 AM	00:15:30.0	Visible black smoke escaping top of cabinet
9:30:53 AM	00:16:05.4	Fourth runaway event
9:31:44 AM	00:16:55.8	Fifth runaway
9:31:44 AM	00:16:56.4	Loss of internal camera
9:33:53 AM	00:19:05.4	Visible sparking inside door gap
9:34:44 AM	00:19:55.8	Visible sparking inside door gap
9:35:03 AM	00:20:15.0	Visible sparking inside door gap
9:39:29 AM	00:24:41.4	End of visible smoking - end of test

Figure 11 – Select video images from Test 2

Initial thermal runaway

Small visible flame in gap between packs -

	
Second thermal runaway event	Flame growth after initial after thermal runaway events
	
Third thermal runaway event	First visible CellBlockEX released away from camera side of packs

	
Flame growth continues	Additional thermal runaway event
	
Additional thermal runaway event	Additional thermal runaway event

The CellBlockEX granules were only released in the initiating shelves, with some spill onto the shelf below after the door was opened. The post-test condition of the interior of the cabinet during both tests are shown in Figure 12.

Figure 12 – Post-test interior of the cabinet after Test 1 (left) and Test 2 (right)

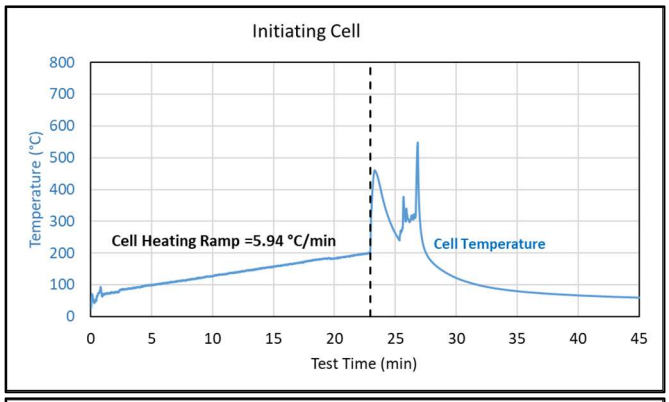
In Test 1, only the initiating cell entered thermal runaway and only minimal thermal damage (melting of wrappers) were observed on adjacent cells. In Test 2, many of the cells in the initiating pack entered thermal runaway and there was significant thermal damage and soot exposure to adjacent packs. The post-test condition of cell packs are shown in Figure 13.

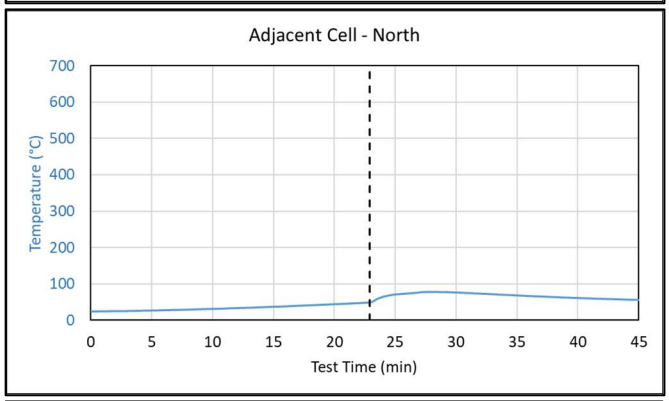
Figure 13 – Post-test condition of the initiating pack in Test 1 (left) and Test 2 (bottom right)

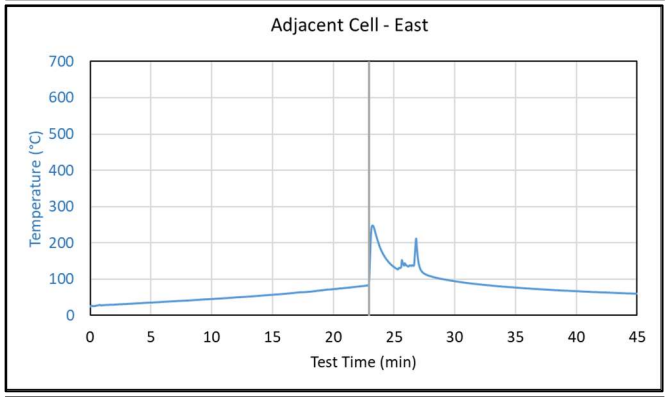
Temperature measurements throughout the XL Cabinet and on cells are shown in Table 5.

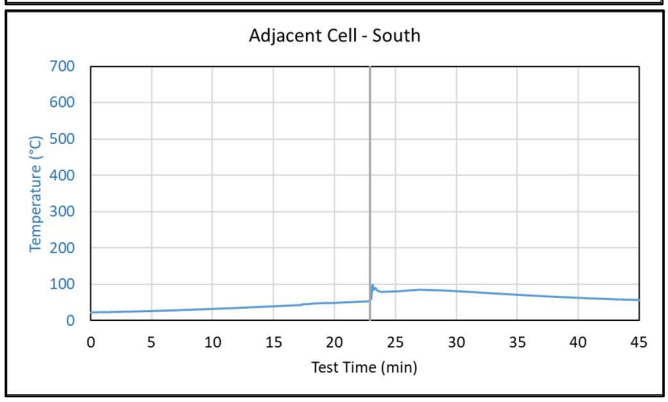
Table 5 – Temperatures in the initiating packs in Test 1 and Test 2

Test 1

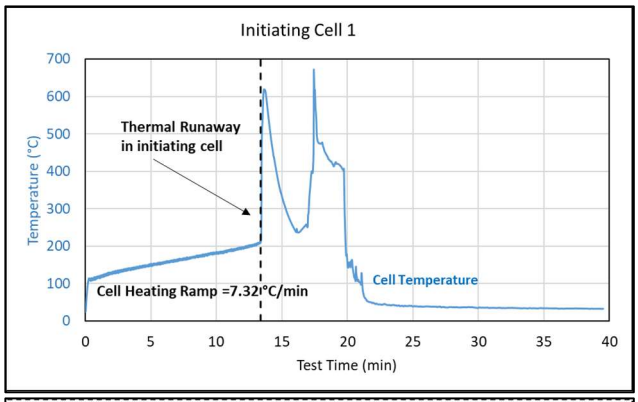


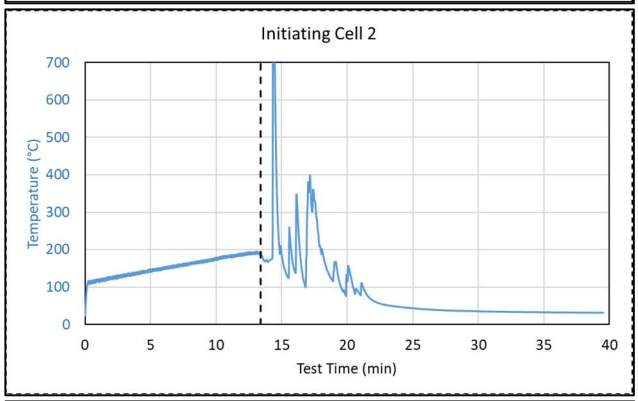


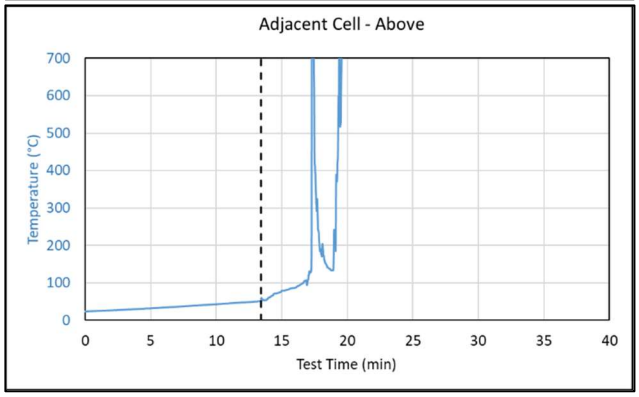


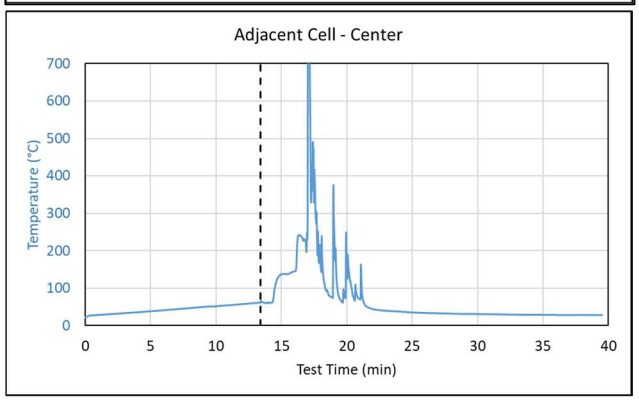


Test 2

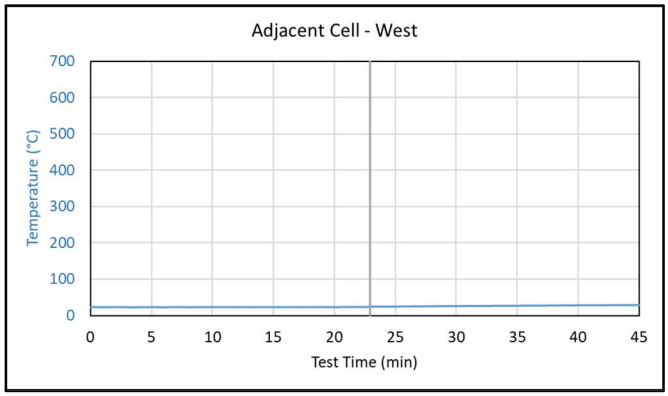


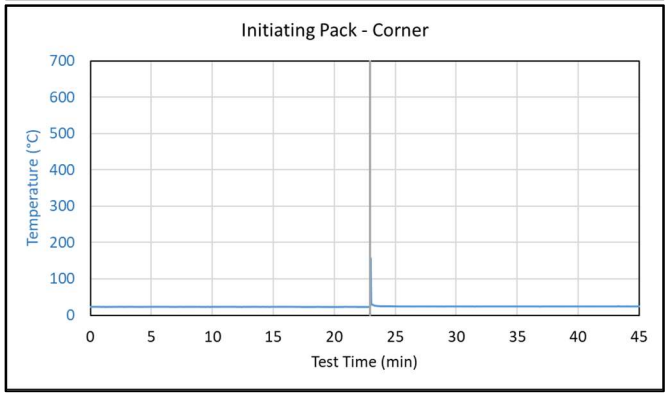




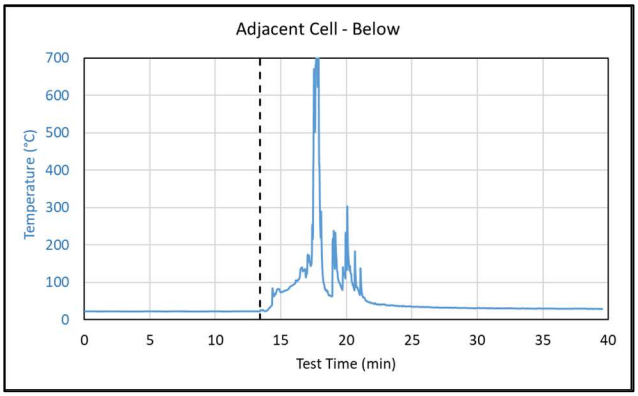


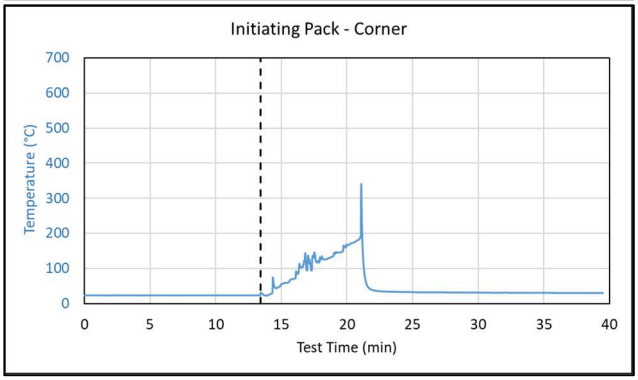
Test 1





Test 2

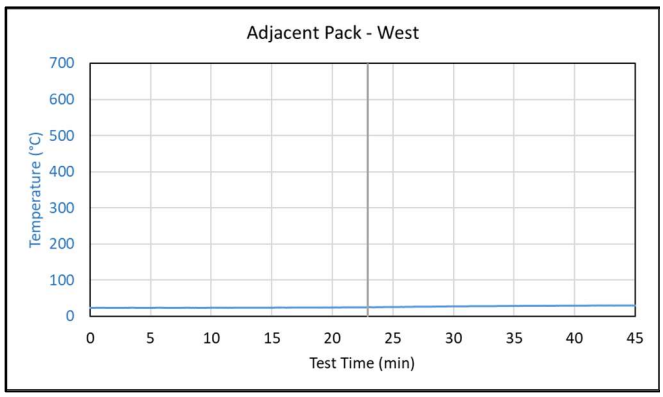




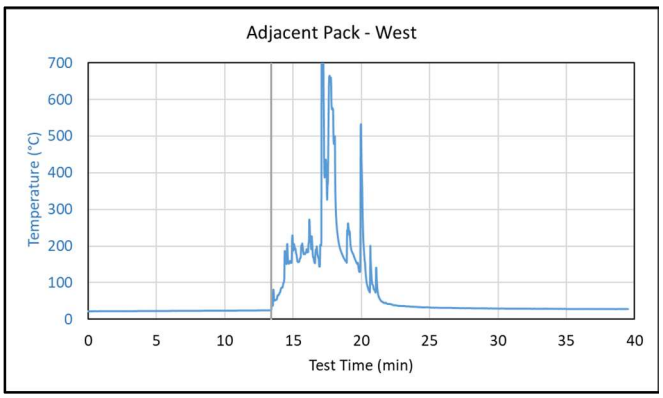
Temperatures in the target cells and packs within the initiating shelf, and the air temperature in the initiating shelf is shown for both Test 1 and Test 2 in Table 6.

Table 6 – Temperatures in target cell packs in Test 1 and Test 2

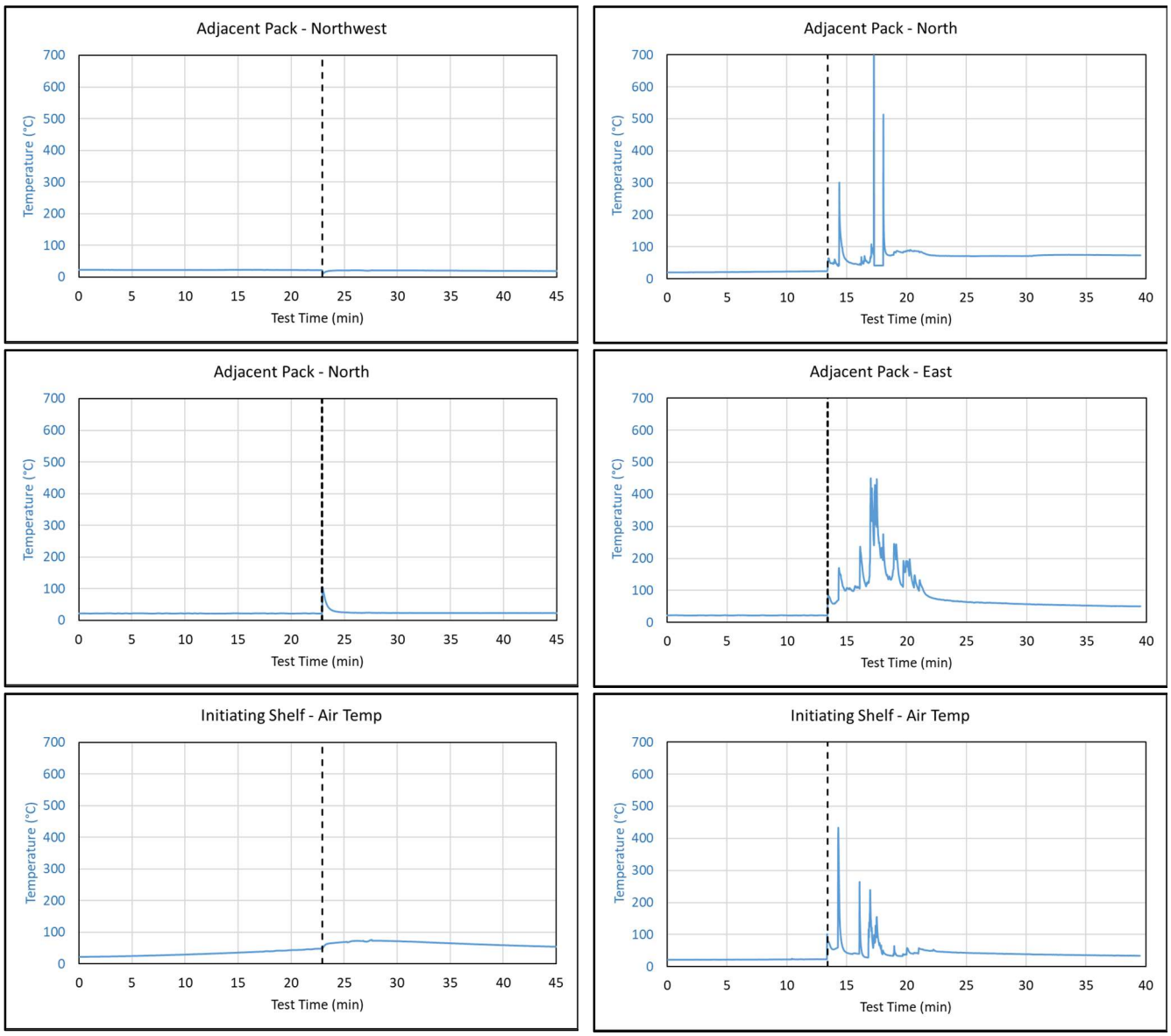
Test 1



Test 2

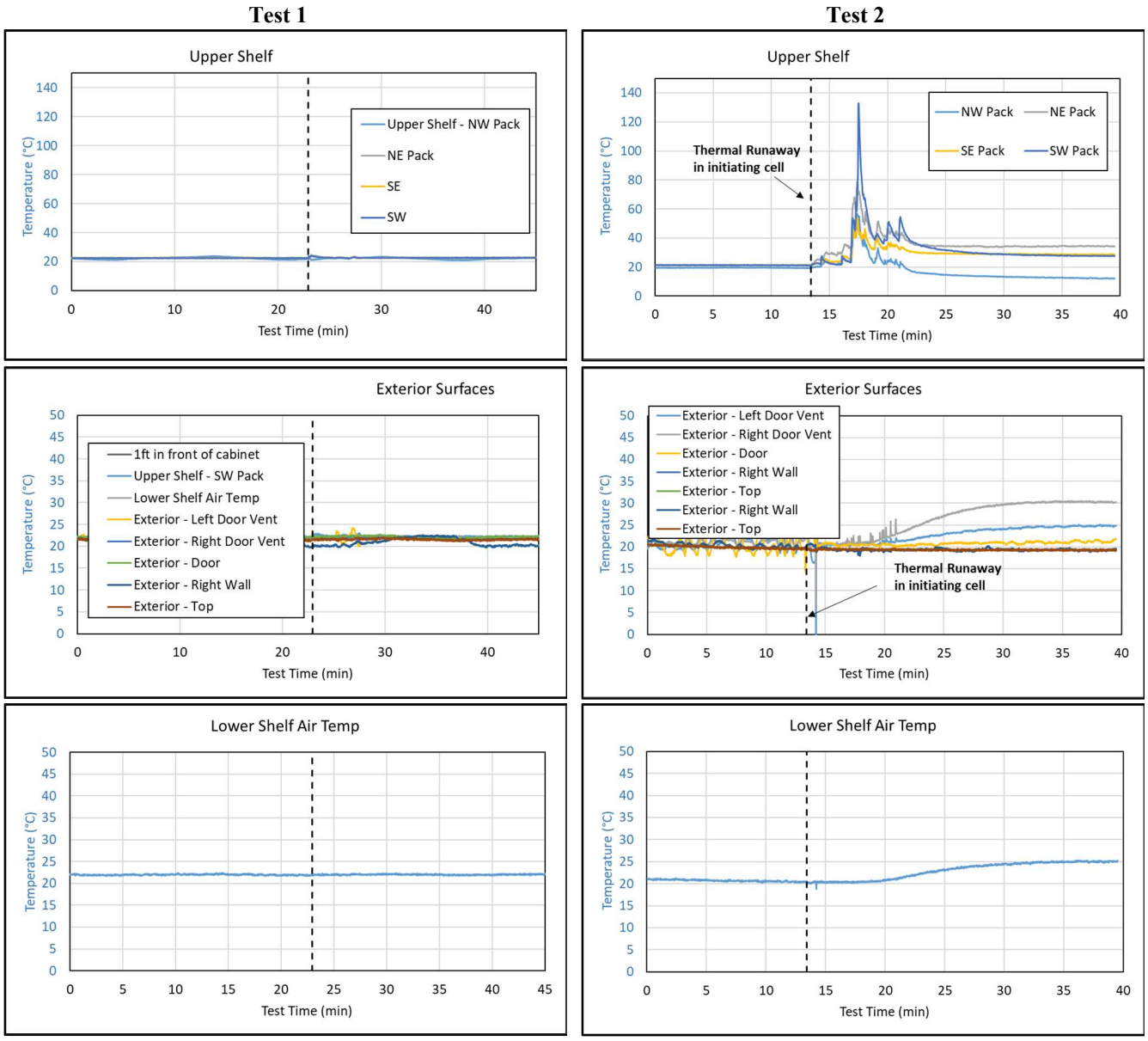


Test 1 **Test 2**



Temperatures measured in the remote sections of the cabinet, on the upper and lower shelves and on the exterior are shown in Table 7.

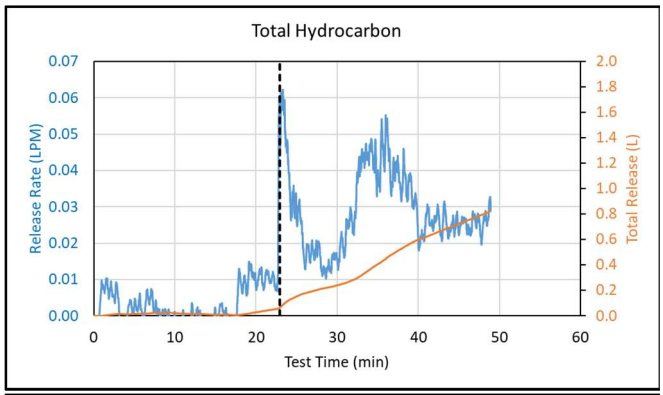
Table 7 – Temperatures measured away from the initiating shelf

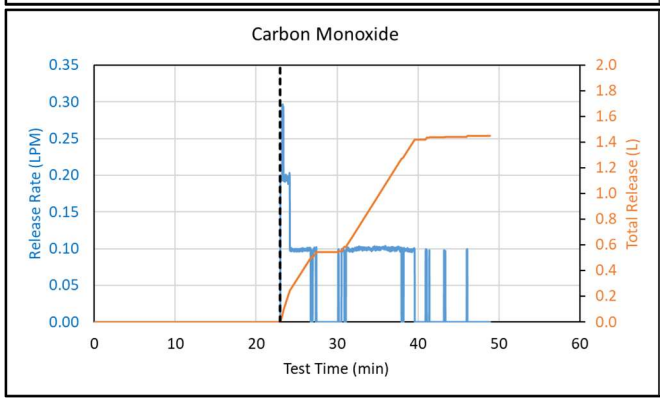


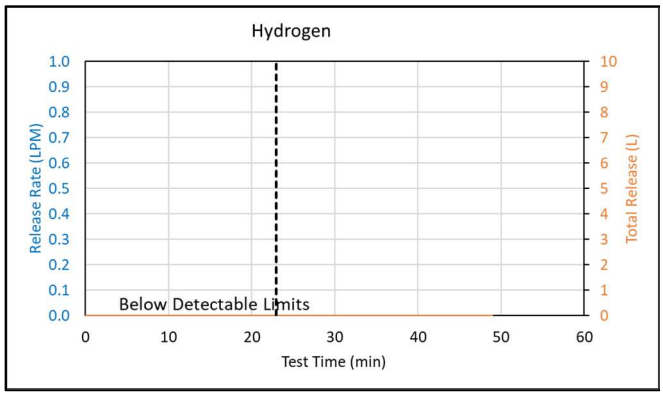
The total measured release of gas, smoke, and heat during Test 1 and Test 2 are provided in Table 8.

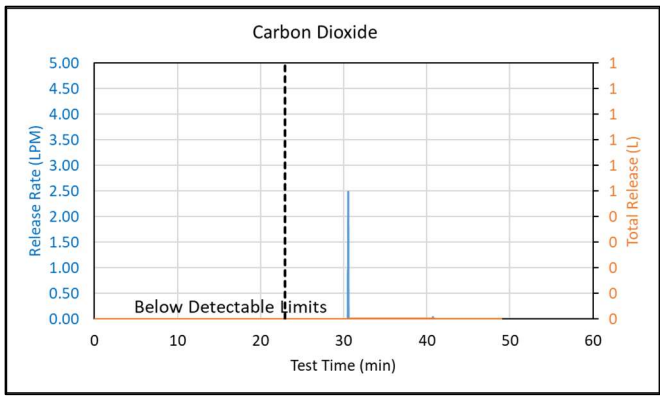
Table 8 – Gas and smoke measurements in Test 1 and Test 2

Test 1

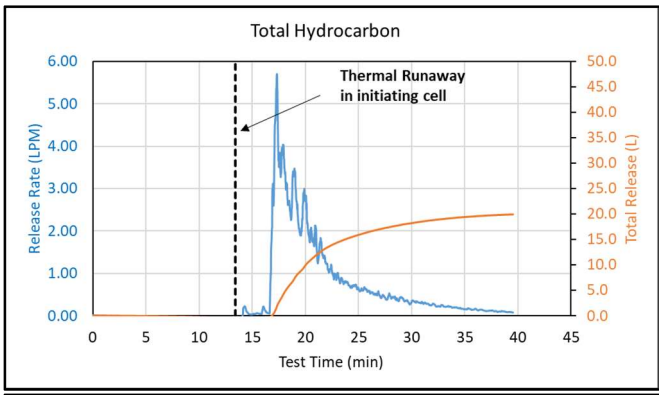


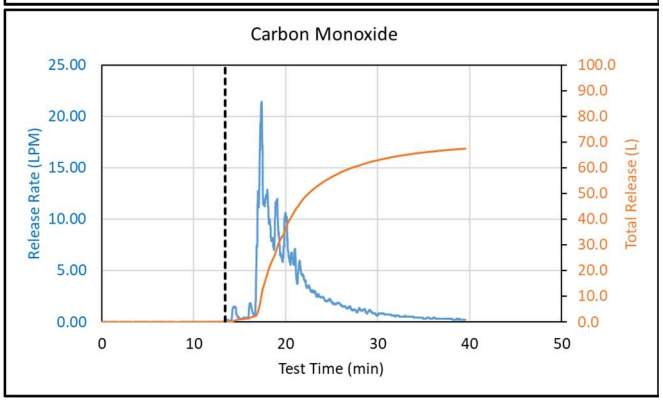


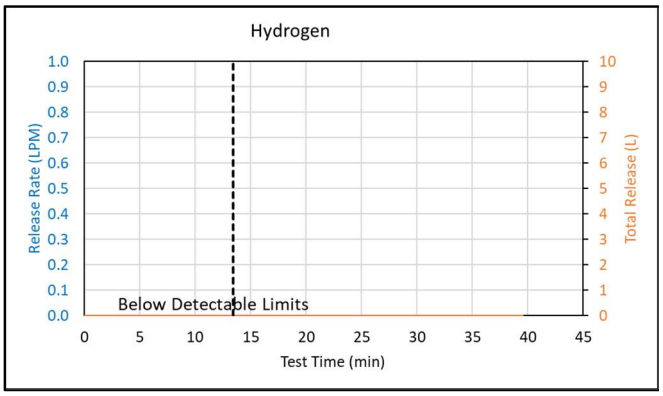




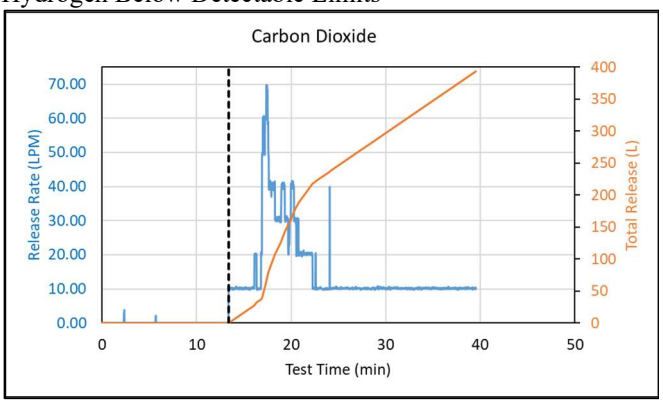
Test 2

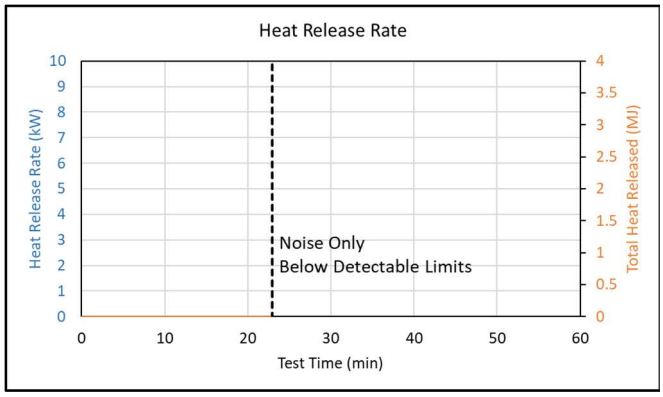


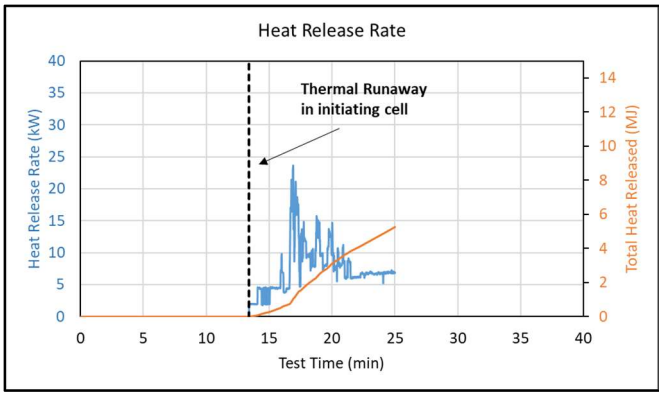




Hydrogen Below Detectable Limits







No observable damage was seen in any cells on the upper or lower shelves in either Test 1 or Test 2, and no CellBlockEX was released from the shelves at those levels.

Conclusion

A thermal runaway event was initiated on one level of the CellBlock XL cabinet in an 18650 lithium-ion cell (two cells in Test 2). Each shelf contained a total of 1.407 kWh of energy (100 cells) in different arrangements between the two tests. Test 2 created a far more severe thermal propagation event due to heating of two cells and placement of cells directly above the initiating cells. In both tests CellBlockEX granules were released from the tray above the thermal runaway event. In Test 1, there was no propagation of thermal runaway and after the test the entire initiating cell packs were covered with CellBlockEx granules. In Test 2, thermal runaway was propagated to several cells within the initiating pack and severe thermal damage was observed on cells throughout the shelf. There was a large amount of CellBlockEX granules released and not all cells on the initiating shelf entered thermal runaway.

Fully charged target batteries were placed on the shelves above and below the initiating cell. No damage was observed to occur to any cells on these levels during testing.

---End of Report---