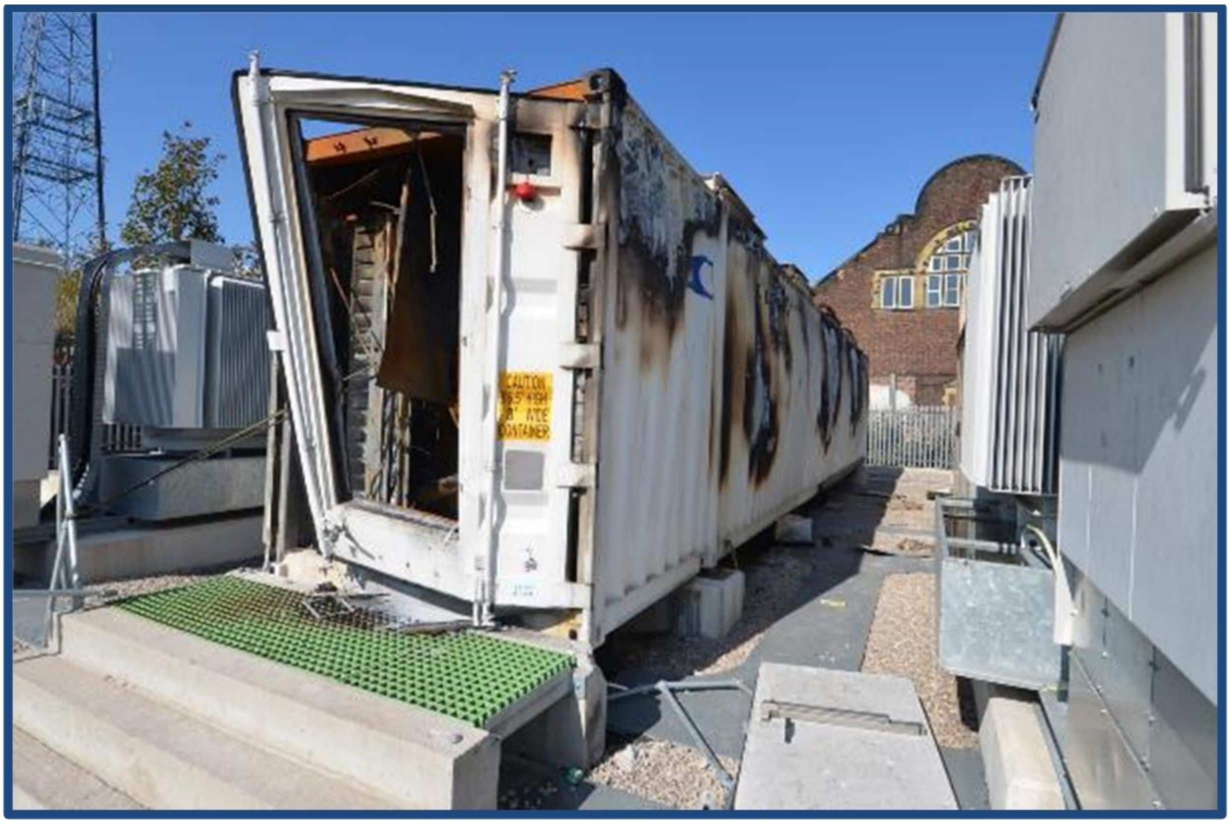
MERSEYSIDE FIRE & RESCUE SERVICE

Incident Investigation Team

Community Prevention Dept.

Community Risk Management



Fire Investigation Report 132-20

Incident Number 018965

Ørsted BESS,

Carnegie Rd,

Liverpool,

L13 7HY

Compiled by Station Manager [redacted]

Incident Investigation Team, Merseyside Fire and Rescue Service

Contents

MERSEYSIDE FIRE & RESCUE SERVICE

INCIDENT INVESTIGATION TEAM

PREMISES:	Ørsted BESS, Carnegie Rd, Liverpool, L13 7HY
INCIDENT NUMBER	018965
DATE:	15th September 2020
TIME OF CALL:	00:49 hrs.
METHOD OF CALL:	999
TYPE OF PROPERTY:	Battery energy storage site BESS
AUTOMATIC FIRE DETECTION:	Yes
BUILDING OWNER:	Ørsted Energy
NUMBER OF FIRE APPLIANCES:	5 Fire Appliances, 1 High Volume Pump
INITIAL INCIDENT COMMANDER:	Watch Manager [redacted]
INCIDENT COMMANDER:	Group Manager [redacted]
HMEPO:	Station Manager [redacted]
FIRE INVESTIGATION OFFICER:	Station Manager [redacted]

1 SUMMARY

1.1 At 00:49hrs on 15th September 2020, calls were received by Merseyside Fire and Rescue (MFRS) Fire Control reporting an explosion with smoke and flames visible from the Fisheries, Lister Drive, Old Swan, near to Carnegie Rd. Two appliances, Old Swan [redacted] and Liverpool City [redacted] responded to the incident. They arrived within 5 minutes of the first call at a secure, double gated site, that had four 12m long shipping containers within the inner compound; one of these was alight and had signs of an explosion. Parts of this container were blown across the compound the furthest of which had travelled 23m.

1.2 The explosion was a result of a failure within Battery Zone 3-Rack 7 Module 6 (BZ3-R7M6) which led to a thermal runaway, which, in turn produced gases within the container culminating in a deflagration.

1.3 After reviewing all available evidence and the report provided by [redacted] following his review of the CT scans which were taken of the cells recovered from both the effected container and a neighbouring container, I have been unable to identify the root cause of the failure within module 6. There is evidence on the exemplar cells from the neighbouring container demonstrating that a gas build-up had occurred leading to some internal distortion within some of the cells.

2 PURPOSE OF REPORT

2.1 This report consists of 57 pages and outlines the details of the fire that occurred at Ørsted Battery Energy Storage Site (BESS), Carnegie Rd, and to identify the cause, origin of the fire and the subsequent fire spread. As such, I examined the scene of the fire to determine the area of origin and the most likely cause.

3 INVESTIGATION METHODOLOGY

3.1 *‘**The Systematic Approach**: The systematic approach is based on the scientific method. This method provides an organisational and analytical process that is desirable and necessary in a successful fire investigation´*

3.2 This investigation was based around the ‘scientific method' which is outlined below:[1]

- Recognise the need
- Define the problem
- Collect data
- Analyse the data
- Development of a hypothesis
- Test of the hypothesis
- Select final conclusion

3.3 To interpret and examine the scans taken of the cells, Merseyside Fire Service entered in to a consultancy agreement with [redacted] from [redacted] to undertake the analysis of the images. His findings have been used when forming my conclusion.

3.4 Ørsted has been cooperating closely with the MFRS both before the incident and during in the fire investigation. This has been done, from both sides, not only to carefully identify the source of the fire, but also to assist the MFRS in expanding its knowledge of batteries and further improve the fire safety standards for the whole industry. Ørsted is currently working on the rebuild of the site to the highest available safety standards, and, has and will continue to involve MFRS in the protocols and procedures to be in place before the asset is made operational again.

[1] 2020. *NFPA 921*. [S.l.]: NFPA, pp.921-20.

4 DESCRIPTION OF PROPERTY

4.1 Ørsted BESS, Carnegie Rd, Old Swan is a secure compound and is classed as a Battery Energy Storage Site which is used to balance the national grid load in times of high demand. This site, and others like it, are designed to store energy for longer durations to shift peaks of supply to match demand. The site is located next to a high voltage electrical substation.

Image 1 is a Google map of the site before the BESS was in place [2]

4.2 A company called "Ørsted" remotely manage the site, and were able to alert a key-holder that there had been an activation of the fire alarm system. The fire alarm system includes an internal and external strobe and sounder system.

The fire detection and suppression system alarms are linked to the NEC AEROS control software and the operational and maintenance interface report system alarms. This includes, related warning and alarms to site operators and NEC. *The AEROS control system measures module temperature and records the min/max of a rack. The thermistors are located in the centre of the cells, any heat radiating from a failing cell will have to pass up to six other cells before the temperature is recorded.*

4.3 The container affected by fire was at the end of the row, it exhibited clear signs of pressure building-up and deflagration. This was evident by the expansion and distortion of the sides and top of the container.

---

[2] BESS Site in photograph *Google Maps, 2021*

Image 2 shows the damaged container with signs of expansion/distortion that is equal across the container and not localised to the area of the initial failure.

4.4 The containers have four heating, ventilation, and air conditioning units (HVACs) fitted to the roof that maintain the internal temperature between 20^0 and 35^0 C and automatically activate when a reduction in temperature is required.

4.5 Each of the three containers had two smoke detectors fitted which cross zones with linear heat sensors (LHS) that melt at 88^0C. The system is remotely monitored in Denmark but the suppression system (which the sensors are connected to) is not set-up to be activated remotely.

4.6 All three containers are fitted with a NOVEC 1230 fire suppression system. The system contains 3.164kg of Halocarbon media that has a discharge time of 10 seconds. The media is contained in a vessel at the end of each container, it has pipe work running along the upper parts of the container terminating at discharge nozzle(s) and is triggered by the smoke detection and linear cable activating it, or a manual break glass located beneath the fire alarm panel.

5 INCIDENT BACKGROUND

5.1 Merseyside Fire and Rescue Service (MFRS) were alerted by multiple calls of an explosion and smoke in the area near the Fisheries. The first call was received on Tuesday 15th September 2020 at 00:49 hrs.

5.2 On arrival, the crews arrived to find a container on fire within the site. The site has a secure compound that is spilt in two and was secured by locked gates. This area contains a rest facility for engineers and also gives access via another gate to the containers. The first container is the control unit followed by three BESS containers. There are also two empty concrete pads where two more BESS could be placed. Next to each BESS is a high voltage switch Ring Main Unit (RMU) (yellow arrow on the photograph), Transformer 33kV – 415V (red arrow on the photograph) and a cooler inverter (blue arrow on the photograph). On the top of the BESS containers are four HVAC systems.

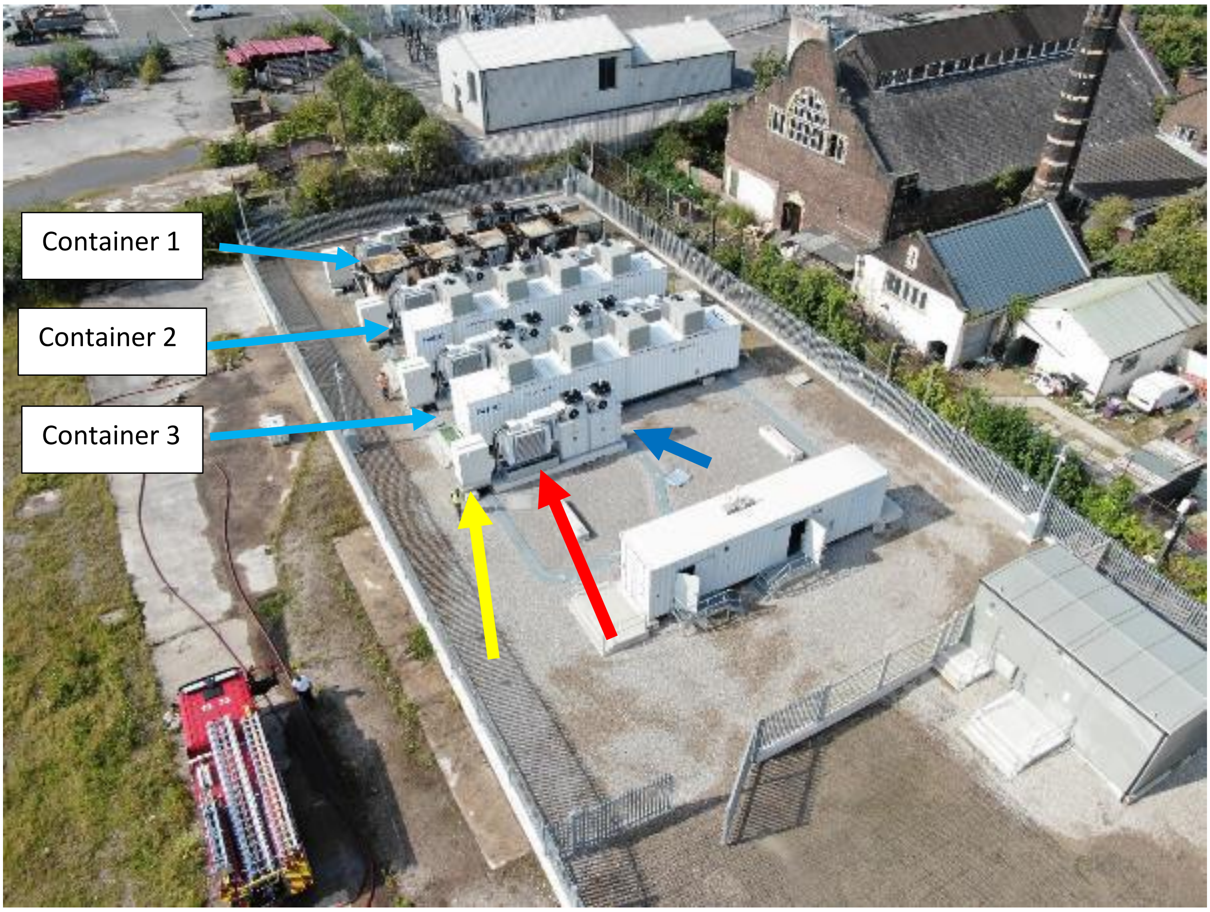


Image 3 shows the inner compound layout

5.3 The following time line includes partial data supplied by the responsible person and information collated as a part of my investigation. The data showed (S10 and S22 are specific NEC fault codes):

- *At 00:29:02 hrs event/fault with the rack temperature mismatch >10^0c S10, rack temperature spread out of range S22, module temperature above the maximum safe level S11 BZ3-Rack 7 Module 6*
- *A temperature rise of 40^0C in less than 2 minutes was recorded indicating a rapid independent excursion.*
- *00:29:36 Alarm for BZ3R7M6 temp above 45c max safe level*
- *00:31 hrs - Fire System Warning Zones 1-5 container 1 (Note: There is no discharge alarm). NEC received urgent alerts.*
- *00:31:02 hrs Smoke alarm went off. All communication to the rack has now stopped as the rack powered off.*
- *00:39 hrs - explosion occurs (Taken from CCTV provided by the responsible person RP)*
- *00:41 hrs - Fire system warning cleared - Ørsted control room in Denmark which monitors the site 24/7 event data shows that the user who cleared them was "kyv_adm/operator"*
- *00:49 hrs - Call received by MFRS from the public*
- *01:02 hrs - Call from Ørsted to NEC emergency line stating "Fire in control room alarm" and that emergency responders were called. This could have been a misinterpretation of location as this was a verbal conversation.*
- *01:18 hrs - Fire System Warning Zones 6-10 container 2 (no discharge alarm received regarding the Novec system)*
- *01:26 hrs (Call to Merseyside's Fire control was received from Denmark whilst crews were in attendance.)*
- *01:50 hrs -* [redacted] *(NEC USA) contacts Operations desk and customer offering support.*
- *01:53 hrs - Operations desk confirms site is on fire via email to* [redacted] *and fire department is on site*
- *02:19 hrs - Entire Site goes offline*
- *02:35 hrs - Ørsted confirms Scottish Power opened breaker and National Grid was informed. Fire "seems under control" per CCTV.*
- *03:47 hrs - Notified by operations desk (Ørsted to NEC) that the "fire in the container should be out now"*

5.4 The weather records in the local area from 00:00 hrs until 01:20 hrs, shows the wind blowing East to South East and a wind speed of around 5mph with a temperature of around 16^{O}C.[3]

Time	Temp	Dew Point	Humidity	Wind	Wind Speed	Wind Gust	Pressure	Precip.	Condition
12:20 AM	17C	13C	82 %	ESE	5 mph	0 mph	30.00 in	0.0 in	Fair
12:50 AM	16C	12C	82 %	ESE	5 mph	0 mph	30.00 in	0.0 in	Fair
1:20 AM	16C	12C	82 %	ENE	5 mph	0 mph	30.00 in	0.0 in	Fair

Image 4 weather records

5.5 The temperatures within the containers prior to the system being shut down by the smoke detection system (container 1 and 2) and the site being shut down (container 3) shows that container 2 was below 25^{0}C and container 3 was below 27^{0}C.

5.6 The site was at ~86.9% state of charge and was discharging around 1.9mW. The site specification for maximum power is 20MW. The specified state of charge percentage operating range is 0 – 100%. Each rack has a power rating of +/- 224kW.

The aggregated energy throughput for the 48 hrs prior to the incident was:

- Net Energy Throughput (kWh) -21.1950362
- Discharge Energy (kWh) 332.0728309
- Charge Energy (kWh) -353.2678671

5.7 At the time of the incident the site had 3 racks off line, BZ8-R4, BZ9-R1 (Container 2) BZ12-R1 (Container 3).

[3] Weatherdata:https://www.wunderground.com/history/daily/EGGP/date/2020-9-15 [Accessed 12 Oct. 2020]

6 FIRE INVESTIGATION / FINDINGS

6.1 I initially attended the incident scene at 10:17hrs, where I received a briefing from the Officer In Charge (OIC) before photographing the scene and making some initial notes. The firefighting plan was to cool and monitor the fire as smoke was being produced when water from firefighting hoses was turned off. The unknown state of the power supplies in the damaged container prevented an internal scene examination being carried out due to the possibility of stranded energy at this time. I documented the scene and gathered information from relevant personnel.

6.2 A number of photographs were taken by the initial officers that attended during the firefighting phase.

6.3 The responsible person for Cobalt Energy (acting for Ørsted Energy to provide technical advice) attended and explained how the site operated. He provided me with contact details for the management team in America and Denmark. A responsible person for NEC Energy Solutions was also in attendance.

6.4 He informed me that the event occurred in a purpose fitted ISO container which is used to stabilise the National Grid; for example, absorbing energy when there is less demand and feeding the National Grid when demand is high.

6.5 The affected container holds 5 Battery Zones, 9 racks per zone and 17 modules which is an assembly containing lithium ion cells. (Image 5)

6.6 Racks line both sides of the container and each rack has a vented doors. (Image 6 & 9)

Image 5 is an example of how the containers are set up [4]

[4] NEC Energy Solutions, Inc, supplied to MFRS 3rd February 2022.

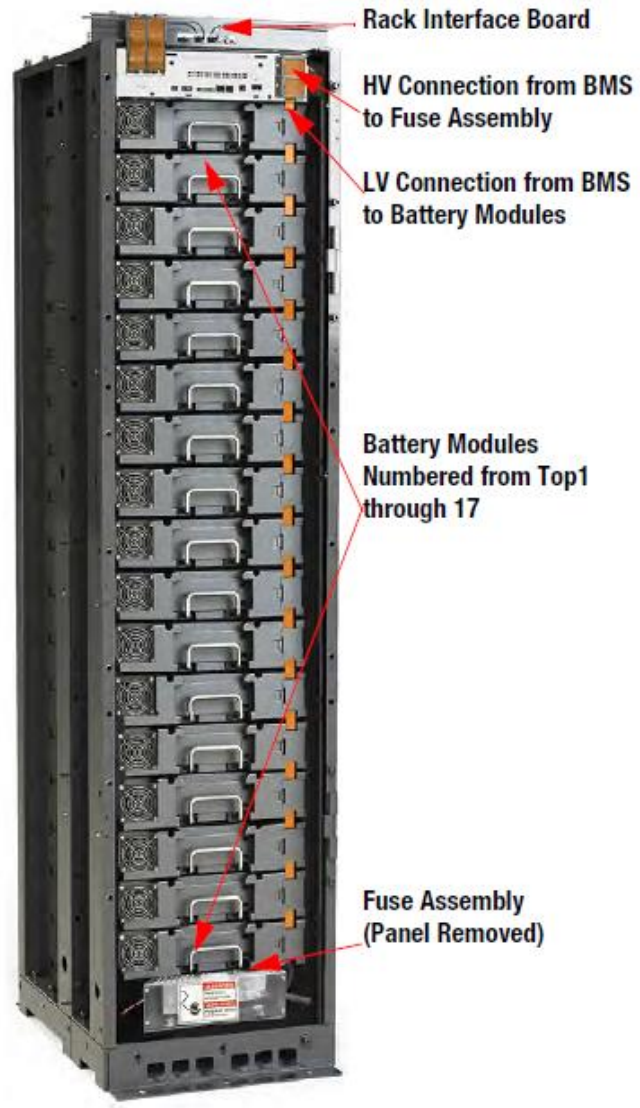


Image 6 shows the arrangement of racks in the container which have rusted since the fire indicating they are made from a carbon steel. Fans are fitted to the racks to blow cold air that is produced by the HVAC through each module. [5]

[5] NEC Energy Solutions, Inc, supplied to MFRS 3rd February 2022.

Image 7 is an example of the Control System Monitors at the Module, Rack, Zone, Powerblock and System Levels[6]

[6] NEC Energy Solutions, Inc, supplied to MFRS 3rd February 2022.

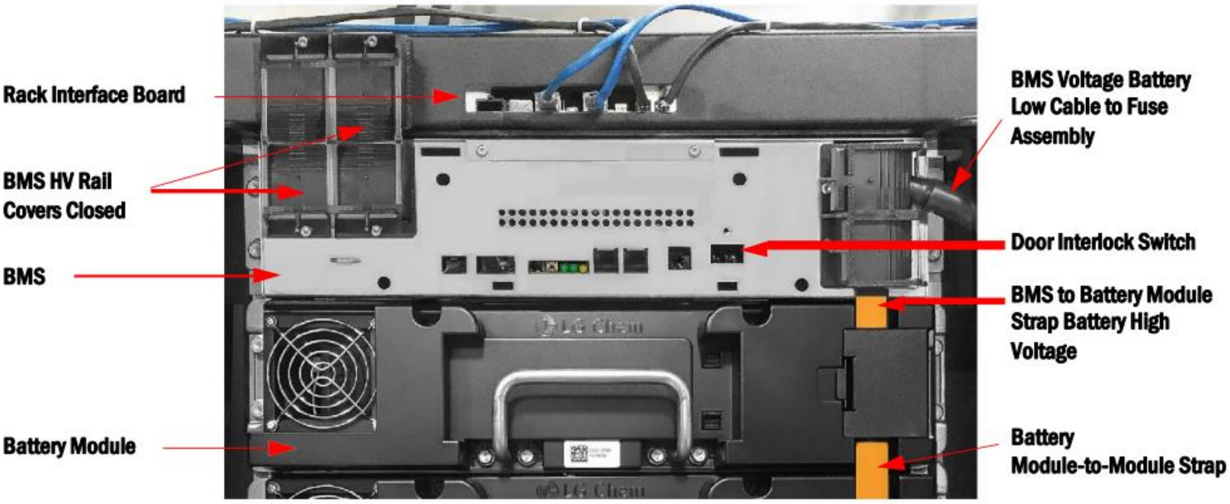


Image 8 shows the MD Rack, BMS, BMS HV strap and the battery module detailed view.[7]

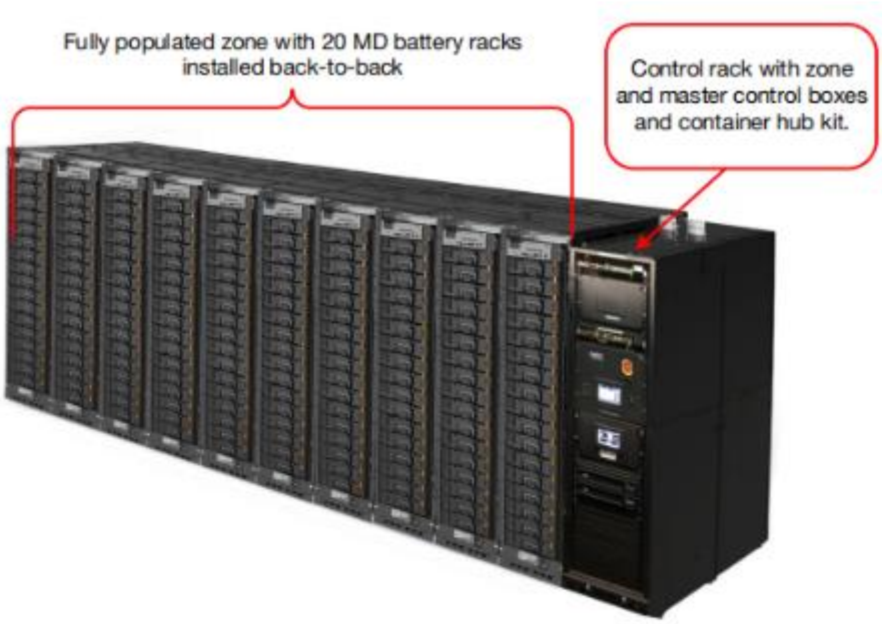


Image 9 is an example of a populated array of 20 racks (two rows of 10, installed back to back) and a control rack.[8]

6.7 Documents have been provided that show that there is a preventive maintenance (PM) plan in place: This is completed by the company service team who plan and perform the PM and provide a service report to the customer. I am in receipt of the PM which was conducted in August of 2020 and the last 3 Fire inspections paperwork covering April 13 2021, May 11 2020 and Feb 13 2020. They use a checklist that appears suitable and sufficient for reporting and customise it to represent the sites actual number of zones, HVAC, inverters, etc. The service teams' site visit reports should also include a copy of the PM checklist. The completed service report, site inventory equipment list and PM checklist are then stored in NECs service system. The last service was performed on the 26th August 2020.

[7] NEC Energy Solutions, Inc, supplied to MFRS 3rd February 2022.
[8] NEC Energy Solutions, Inc, supplied to MFRS 3rd February 2022

6.8 Orsted are not aware of any Industry standard for what is considered "adequate" maintenance but conduct maintenance in conjunction with the warranty agreement and what is recommended by the provider.

6.9 ASET who have conducted the inspection have stated:

'We carry out a service on the fire alarm system installed in the LV/HV unit, this is required every 6 months. At the same time we carry out testing of the fire suppression systems in each battery unit and check operation of the firing pin using the automatic detection and MCP method. This only has to be carried out every 12 months, however we always test the suppression system whilst on site testing the fire alarm panel. (So every 6 months the full suppression system is tested).

6.10 On 23rd July 2020, NEC issued a LG Module extended replacement Service Campaign following which a plan was put in to place to switch out any relevant modules.

This service bulletin stated that:

LG has initiated a battery module replacement program related to a manufacture date in 2017 at a plant in Nanjing, China. LG has stated that this replacement program was prompted by the Korean Government's investigation Committee report concerning events experienced by large-scale energy storage systems in Korea in 2019. LG states this replacement program is being done out of an overabundance of caution and is voluntarily replacing batteries due to its commitment to continuous improvement for customers and industry stakeholders. LG does not acknowledge there is a defect in their modules that contributed to the Korea events. A list of recalled modules for each site is attached.

NEC Service Engineers will coordinate with customers to arrange the change out. Battery module replacement will be conducted according to standard procedures and NEC will handle all the logistics of getting modules to/from sites. [9]

6.11 On the 15th September 2020, the monitoring system recorded at 00:29 hrs: an event/fault with the rack temperature mismatch. The rack temperature spread out of range and the module temperature increased to above the maximum safe level. A temperature rise of 40^{0}C in less than 2 minutes was also recorded indicating a rapid independent excursion.

[9] 2020. *LG Module Extended Replacement Service Campaign*. SRO-1220. NEC, p.1.

6.12 During the early stages of my investigation, I conducted a scene examination without entering the damaged container and, I also documented an exemplar container on the same site for comparison this was due to concerns involving stranded energy and contamination. I noted the following:

- Light weight parts of the HVAC system had been thrown up to 23m from the container towards the control room within the fence line.
- The container walls and roof had bowed outwards.
- All four HVACs had come detached from their fittings and landed in a row alongside the container and did not display much fire damage (see photo 4 & 5 in section 13).
- The door closest to The Fisheries had been blown off its hinges and had ripped through the yellow safety rails before landing in the compound. These doors are of substantial weight and it would have taken great internal pressure and force to eject them to the distance observed.
- The larger door at the opposite end to the internal CCTV camera (there are internal CCTV cameras in each container and externally in the compound) was blown open with the smaller door becoming detached and landing next to the container (see photo 2 section 13).
- The internal racking and contents had been extensively damaged and there was significant evidence that the internal container suffered weakening from the heat and the blast (see photo 6 section 13).
- On inspecting the suppression pipework, I noted that the discharge heads were missing and only appeared to have been attached by three threads. The responsible person informed me that PTFE tape and lock tight sealant was used to keep the heads in place.
- The containers are fitted with a NOVEC automatic fire detection system that operates on a double knock system which has two independent fire detection devices: 1, Automatic Smoke Detection System and 2, linear heat sensors (LHS)

6.13 Each of the containers on site had been built in China around 2018 to the NFPA 855 standard (standard for the installation of stationary energy storage systems), although this may not be the most recent edition of the NFPA standards. At the time of writing this report I am unaware of which

edition of NFPA 855 was used. At the time of writing this report there were no UK equivalent standard in place.

6.14 The containers are lined with a foam insulation that is fitted for thermal insulation. Each container has a separation of approximately 5m from the next with inverters and transformers providing a barrier between them.

7 TESTING AND INSPECTIONS (prior to the event)

7.1 The modules were declared compliant with UL9540 (an American industry standard for safety energy storage systems and equipment) I have requested a copy of the UL9540 standard and a copy of any documentary evidence that confirms compliance to this standard. To date this evidence has not been made available to this investigation.

7.2 Ørsted informed me that they have exchanged 32 modules in the past on this site and have noted that there were no signs of swelling of the cells or any signs of failure or damage across their sites.

7.3 The responsible person, when asked, did not have any documentary confirmation to show what tests have been conducted by the manufacturer, supplier or customer regarding the safety of the cells, or if they have been tested to destruction. It has been confirmed by the responsible person for the site that, testing under the transportation regulations UN38.3 was conducted for T1-T5 and T7, I am not in possession of the results. The tests are as follows:

T1 – Altitude Simulation (Primary and Secondary Cells and Batteries)

T2 – Thermal Test (Primary and Secondary Cells and Batteries)

T3 – Vibration (Primary and Secondary Cells and Batteries)

T4 – Shock (Primary and Secondary Cells and Batteries)

T5 – External Short Circuit (Primary and Secondary Cells and Batteries)

T6 – Impact (Primary and Secondary Cells)

T7 – Overcharge (Secondary Batteries)

T8 – Forced Discharge (Primary and Secondary Cells)

7.4 Prior to the incident, data shows that none of the cells within the effected container showed signs of charging slower than normal or any other anomalies.

7.5 The site is inspected every month. The inspections are general examinations and groundwork maintenance lasting for approximately 6 to 8 hrs. This includes a basic inspection inside the containers consisting of a 15-minute visual inspection.

7.6 NEC conduct longer maintenance sessions every 6 months on the batteries which includes a thermal check of the power connections after running at full load for 20 minutes. Workers are on site for two days over this period and normally have the fire systems maintenance contractors with them at the same time.

8 CAUSE OF THE FIRE (Range of ignition sources)

8.1 During the course of the investigation and scene examination I considered a number of ignition sources including; deliberate ignition and cell defect. Other sources of ignition such as, smoking and fireworks were ruled out, as there was no evidence to suggest that these were likely sources of ignition due to the security of the site, the container being secured and the CCTV footage showing that no one had been on site leading up to the ignition.

8.2 I have conducted an internal examination of the container and affected rack as well as an examination of exemplar modules taken from the other containers.

8.3 Examination of the identified racks, modules and remaining cells in situ was conducted jointly in May 2021. In the time since the incident occurred there has been on site security at all times. Although some parts of the container were exposed to the elements, the area of interest was protected by the walls and roof of both the container and the rack itself.

8.4 The co-operation Ørsted and other relivant parties has aided me with my investigation. This has been through the sharing of information, research, data and joint examinations.

8.5 **Deliberate ignition**

The investigation found no evidence that the fire was caused by deliberate ignition, in drawing this conclusion I considered both the CCTV footage and that the site was secure with restricted access.

8.6 **Cell failure**

Due to the extent of the damage to the racks and modules within the container, I have relied on the information provided by the responsible people for the site and equipment, along with the data that has been captured from the sites management system and the examination of scans of both damaged and exemplar cells by [redacted]. The data shows that there were issues with battery zone BZ3-R7M6 prior to the explosion.

8.6.1 When reviewing the internal CCTV, there is evidence of fumes and vapours (produced by thermal runaway of the cell) transiting through the container at low level until reaching the door closest to the Fisheries which is where the camera was positioned. Light can be seen at the opposite end of the container which appears to be the emergency lightings which was illuminating the exit signs.

8.6.2 The vapours are likely to be the result of a cell or cells venting as a consequence of overheating. The cause of which is unknown at this time but, it could be attributed to either:

- Thermal abuse – exposed to high heat from external sources; (no evidence found in data provided)
- Electrical abuse – overcharging, rapid discharging, unbalancing; (no evidence found in data provided)
- Mechanical abuse – development of an internal short circuit, leading to a high current flow with consequent local heating; (no evidence found in data provided)
- Internal defects – detritus, other contaminants; (due to the cell damage I was unable to discount any defects internally)
- Environmental abuse – seismic, flooding, absent or poorly designed HVACs. (no evidence found in data provided)

8.6.3 The failure of the cells caused it to enter thermal runaway. *The thermal runaway can be described as 3.3.20. The condition when an electro- chemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion.* (NFPA 855 , 2020) (NFPA 855 , 2020)

Ørsted informed me that: ***Some swelling is expected to occur during normal operation of a well-manufactured lithium-ion cell. Gas generation in the cell, which causes swelling, is a result of electrolyte decomposition. There is minor incompatibility between the liquid electrolyte and electrodes used in conventional, commercially available cells. As such, the electrolyte breaks down where it meets the electrode, resulting in gas generation and solid passive layer that forms over the electrode surfaces. Additionally, any external temperature increases could cause further electrolyte degradation within the cell and lead to swelling. As I have not seen the design specification I have been unable to verify if the swelling is a design feature.***

It is possible that the cells have been fitted close together in the module limiting any expansion area. This would present increased thermal contact between the cells. At this point the internal vapours and fumes would then vent which was witnessed filling the container on the internal CCTV.

The following was also noted from the CCTV footage:

- 00:37 hrs the doors appear to be in the closed position. The power is still on to the container and the racks and the lights can be seen on the alarm panel.
- 00:38 hrs camera becomes obscured with smoke/vapours gasses
- 00:39 hrs vision becomes clear and the doors are open. The smoke and vapours dissipate and items can be seen on the floor of the container.
- The external camera shows the doors being blown off and a spray of flame and sparks briefly being expelled before dying back
- 00:57 hrs Significant free burning now visible on the external camera

The module data showed as failing first was on the replacement program which was planned for changing in December 2020 and is referenced in section 6.8 page 15.

Based on my investigations, the evidence is consistent with the initial cell having suffered an exothermic reaction which then lead to a thermal runaway which resulted in flammable and toxic vapours being produced. Work conducted by Pacific Northwest National Laboratory shows that cells can give off the following toxic vapours:

Hydrogen Fluoride, Hydrogen Sulphide, Hydrogen Chloride, Hydrogen Cyanide, Hydrogen,

Propylene, Methane, Carbon Monoxide, Sulphur Dioxide, Ethylene, Ethane

The internal CCTV shows the vapours (vented gases-droplets of organic solvent from the cells) building up at low level filling the container as to started to reach their flammable limits, before coming into contact with an ignition source, the exact ignition source within the container is not known. The vapours ignited causing a deflagration which blew off both doors and caused the HVACs to come detached from the roof as well as deforming the container.

9 FIRE SPREAD

9.1 The thermal runaway started in module BZ3-R7M6 when the lithium ion battery cells failed. This led to a rapid rise of temperature of this cell which then caused a chain reaction of the other cells within

the module. The vapours being given off by the cells subsequently filled the compartment and activated the detection system. As the reaction remained localised, within rack three, in zone seven, and modules BZ3R7M1, BZ3R7M2, BZ3R7M3, BZ3R7M4, BZ3R7M5, BZ3R7M6, BZ3R7M7, BZ3R7M17 and run 1 to 17 from top to bottom, (data shared by Ørsted as seen in image 6 page 13). The BMS reported a maximum temperature being reached. This localised containment prevented linear heat cable being affected, which consequently led to the suppression system not activating immediately.

9.2 After attending a joint online examination of the cylinder and activator due to Covid restrictions, it indicated that the suppression system had been released electronically (the pin was in the activated position). The records from the monitoring system suggests that this was not whilst the communications were still functioning. i.e. the system did not operate due to the detection system in conjunction with the thermal wire. It is my opinion that it possibly activated as the event escalated and after communications were lost at the point when the deflagration occurred. The deflagration moving through the container would have had the force to trigger the break glass point below the fire alarm panel.

9.3 The examination of the suppression assembly also showed that the bursting disk had operated, which may be due to the cylinder discharging as the release valve resets and seals the cylinder; as the fire heated the sealed vessel, the bursting disk might have then triggered/operated. Alternatively, the activator could have triggered, but failed to release the contents, leaving it full and causing the bursting disk to operate when it was heated.

10 CONCLUSION

10.1 The findings of this investigation conclude that this event occurred following a failure within Battery Zone 3-Rack 7 Module 6 (BZ3-R7M6) which led to a thermal runaway. The thermal runaway caused the cell to vent vapours and, when a flame was present within the container ignited vapours/gases causing a deflagration forcing the doors off ether end and causing the HVACs to become unmounted from the roof. I have been unable to identify the root cause of the failure within module 6.

10.2 The suppression system was most likely discharged due to the deflagration which either, activated the alarm or the pressure activated the break glass media trigger below the alarm panel.

10.3 Following [redacted] review of the CT scans he has stated:

X-ray Computed Tomography (CT) provides a non-destructive tool for 3D imaging which has been widely applied to batteries. The physical size of the object is inversely proportional to the resolution

that can be achieved (i.e. smaller feature sizes are observable in smaller samples); therefore owing to the large form factor of the batteries in question, the resolution that has been achieved is limited and only macroscopic features within the cell architecture are visible.

Furthermore, the fire damaged batteries recovered from the incident had undergone such significant failure, that the scans of these batteries have not provided substantive insight as all registration of the cell architecture has been lost. This is not uncommon in battery failures where the excessively high temperatures during thermal runaway processes can destroy the cell components.

X-ray images of exemplar cells recovered from neighbouring containers do provide some information relating to the state of health of the (non-failed) cells. Clearly, these cells have not undergone failure and to my understanding were in operation up until the point of the incident, after which they were recovered from the scene having not themselves failed. Within these exemplar cells, there are indication of gas generation; this has been observed both by a simple visual inspection of the cells (which shows pockets of gas immediately adjacent to the cell surface), and by X-ray CT which shows the presence of gas leading to distortion of the cell architecture in some cases.

Gas generation in Li-ion batteries principally occurs due to electrolyte decomposition – this can happen due to excessive heat, or over-voltage in service (which could be external or could be a result of a defect with the cell or BMS), but is more likely associated with solid electrolyte interphase (SEI) formation during formation and operation:

The electrolytes used in Li ion batteries are not stable across the full voltage window of operation, and they decompose to form a SEI layer at the anode. This happens in large measure during the original manufacturing process where the cells undergo a highly managed 'formation process' whereby the cells are cycled at very low rates to form a stable SEI. The accompanying gas generation can then be managed, by degassing the cell before production is finalised. Some cell geometries have hard cases and 'empty space' which can accommodate the generated gas, but pouch cells would usually require degassing as the soft casing material cannot withstand over pressure, and there is not empty volume for generated gas. After manufacture, the formation of the SEI layer will continue but at a much lower rate, and there before the accompanying gas evolution is much lower. SEI will continue to form over the lifetime of the cell, but excessive SEI

formation and accompanying gas evolution causing the cell to swell is of concern and has safety implications.

Within the exemplar cells, there is evidence of gas generation, although not to the extent that it has caused failure. Without a granular understanding of the operational history of each of these exemplar cells, it is not possible to assign the root cause of this gas generation with certainty, or to predict how this may have progressed were the cells to continue operational service. However, the presence of gassing indicates that the exemplar cell's state-of-health had degraded.

11 GLOSSARY OF TERMS

Area of Origin

The specific location or place where the fire initially started.

Automatic Fire Detection (AFD)

A fire alarm system comprising components for automatically detecting a fire, initiating an alarm of fire and initiating other action as arranged; the system may include manual call points.

BESS

Battery Energy Storage Systems

BMS

Battery Management System

Burn Pattern

Created when applied heat flux are above the critical thresholds to scorch, melt, char or ignite a surface.

Combustion

Oxidisation that generates detectable heat and light.

Deflagration

A very rapid oxidation with the evolution of heat and light and the generation of a low-energy pressure wave that can accomplish damage. The reaction proceeds between fuel elements at subsonic speed.

Exemplar

A person or thing serving as a typical example or appropriate model

Exothermic reaction

Generating or giving off heat during a chemical reaction

Fire

A rapid oxidation process with the evolution of light and heat in varying intensities.

Fire Investigation

The process of determining the origin, cause and development of a fire or explosion.

Fire Spread/Development

The movement of fire from one place to another

Flame

The luminous portion of burning gases or vapours.

Fire Appliance

An appliance that is capable of carrying a multitude of equipment and firefighting media (such as water and foam) to deal with different types of emergencies.

Fire Control

A control room used to handle emergency calls for the fire services and mobilise resources to deal with incidents.

GBS

Grid balancing system

Heat transfer

Spread of thermal energy by convection, conduction or radiation.

HMEPO

Hazardous Materials and Environmental Protection Officer

Ignition

The process of initiating self-sustaining combustion.

Linear heat detection

The heat from a fire causes the LHS cable's special insulation to melt at a specific temperature, allowing the two conductors to short together, thus creating an alarm condition on the fire control panel. The LHS cable may also be used as a stand-alone contact device. The LHS normal operating state is an open circuit.

Lithium-Ion Battery Energy Storage Systems:

A system comprised of one or more lithium-ion batteries assembled together, capable of storing energy in order to supply electrical energy at a future time

Point of Origin: The physical location where a heat source and a fuel come into contact with each other and a fire begins.

Radiated Heat: Energy radiated by solids, liquids or gases in the form of electromagnetic waves as a result of their temperature.

Self-heating

An exothermic chemical or biological process that can generate enough heat to become an ignition source; spontaneous ignition.

Stored/Stranded Energy:

A condition where the system has been electrically isolated but there is still residual charge in the batteries.

Suppression system

Fire suppression systems are used to extinguish or prevent the spread of fire in a building. Suppression systems use a combination of dry chemicals and/or wet agents to suppress equipment fires.

Scientific Method:

The systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypothesis.

Smoke:

Airborne products of incomplete combustion.

Soot:

Black particles of carbon produced in a flame

Thermal runaway:

Thermal runaway is defined with in NFPA 855 3.3.20 2020 as, Thermal Runaway. The condition when an electro- chemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion.

Vapour:

The gas phase of a substance, particularly of those that are normally liquids or solids at ordinary temperatures.

<u>Signed</u>

[redacted]

Station Manager

Incident Investigation Team

08th February 2022

12 AERIAL VIEW OF SITE

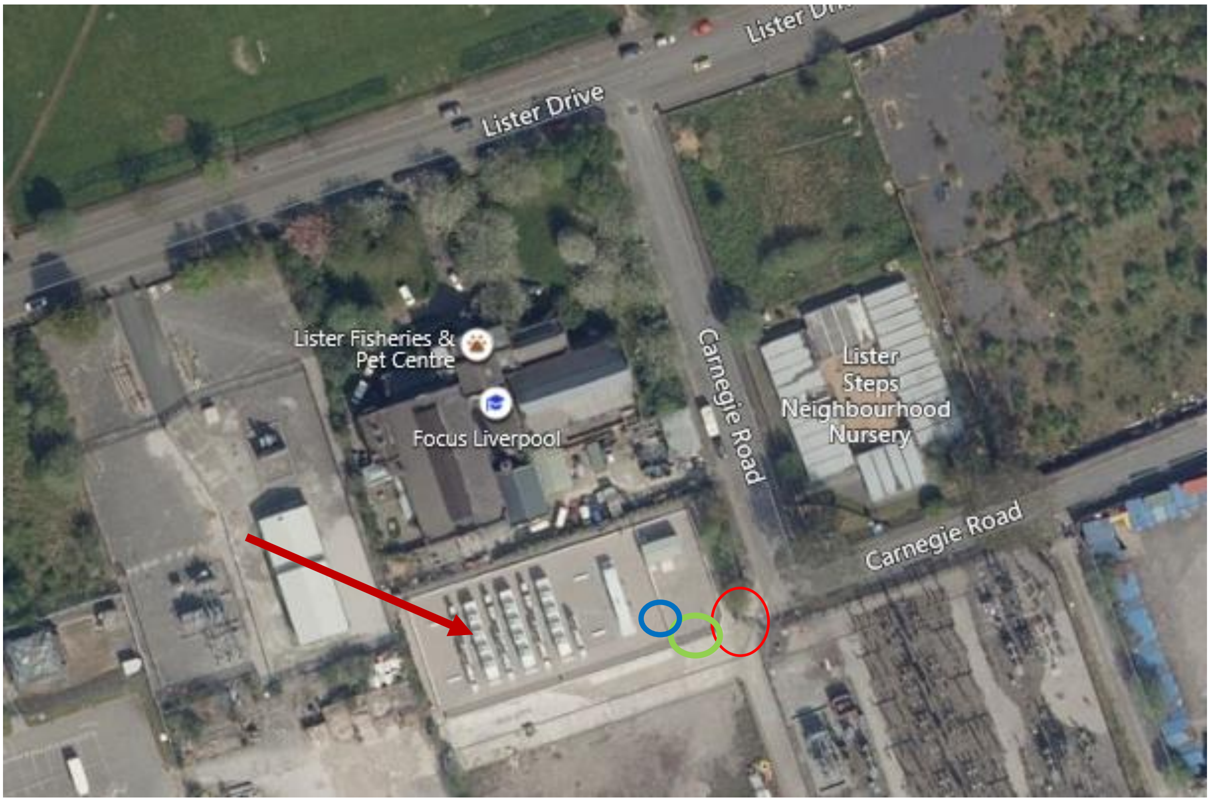


Image 15

Main gate was secure on arrival (red circle)

Second gate (green circle)

Third gate (blue circle)

Affected container (red arrow)

13 KEY PHOTOGRAPHS

	Description	Frame number
1	Over view of the scene	IIT_5248
2	Air unit overview	DJI_0237
3	Left aspect of container one	IIT_5290
4	Right aspect of container one	IIT_5303
5	HVACS after coming dismounted from the container roof	IIT_5329
6	Internal view of container one from the Fisheries side.	IIT_5519
7	Consumer unit in container one	IIT_5518
8	NOVEC system in container one with damaged pipe work	IIT_5516
9	NOVEC system in unit two	IIT_5505
10	Alarm panel, emergency activation points and consumer unit	IIT_5504
11	External CCTV pre blast	CCTV
12	External CCTV at point of blast for the door fails	CCTV
13	External CCTV showing flaming discharge consistent with a failing Lithium cell failing	CCTV
14	External CCTV showing the door being blown open and the smaller door coming detached	CCTV
15	Internal CCTV showing the activated alarm panel to the bottom left, the NOVEC system to the bottom right and the fire exit door in the bottom centre.	CCTV
16	Internal CCTV 00:37 vision begins to become obscured	CCTV
17	Internal CCTV 00:38 vision becomes clearer and the fire exit door has failed. No power can be seen on the fire alarm panel	CCTV
18	R7 Z3 after the containers had been cut in to sections	MB0_7375
19	Location that module 6 would have been pre fire. The modules had melted and collapsed	MB0_7397
20	R7 after the side of the rack had been cut away	MB0_7402
21	Close up of the module of interest before removal	MB0_7421
22	Shows the flooring at the foot of R7. The floor had wood boarding fitted which had burnt through.	MB0_7450

1

Overview of the scene

2

Air unit overview. The red arrows show the resting place of the doors

Fire Investigation

3

Left aspect of container 1

Fire Investigation

4

Right aspect of container one

Fire Investigation

5

HVACS after coming dismounted from the container roof

6

Internal view of container one from the Fisheries side

7

Consumer unit in container one

8

NOVEC system in container one with damaged pipe work

Fire Investigation

9

NOVEC system in unit two

10

Alarm panel, emergency activation points and consumer unit

11

External CCTV pre blast

12

External CCTV at point of blast for the door fails

13

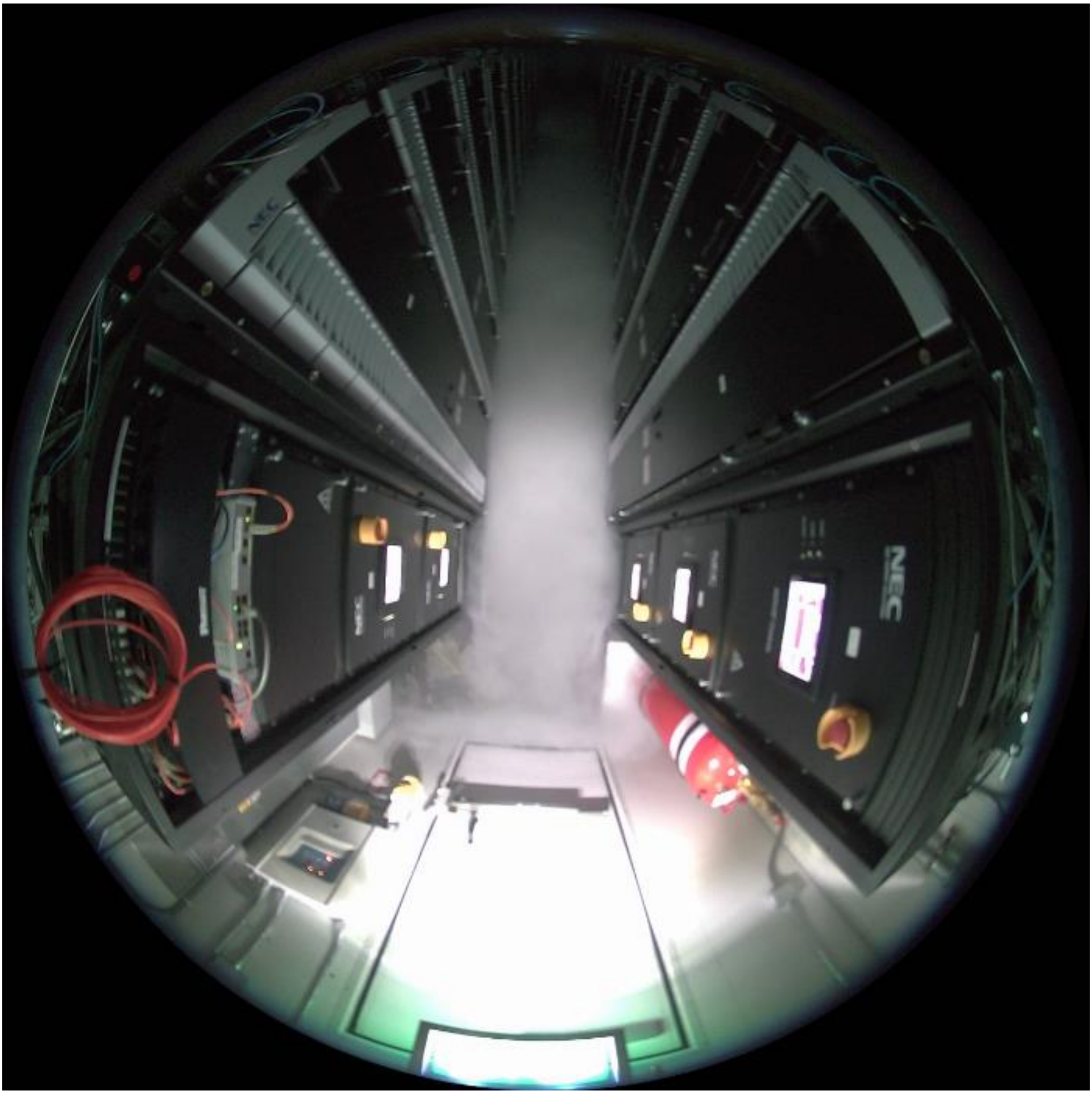
External CCTV showing flaming discharge consistent with a failing Lithium cell

14

External CCTV showing the door being blown open and the smaller door coming detached

Fire Investigation

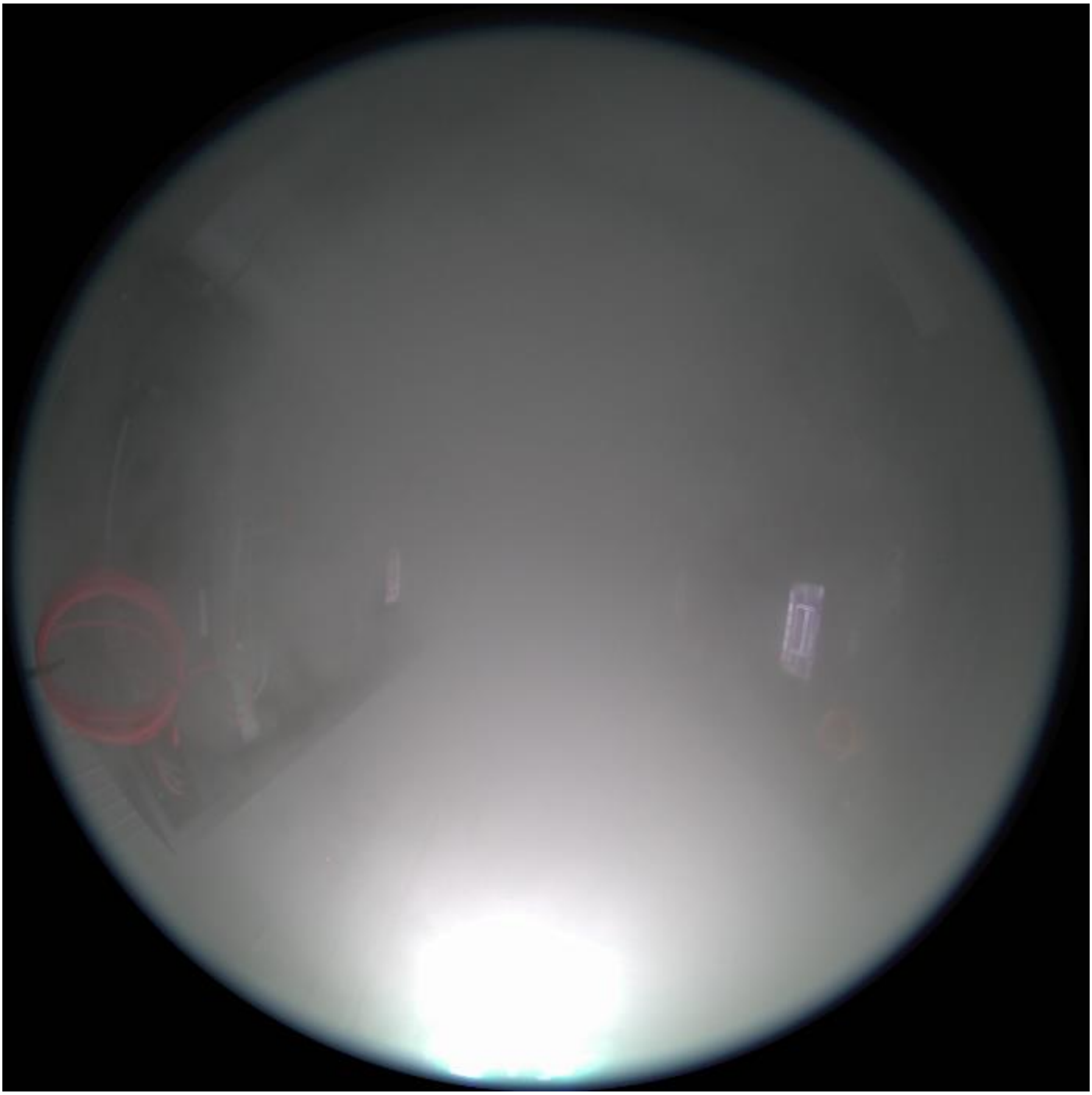
15



Internal CCTV showing the activated alarm panel to the bottom left, the NOVEC system to the bottom right and the fire exit door in the bottom centre. The fish eye view is due to the position of the CCTV camera located on the ceiling near the rear door. A vapour cloud can be scene within the container

Fire Investigation

16



Internal CCTV 00:37 vision begins to become obscured by the vapour cloud

17

Internal CCTV 00:38 vision becomes clearer and the fire exit door has failed. No power can be seen on the fire alarm panel

Fire Investigation

18

Image MB0_7375 shows R7 Z3 after the containers had been cut in to sections.

19

Image MB0_7397 shows where module 6 would have been pre fire. The modules had melted and collapsed.

Fire Investigation

20

Image MB0_7402 shows the side view of R7 after the side of the rack had been cut away. This view shows how the modules have collapsed making recover difficult. To remove them through the front would have pulled the module apart so, they had to be recovered sideways.

21

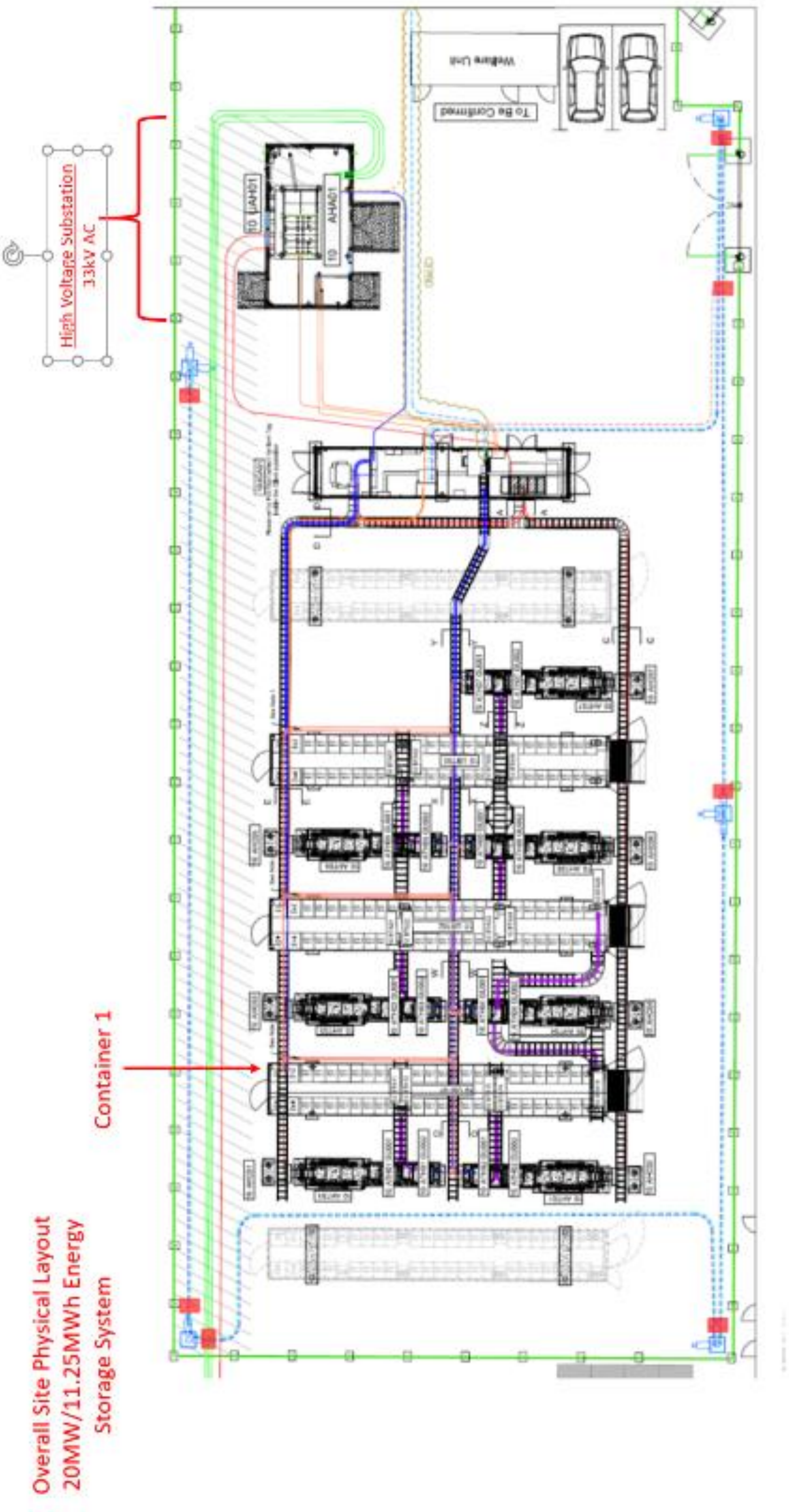
Image MB0_7421 is a close up of the module of interest before removal.

Fire Investigation

22

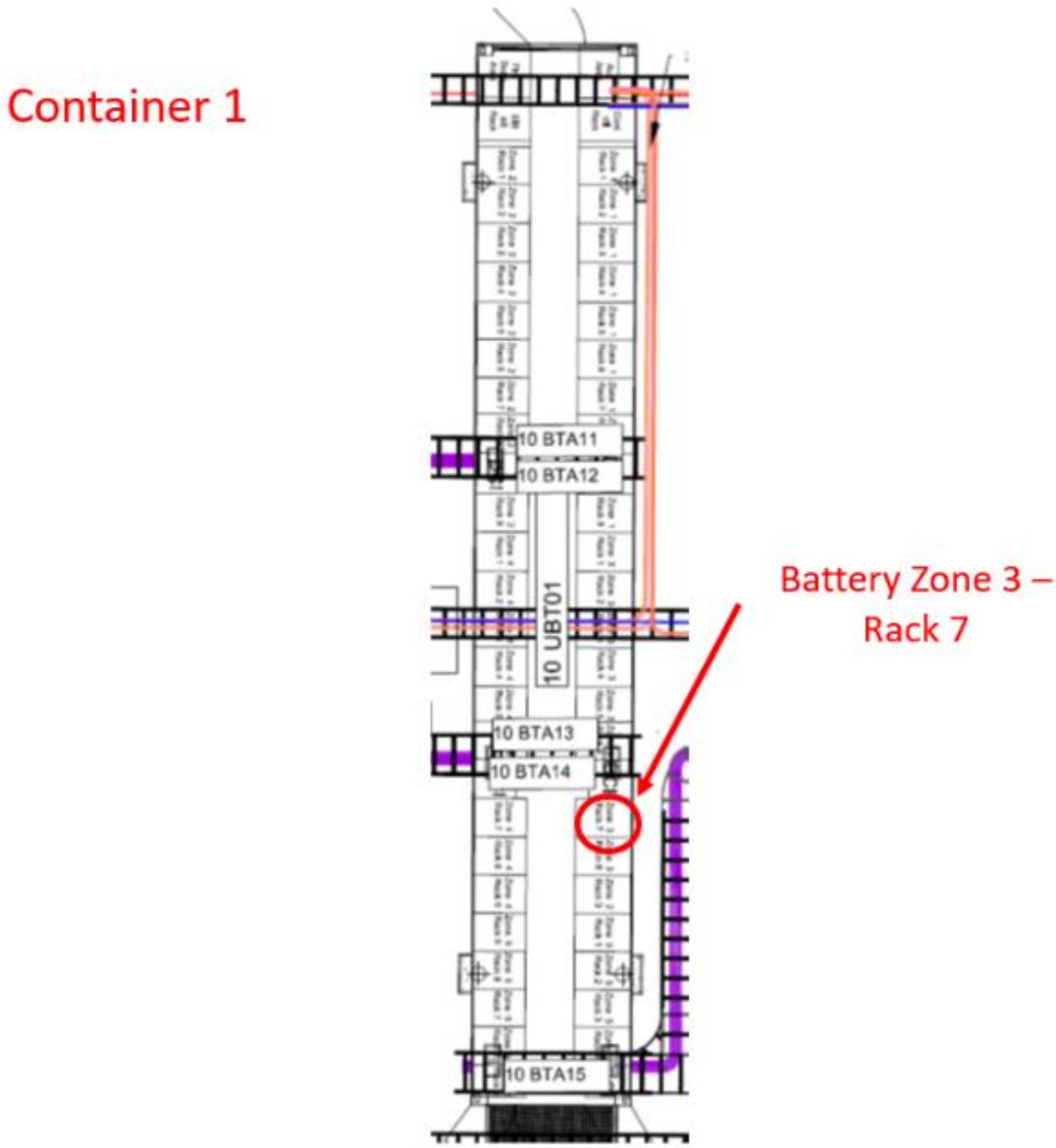
Image MB0_7450 shows the flooring at the foot of R7. The floor had wood boarding fitted which had burnt through.

APPENDIX A Plans



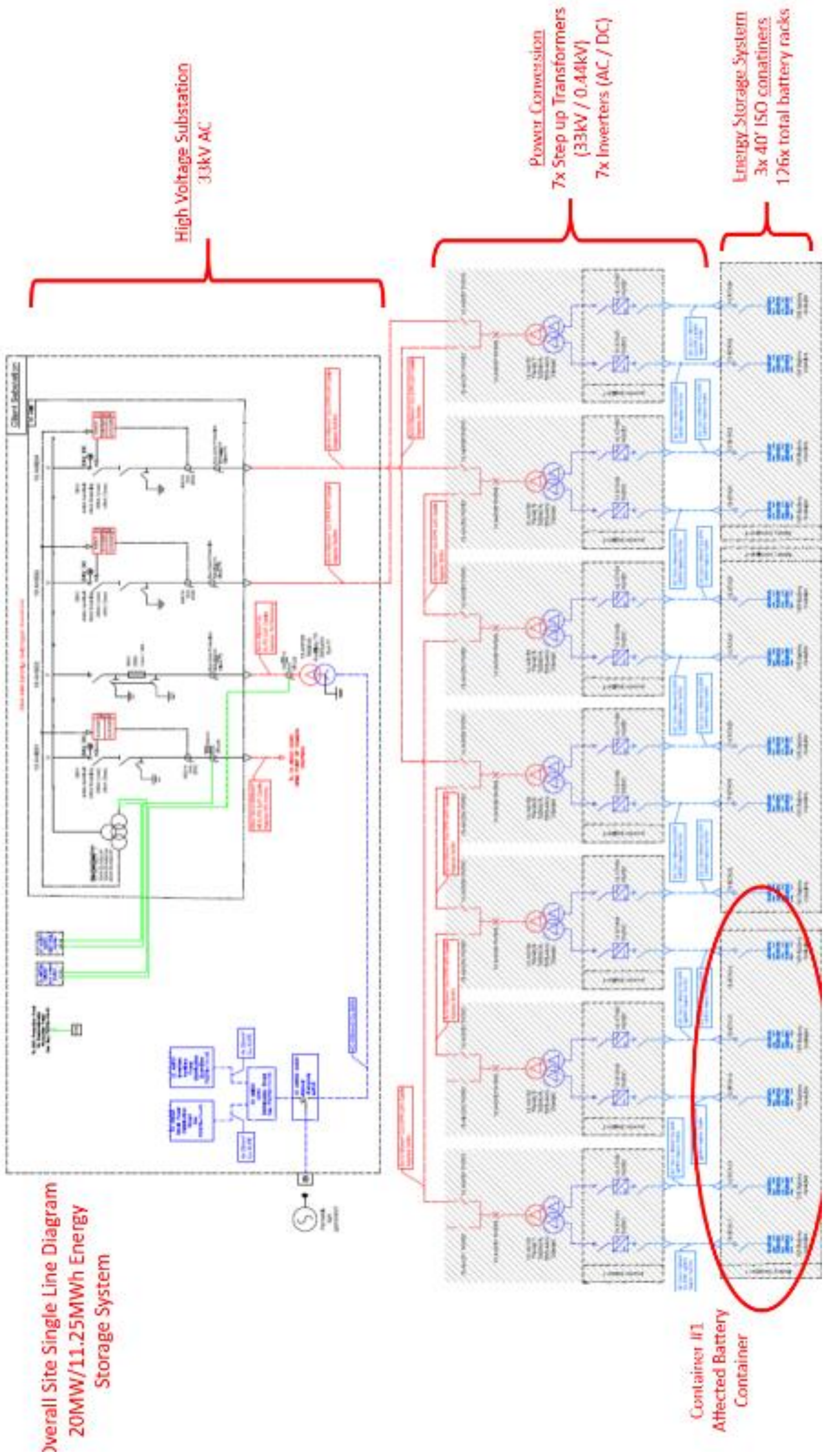
Plan 1 shows the over view of the sites physical layout[10]

[10] 2020. *Overall Site Physical Layout*.



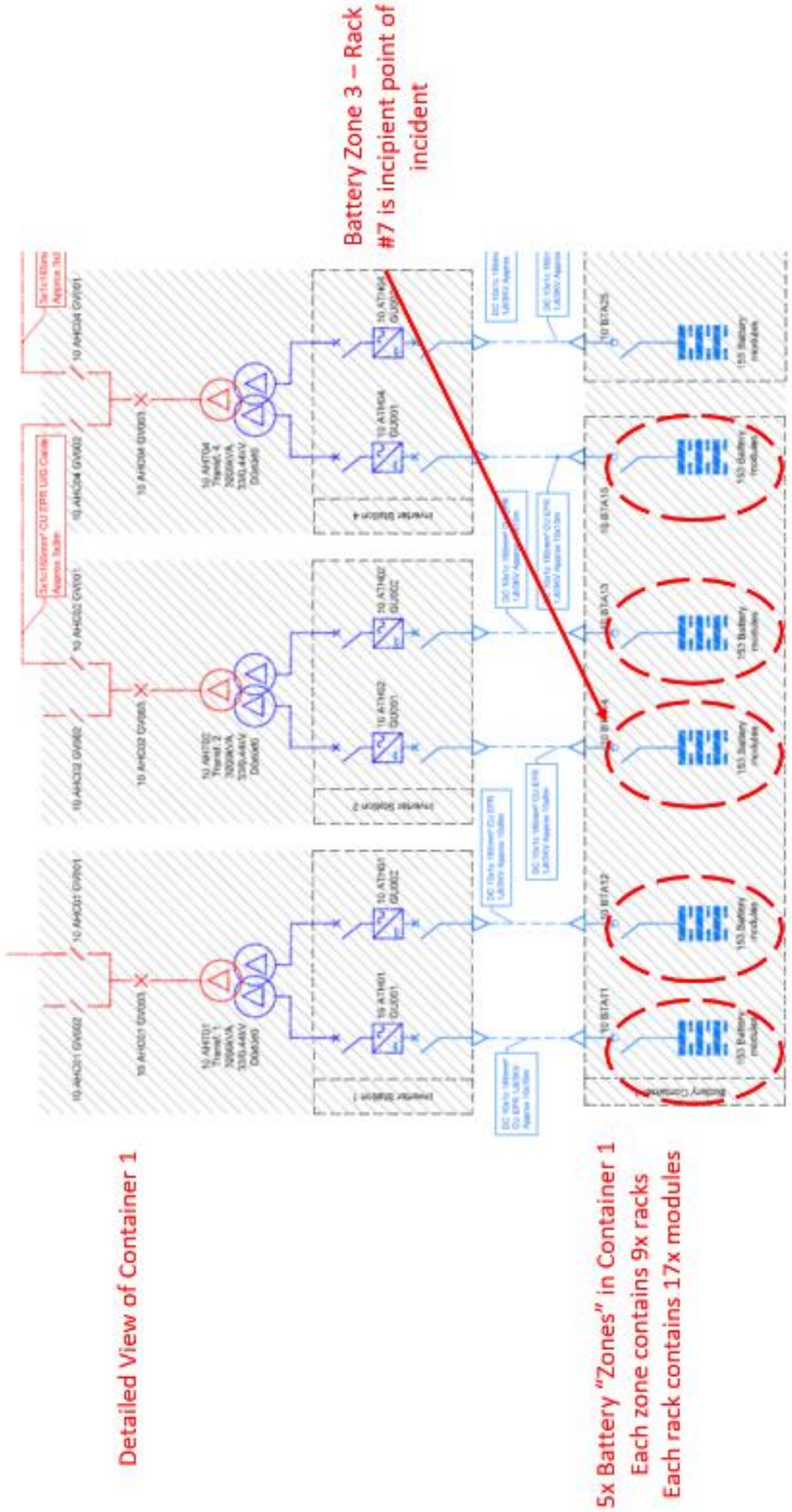
Plan 2 shows the layout of container 1 which is the effected container[11]

[11] 2020. *Overall Site Physical Layout*.



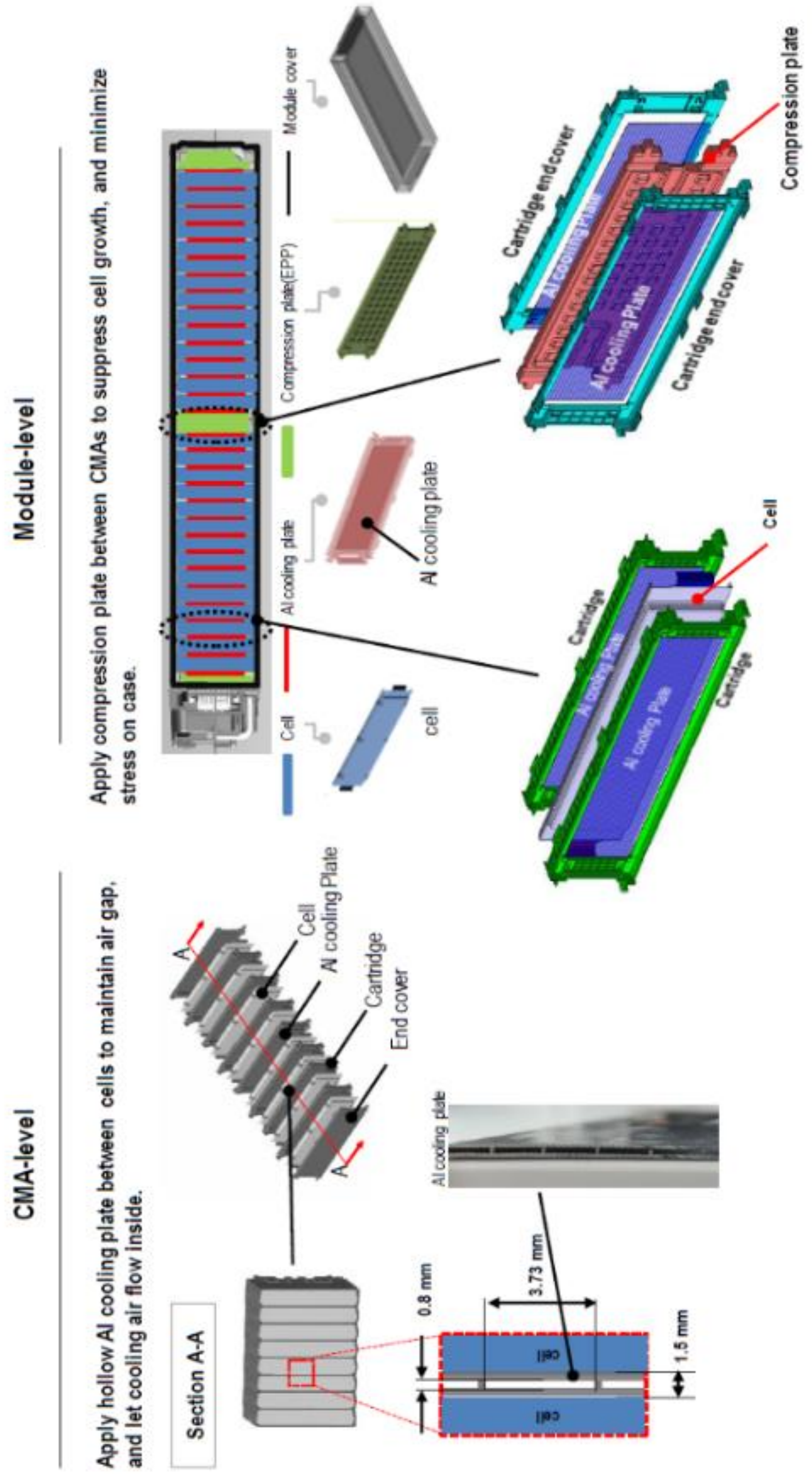
Plan 3 [12]

[12] 2020. *Overall Site Physical Layout*.



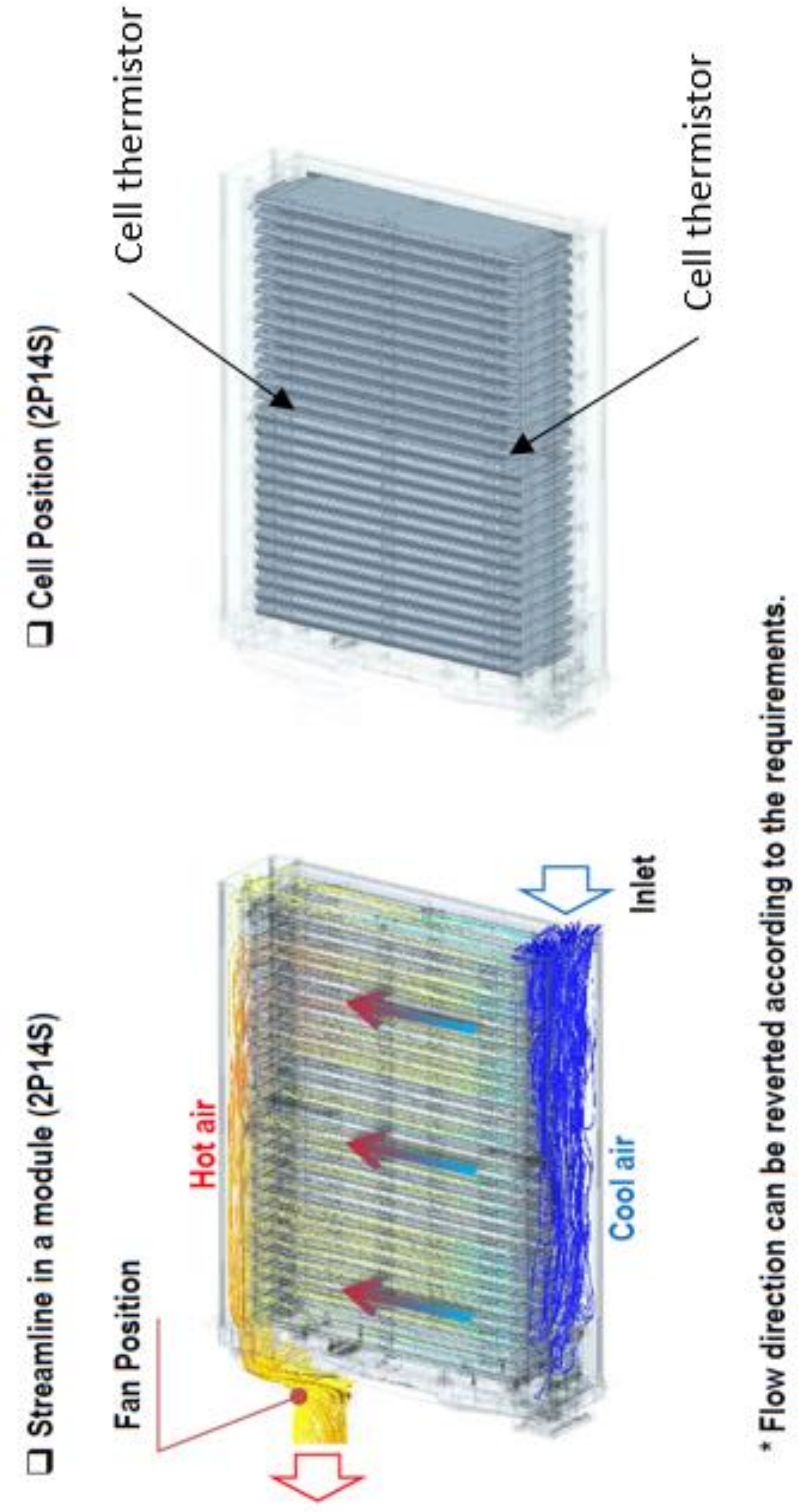
Plan 4[13]

[13] 2020. [redacted], p.4.



Plan 5 is JP3-2P ACP Module Disassembly[14]

[14] 2020. NEC *Rack, Module & Cell Details*.



Plan 6 JP3-2P ACP Module Air Flow[15]

[15] 2020. NEC *Rack, Module & Cell Details*.

APPENDIX B Codes

During my investigation I asked the responsible person which of the following codes applied to this site.

A, Energy Storage Systems

• UL9540, MESA	Yes
• ASME TES-1,	NECA Not listed
• NFPA 791	Not listed

B, Installation/application

• NFPA855	Yes
• NFPA 70	Yes
• UL 9540	Yes
• IEEE C2	Yes
• IEEE 1635/ASHRAE 21	Not Listed
• IEEE P1578	Not listed
• DNVGL GRIDSTOR	Not listed
• FM GLOBAL 5-33	Not listed – insurers normally reference NFPA
• NECA 416	Not listed

C, System components

• UL 1973	Yes
• UL 1974	Not Listed
• UL 810A	Not listed
• UL1741	Yes
• CSA 22.2 no 340-201	Not listed
• IEEE 1547	Yes
• IEEE1679 series	Not listed

There does not seem to be any clear UK industrial standard that I have found at the time of writing this report. There has been a Domestic Battery Energy Storage System review in to safety risks published in September 2020 and I am awaiting to see if the standards will cover commercial BESS. [16]

[16] (BEIS Research Paper Number 2020/037)