REPORT

HAZARD MITIGATION ANALYSIS

Aligned Data Centers, Inc. – Apex Data Centers

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Executive Summary

Jensen Hughes, Inc (Consultant) has been contracted by Aligned (Client) to develop a hazard mitigation analysis (HMA) for lithium-ion ESS installations exceeding the code prescribed maximum allowable capacity at Apex data centers. The Apex data centers are to be constructed in several jurisdictions throughout the United States that apply various versions of the International Fire Code and/or NFPA 855.

This HMA report evaluates various failure modes, assesses the effectiveness of protective barriers in place to mitigate these failures, and identifies potential consequences. All required failure modes were evaluated, and the analysis concludes that the installation will meet AHJ required approval criteria across various codes.

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1.0 Introduction

Jensen Hughes, Inc (Consultant) has been contracted by Aligned Data Centers, Inc. (Client) to develop a hazard mitigation analysis (HMA) for lithium-ion ESS installations utilized within new Apex data centers as uninterruptible power supplies (UPS). The UPS arrangement includes an Eaton 9395XC 2000 kW UPS and ten (10) Samsung Gen-3 136S lithium-ion BESS cabinets rated for 34.6 kW each. As there are multiple UPS systems in each electrical room the aggregate quantity of lithium-ion BESS cabinets within these rooms will exceed 600 kWh, thus requiring an HMA.

This HMA evaluates various failure modes, assesses the anticipated effectiveness of protective barriers in place to mitigate these failures, and identifies potential consequences. Criteria necessary to be met for AHJ approval of the HMA is also reviewed.

1.1 PURPOSE + SCOPE

The purpose of this HMA is to evaluate code required failure modes of the Samsung Gen-3 136S BESS cabinet to demonstrate compliance with codes and standards applicable to jurisdictions throughout the United States. These failure modes will be evaluated as single failure events with discussion on how BESS mitigation barriers and safety systems will aid in satisfying the intent of the codes and standards. Specifically, the following steps are followed in this HMA:

+ **Determination of failure modes and approval requirements (Section 1.3):** Failure modes and approval criteria are specified by the applicable codes and standards for the project. Failure modes identify the scenarios required to be evaluated in the HMA. Approval requirements establish the criteria to which the HMA must be compared to constitute an acceptable BESS installation.
+ **Hazard Mitigation Analysis (Section 2.0):** A failure mode and effects analysis (FMEA) is provided to analyze the required failure mode scenarios and determine the associated consequences and mitigation strategies. A qualitative assessment of the performance criteria to meet the approval requirements is provided.
+ **Recommendations for Approval (Section 3.0):** The consequences of the HMA are compared to the approval requirements for each failure mode scenario to evaluate the Energy Storage System (ESS) installation for compliance. Recommendations are provided where gaps exist between the failure modes consequences and the approval requirements.

1.2 APPLICABLE CODES AND STANDARDS

The following codes and standards were utilized to establish the HMA failure modes and approval criteria:

+ 2018, 2021, and 2024 International Fire Code (IFC) [1].
+ NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems*, 2020 and 2023 Edition [2].

Additionally, the following standards and guidelines were relied upon for assessing the hazards from the proposed batteries and protection methods to mitigate the hazards:

+ UL 9540, *Standard for Energy Storage Systems and Equipment*, 2023 [3].
+ UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*, 2019 [4].

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1.3 ANALYSIS INPUTS

Project documentation provided by the Client to form a foundation of this report includes:

- Eaton. Aligned 2000 kW V4 Submittal. Dated March 13, 2025 [5].
- IE Corp. Aligned Data Centers LBB01 UPS Container. Dated March 19, 2026 [6].
- Aligned. Apex 24 MW Module Concept Design. Dated May 8, 2026 [7].
- Underwriters Laboratory. UL 9540A Test Report for Eaton Corporation on Samsung Gen-3 136S. Issued February 26, 2024 and revised June 3, 2024 [8].

1.4 HMA REQUIREMENTS AND APPROVAL CRITERIA

In essence, there are three key steps to an HMA:

1. Identify challenging conditions relevant to the installation as established by the applicable codes.
2. Evaluate consequences of failure modes established by the applicable codes.
3. Demonstrate that consequences identified in the HMA can be controlled and do not present harmful conditions to occupants.

The IFC and NFPA 855 commonly require an HMA to be prepared for AHJ review when the installation is presented with potentially challenging conditions. Specifically, an HMA is required to be developed where any of the conditions in Table 1, below, are present or specifically required by the AHJ.

Table 1-1: IFC and NFPA 855 HMA Installation Conditions

No.	Installation Condition	IFC Edition Applicability	NFPA 855 Edition Applicability
1.	When ESS technologies not specifically addressed in the Code are provided	2018, 2021, and 2024	2020 & 2023
2.	Where more than one ESS technology is provided in a single fire area where adverse interaction between the technologies is possible	2018, 2021, and 2024	2020 & 2023
3.	When allowed as a basis for increasing maximum stored energy (limited to 600 kWh for lithium-ion batteries)	2018, 2021, and 2024	2020 & 2023
4.	Where required by the AHJ to address a potential hazard with an ESS installation that is not addressed by existing requirements	2024	2023
5.	Where required for existing lithium-ion ESS systems that are not UL 9540 listed	N/A	2023

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No.	*Installation Condition*	*IFC Edition Applicability*	*NFPA 855 Edition Applicability*
6.	For lithium-ion battery ESS in outdoor installations, installations in open parking garages, on rooftops of buildings, and mobile ESS equipment	N/A	2023

When any conditions listed above are present, the HMA must evaluate the consequences of various fault conditions specific to electrochemical BESS. Only single failure modes must be considered at a time:

Table 1-2: IFC and NFPA 855 HMA Fault Conditions

No.	*Fault Condition*	*IFC Edition Applicability*	*NFPA 855 Edition Applicability*
1.	Thermal runaway condition in a single BESS unit	2018, 2021, and 2024	2020 & 2023
2.	Failure of any battery (or energy) management system or fire protection system within the ESS equipment that is not covered by the product listing failure mode effects analysis (FMEA)[1]	2018, 2021, and 2024	2020 & 2023
3.	Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation smoke detection, fire detection, fire suppression, or gas detection system	2018, 2021, and 2024	2020 & 2023
4.	Voltage surges on the primary electric supply	2018, 2021	N/A
5.	Short circuits on the load side of the stationary BESS	2018, 2021	N/A
6.	Required spill neutralization not being provided or failure of the secondary containment system	2018, 2021	N/A
7.	A mechanical failure of a nonelectrochemical ESS unit.	2024	N/A

[1]The underlined portion of Item 2 referring to fire protection systems not covered by the product listing FMEA is applicable only to the 2024 editions of NFPA 855 and the IFC. That is, the prior editions only require failure of the management system.

The AHJ is permitted to approve the HMA if consequences of the analysis demonstrate all the following elements:

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Table 1-3: IFC and NFPA 855 HMA Approval Criteria

No.	*Approval Criteria*	*IFC Edition Applicability*	*NFPA 855 Edition Applicability*
1.	Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified.	2018, 2021, 2024	2020 & 2023
2.	Fires and products of combustion will not prevent occupants from evacuating to a safe location.	2018, 2021, 2024	2020, 2023
3.	Suitable deflagration protection is provided where required.	N/A	2020, 2023
4.	Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the permissible exposure limit (PEL) in the area where the ESS is contained.	N/A	2020
5.	Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes during the time deemed necessary to evacuate from that area.	2018, 2021	2020
6.	Flammable gases released during charging, discharging, and normal operation will not exceed 25 percent of the LFL.	2018, 2021	2020
7.	Flammable gases released from batteries during fire, overcharging and other abnormal conditions shall not create an explosion hazard that will injure occupants or emergency responders.	2018, 2021	N/A

Note, as the codes have progressed, the approval criteria have been condensed into more general statements. Specifically, the 2023 edition of NFPA 855 and the 2024 edition of the IFC include only three and two approval criteria, respectively, where the older editions had up to six criteria. To maintain flexibility of this HMA, all listed approval criteria will be discussed.

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2.0 Hazard Mitigation Analysis

As required by the IFC and NFPA 855, a hazard mitigation analysis has been prepared due to the Aligned Apex data centers having lithium-ion ESS installations exceeding the 600 kWh maximum allowable quantity in a single fire area. A failure modes and effects analysis (FMEA), performed in accordance with IEC 60812, is an acceptable method of performing the HMA and documented herein.

The FMEA only considers single failure modes in the context of the BESS installations and assumes all general provisions and requirements of NFPA 855 and the IFC, whichever is applicable, are fulfilled and satisfactory to the AHJ including but not limited to provision of an automatic fire detection and alarm system, provision of an automatic sprinkler system, and provision of adequate compartmentation via 2-hour fire-resistance rated enclosures.

2.1 FAILURE MODES AND EFFECTS ANALYSIS

2.1.1 Objective

The objective of the FMEA is to explore code required failure modes of the BESS installation and provide commentary on failure effects, mitigation methods, and consequences. The FMEA intends to show failures can be detected and mitigated through system design and that performance criteria required for AHJ approval can be met.

2.1.2 FMEA Subject Elements

The subject of the FMEA is the fire area containing the BESS installation, specifically, the data center Electrical Room. The fire area can be broken into several elements including active protection systems (fire detection, fire suppression, explosion control, etc.) and the BESS installation. The BESS installation can be further broken into battery modules, battery cells, BMS, and integral fire protection systems necessary for the BESS UL 9540 listing.

2.1.3 Failure Mode Definition

This section discusses the various single failure modes required to be addressed in the HMA. All failure modes are assumed to occur during normal operation of the BESS as an uninterruptible power supply. As stated in Section 1.3, the required failure modes are:

+ Thermal runaway condition in a single BESS unit
+ Failure of any battery (or energy) management system or fire protection system within the ESS equipment that is not covered by the product listing failure mode effects analysis (FMEA)
+ Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation smoke detection, fire detection, fire suppression, or gas detection system
+ Voltage surges on the primary electric supply
+ Short circuits on the load side of the stationary BESS
+ Required spill neutralization not being provided or failure of the secondary containment system
    - This failure mode is not applicable to the ESS as lithium-ion technology does not require spill neutralization.

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- A mechanical failure of a nonelectrochemical ESS unit
  - This failure mode is not applicable to the ESS as lithium-ion technology is electrochemical.

2.1.4 Thermal Runaway Condition in a Single BESS Unit

2.1.4.1 Description

The failure mode where a single cell has entered thermal runaway resulting in flames/combustion or production of flammable or explosive gases was investigated.

Thermal runaway is a condition when a battery cell increases its temperature through self-heating in an uncontrollable fashion. This phenomenon typically progresses to a point at which the cell's heat generation is higher than the rate it can dissipate, potentially leading to the release of flammable gas, fire, or explosion. Once thermal runaway has started in a cell, it cannot be stopped. Thermal runaway can produce a significant amount of volatile gas that causes increased pressure within the cell housing and eventually leads to forceful venting. If there is sufficient oxygen and a competent ignition source, these cell vent gases may ignite.

Thermal runaway can be caused by physical damage (puncture, crushing), electrical issues (deep discharge, overcharging), exposure to elevated ambient temperatures, and manufacturer defects (imperfections, contaminants).

Cells in thermal runaway can cause adjacent cells to also undergo thermal runaway in a phenomenon known as thermal runaway propagation. Cells may cause thermal runaway in adjacent cells through one of several heat transfer mechanisms: 1) conductive heat transfer via direct contact between cells, 2) overcurrent caused by damaged circuitry, 3) impingement of hot or flaming vent gases. Cells may also cause thermal runaway in adjacent cells due to the effects of the cell depressurization (thermally from the fireball or mechanically from the force), or due to the original cell swelling into adjacent cells causing physical damage.

Sustained Cell-to-Cell thermal propagation can lead to four primary hazardous scenarios:

- Rapid ignition of flammable gases, sustained propagation, and resultant full-scale fire.
- Multiple cells venting flammable gases without sufficient temperature for ignition.
- Multiple cells venting flammable gases with delayed ignition leading to a deflagration or explosion.
- Multiple cells venting flammable gases without sufficient temperature for ignition until after flammable gas concentrations have exceeded the Upper Flammable Limit (UFL). This condition can create a hazard known as 'backdraft' or 'flashover' in which opening the BESS enclosure and introducing fresh oxygen can cause deflagration.

2.1.4.2 Barriers

The barriers helping to prevent the thermal runaway failure mode from occurring and escalating to propagating cell failure within a module and unit include:

- <u>Cell and module thermal abuse tolerance</u> is the ability of the cells and modules to withstand thermal abuse without going into failure themselves. The cells, modules, and cabinet units used within the UPS are listed to UL 1642. The cells and modules are listed to UL 1973 to withstand some level of thermal abuse (e.g., high temperature, overcharge).

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- Passive battery cell protection via heat insulating mica sheets. This will effectively slow heat transfer during thermal runaway to neighboring cells. Based on UL 9540A unit level large-scale fire testing results, thermal runaway is not anticipated to propagate past the initiating cell.
- Robust battery management system to detect early signs of thermal runaway and other fault conditions (i.e., irregular temperatures, overcharging, etc.). The BMS will automatically shunt the battery breaker if majorly abnormal conditions are sustained, thus isolating the afflicted BESS.
- Active prompt detection of fire via smoke detection and sprinklers within the fire area. Activation of initiating devices will issue an alarm.
- Active suppression and control of fire via automatic fire sprinkler system.
- Emergency response by the local fire department. When alerted of a fire, the local fire department will perform emergency response actions as indicated by a site Emergency Response Plan.

2.1.4.3 Consequences

While numerous safeguards and barriers will be provided, single cell failures are possible due to manufacturing defects or due to cell aging which could lead to the following consequences:

- The heat generated from thermal runaway of a single cell can cause further cell failures and propagation throughout the module. UL 9540A unit level testing demonstrated thermal runaway to be limited to the initiating cell but can cause venting of adjacent cells.
- Toxic smoke and gases resulting from a full-scale fire event will be at an elevated temperature, causing the gases to rise and dissipate into the large electrical room. While occupants in nearby areas could potentially experience some exposure to released gases, they should be able to adequately evacuate away from the source of smoke and toxic gases.
- Thermal runaway, if stopped in time and limited in damage, will still require investigation and disrupt business continuity operations.

2.1.5 Failure of the BMS or Fire Protection System Not Covered by the Product Listing

2.1.5.1 Description

The failure mode where the battery management system (BMS) fails was investigated. The Samsung Gen-3 136S lithium-ion BESS cabinet BMS actively monitors and balances the voltage, current, temperature, state of charge, and state of health of the battery cells within their designed operating window and the manufacturer's specifications. This BMS failure mode involves failure of the cell/module-level monitoring and control systems, resulting in the inability for automatic shutdown, reporting of adverse conditions, and ability to monitor, balance, or protect the system.

The failure of fire protection systems inherent to the BESS container design will be specifically addressed in independent sections.

2.1.5.2 Barriers

- Routine monitoring of the BMS systems to ensure proper operation and maintenance. In case of BMS faults, the BESS user manual includes multiple troubleshooting and emergency plan methods. The BMS includes means for external communication and ability to be monitored by the building management or fire alarm system.

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- Durability and reliability of the BMS under stressful conditions as proven in UL 1973, UL 1998, and UL 991 listings and tests.
- Cell, module, and unit electrical abuse tolerance via UL 1642 and UL 1973 certifications, proving the ability to withstand some level of electrical abuse (e.g., high temperature, overcharge, over-discharge, high currents).
- System electrical abuse tolerance via UL 9540 certification proving its ability to withstand adverse electrical abuse such as overcharge or dead shorts without failure.
- Passive circuit protection design: Built-in isolated DC-DC architecture of the pods within the UPS unit combined with parallel design reduces electrical fault propagation.

2.1.5.3 Consequences

The failure of the BMS increases the chances of failure and damage at the cell level due to loss of unit temperature and load monitoring. This damage could ultimately lead to a thermal runaway event, which could escalate to venting of the failed cell(s). In any case, the major consequence would be that of thermal runaway which is described in Section 2.1.4.3. Minor consequences would include interruptions in business continuity for repair or maintenance of the BMS.

2.1.6 Failure of a Required Exhaust System

2.1.6.1 Description

The event where a required exhaust system fails was investigated. The IFC and NFPA 855 requires lithium-ion BESS to have an explosion control system in the form of an NFPA 69 explosion prevention system or an NFPA 68 deflagration venting system unless waived by the AHJ. A study on the ESS UL 9540A large-scale fire testing was performed and concluded that cell vent gas accumulation during thermal runaway would not create a global flammability limit exceeding the mixture's 25% LFL. Thus, explosion control is permitted to be waived by the AHJ. However, in the case that explosion control is still required, the exhaust system's failure was investigated. Components of the exhaust system include exhaust fans, dampers, and control interlocks with gas detectors.

2.1.6.2 Barriers

- Routine inspection of the exhaust ventilation system for minor and major faults contribute to hazard mitigation. Once installed, inspection, testing, and maintenance operations must occur in accordance with NFPA 69.
- Monitoring of the gas detection system's integrity as required by NFPA 855. A fault in the system will trigger a trouble signal to the fire alarm system and detection of 10% of the flammable gas LFL will trigger an alarm signal.
- Limited production of combustible vent gases during a fire is supported by large-scale fire testing. Based on test data provided, thermal runaway of one cell will not propagate venting or thermal runaway to adjacent cells. The vent volume of one cell is not enough to produce a combustible environment within the Electrical Room.

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2.1.6.3 Consequences

Since lithium-ion battery technology does not produce toxic or combustible gas during normal operation, this failure mode will only have adverse effects when combined with the unlikely event of a fire involving the BESS. Failure of the exhaust system will not impact BESS health or performance as the systems are independent of each other. The consequences are limited to interruptions in business continuity to perform maintenance on the impaired equipment.

If there is failure in the NFPA 69 exhaust equipment (i.e., fans are not functioning) during a fire, the consequences will be damage to the BESS unit and surrounding equipment due to smoke generation. Based on UL 9540A Cell Level test results and Unit Level cell-to-cell behavior during thermal runaway, a deflagration event is not anticipated to occur once the flammable gas is outside the cabinet. In such a scenario, the automatic fire detection devices (i.e., smoke detectors and sprinklers) will be actively working for prompt detection and intervention by first responders in accordance with the Emergency Response Plan prepared by the building owner.

2.1.7 Failure of the Smoke, Fire, or Gas Detection System

2.1.7.1 Description

The failure of the smoke detection system provided may result in a failure to provide prompt notification to the fire alarm control panel (FACP) and central station in case of a fire. Failure of the smoke detection system can be due to faulty wiring, loss of power to devices, or removal/tampering of devices.

Note, an explosion control analysis has been performed which supports omission of deflagration prevention and gas detection. However, if gas detection were provided for explosion control, it would have the same failure causations as the smoke detection system.

2.1.7.2 Barriers

+ Design and performance reliability provided in the initial design of the system. Fire detection and alarming will be designed in accordance with NFPA 72.
+ Installation and commissioning safeguards to ensure the design objectives are met. NFPA 72 contains stringent requirements for acceptance testing to ensure releasing devices and installations operate as intended and meet the approved design. Where multiple systems are interlocked, integrated testing in accordance with NFPA 4 must be conducted and documented prior to occupancy.
+ Routine inspection of the smoke detection system for minor and major faults contributes to hazard mitigation. Once installed, inspection, testing, and maintenance operations must occur in accordance with NFPA 72 and the manufacturer’s specifications.
+ Monitoring the smoke detection system’s integrity will result in a prompt response for investigation by building personnel.

2.1.7.3 Consequences

During normal operations, the failure of the fire detection system would have minor consequences in terms of business continuity due to interruptions for system repair, maintenance, and testing.

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This failure mode will only have adverse effects when combined with the unlikely event of a fire within the Electrical Room. If the smoke detection system fails during a fire, the fire may not be detected in its incipient stage, thereby allowing it to grow before personnel are notified. A prolonged fire within the Electrical Room could cause thermal runaway of cells, accumulation of combustible gases, and the remote possibility of a deflagration event.

However, since the smoke detection system's integrity is monitored by the fire alarm system, a trouble signal will be produced at the FACP for investigation which would allow for manual detection of any fire. Each BESS cabinet's BMS would also be able to work independently of the smoke detection system and can alert if abnormal cell temperatures due to a fire are detected.

Similar to smoke detection, if gas detection is provided as part of explosion control it will only have adverse effects during a fire or cell venting. As a result, the explosion control system would not automatically activate, though, conditions within the Electrical Room are not expected to reach untenable levels based on an explosion control analysis utilizing large-scale fire testing data. The smoke detection and sprinkler system would still be available for prompt detection and suppression.

2.1.8 Failure of the Fire Suppression System

2.1.8.1 Description

The failure of the suppression system protecting the dedicated electrical room was investigated. The room will be protected by an overhead automatic sprinkler system designed to at least NFPA 13 Extra Hazard criteria.

2.1.8.2 Barriers

+ Design and performance reliability provided in the initial design of the systems. The flow density and operating area of the sprinkler system will be designed in accordance with NFPA 13 and NFPA 855.
+ Installation and commissioning safeguards to ensure the design objectives are met. NFPA 13 contains stringent requirements for acceptance testing to ensure releasing devices and installations operate as intended and meet the approved design. Where multiple systems are interlocked, integrated testing in accordance with NFPA 4 shall be conducted and documented prior to occupancy.
+ Routine inspection and monitoring of all valves and system components in accordance with NFPA 13 and NFPA 25.

2.1.8.3 Consequences

During normal operations, the failure of the fire suppression system would have minor consequences in terms of business continuity due to interruptions for system repair, maintenance, and testing.

This failure mode will only have adverse effects when combined with the unlikely event of a fire within the Electrical Room. Under this failure mode all other active protection systems including cabinet BMS and smoke detection will be available. BMS detection of abnormal cell conditions and smoke detection of an incipient fire will occur prior to sprinkler system activation, especially since the sprinkler system is interlocked with the smoke detection system. In such cases, a fire would be detected, the facility fire alarm will activate to initiate occupant egress, and first responders will be dispatched per central station monitoring. The electrical rooms are also

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enclosed with 2-hour fire resistance rated barriers to ensure containment until the fire department arrives. The top consequence would be that of thermal runaway which is described in Section 2.1.4.3.

2.1.9 Voltage Surges on the Primary Electric Supply System

2.1.9.1 Description

The failure mode where the primary electric supply undergoes voltage surges was investigated. In the event of a voltage surge from the primary electric supply, the BMS will discontinue charging the cell.

2.1.9.2 Barriers

The barriers preventing the voltage surge failure mode from escalating include manual disconnects, voltage monitoring, BMS control, automatic system shutdown, passive circuit protection/design, and system electrical abuse tolerance.

Even under the condition that the voltage monitoring and BMS controls cease to function, overcurrent protection is also provided for the primary electrical supply as well as at the unit and module level.

Additionally, the cell, module, and unit have been tested for electrical resilience in accordance with UL 1642 and UL 1973. Thus, the UPS has sufficient electrical abuse tolerance to reduce the likelihood of fires and/or deflagrations under voltage surge conditions.

2.1.9.3 Consequences

If the charging voltage is increased beyond the recommended maximum cell voltage, excessive current could flow, giving rise to lithium plating and cell failure. Allowing the cell voltage to fall below certain limits by over-discharging or storage for an extended period results in the progressive breakdown of the electrode materials, ultimately resulting in a short circuit between the electrodes. Cell abuse due to hazardous voltage conditions may damage the cells and lead to a thermal runaway event. The consequences of a thermal runaway event are described in Section 2.1.4.3.

2.1.10 Short Circuits on the Load Side of the ESS

2.1.10.1 Description

The failure mode where there is a short circuit on the load side of the UPS was investigated. Hazardous high current conditions may be due to issues from the inverter or internal interconnections.

2.1.10.2 Barriers

The barriers preventing the short circuit failure mode from escalating include monitoring for discharge short circuit current faults, BMS control, passive circuit protection and design, and system electrical abuse tolerance. Even under the condition that the voltage monitoring and BMS controls cease to function, overcurrent protection is also provided for the primary electrical supply as well as at the unit and module level.

Additionally, the cell, module, and unit have been tested for electrical resilience in accordance with UL 1642 and UL 1973. Thus, the UPS has sufficient electrical abuse tolerance to reduce the likelihood of fires and/or deflagrations under short-circuit conditions.

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The UPS electrical system is designed with fusible links between the DC power supply and each battery rack to prevent overcurrent. The electrical system is also designed with circuit breakers and fuses throughout. The BMS system monitors overcurrent and will display warning signals when the charging or discharging current of batteries is outside of the permissible limit.

2.1.10.3 Consequences

Cell abuse due to hazardous overcurrent conditions can lead to a rapid thermal runaway event. The consequences of a thermal runaway event are described in Section 2.1.4.3.

UL 9540 provides specific construction requirements to prevent short circuits and ensures the durability of the system to withstand short circuits when they do occur. Without this listing, the construction and reliability of the electrical system are unknown.

In a best-case scenario, the short circuit will cause a fusible link or circuit breaker to trip, cutting power to the specific rack. Cutting power will reduce the energy draw and sequentially reduce excess heat generation. The BMS system should alert operators and isolate the affected battery modules.

Unlisted electrical equipment is considered to have a higher probability of failing than listed equipment. In the worst-case scenario, the circuit breaker fails to activate in a timely manner, and the batteries continue to generate heat due to excess energy draw. Without timely manual intervention, this could ultimately lead to a thermal runaway event. The consequences of a thermal runaway event are described in Section 2.1.4.3.

2.2 PERFORMANCE CRITERIA QUALITATIVE ASSESSMENT

A qualitative assessment was performed on the various performance criteria that the IFC and NFPA 855 require the installation to meet in the presence of fault conditions regarding the lithium-ion batteries. These qualitative assessments substantiate compliance with the seven (7) acceptance criteria discussed in Section 1.4. For convenience, the criteria are listed below:

1. Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified.
2. Fires and products of combustion will not prevent occupants from evacuating to a safe location.
3. Suitable deflagration protection is provided where required.
4. Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the permissible exposure limit (PEL) in the area where the ESS is contained.
5. Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes during the time deemed necessary to evacuate from that area.
6. Flammable gases released during charging, discharging, and normal operation will not exceed 25 percent of the LFL.
7. Flammable gases released from batteries during fire, overcharging and other abnormal conditions shall not create an explosion hazard that will injure occupants or emergency responders.

Note, the criteria above were qualitatively assessed for an indoor installation and assuming the installation design is compliant with the governing fire and building codes of the project site. In cases where the proposed

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BESS installation does not comply with NFPA 855 or the IFC, whichever is applicable, these performance criteria will require re-evaluation.

2.2.1 Criteria 1: Fire Containment to Unoccupied ESS Room

The UPS skids will be located within a 2-hour fire resistance rated enclosure (Electrical Room). Each Electrical Room will be protected by automatic smoke detection and an automatic sprinkler system. If a fire were to occur within the room, it will be promptly detected by the smoke detection system, send a fire alarm signal to the building FACP, and alert the central monitoring station to dispatch first responders. If the fire persists, the sprinkler system will activate to cool the room, BESS cabinets, and contain the fire until fire department intervention. Based on the provided active and passive protection systems, a fire within the BESS room will be contained for at least 2 hours.

2.2.2 Criteria 2: Occupant Egress

The UPS skids will be located within a 2-hour fire resistance rated enclosure that is not typically occupied. In the event that building personnel are in the Electrical Room of fire origin, there is egress out to the building exterior or to the adjacent 2-hour fire resistance rated Electrical Room. As described in Criteria 1, the fire would be contained for the duration of the room's 2-hour fire barriers which allows ample time for building occupants to evacuate safely and without disruption due to the fire.

2.2.3 Criteria 3: Suitable Deflagration Protection

A study on the ESS UL 9540A large-scale fire testing was performed and concluded that cell vent gas accumulation during thermal runaway would not create a global flammability limit exceeding the mixture's 25% LFL. Thus, explosion control is permitted to be waived by the AHJ. It is understood that explosion control will not be provided within UPS rooms.

2.2.4 Criteria 4: Toxic Gas Release During Normal Operations

Under normal conditions, lithium-ion battery technology is not known to vent toxic gases while operating. This is reinforced by NFPA 855 and the IFC not requiring lithium-ion batteries to have an exhaust ventilation system unlike their lead-acid or nickel battery counterparts. As such, under normal operating conditions, toxic gas concentrations will not exceed the PEL.

2.2.5 Criteria 5: Toxic Gas Release During Fires

It is known that toxic gases may be released as products of combustion during lithium-ion battery fires. However, UL 9540A unit level test data shows cell venting and thermal runaway is limited to the initiating cell which would vent freely into the Electrical Room's large volume. Accumulation of gas concentrations to toxic levels is not anticipated within the global Electrical Room environment and would not exceed IDLH levels in the immediate vicinity or in means of egress routes.

2.2.6 Criteria 6: Flammable Gas Release During Normal Operations

Under normal conditions, lithium-ion battery technology is not known to vent flammable gases while operating. This is reinforced by NFPA 855 and the IFC not requiring lithium-ion batteries to have an exhaust ventilation

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system unlike their lead-acid or nickel battery counterparts. As such, under normal operating conditions, flammable gases will not exceed 25% of the LFL.

2.2.7 Criteria 7: Mitigation of Explosion Hazards During a Fire and Abnormal Conditions

Similar to Criteria 3. A study on the ESS UL 9540A large-scale fire testing was performed and concluded that cell vent gas accumulation during thermal runaway would not create a global flammability limit exceeding the mixture's 25% LFL. Thus, explosion control is permitted to be waived by the AHJ. It is understood that explosion control will not be provided within UPS rooms.

3.0 Recommendations for Approval

The HMA demonstrates compliance given that the conditions stated in Section 1.3 of this report are provided. These acceptance criteria are subject to the fire safety recommendations to be implemented and are summarized in Table 3-1.

Table 3-1: Approval of HMA

Condition	Y / N	Comment
1. Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified.	Y	Due to the cumulative efforts of active and passive protection systems present in the Electrical Room Battey Room, fires will be contained for the 2-hour fire barrier duration.
2. Fires and products of combustion will not prevent occupants from evacuating to a safe location.	Y	Egress to the building exterior is readily available with paths offering minimal interaction with the Electrical Room (assumed location of fire origin). Additionally, the rooms are provided with passive fire barriers to provide ample time for evacuation.
3. Suitable deflagration protection is provided where required.	N/A	It is understood that deflagration prevention will not be provided within the Electrical Room based on analysis of the BESS large-scale fire testing which demonstrates battery gases are limited to below 25% of the LFL with the postulated thermal runaway event.

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Condition	Y / N	Comment
4. Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the permissible exposure limit (PEL) in the area where the ESS is contained.	Y	Li-Ion batteries do not release toxic gas during charging, discharging, and normal operation.
5. Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes during the time deemed necessary to evacuate from that area.	Y	Based on UL 9540A unit level test data showing limited gas release during induced thermal runaway, accumulation of gas concentrations to toxic levels is not anticipated within the global Electrical Room environment and would not exceed IDLH levels in the immediate vicinity or in means of egress routes.
6. Flammable gases released during charging, discharging, and normal operation will not exceed 25 percent of the LFL.	Y	Li-Ion batteries do not release flammable gas during charging, discharging, and normal operation.
7. Flammable gases released from batteries during fire, overcharging and other abnormal conditions shall not create an explosion hazard that will injure occupants or emergency responders.	Y	It is understood that deflagration prevention will not be provided within the Electrical Room based on analysis of the BESS large-scale fire testing which demonstrates battery gases are limited to below 25% of the LFL during abnormal events such as thermal runaway.

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4.0 Conclusions

The Aligned Apex data centers will utilize Eaton's 9395XC and Samsung Gen-3 136S lithium-ion BESS cabinets as a UPS. BESS installed within the building's Electrical Rooms will be on skids and will exceed the code prescribed maximum allowable quantity for lithium-ion technology, 600 kWh. Accordingly, this HMA serves as justification for exceeding the maximum allowable quantity by addressing failure modes of the BESS and BESS room protection features.

Failure modes required to be addressed within the HMA were investigated through an FMEA, and a qualitative consequences-based analysis was carried out to show how provided barriers would deal with the failure modes and what consequences may develop.

Based on the HMA, the lithium-ion BESS cabinet installations within the data center are adequately protected through active and passive protection systems and are inherently resistant to thermal runaway propagation as shown in large-scale fire testing. The installation meets the performance criteria required by code and an increase in allowable quantity is recommended to be approved by the AHJ.

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5.0 References

The following references were used in the development of this report:

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6.0 Tables

Table 1-1: IFC and NFPA 855 HMA Installation Conditions ... 6

Table 1-2: IFC and NFPA 855 HMA Fault Conditions ... 7

Table 1-3: IFC and NFPA 855 HMA Approval Criteria ... 8

Table 3-1: Approval of HMA ... 18

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