Joyce L. Connery, Chair
Thomas A. Summers, Vice Chair

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

August 13, 2024

The Honorable Jennifer Granholm
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Granholm:

In recent years, several U.S. Department of Energy (DOE) defense nuclear facilities have assessed the use of large lithium-ion batteries for applications ranging from heavy vehicles to emergency power backup systems. In 2021, the management and operating contractor at the Nevada National Security Site (NNSS) replaced the uninterruptible power supply (UPS) for the Device Assembly Facility (DAF) with a new system using large format lithium-ion batteries. This represents a first-of-its-kind use of a lithium-ion-battery energy storage system to serve a safety significant function in a DOE defense nuclear facility. The UPS is designated as a safety significant system because it is credited to supply power to the emergency lighting system, which is needed to ensure that operations involving high explosives can be placed in a safe and stable configuration if electrical power is lost.

The Defense Nuclear Facilities Safety Board (Board) completed its safety review of the new lithium-ion battery UPS at DAF. The Board found that DOE has not issued requirements nor provided guidance to assess the hazards and identify safety controls necessary for the use of lithium-ion energy storage systems. The Board recognizes the advantages that lithium-ion batteries have over conventional lead-acid batteries; however, lithium-ion battery technology has inherent safety risks. Because of their unique chemistry, lithium-ion battery fires are difficult to suppress and extinguish. Fires involving lithium-ion batteries have the potential to threaten high-hazard operations, special nuclear material, and facility worker safety at DAF.

The Board also identified specific safety concerns with the lithium-ion battery UPS at DAF including: (1) inadequate hazard analysis for loss of emergency lighting in the safety basis, a credible scenario due to the co-location of the UPS with high energy equipment in the electrical room; (2) incomplete assessment of battery failure leading to thermal runaway, a susceptibility indicated by third-party testing; and (3) inadequate fire protection measures to mitigate the effects of a fire involving the batteries. These safety issues are discussed further in the enclosed staff report.

Pursuant to 42 United States Code §2286b(d), the Board requests a briefing and written response within 90 days of receipt of this letter addressing any actions DOE has taken or plans to take to:

- Develop or adopt requirements and provide guidance on hazard analysis and controls for lithium-ion battery energy storage systems at defense nuclear facilities; and

- Address the identified safety issues with the lithium-ion battery UPS now installed at DAF.

Sincerely,

Joyce L. Connery
Chair

Enclosure

c: The Honorable Jill Hruby, Administrator, National Nuclear Security Administration (NNSA)
Mr. Todd Lapointe, Director, Office of Environment, Health, Safety and Security
Dr. David Bowman, Manager, NNSA Nevada Field Office
Mr. Joe Olencz, Director, Office of the Departmental Representative to the Board

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Report

June 14, 2024

Use of Lithium-Ion Batteries for Uninterruptible Power Supplies in the Device Assembly Facility at Nevada National Security Site

Summary. The management and operating contractor at Nevada National Security Site (NNSS), Mission Support and Test Services, LLC (MSTS), replaced the uninterruptible power supply (UPS) system at the Device Assembly Facility (DAF) in 2021. The replacement UPS is supplied by lithium-ion batteries while the legacy UPS used lead-acid batteries. This represents the first installation of a lithium-ion-battery energy storage system to serve a safety significant function at a U.S. Department of Energy (DOE) defense nuclear facility.

A staff review team from the Defense Nuclear Facilities Safety Board (Board) assessed the UPS replacement to determine whether MSTS appropriately identified hazards and effective safety controls for the unique hazards of large-format lithium-ion batteries. In addition to substantial document reviews, the staff team discussed its safety concerns with personnel from the National Nuclear Security Administration's Nevada Field Office and MSTS. The staff team identified several safety issues with the new UPS system:

- DOE has not issued requirements nor provided guidance for analyzing and mitigating hazards associated with lithium-ion batteries used in energy storage systems.
- The DAF safety basis does not adequately characterize the hazard posed by the new UPS. Due to the configuration and physical arrangement of the UPS system, a single high energy event (e.g., fire) in the electrical equipment room could compromise both normal and emergency lighting in buildings where high explosive operations are authorized.
- MSTS provided third-party testing data to NNSA that indicated the new lithium-ion UPS batteries are susceptible to thermal runaway.
- The existing sprinkler system is not adequately sized to suppress a worst-case fire involving the UPS batteries.

Background. In 2018, MSTS initiated replacement of the legacy UPS system that was beyond its service life with a new UPS system that uses lithium-ion batteries. This represents DOE's first installation of a lithium-ion-battery energy storage system in a safety significant system. MSTS installed three UPS units (one of which is safety significant), consisting of 14 cabinets each containing 20 Valence U27-XP24 lithium iron phosphate battery modules. The aggregate capacity of the UPS systems is 515.2 kilowatt hours (kWh)—or about the equivalent of between 6–8 common electric vehicles.[1] The UPS-400-3 unit is designated as a safety significant system because it is credited to supply power to the emergency lighting system, which is needed to ensure that operations involving high explosives can be placed in a safe and stable configuration if electrical power is lost. The safety significant emergency lighting system decreases the likelihood of a high explosive violent reaction event during operations.

The staff team transmitted a review agenda to the Nevada Field Office and MSTS on October 17, 2023, and held a teleconference with project personnel on November 13, 2023. The staff team presented its preliminary staff observations to NFO and MSTS on March 11, 2024. MSTS personnel provided feedback on March 21, 2024.

Discussion. The staff team reviewed the safety basis and design documents associated with the UPS replacement project, including the system design description [1], commercial-grade dedication procurement documents, the documented safety analysis (DSA) [2], fire hazards analysis [3], and other supporting documents. Based on the review of these documents, the staff team identified the following safety issues.

Lack of DOE Requirements and Guidance on Lithium-Ion Batteries—DOE has not issued requirements and guidance to its contractors on how to analyze and control hazards associated with the use of lithium-ion-battery energy storage systems at defense nuclear facilities. The DAF lithium-ion UPS is a first-of-its-kind use of the technology for a DOE defense nuclear facility. Given the novelty of lithium-ion batteries in the sector, and the unique hazards these batteries present, the lack of specific guidance from DOE places significant responsibility on contractors to analyze, adopt, and apply the most pertinent standards for their projects to adequately assess and control these hazards. This similarly creates challenges for safety basis approval personnel in DOE field offices.

While DAF represents the first deployed use of this technology, other sites and facilities are analyzing lithium-ion batteries for applications including energy storage and electric vehicles. For example, in a report produced in 2022, Sandia National Laboratories studied the safety of lithium-ion batteries for potential use in heavy electric vehicles at the Waste Isolation Pilot Plant [4]. Then in 2023, National Nuclear Security Administration personnel identified significant challenges with using lithium-ion batteries for a UPS system at the Principal Underground Laboratory for Subcritical Experimentation at NNSS, in part, due to the well-documented phenomena of thermal runaway events [5].

Several consensus standards and guidance documents regarding the safety and hazards associated with lithium-ion battery energy storage systems were available for reference between 2018 and 2019 when MSTS was planning the UPS replacement. These include:

- In May 2018, DOE's Office of Electricity Delivery and Energy Reliability issued a report [6] that provided information on efforts by consensus standard organizations

[1] Based on average electric vehicle battery capacity derived from https://ev-database.org, accessed June 12, 2024.

focused on energy storage system safety, including lithium-ion-battery storage systems.

- In 2017, the National Fire Protection Association (NFPA) issued the initial draft of Standard 855, *Standard for the Installation of Stationary Energy Storage Systems* [7] for public review. NFPA 855 offers the most comprehensive criteria for fire protection of lithium-ion-based energy storage systems, including minimum hazard mitigation requirements. NFPA issued the final standard in 2019.

- In 2017, Underwriters Laboratories published UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems* [8], to develop a methodology for conducting fire tests of battery energy storage systems.

- In 2018, the International Fire Code [9] and the NFPA 1, *Fire Code* [10], introduced size, separation, and maximum allowable quantity requirements to address uncertainties with thermal runaway and fire propagation in battery energy storage systems.

To ensure safe implementation of the technology, DOE needs requirements and guidance for performing hazard analyses and employing safety control strategies for large format lithium-ion batteries used at its defense nuclear facilities—this could be accomplished by adopting consensus standards or developing its own guidance.

Inadequate Hazard Analysis in DAF Safety Basis—The Board's staff team found that the safety significant emergency lighting system is operating at increased risk because its credited power supply, UPS-400-3, does not meet longstanding physical and electrical separation criteria to protect it from common-cause failure. As such, a single high energy event (e.g., fire) in the electrical equipment room could compromise both normal and emergency lighting.

The UPS electrical configuration and physical location is contrary to the guidance and requirements in NFPA 110, *Standard for Emergency and Standby Power Systems* [11], and DOE Order 420.1C, *Facility Safety* [12]. The code of record for the DAF emergency lighting system is NFPA 101, *Life Safety* [13]. NFPA 101 requires equipment that provides power to emergency lighting systems to be installed, inspected, tested, and maintained in accordance with NFPA 110. Per NFPA 110, the rooms housing emergency power supply system equipment shall be located to minimize the possibility of damage from flooding, firefighting, and material and equipment failures, and consideration shall be given to the location of emergency power supply system equipment to minimize the possibility of damage resulting from interruptions of the emergency power source. DOE Order 420.1C [12] specifies that for safety structures, systems, and components (SSC), interfaces may exist between safety-SSCs and non-safety-SSCs, and these interfaces must be evaluated to identify failures (direct or indirect) that would prevent safety-SSCs from performing their intended safety function.

Contrary to NFPA 110 [11] and DOE Order 420.1C [12], the credited UPS-400-3 and emergency lighting could be compromised because of several accident scenarios that can occur in the electrical equipment room. The electrical equipment room contains high energy equipment (e.g., switchgear, multiple UPS systems) and other potential initiating sources of fire hazards. Thermal energy from a fire in a non-safety-SSC could affect adjacent safety-SSCs. The safety-significant UPS-400-3 unit is collocated with high energy electrical equipment and is located within the area of influence of the fixed automatic fire suppression system. Water from activation of sprinkler heads from a fire involving non-safety SSCs could damage or cause adjacent safety-SSC UPS systems to shut down. In addition to this physical arrangement, the safety significant UPS-400-3 shares electrical circuitry with non-safety equipment loads. The physical configuration of the UPS makes the loss of normal lighting concurrent with loss of emergency lighting a credible accident scenario.

The DAF DSA [2] does not analyze consequences associated with the loss of emergency lighting concurrent with the loss of normal power. DOE Standard 3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [14], requires the safety basis to evaluate all accident conditions to which an operation can be subjected.[2] The DSA [2] includes hazard scenarios involving impacts to normal lighting and scenarios involving impacts to the UPS; however, the DSA does not analyze the loss of normal lighting concurrent with the loss of emergency lighting that is powered by the credited UPS-400-3. This accident scenario is important because a single high energy event (e.g., fire) in the electrical equipment room could compromise both normal and emergency lighting. Such an event could leave some areas where high explosive operations may be performed without sufficient lighting and could prevent the safe suspension of assembly activities involving high explosive operations.

DAF is equipped with alternate safety significant emergency lighting in the form of battery backup tubes designed to operate upon a loss of normal power. These backup tubes would also be available upon loss of emergency power supplied by UPS-400-3. However, following discussions with MSTS personnel, the staff team understands that the battery backup lighting tubes are not installed in all areas where high explosive operations are authorized.

Testing Indicates Potential for Thermal Runaway—Testing by an accredited third-party laboratory indicates that the DAF UPS lithium-ion batteries could experience thermal runaway, a phenomenon in which a lithium-ion battery cell enters an uncontrollable, self-heating state. Under normal operating conditions, heat (from electricity) can dissipate from the cell. However, in thermal runaway, the lithium-ion cell generates heat much faster than the rate at which heat can dissipate from the cell. This may lead to fire, explosion, and generation of toxic and flammable gas.

In June 2019, MSTS completed an unreviewed safety question process review of the design [15] for the UPS replacement project and a subsequent change notice (CN10) to the DSA. MSTS concluded that the new UPS system did not introduce any new or different hazards from those already analyzed in the safety analysis. The fire hazards analysis [3] states that the Valence U27-24XP lithium iron phosphate batteries used in the UPS do not experience thermal runaway. The fire hazards analysis supports this statement using the battery manufacturer’s data sheet [16]. The staff team found no objective evidence that MSTS validated this information prior to procuring the batteries in 2019. This is concerning because testing performed in 2020

---

[2] MSTS applied DOE Standard 3009-94 to the UPS replacement project when it determined the project did not meet criteria for application of DOE Standard 3009-2014. Both versions include the same basic requirement.

per UL 9540A, *Battery Energy Storage System Test Method* [8], suggests that thermal runaway is a credible hazard.

UL9540A is a test methodology that determines the capability of a battery technology to undergo thermal runaway and then evaluates the fire and explosion hazard characteristics of battery energy storage systems that demonstrate a capability to undergo thermal runaway. The test method involves a series of progressively larger fire tests, beginning at the cell level and progressing to the module level, unit level, and finally the installation level. Each test generates specific data used to evaluate thermal runaway characteristics, fire propagation, and adequacy of the fire suppression system design, respectively.

In October 2020, the UPS vendor, LiiON LLC (LiiON) contracted the Canadian Standards Association (CSA) Group to conduct UL9540A fire testing on the lithium iron phosphate cells (ANR26650M1B) that make up the Valence U27-XP24 batteries used in the system installed at DAF. CSA Group is a nationally recognized testing laboratory in the U.S. and an accredited certification organization by the Standards Council of Canada.

According to the resultant test report [17], CSA Group successfully induced thermal runaway in the ANR26650M1B cells. Specifically, UL9540A cell level testing results showed hydrocarbon gas venting between 158.6 and 161°C, and thermal runaway between 170.8 and 179.5°C. Because thermal runaway was at the cell level, the UL9540A testing method would require testing of the U27-XP24 battery at the module level to determine if thermal runaway is contained by the module design. During an interaction with the staff team held on November 13, 2023, MSTS personnel indicated that module testing would be conducted in 2023. However, as of March 11, 2024, MSTS could not verify whether module testing of the U27-24XP battery had been performed. MSTS has offered no further information on the status of the module test or whether the test will be performed. Without successful module level testing, the UL9540A results suggest that the DAF UPS lithium-ion batteries could undergo thermal runaway.

Existing Fire Suppression System is Inadequate—The current fire sprinkler system is not adequately sized to suppress, extinguish, or otherwise mitigate the effects of a worst-case fire involving the UPS lithium-ion batteries. The sprinkler system was originally established as a pipe schedule system around 1985. According to the fire hazards analysis, based on subsequent hydraulic calculations, the design of the sprinkler system in the electrical equipment room where MSTS installed the lithium-ion UPS system appears to have been based on an ordinary hazard classification as defined in the 2010 edition of NFPA 13, *Standard for the Installation of Sprinkler Systems* [18]. Specifically, the sprinkler design density for ordinary hazard is 0.15 gallons per minute (gpm) per square foot (ft^2) over a minimum design area of 1,500 ft^2. Per the standard, this density is suitable for rooms or areas where contents have low combustibility, the quantity of combustibles is moderate, and fires with moderate rates of heat release are expected.

The introduction of UPS lithium-ion batteries presents a new fire hazard that challenges the previous NFPA-13 ordinary hazard classification. The lithium-ion batteries significantly increase the fuel loading and potential heat release rate in the electrical equipment room. In addition, the legacy lead-acid batteries were installed in a separate battery room with a one-hour fire barrier separating it from the electrical equipment room.

For the UPS energy storage system, NFPA 855 [7] requires a sprinkler system installed in accordance with NFPA 13 (or equivalent standard) with a minimum sprinkler system design density of 0.3 gpm/ft^2 over the lesser of either a 2500 ft^2 design area or the entire room housing the lithium-ion battery UPS system. Per NFPA 13 [18], this higher design density of 0.3 gpm/ft^2 equates to an extra hazard classification, which is defined for areas where combustibility of contents is very high and rapidly developing fires with high rates of heat release are possible.

NFPA 855 [7] is not the code of record for DAF; instead, MSTS documentation references guidance from the Fire Industry Association (FIA) [19] for the UPS replacement. FIA guidance provides information on issues related to the use of lithium-ion batteries, how fires start in batteries, and how they may be detected, controlled, suppressed, and extinguished. For lithium-ion energy storage systems, FIA guidance recommends a sprinkler system design with an application density of 12.2 liters/minute/m^2 and an assumed area of operation of 230 m^2. The staff team noted that this design specification is equivalent to the 0.3 gpm/ft^2 over 2500 ft^2 required by NFPA 855.

Despite MSTS documentation referencing the FIA guidance, the sprinkler system in the electrical equipment room does not meet the minimum design requirements in NFPA 855 [7] or the FIA guidance document [19]. MSTS did not formally evaluate the adequacy of the sprinkler design or otherwise determine where vulnerabilities exist in the protection measures for the lithium-ion battery UPS system. MSTS personnel did not dispute the staff team's findings but contended that the fire suppression system is adequate to mitigate a lithium-ion battery UPS fire in the electrical equipment room.

At the conclusion of the staff team's review in March 2024, MSTS had not committed to revisiting the hazard analysis in the fire hazard analysis associated with a lithium-ion battery fire or reevaluating the sprinkler system in the electrical equipment room. MSTS should analyze the fire protection system to determine the need for compensatory measures and corrective actions.

Conclusion. The Board's staff team identified several safety issues with the UPS replacement in DAF including the lack of physical and electrical separation of the UPS system, high explosive operating areas that are not equipped with alternate emergency lighting tubes, and insufficient fire suppression to mitigate fires involving the UPS lithium-ion batteries. These safety issues remain unaddressed.

The staff team recognizes the advantages that lithium-ion batteries have over conventional lead-acid batteries; however, lithium-ion battery technology has inherent safety risks. The new UPS system uses large-format lithium-ion batteries that pose unanalyzed hazards to operations at DAF.

Because of their unique chemistry, lithium-ion battery fires are difficult to suppress and extinguish. Fires involving lithium-ion batteries have the potential to threaten high-hazard operations, special nuclear material, and facility worker safety at DAF. The Board's staff team concludes that it would be appropriate for DOE to provide requirements and guidance to evaluate and mitigate hazards associated with energy storage systems that use lithium-ion batteries in defense nuclear facilities.

References

[1] Mission Support Test Services, LLC, *Device Assembly Facility System Design Description Uninterruptible Power Supply*, DAF-SDD-UPS, Revision 6, May 2018.

[2] Mission Support Test Services, LLC, *Nevada National Security Site Device Assembly Facility Documented Safety Analysis*, DAF-DSA-01, Revision 5, September 2021.

[3] Mission Support Test Services, LLC, *Fire Hazards Analysis of the Device Assembly Facility*, Revision 11, December 2022.

[4] D. Rosewater, Torres-Castro, L., Shoemaker, P., *White Paper on Lithium-Ion Battery Safety for use in Safety Planning at the Waste Isolation Plant*, Sandia National Laboratories, December 2022.

[5] National Nuclear Security Administration, *Final Report Fire Protection Systems Alternatives Analysis for U1a*, October 27, 2023.

[6] Sandia National Laboratories, Pacific Northwest National Laboratories, and Department of Energy Office of Electricity and Energy Reliability, *Energy Storage Systems Safety Roadmap Focus on Codes and Standards*. May 2018. Available: https://www.sandia.gov/app/uploads/sites/213/2022/06/Roadmap-CS-report-May-2018-FINAL-v3.pdf, accessed January 8, 2024.

[7] National Fire Protection Association, *Standard for the Installation of Stationary Energy Storage Systems*, NFPA 855, 2020 Edition, August 25, 2019.

[8] American National Standards Institute and Underwriters Laboratory, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*, ANSI/UL 9540A, November 12, 2019.

[9] International Code Council, *International Fire Code*, 2018 edition.

[10] National Fire Protection Association, *Fire Code*, NFPA 1, 2018 edition.

[11] National Fire Protection Association, *Standard for Emergency and Standby Power Systems*, NFPA 110, 1988 Edition, January 1, 1988.

[12] Department of Energy, *Facility Safety*, DOE Order 420.1C, December 4, 2012.

[13] National Fire Protection Association, *Life Safety Code*. NFPA 101. Quincy, MA.

[14] Department of Energy, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, DOE Standard 3009-94, July 1994.

[15] Mission Support Test Services, LLC, *Unreviewed Safety Question Determination, DAF UPS Replacement Project (End State Design)*, CT-2026 Rev. 2, USQ Number: DAF-19-0284-D, April 2019.

[16] Lithion, *U27-24XP Data Sheet*, https://www.lithionbattery.com/wp-content/uploads/2019/12/Valence-U27-24XP-Data-Sheet-210623.pdf, December 2019.

[17] Canadian Standards Association Group, *UL9540A Report and Test Result: Secondary LiFEPO4 Cell, 3.3V, 2.5Ah*, (Project No. 80036936), October 21, 2020.

[18] National Fire Protection Association, *Standard for the Installation of Automatic Sprinkler Systems*, NFPA 13, 2010 edition, August 26, 2009.

[19] Fire Industry Association, *Guidance on Li-Ion Battery Fires*, December 2020.