SAVER TechNote

July 2023

NUSTL
NATIONAL URBAN SECURITY TECHNOLOGY LABORATORY

The U.S. Department of Homeland Security (DHS) established the System Assessment and Validation for Emergency Responders (SAVER) program to inform emergency responder equipment selection and procurement decisions.

Under the Science and Technology Directorate, the National Urban Security Technology Laboratory (NUSTL) manages the SAVER program, which – with the participation of emergency responders – performs objective operational assessments of commercially available equipment.

SAVER knowledge products provide information about equipment that falls under the DHS Authorized Equipment List (AEL) categories and focus on two questions for the responder community: "What equipment is available?" and "How does it perform?"

To explore the full library, visit SAVER online at www.dhs.gov/science-and-technology/saver-documents-library.

For additional information on the SAVER program, email NUSTL at NUSTL@hq.dhs.gov.

Science and Technology

BATTERIES FOR FIREFIGHTING EQUIPMENT

Rechargeable or single-use batteries power electronic-based firefighting equipment, such as the self-contained breathing apparatus (SCBA). Each battery type has unique characteristics: performance, environmental response, and risk of thermal runaway. Batteries for firefighting equipment align with Authorized Equipment List reference number 10BC-00-BATT, titled "Batteries, All Types, Sizes."

Overview

Single-use batteries, such as alkaline AAs, in firefighting equipment offer low initial costs, are readily available, and enable a degree of power source interoperability due to their standardized shape. Rechargeable batteries, such as lithium-ion (Li-ion) batteries, may cost less over time and can be manufactured to fit a specific device. The various battery chemistries have unique characteristics and applications.

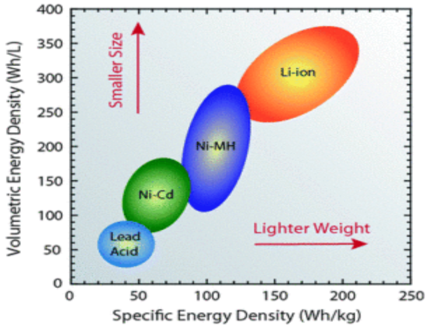

Figure 1 Energy density and specific energy of rechargeable batteries

Image credit: University of Washington Clean Energy Institute [10].

Battery Performance

Capacity refers to both the total charge a battery holds measured in ampere-hours (Ah) and the total energy a battery holds measured in Watt-hours (Wh). Rechargeable batteries, particularly Li-ion batteries, exhibit higher specific energy (energy per unit mass) and energy density (energy per unit volume), making them smaller and lighter than single-use batteries with an equivalent capacity.

Battery capacity, the device's current draw, and charging infrastructure influence battery life and charge time. In SCBAs, powering peripheral devices, such as remote gauges, telemetry equipment, and a Personal Alert Safety System (PASS) device, will reduce battery life.

Cycle life refers to how many times a battery can be fully discharged and then recharged. Capacity decays as a battery approaches its total cycle life. For example, one manufacturer's SCBA Li-ion battery pack has a stated lifespan of 400 cycles [1].

Environmental Response

In both single-use and rechargeable batteries, performance and battery life are affected by operating temperature. At higher temperatures, single-use battery capacity (energy) temporarily increases [2]. Rechargeable batteries charge more quickly but also decay more quickly [3]. Exposure to high temperatures also contributes to thermal runaway risks. In cold temperatures, single-use battery capacity (energy) decreases [2]. while rechargeable batteries experience longer charging times [3]. Reduced power supply from a cold battery decreases device performance. Alternately, forcing a higher current draw in cold temperatures contributes to thermal runaway risks.

Environmental Response (continued)

A study of SCBA power sources measured total discharge times of various battery types in cold conditions (-4°F), room temperature (72°F), and hot conditions (130°F). The study revealed that single-use AA batteries and C cell batteries are more effective at higher temperatures than other battery types examined; a single-use CR123 Lithium battery did not discharge at all in hot conditions [4]. As such, AA and C cell batteries are well-suited for equipment to be used in fire conditions and extreme high temperatures.

Conversely, single-use CR123 Lithium batteries and rechargeable Li-ion batteries are more effective at lower temperatures than other battery types examined [4]. Lithium-based batteries are well-suited for equipment to be used in extreme low temperatures outside of fire conditions.

Table 1 Change in Total Discharge Time Compared to Room Temperature

Battery Type	Avg. Change in Cold Conditions	Avg. Change in Hot Conditions
Single-use AA	-73%	+27%
Single-use C cell	-81%	+71%
Single-use CR123 Lithium	-45%	-100%
Rechargeable Li-ion	-2%	-4%

Thermal Runaway

Thermal runaway occurs when a battery enters an uncontrolled self-heating cycle triggered by abuse or damage, such as penetration, overcharging, or overheating. Thermal runaway reactions include ignition, combustion, and release of toxic gases. Li-ion batteries, which have relatively low temperature ratings, are particularly susceptible to thermal runaway and start this uncontrolled cycle at over 284°F [5].

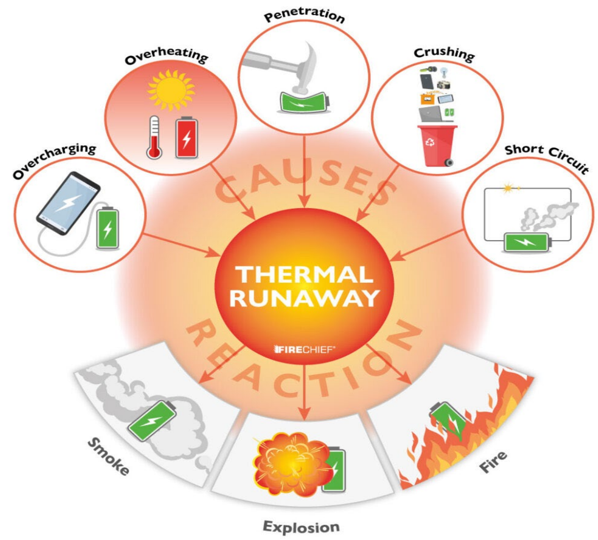

Figure 2 Thermal runaway triggers

Image credit: FireChief [11]

To effectively prevent abuse, operators must install, operate, and maintain batteries according to manufacturer's instructions. This includes using the battery within manufacturer and Underwriters Laboratory (UL) temperature ratings. Shielding the battery lessens the effects of abuse. For example, insulating the battery from external heat increases the time to enter thermal runaway by at least one hour [6].

Relevant Standards/Regulations

Various UL standards, such as UL1642 (Lithium Batteries) [7] and UL2054 (Household and Commercial Batteries) [8], address design and performance requirements for batteries to mitigate the risk of ignition or explosion, which can injure users.

Device-specific standards outline additional requirements for batteries in firefighting equipment. For example, National Fire Protection Association (NFPA) 1981 (Standard on Open-Circuit Self Contained Breathing Apparatus (SCBA) for Emergency Services) lists design requirements for SCBA power sources [9].

References

[1] MSA, "MSA G1 Battery Frequently Asked Questions," 2016.

[2] Energizer, "Alkaline Manganese Dioxide Handbook and Application Manual," 2018. [Online]. Available: https://data.energizer.com/pdfs/alkaline_appman.pdf. [Accessed 2023].

[3] D. Agwu Daberechi, F. Opara, N. Chukwuchekwa, D. Dike and L. Uzoechi, "Review Of Comparative Battery Energy Storage Systems (Bess) For Energy Storage Applications In Tropical Environments," in *IEEE 3rd International Conference on Electro-Technology for National Development*, Owerri, Nigeria, 2017.

[4] Pacific Northwest National Laboratory, "SAVER SCBA Lab Testing Summary," U.S. Department of Energy, 2023.

[5] X. Feng, M. Ouyang, X. Liu, L. Lu, Y. Xia and X. He, "Thermal runaway mechanism of lithium ion battery for electric vehicles: A review," *Energy Storage Materials,* vol. 10, pp. 246-267, 2018.

[6] Det Norske Veritas (USA), Inc. (DNV GL), "Considerations for ESS Fire Safety," DNV GL, New York, NY, 2017.

[7] Underwriters Laboratory, "UL1642 Lithium Batteries," 2020. [Online]. Available: https://www.shopulstandards.com/ProductDetail.aspx?productId=UL1642 [Accessed 2023].

[8] Underwriters Laboratory, "UL2054 Household and Commercial Batteries," 2021. [Online]. Available: https://www.shopulstandards.com/ProductDetail.aspx?productId=UL2054.

[9] National Fire Protection Association, "NFPA 1981 Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services," 2019. [Online]. Available: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1981. [Accessed 2023].

[10] University of Washington Clean Energy Institute, "Lithium-Ion Battery," University of Washington Clean Energy Institute, 2020. [Online]. Available: https://www.cei.washington.edu/education/science-of-solar/battery-technology/. [Accessed 2022].

[11] FireChief, "What causes Lithium-ion battery fires?," FireChief, 2023. [Online]. Available: https://batteryfiresafety.co.uk/what-causes-lithium-ion-battery-fires/. [Accessed 2023].