



IEEE Guide for Batteries for Uninterruptible Power Supply Systems

STANDARDS

IEEE Power and Energy Society

Developed by the
Energy Storage & Stationary Battery Committee

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IEEE Guide for Batteries for Uninterruptible Power Supply Systems

Developed by the

Energy Storage & Stationary Battery Committee
of the
IEEE Power and Energy Society

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IEEE SA Standards Board

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Abstract: Abstract: Various battery systems are discussed so that the user can make informed decisions on selection, installation design, installation, maintenance, and testing of stationary standby batteries used in uninterruptible power supply (UPS) systems. UPS battery charging and converter components relation to the selection of the battery systems is described. Design requirements of the UPS components are beyond the scope of this document. Battery back-up systems for dc-output rectifiers are also beyond the scope of this document.

Keywords: battery system, IEEE 1184™, lithium-ion (Li-ion) batteries, nickel-cadmium (Ni-Cd) batteries, nickel-zinc (Ni-Zn) batteries, uninterruptible power supply, UPS, valve-regulated lead-acid (VRLA), vented lead-acid batteries (VLA)

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Introduction

This introduction is not part of IEEE Std 1184-2022, IEEE Guide for Batteries for Uninterruptible Power Supply Systems.

Our society's increasing dependence on computerized information has resulted in the expanded use of uninterruptible power supply (UPS) systems to improve the integrity of essential power systems. These systems require that stored energy be available to maintain operation. Although energy storage methods such as rotating inertia, hydro, compressed air, thermal, biological, and other technologies are available, batteries remain the preferred and most practical method of energy storage for UPS systems. An array of battery designs and extensive technologies are available to the user. This guide is intended to inform the user of the various battery technologies available and some of the design points to be considered when selecting a battery for UPS applications. Some of the battery design options that result in volumetric efficiency may also result in reduced life. This guide can help the user to become aware of the trade-offs of various designs and operating procedures that can result in optimum battery life.

This guide may be used as a stand-alone document, but for more in-depth information on sizing, installation, and maintenance, the reader is referred to IEEE Std 450™ [B14], IEEE Std 484™ [B15], IEEE Std 485™ [B16], IEEE Std 1106™ [B19], IEEE Std 1187™ [B21], and IEEE Std 1188™ [B22].

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IEEE Guide for Batteries for Uninterruptible Power Supply Systems

1. Overview

1.1 Scope

This guide [provides information](#) ~~discusses various battery systems so that the user can make informed decisions~~ on selection, [sizing](#), installation design, installation, maintenance, and testing of stationary standby batteries used in uninterruptible power supply (UPS) systems [having an ac output](#). ~~This guide describes how the UPS battery charging and converter components can relate to the selection of the battery systems.~~ Design requirements of the UPS components are beyond the scope of this document. ~~Battery back-up systems for dc output rectifiers are also beyond the scope of this document.~~ While this document applies to all UPS systems, it may be impractical to implement some of its guidance and recommendations with small, self-contained systems, such as products intended to back up individual personal computers.

~~This guide divides the available technologies into the following three main categories:~~

- ~~—Vented lead acid batteries (VLA)~~
- ~~—Valve regulated lead acid (VRLA)~~
- ~~—Ni-Cd batteries (Ni-Cd)~~

~~For each category, the technology and the design of the battery are described in order to facilitate user selection. The specific advantages for particular applications are also listed.~~

1.2 Purpose

This guide is intended to assist those involved with batteries ~~battery systems~~ for uninterruptible power supply systems to make informed decisions regarding the topics covered in 1.1 and the rest of the document. ~~Proper design, installation, and maintenance will enable the user to manage the battery system for optimum operation and results.~~

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6, 7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

~~The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.~~

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

~~IEEE Std 1188TM; IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.~~

2. Definitions, acronyms, and abbreviations

2.1 Definitions

For the purposes of this document ~~guide~~, the following terms and definitions apply. The ~~Authoritative Dictionary of IEEE Standards~~ Dictionary Online or IEEE Std 1881TM Terms, Seventh Edition ~~[B2]³~~, should be consulted ~~referenced~~ for terms not defined in this clause.⁸

aging factor: The factor included during battery sizing to compensate for the end-of-life capacity loss.

aqueous electrolyte: An ion-transport medium, which may be immobilized, in which water is the solvent.

battery management system (BMS): A system that includes active functions necessary to control activities such as charging, discharging, thermal management, and safety.

NOTE—A battery management system uses application-specific algorithms to manage a rechargeable battery by monitoring its state, calculating secondary data, reporting that data, protecting the battery, controlling its environment and/ or balancing it.⁹

battery monitoring system: A permanently installed system for measuring, storing, and reporting battery operating parameters.

commissioning: A process that assures that a component, subsystem, or system will meet the intent of the designer and the user.

⁸IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

⁹Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

cycle: A ~~battery~~ discharge and subsequent charge of a battery. ~~followed by a complete recharge.~~ A deep discharge cycle is described as the removal and replacement of 80% or more of the cell's design capacity.

NOTE—This includes a full or partial discharge event followed by a charge.

cycling: The repeated charging and discharging of a ~~storage~~ battery.

NOTE—Some batteries are rated by their ability to withstand repeated, deep discharge cycles.

depth of discharge: The energy ~~ampere-hours~~ removed from a fully charged battery, expressed as a percentage of its rated capacity at the applicable discharge rate.

equalizing charge voltage: A charge, at a level ~~voltage,~~ higher than the normal float voltage, applied for a limited period of time, ~~used~~ to correct inequalities of voltage, specific gravity, or state of charge that may have developed between the cells during service.

equalizing voltage: The voltage at which an equalizing charge is performed.

float charge: A constant-voltage charge applied to a battery to maintain it in a fully charged condition, while minimizing degradation or water consumption.

float service: Operation of a dc system in which the ~~standby battery at a continuous charging voltage selected to maintain a full state of charge and optimize~~ battery spends the majority of the time on float charge with infrequent discharge. ~~life.~~

internal ohmic measurement: A measurement of the electronic and ionic conduction paths within a cell or unit, expressed in terms of conductance, impedance, resistance, or admittance.

internal resistance: The resistance to the flow of electric current within a cell or battery.

NOTE—Used for calculating short-circuit current and sizing conductors. When applied to battery measurements, internal ohmic measurement is preferred.

lead-acid cell: Secondary cell in which the active material of the positive electrode is lead dioxide, the active material of the negative electrode is lead, and the electrolyte is dilute sulfuric acid.

lithium-ion cell (Li-ion): A rechargeable cell in which lithium ions move via an electrolyte from the negative electrode to the positive electrode during discharge and in reverse when charging, and in which the negative electrode is an intercalated lithium compound, rather than metallic lithium.

nickel-cadmium (Ni-Cd) cell: A secondary cell in which the active material of the positive electrode is nickel oxyhydroxide, the active material of the negative electrode is cadmium, and the electrolyte is a dilute solution of potassium hydroxide.

nickel-zinc (Ni-Zn) cell: A secondary cell in which the active material of the positive electrode is nickel oxyhydroxide, the active material of the negative electrode is zinc, and the electrolyte is a dilute solution of potassium hydroxide.

nominal battery voltage: The value assigned to a battery of a given voltage class for the purpose of convenient designation. The operating voltage of the system may vary above or below this value.

~~3.7—**ohmic value:** A value derived from the measurement of a cell's internal resistance, conductance, or impedance; used as one element of determining a battery's state of health.~~

rated capacity: The ~~ampere-hour~~ capacity assigned to a ~~storage~~ cell by its manufacturer for a given discharge rate ~~and time~~, at a specified electrolyte temperature ~~and specific gravity~~, to a given end-of-discharge voltage.

temperature compensation: The adjustment of charging voltage with respect to temperature, normally accomplished using a slope or step function.

thermal runaway: A condition that is caused by a battery charging current or other process which produces more internal heat than the battery can dissipate.

NOTE—The emphasis of this definition is on the presence of excessive internal heat, irrespective of the cause, which could be joule heating and/or high ambient temperature. The consequences of thermal runaway vary by cell chemistry. An increase in current causes an increase in temperature which results in further increase in current until the battery or unit self-destructs.

~~temperature-compensated charging: A charging technique in which battery temperature is measured and the charging voltage is adjusted in proportion to changes in temperature.~~

~~3.10 valve-regulated lead-acid (VRLA) cell: A cell that is sealed with the exception of a valve that opens to the atmosphere when the internal gas pressure in the cell exceeds atmospheric pressure by a pre-selected amount. VRLA cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption.~~

uninterruptible power supply (UPS): A device or system that provides quality and continuity of an ac power source through the use of a stored energy device as the backup power source during any period when the normal power supply is incapable of performing acceptably.

valve-regulated lead-acid (VRLA) cell: A lead-acid cell that is sealed with the exception of a valve that opens to the atmosphere when the internal pressure in the cell exceeds atmospheric pressure by a pre-selected amount. VRLA cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption.

vented lead-acid (VLA) cell: A lead-acid cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated. ~~These batteries are commonly referred to as flooded.~~

NOTE—Vented cell is the preferred term that should be used in place of wet cell or flooded cell.

2.2 Acronyms and abbreviations

ABS acrylonitrile butadiene styrene

AGM absorbed glass mat (separator in a type of VRLA battery/cell)

AHJ authority having jurisdiction

ANSI American National Standards Institute

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

AWG American Wire Gauge

BMS battery management system CFR Code of Federal Regulations

CT current transformer

DOD depth of discharge

EOD end of discharge

IBC[®] International Building Code[®] [B8]^{10, 11}

ICC[®] International Code Council[®]¹²

IEC International Electrotechnical Commission

IFC[®] International Fire Code[®] [B9]¹³

IGBT insulated gate bipolar-junction transistor

IP Internet Protocol

IR infrared

IT Information Technology

GR Ericsson/Telcordia Generic Requirements document

HVAC heating, ventilation, and air-conditioning

LCO lithium cobalt oxide (a Li-ion cell chemistry)

¹⁰IBC and International Building Code are registered trademarks of the International Code Council.

¹¹³The numbers in brackets correspond to those of the bibliography in Annex A.

¹²ICC is a registered trademark of the International Code Council.

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LFP lithium iron phosphate (a Li-ion cell chemistry)

Li-ion lithium-ion (battery/cell family of chemistries)

LMO lithium manganese oxide (a Li-ion cell chemistry)

LTO lithium titanite oxide (a Li-ion cell chemistry)

M monthly

max maximum

MOSFET metal-oxide semiconductor field effect transistor

MTBF mean time between failure

MTS Maintenance Testing Standard

NCA nickel cobalt aluminum (a Li-ion cell chemistry)

NEBS™ Network Equipment—Building System¹⁴

NEC® National Electrical Code® (NFPA 70-2020 [B31])¹⁵

NEMA® National Electrical Manufacturers Association¹⁶

NETA® International Electrical Testing Association

NFPA National Fire Protection Association

Ni-Cd nickel-cadmium (battery/cell)

¹⁴NEBS is a trademark of Ericsson's Telcordia standards division.

¹⁵The NEC is published by the National Fire Protection Association (<https://www.nfpa.org/>). Copies are also available from the Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹⁶NEMA publications are available from the National Electrical Manufacturers Association (<https://www.nema.org/>).

Ni-Zn nickel-zinc (battery/cell)

NMC nickel manganese cobalt (a Li-ion cell chemistry)

nom nominal (voltage)

oc open circuit (voltage)

OSHA Occupational Safety and Health Administration (of the U.S. Department of Labor)

P (strings) in parallel

PBE plastic-bonded electrode (one type of plate construction in Ni-Cd cells)

PC polycarbonate

PIP Process Industry Practices

PP polypropylene

PS polystyrene

PVC polyvinyl chloride

S (cells) in series

SAN styrene-acrylonitrile

SCR silicon-controlled rectifier

SELV safety extra-low voltage

SNMP Simple Network Management Protocol

SOC state of charge

SOH state of health

TCP Transmission Control Protocol

UL[®] Underwriters Laboratories¹⁷

UPS uninterruptible power supply

VLA vented lead-acid

VRLA valve-regulated lead-acid

3. Battery types

3.1 General

Battery types are typically characterized by their general chemistry. For example, stationary batteries can be found as lead-acid, nickel-cadmium, lithium-ion, etc. All batteries will store energy, but the chemistry determines the vast majority of the important considerations and differences, such as cell voltage, mode-of- failure, and service life. The chemistry is also key to the sizing, performance, and maintenance differences. Additionally, within the chemistry, there are often design variations used by manufacturers to optimize the performance for specific applications.

The smallest unit of a battery is the cell, which has the following basic components:

- Container
- Positive plates
- Separators/retainers
- Negative plates
- Electrolyte
- Cover
- Flame arrestor with vent or valve for aqueous chemistries

¹⁷UL publications are available from Underwriters Laboratories (<https://www.ul.com/>).

- Plate straps, terminal posts, and other current-carrying components

These components may be designed and implemented in various ways to optimize performance for specific applications. (See Annex C and Annex D.)

3.2 Performance considerations

Battery designs within each chemistry are often categorized by their discharge times ~~available for the following standby applications:~~

- Long-duration (~~i.e.g.~~, telecommunications or low discharge rate) batteries are designed for applications in which the standby loads are relatively constant current, and the battery is required to supply these loads for a minimum of 3 h. ~~Long duration batteries are characterized by thicker plates.~~
- General-purpose (~~i.e.g.~~, switchgear and control) batteries are similar to the long-duration battery, but have additional design features to reduce internal resistance. ~~improve conductivity.~~ In uninterruptible power supply (UPS) applications, general purpose vented designs are this design is best suited for discharge times of 1 h to 3 h, or duty cycles that include both high-rate discharges and long-duration discharges.
- Short-duration (also known as ~~(i.e., UPS or high-~~ discharge rate) batteries are designed to supply ~~large amounts of~~ power for a relatively short period of time (~~(-Thinner plates-~~ typically less than 1 h, and often designed for 5 min to 15 min of backup). High-rate characterize short duration batteries are the most commonly used. ~~These~~ batteries ~~are best suited~~ for UPS applications ~~requiring reserve times of 1 h or less.~~

In addition to these designs, which typically serve stationary standby or float service applications, there are batteries optimized available for a variety of other applications (such as engine starting [very high-rate], heavy cycling, etc.). Such batteries are rarely used for UPS applications.

Because of the size and cost to provide long-duration backup power, the traditional Information Technology (IT) UPS battery has been historically sized for 15 min or shorter discharge times, with an automatic transition to a generator. Increased confidence in backup standby power systems, such as the diesel engine generator plant, has led to the reduced backup time of the IT UPS stationary battery. This is exemplified in the ever more common selection of a 5 min or less battery run time. There are important considerations and cautions that should be evaluated if such a shortened battery runtime is selected.

Note that changing out a UPS battery from one basic cell chemistry to another generally requires system adjustments in float voltages, boost voltages, alarm threshold settings, maintenance procedures, etc.

3.3 Safety standards

Battery safety is a concern for regulatory bodies and jurisdictions around the world. Therefore, many have imposed rules regarding such things as energy, spacing, etc. For example, the IFC [B9], NFPA 1 [B30], NFPA 70 [B31], NFPA 70E [B32], and NFPA 855 [B34] contain safety restrictions for the various battery chemistries. The relevant codes¹⁸ should be checked for their impact, if any, on the selection of battery chemistry.

3.4 Vented lead-acid (VLA) batteries

3.4.1 General

VLA cells are constructed with the liquid electrolyte completely covering (flooding) the ~~closely spaced~~ plates. The electrolyte maintains uniform contact with the plates. Depending on plate thickness, and ~~(among~~ other factors, the) cells ~~of this design~~ can be designed for a range of discharge times (see 3.2 and ~~provide a very high, short duration current due to their low internal resistance.~~ ~~(See Annex C).~~

¹⁸Model codes can be adopted in whole or in part by local jurisdictions, and they can impose additional requirements or make exceptions. Even when model codes are adopted, they may not be the latest revision.

3.4.2 Voltage characteristics

Average recommended float voltages of VLA cells ~~The fully charged lead acid cell has an open circuit voltage of approximately 2.10 V, which varies as a function of cell specific gravity and temperature. Open circuit voltage increases with specific gravity and decreases with temperature, and typically ranges from 2.06 V/cell to 2.10 V/cell. The float voltages~~ range from 2.15 V/cell to 2. 26 ~~30~~ V/cell, depending on ~~individual cell~~ design, temperature, specific gravity, and manufacturer recommendations. In the rare cases where temperature- compensated charging is used (see 4.4.1) with VLA cells, average voltages may be outside this range.

If VLA cells are equalized, the average recommended equalize voltage ranges from 2.33 V/cell to 2.45 V/cell. During discharge, design end voltages in UPS applications typically range from 1.60 V/cell to 1.75 V/cell.

3.4.3 Construction

Lead-acid batteries are described by their plate construction and the alloying elements (if any) that are used to strengthen the plate structure. Several designs have been created to improve performance characteristics, including cycling and life expectancy. Each design, however, places its own constraints on cell operation. (See C.2 for plate construction.)

3.4.4 Flame-arrestors

After the VLA cell(s) are stationed on a suitable battery rack (either temporarily or permanently) and prior to placing a charge on the cells, shipping plugs should be replaced with the correct flame-arrestors for the container. Flame arrestors allow the exchange of gases between the inside of the cell container and the ambient air without presenting a risk of an unintended flame or spark entering the container and igniting the hydrogen and oxygen gas in the headspace. Flame arrestors are required (see NFPA 70-2020 [B31] for example) and should be periodically inspected (NFPA 70E [B32]).

3.5 Valve-regulated lead-acid (VRLA) batteries

3.5.1 General

VRLA cells are sealed, with the exception of a valve that opens as required to relieve ~~excessive~~ internal pressure. These cells provide a means for recombination of gases to limit water consumption. This is accomplished by allowing oxygen evolved from the positive plate to pass across to the negative, where the recombination reaction occurs. The valve regulates the internal pressure to optimize recombination efficiency; hence, the term *“valve-regulated.”*

VRLA cells are more sensitive to elevated operating temperatures and abusive conditions. In extreme cases ~~such abuse this~~ can lead to ~~can lead to~~ thermal runaway ~~of VRLA batteries.~~ (See ~~5.4.6.3 2; Annex C~~ for further information on recombination heating and thermal runaway of VRLA batteries construction).

3.5.2 Voltage characteristics

Average recommended float voltages of VRLA cells range from 2.20 V/cell to 2.30 V/cell, depending on individual cell design, temperature, specific gravity, and manufacturer recommendations. If temperature-compensated charging is used (see 4.4.1), average voltages may be outside this range. ~~The fully charged VRLA cell has an open circuit voltage of approximately 2.15 V, which varies as a function of cell specific gravity and temperature. Open circuit voltage increases with specific gravity and decreases with temperature, and may range from 2.06 V/cell to 2.17 V/cell. The float voltage ranges from 2.20 V/cell to 2.30 V/cell, depending on individual cell design, temperature, specific gravity, and manufacturer recommendations. If temperature-compensated charging is used (see 4.4.1), average voltages may be outside this range.~~

It is not generally recommended to equalize VRLA cells.

During discharge, design end voltages in UPS applications typically range from 1.60 V/cell to 1.75 V/cell.

3.5.3 Construction

3.5.3.1 General

Construction of VRLA batteries is similar to VLA batteries, but the following subclauses note some differences.

3.5.3.2 Recombination

A VRLA battery utilizes a one-way, pressure-relief valve system to attain a gas “recombinant” mechanism. Normal float charging breaks down water to produce oxygen at the positive plate, which passes through voids in the electrolyte/separator to the negative, where it recombines with hydrogen ions to produce water, thus retaining moisture in the battery and suppressing hydrogen evolution. A small proportion of the float current will unavoidably lead to corrosion of lead in the positive grid to produce lead dioxide. In this case, water has been consumed, but the oxygen is unavailable for recombination and the only possible reaction at the negative plate is hydrogen evolution. This reaction causes a gradual increase in internal pressure, which results in periodic release of hydrogen through the pressure relief valve. The water consumed in this process cannot normally be replaced and there is a gradual dry-out of the cell.

3.5.3.3 Electrolyte immobilization

One of the requirements for effective recombination is that the electrolyte must be immobilized. There are two means by which this can be accomplished, known as *absorbed electrolyte* and *gelled electrolyte*.

3.5.3.3.1 Absorbed electrolyte cells systems

VRLA cells of this design are constructed with a controlled volume of liquid electrolyte contained in a highly absorbent non-woven glass-fiber mat, compressed ~~blotter-like separator, positioned~~ between closely spaced plates.

The topology of this type of VRLA cell generally ~~This non-woven separator~~ distributes the electrolyte uniformly and maintains it in contact with the plate active material, while permitting the passage of oxygen evolved during charging. Cells with absorbed electrolyte technology have inherently low internal resistance and can be designed to provide a very high-rate, short-duration discharge. Because of the use of this non-woven separator material, the topology for this type of VRLA cell is generally referred to ~~current. Cells with absorbed electrolyte are also known as~~ *"absorbed glass mat" (AGM) types.*

3.5.3.3.2 Gelled electrolyte cells ~~systems~~

VRLA cells of this design are similar to vented designs, except that the electrolyte has been immobilized by addition of a paste like gelling agent, hence the common name "gel cell." ~~gelled to immobilize it.~~ They have ~~can provide a high-rate, short-duration current, but because of the~~ higher internal resistance than their AGM counterparts, so they are less frequently used for high-rate, short-duration discharges ~~not as effective as the absorbed electrolyte design.~~ However, the higher thermal conductivity in gelled designs makes them better suited for elevated temperature and high dc bus ripple applications (see Annex I) ~~than equivalent absorbed electrolyte cells.~~ A gelled electrolyte cell is typically heavier and larger than an AGM ~~absorbed electrolyte~~ cell for a given capacity. Gelled electrolyte cells are more resistant to the effects of overdischarge than AGM.

3.5.4 Valves and flame arrestors

Whichever electrolyte immobilization technique is selected, this cell design will employ a pressure relief valve, which has typically been tested for safety (UL 1989 [B40]). This valve is designed to:

- Limit the maximum pressure within the cell, and control the pressure to improve recombination efficiency.
- Prevent the oxygen of the atmosphere from entering the cell and discharging the negative plates.

If this valve or other seals should fail, the cell would start to perform as a vented cell, release gases, and eventually dry out.

Under most operating conditions, the headspace of a VRLA cell does not contain an explosive gas mixture (see 3.5.3.2. However, under certain conditions, it may contain both hydrogen and oxygen, and thus a flame arrestor is integrated into the cover and/or valve/vent assembly to prevent flames or sparks from entering the cell and igniting the gas mixture. ~~There are conditions, the headspace of a VRLA cell does not contain an operation where explosive gas mixture (see 3.5.3.2. However, under certain conditions, it may mixtures of hydrogen and oxygen, and thus a may be present; therefore, flame arrestors should be provided.~~

In some VRLA cells, for the purpose of extending product life, the valve assembly also contains a catalyst, which serves to further decrease released gas (and thus dry out) and increase negative plate polarization.

4.4.5 Ventilation

~~Valve-regulated cells should be placed in a controlled environment that is well ventilated, and should not be placed in the heat flow of electronic equipment within the same enclosure. Proper cell ventilation around the cell casing is recommended to reduce the possibility of thermal runaway.~~

~~Under normal recombination operation, valve-regulated cells periodically vent small amounts of hydrogen, and some hydrogen may also diffuse through the plastic case. Larger amounts of gas are emitted when the battery is overcharged. Users should consult the manufacturers' specifications to determine whether additional ventilation is required for a particular application.~~

3.6 Vented nickel-cadmium (Ni-Cd) batteries

3.6.1 General

Ni-Cd batteries use an alkaline electrolyte (potassium hydroxide). The active materials are nickel oxyhydroxide (NiOOH) in the positive plate, and cadmium metal (Cd) in the negative plate.

The electrolyte in the Ni-Cd battery does not take part in the overall cell reaction, so the specific gravity does not change during charge and discharge. The electrolyte retains its ability to transfer ions between the cell plates, irrespective of the charge level, and ~~also~~ acts as a preservative of steel components in the cell mechanical structure.

The batteries are resistant to mechanical and electrical stresses, operate ~~well~~ over a wide temperature range, and can tolerate frequent shallow or deep discharging.

3.6.2 Voltage characteristics

Average recommended float voltages of Ni-Cd cells range from 1.39 V/cell (IEEE Std 1115 [B20]) to 1.45 V/cell, depending on design, temperature, and manufacturer recommendations. In the rare cases where temperature-compensated charging is used (see 4.4.1) with Ni-Cd cells, average voltages may be outside this range.

If Ni-Cd cells are given a high-rate charge, the average recommended voltage ranges from 1.45 V/cell to 1.55 V/cell.

During discharge, design end voltages in UPS applications typically range from 1.00 V/cell to 1.14 V/cell.

4.5.2 Characteristics

~~The Ni-Cd cell has an open-circuit voltage of approximately 1.30 V and a nominal discharge voltage of 1.20 V. The manufacturers' recommendations indicate a range of float voltages of 1.40 V/cell to 1.47 V/cell and high-rate voltages of 1.45 V/cell to 1.65 V/cell, depending on their individual designs and the requirements of the application. Ni-Cd cells can tolerate very high charge rates without damage. Some designs may be stored for years with no life loss.~~

~~The cell can tolerate complete discharge with almost no permanent deterioration of capacity or life. Depending on the number of cells used, the typical end-of-discharge voltage in this application may vary from 1.00 V/cell to 1.10 V/cell. It is advisable to use the lowest end-of-discharge voltage and the largest possible number of cells that will satisfy the manufacturer's charging recommendations, since this will result in the most economic battery for the application.~~

3.6.3 Construction

Several designs of vented Ni-Cd batteries are available, depending on plate construction. The designs most commonly used ~~designs are the~~ pocket plate, ~~the~~ fiber plate, ~~the~~ sintered plate, and foam plate. Sintered and foam positives are combined with ~~the~~ plastic bonded negatives ~~plate~~. The construction of Ni-Cd batteries is detailed in Annex D.

Similar to vented lead-acid designs, vented Ni-Cd cells are usually designed with varying plate thickness. For long-duration, low-discharge rates, thick plates (3 mm to 4 mm) are used. Medium rate cells, often used in applications where a combination of high- and low-discharge currents is required, have thinner plates (2 mm to 3 mm). For short-duration, high-rate performance (i.e., most UPS applications), which depends more on the active plate surface available rather than the total amount of active material, thin plates (0.8 mm to 1.5 mm) are used.

3.6.4 Ventilation caps

Vented Ni-Cd cells are supplied with required (NFPA 70-2020 [B31]) flame-arresting vent caps which allow gasses produced inside the cell to escape to the atmosphere while preventing the propagation of sparks or flame through the arrestor. These are supposed to be periodically inspected (NFPA 70E [B32]).

3.7 Partially recombinant ~~Sealed~~ Ni-Cd batteries

Partially recombinant Ni-Cd cells are similar to their vented counterparts with several notable exceptions. Partially recombinant Ni-Cd cells typically utilize a felted separator instead of a grid separator between the plates with the intent of increasing the gas recombination characteristics of the cell. Some designs are fitted with a self-sealing, low-pressure valve¹⁹ (sometimes fitted with a catalyst) instead of the standard vent which also reduces water loss. Partially recombinant Ni-Cd cells have a significantly reduced gassing rate compared to vented Ni-Cd cells. Recombination efficiency is usually on the order of 90% or greater resulting in a lower maintenance requirement due to extended watering intervals, typically up to the service life of the battery. Partially recombinant Ni-Cd cell design still maintains a large free electrolyte reserve inside the cells. Electrolyte immobilization is not used, thereby nearly eliminating the potential for thermal runaway due to battery dry-out.

~~Sealed Ni-Cd cells are normally used in electronics and consumer equipment, such as cordless power tools. They are limited in capacity and are therefore used mainly in small UPS applications.~~

~~The cells are typically constructed from sintered or pasted electrodes that are wound together with a separator to form a cylindrical plate group. The cell container is completely sealed and no gas is released under normal operating conditions. Recombinant designs are also available for larger capacities. In construction they resemble vented cells, but also incorporate a special separator, which allows charge gases to recombine.~~

3.8 Nickel-zinc (Ni-Zn) batteries

3.8.1 General

Chemically, the nickel-zinc cell is similar to a nickel-cadmium cell. The cell construction utilizes a nickel positive electrode and a zinc negative electrode. The electrolyte is an alkaline metal hydroxide solution.

¹⁹Hermetically sealed Ni-Cd cells are limited in capacity and cannot be float-charged. Therefore, they are not applicable to the UPS applications discussed in this document.

3.8.2 Voltage characteristics

Nickel-zinc chemistry open-circuit voltage is approximately 1.73 V, and has a nominal voltage of 1.6 V.

It is not recommended to float charge Ni-Zn technology. Maximum recommended charge voltage range for Ni-Zn cells is approximately 1.88 V/cell to 1.90 V/cell. Charge controllers may be installed with the batteries that intermittently charge and rest the batteries.

During discharge, design end voltages in non-industrial UPS applications typically range from 1.00 V/cell to 1.10 V/cell.

3.8.3 Construction

Nickel-zinc cells may be either hermetically sealed²⁰ or sealed with the exception of a pressure relief valve in each cell to maintain an optimal pressure range inside the cell. Since the battery is recombinant, positive pressure is necessary. The sealed cell with the pressure relief valve construction is typically a prismatic design and may be packaged as either a single cell or as a multi-cell unit.

The nickel-zinc cell is tolerant of temperature extremes ranging from -20 °C to 50 °C (-4 °F to 122 °F).

3.8.4 Chemistry

The active material of the positive electrode is nickel oxyhydroxide; and for the negative electrode it is high surface area metallic zinc. The electrolyte is typically an alkali metal hydroxide solution in which specific additives may be added to modify the charge-discharge behavior of the zinc electrode to help inhibit dendrite formation.

²⁰Sealed Ni-Zn cells are limited in capacity and cannot be float-charged. Therefore, they are not applicable to the UPS applications discussed in this document.

Oxygen generated at the positive electrode is recombined at the negative electrode. This process is not 100% efficient, so some hydrogen evolution occurs at the negative electrode. Recombination of that hydrogen can also occur at the positive electrode. The latter reaction is much slower than the reaction at the negative electrode and requires higher pressure or the presence of catalysts before there is significant impact on cell chemistry.

3.9 Lithium-ion (Li-ion) batteries

3.9.1 General

The term *Li-ion battery* covers a broad range of chemistries that all have the common characteristics of using lithium ions as the charge carriers, and a distinctive method of storing these ions within the electrode layers, known as *intercalation*. This prevents lithium metal from ever being present within the cell, one of the key safety requirements.

Subclauses 3.9.2 through 3.9.5 provide general information on Li-ion technology. Additional details are provided in Annex E.

3.9.2 Voltage characteristics

The voltage characteristics of the various commercial Li-ion chemistries have some variance. See Table 1, but consult the manufacturer documentation and follow their recommendations for voltage settings.

Some Li-ion technologies have a sloping characteristic of voltage as a function of state of charge, and 100% of rated capacity is only available at a specific float voltage. Floating at a lower voltage will decrease available capacity, while also extending life to some extent. Do not charge above the maximum voltage as this could lead to battery disconnection or possibly even a fire.

Table 1—Typical cell voltage characteristics of various Li-ion chemistries

Chemistry	$V_{nom/oc}$	V_{float}	$EOD_{typical}$	EOD_{max}
Lithium cobalt oxide (LCO)	3.6 to 3.8	4.0 to 4.2	3.0	2.5
Nickel cobalt aluminum (NCA)				
Nickel manganese cobalt (NMC)				
Lithium manganese oxide (LMO)				
Lithium iron phosphate (LFP)	3.2 to 3.3	3.6 to 3.7	2.8	2.5
Lithium titanite oxide (LTO)	2.3 to 2.4	2.7 to 2.8	1.8 to 2.0	1.5

(New)

3.9.3 Construction

3.9.3.1 Li-ion cell

Li-ion electrodes require compression to maintain their desired internal impedance. Cylindrical cells naturally maintain electrode compression. Prismatic and pouch cells may require structural containers or external compression for proper operation.

Cells evolve no gases during normal operation. Because of this, the cells are fully sealed, with only a one-time vent for safety. Cells can also have safety devices built internally, such as current, pressure, or thermal fuses. Additional description of cells can be found in IEEE Std 1679.1 [B27].

3.9.3.2 Battery architecture

Lithium-based battery systems generally contain the individual cells, the battery management system (BMS), safety systems as necessary, thermal systems as necessary, and either a charger or the interface to an external charger.

The individual cells in a Li-ion battery are generally small in capacity compared to the other chemistries covered in this document, so they must not only be placed in series to achieve the desired voltage(s), but they are often internally paralleled as well to achieve the desired capacity in an individual module or string. The individual modules are then placed in series and/or parallel to obtain the overall desired system capacity, similar to what is done with multi-cell lead-acid units and strings. Unlike traditional lead-acid or Ni-Cd batteries, each module and/or string of a Li-ion battery system has its own BMS.

All series-connected strings of cells are subject to single points of failure in the individual cells and intercell/ unit connections, but Li-ion batteries (or any battery using a BMS) have an additional single point of failure of the BMS. So, Li-ion battery systems for medium-sized and large UPS are usually deployed in configurations (such as parallel strings) where the failure of a single BMS will not remove all of the capacity of the overall battery system from the dc bus. This is similar to the idea of multiple strings of VRLAs in a medium-sized or large UPS.

Because of the proprietary nature of the cells, it is common for a Li-ion manufacturer to provide, and also require, that only their BMS may be used with their cells.

3.9.3.3 Battery management system (BMS)

A key determination in evaluating a lithium-based battery is the ability of its BMS to reliably and safely monitor and control the parameters of operation. Common monitoring functions of the BMS include cell voltage (which it also controls via balancing circuitry), battery voltage, cell temperature, string current, and ambient temperature. The BMS may also monitor ancillary systems (if included), such as the operation of the heating, ventilation, and air-conditioning (HVAC) system, safety devices (such as contactors, fuses, or circuit breakers), and the charger operation. The BMS verifies that charging and discharging operations are within the allowed parameters and provides actions and alarms as required. Often the BMS is built into the battery pack/ module, and the modules/packs are then paralleled (for small UPS there may only be one of these modules/ packs with the BMS built in). In these cases, there may be a primary BMS that communicates with all of the other BMS via a communication bus. This primary BMS then becomes the primary interface for the UPS electronics and/or the UPS user.

Dry contacts may also be provided to interface with the UPS for alarms and warnings and other functions. Often the UPS does not need to use a communication bus to control the battery, but charging current and voltage set-point should be agreed upon with the battery manufacturer.

3.9.4 Types of Li-ion batteries

Li-ion battery types can be distinguished by many characteristics. The two most common differentiators are discharge performance and chemistry.

Application-specific Li-ion designs are most commonly differentiated by their optimized discharge rate. Batteries designed to have higher energy capacity and allow runtime measured in hours are often referred to as *energy cells*. Energy cells have high energy density and specific energy but lower current-carrying and heat-dissipating abilities. Cells designed to offer high power densities are referred to as *power cells*. A higher portion of the energy can be supplied to the load in a short period of time (minutes) and at a higher current. This characteristic makes power cells the dominant choice for UPS applications. Because power cells have a lower energy density and lower internal resistance, they generate less heat and can dissipate that heat more readily.

Li-ion cells are also commonly differentiated by their internal chemistry, primarily that used in the positive electrode. New formulations are being continuously tested and offered to extend the limits of today's Li-ion battery technology. Li-ion batteries are often classified according to the active positive chemical material.

There are variations of each base chemistry, many of which are proprietary and exclusive to a single manufacturer. For example, lithium nickel manganese cobalt (NMC) can be used as a positive electrode material, and thus the Li-ion cells is described as an "NMC type." However, the ratio of materials within this NMC chemistry for one manufacturer and model might have a 1:1:1 ratio of nickel, manganese, and cobalt, while an NMC chemistry with a different model number and/or manufacturer might have a ratio of 5:2:3. This can result in significant differences in the cell performance and attributes, including performance, safety, and life.

The commercially common types of Li-ion chemistry include:

- LCO (lithium cobalt oxide)
- NCA (lithiumnickel-cobalt-aluminum oxide)
- NMC (lithium nickel-manganese-cobalt oxide)
- LMO (lithium manganese oxide)
- LFP (lithium iron phosphate)
- LTO (lithium titanate oxide—a negative material)

Each chemistry has differing attributes in the important characteristics of:

- Operating voltage
- Safety
- Performance
- Life on float
- Cycle life
- Cost

Some manufacturers mix or blend the aforementioned chemistries to optimize the characteristics for the application. As this is a rapidly changing area, it is important that the user examines all attributes of the cell type under consideration to check that it is appropriate for the application. Additional guidance in this area is provided in Clause 4 of this document. If more detail is desired on some of the most common base chemistries, consult IEEE Std 1679.1 [B27], among other sources.

3.9.5 Safety

Li-ion batteries have so far proven to have more inherent safety issues than the other technologies covered in this document, thus additional guidance on design for safety is given here in this subclause.

Due to their higher specific energy and a greater sensitivity to abuse, Li-ion batteries need to be properly managed. The level of management depends on specific chemistry chosen. If improperly managed, some Li-ion batteries can reach a “thermal runaway” state relatively easily. For further details, see Figure 2 in IEEE Std 1679.1–2017 [B27].

For safety reasons, it is important that Li-ion batteries be qualified to UL 1973 [B39] and/or IEC 62619 [B13]. (Note that the IEC 62619 standard allows for two methods of initiating cell thermal runaway: internal short circuit and external heating, while UL 1973 only allows external heating. Internal shorting more closely reflects real-life cell failures but requires that special cells be produced to allow the short to be initiated. External heating is less realistic but easier to implement.)

Large-scale fire testing (UL 9540A [B42]) helps the authority having jurisdiction (AHJ) and code officials to understand the severity of reactions involved with a battery fire. Such testing will be required whenever it is proposed to exceed the size and spacing limitations in the applicable code.

4. Selection considerations

4.1 General

Many factors affect the decision of what battery technology to use to support a UPS. The following subclauses provide some of the technical attributes of the various battery technologies used in UPS so that users can compare the attributes of most importance to them.

Almost all types of battery cells (regardless of chemistry) can be optimized for cycling, long-duration, medium-duration, high-rate, and engine-starting (super high-rate). High-rate designs are typically chosen for UPS applications with backup times under 60 min, medium-duration designs for UPS backup times between 1 h to 3 h, and long-duration designs for UPS with reserve times longer than 3 h.

4.2 Reliability

Reliability is affected by many factors, including but not limited to:

- Application
- Environmental conditions
- Battery technology
- Number and depth of discharge cycles
- Open-circuit versus short-circuit failure modes
- Maintenance
- Reliability of battery management system

~~5.1 Design considerations~~

~~5.1.1 Lead-acid cells~~

~~There are special designs for long duration, general purpose, and short duration applications, typically characterized by their plate thickness (see 4.2). The thinner plate designs are optimized for high rate, short duration discharges.~~

a) ~~Vented cells:~~ The plates of a VLA cell are immersed in a liquid electrolyte and housed in a clear container. The clear container allows for visual inspection of the plates and internal components. Normal charging results in gassing and water consumption. While this will necessitate electrolyte maintenance, the ability to replenish lost water makes vented cells more tolerant than VRLA cells to overcharging and operation at elevated temperature.

b) ~~VRLA cells:~~ AGM cells are generally more suitable for high rate, short duration discharges, whereas gelled electrolyte types are more suited to longer discharges (see 4.4.2). However, the higher energy density of AGM designs often favors them where space is limited, regardless of discharge duration.

5.1.2 Ni-Cd

Ni-Cd cells are designed for long duration, general purpose, and short duration. These designs are primarily based on plate thickness. The life expectancy, however, is not directly related to the thickness of the plate. The active material ages gradually and there is no degradation of the plate structure, so there is no sudden fall-off in cell capability.

5.1.3 Reliability

In most cases, the reliability of a VLA is better than VRLA cells given similar environments. VLA batteries are also more robust to environmental conditions such as temperature and ripple current (see 6.2.2).

Ni-Cd cells have similar reliability to VLA batteries. Ni-Cd cells may perform better than VLA in applications with temperature extremes.

4.3 Battery footprint and floor loading

Considerations for footprint and floor loading include (but are not limited to):

— Code requirements

— Weight and volume

- [— Battery technology](#)
- [— Available space](#)
- [— Floor load capacity](#)
- [— Orientation](#)
- [— Environment](#)
- [— Seismic requirements](#)
- [— Ventilation](#)

~~Vented batteries (VLA and Ni-Cd) require that they be oriented with the cell vent facing upward. Some VRLA batteries can be oriented in the horizontal position allowing for a smaller footprint than a similar sized vented battery. In general, VRLA batteries have higher volumetric energy densities than VLA and, therefore, can have a smaller footprint. Floor loading should always be considered in system design.~~

4.4 Battery life

4.4.1 Operating temperature

[4.4.1.1 General](#)

[Rated performance of cells is typically between 20 °C and 25 °C. Prolonged use at elevated temperatures will shorten battery life. Low-temperature operation will reduce battery capacity. Cooler temperatures \(below 20 °C will lengthen life \(especially if float voltage is properly compensated for the lower temperature with VRLA batteries, but the effect is not as pronounced as the premature aging effect of temperatures above 25 °C, and the manufacturer will not provide a longer warranty for these cooler temperature operating environments.](#)

[Battery charging temperature compensation may reduce the effect of temperature on battery life.](#)
~~Rated performance of cells are typically at 25 °C. A location where this temperature can be maintained will contribute to optimum battery life, performance, and cost of operation. Extreme ambient temperatures should be avoided because low temperatures decrease battery capacity, while prolonged high temperatures shorten battery life and increase maintenance cost.~~ Installation in a location with an ambient below the rated temperature will affect sizing. Refer to IEEE Std 485 [\[B16\]](#), [IEEE Std 1115 \[B20\]](#),⁴ and IEEE Std [1679.1 \[B27\]](#) ~~1115~~.

4.4.1.2 VLA

Vented cells are more tolerant to environmental and system [variations](#) ~~abuses~~ than VRLA.

The location and arrangement of cells should result in no greater than a 3 °C temperature differential between cells at a given time. Avoid conditions that result in spot heating or cooling, as temperature variations will cause the battery to become electrically unbalanced. [Typically, for VLA batteries,](#)
~~Elevated temperature operation will shorten battery life. A general rule of thumb for lead acid batteries is that~~ prolonged use at elevated temperatures will reduce the battery life by approximately 50% for every [10 8°C rise in electrolyte temperature](#) above 25 °C. ~~Ni-Cd cells are less affected, with a life reduction of about 20% for the same temperature increase.~~

⁴~~Information on references can be found in Clause 2.~~

4.4.1.3 VRLA

For VRLA batteries, optimal gas recombination is a function of operating temperature and float voltage. The additional issues of possible dry-out and thermal runaway with VRLA batteries should be carefully assessed for elevated temperature operation. Consideration should also be given to current limiting chargers for elevated temperature applications. In addition, the use of temperature-compensated chargers is recommended for those applications where temperature variations can be expected. The location and arrangement of cells should result in no greater than a 3 °C temperature differential between cells or multi-cell units at a given time. Avoid conditions that result in spot heating or cooling, as temperature variations will cause the battery to become electrically unbalanced. Typically, for VRLA batteries, prolonged use at elevated temperatures will reduce the battery life by approximately 50% for every 8 °C rise in electrolyte temperature above 25 °C. The difference in aging rate between VRLA and VLA cells is because the exothermic recombination reaction causes a slight elevation in operating temperature for VRLA units.

4.4.1.4 Ni-Cd

A Ni-Cd battery will not be damaged by low temperatures or freezing. Typically, for Ni-Cd batteries, prolonged use at elevated temperatures will reduce ~~With a normal electrolyte, the battery life by approximately 20% for every 10 °C above 25 °C. Depending on the technology, temperature-compensation of the charging voltage may not be recommended above 25 °C. Consult the manufacturer for recommendations. will operate at temperatures as low as -20 °C; with a higher specific gravity electrolyte, it will operate at even lower temperatures. The available capacity is reduced at low temperatures, but at -40 °C, a Ni Cd battery can deliver 60% or more of rated capacity.~~

Ni-Cd batteries are often chosen for wider operating temperature ranges because the effects on the lifetime of the battery are not as significant as they are for lead-acid or Li-ion. This is partially because the Ni-Cd grids do not corrode via an exothermic reaction because the potassium hydroxide electrolyte is only a charge carrier.

4.4.1.5 Ni-Zn

Nickel-zinc batteries offer many of the same benefits as nickel-cadmium with regard to operating temperature. Nickel-zinc batteries will function at temperatures as low as -20°C and as high as 50°C . The optimum operating temperature is from 10°C to 35°C with some short-duration excursions at higher temperatures tolerated well.

4.4.1.6 Li-ion

Like other technologies, the life of lithium-ion batteries is shortened at high temperatures. At low temperatures, charging Li-ion batteries at rates in excess of those recommended by the manufacturer can also cause accelerated aging. Most Li-ion batteries are designed to be maintained at 20°C to 25°C . Except for cells with lithium titanate oxide (LTO) negatives, most Li-ion chemistries have a relatively narrow temperature range at which the full charge current can be accepted, generally between about 18°C and 41°C [65°F to 105°F]. The battery management system (BMS) will allow limited, controlled charging outside of this window up to a maximum and down to a minimum temperature. In addition to charging, the discharge capacity of most Li-ion batteries tapers off at low temperatures. Li-ion batteries lose significant life if operated at high temperatures for prolonged periods (a half-life for every 10°C above 30°C is a common rule of thumb for most Li-ion chemistries).

Temperature compensation of the charging voltage is not needed, and this feature should be disabled because it may reduce capacity, shorten the battery life, or cause the BMS to disconnect the battery.

4.4.2 Service life ~~Frequency~~ and depth of discharge

4.4.2.1 General

The life of a battery is related to the number ~~frequency~~ and depth of discharges, time spent on float charge, ripple on the dc bus, and temperature. A battery can provide more short-duration, shallow cycles than long-duration, deep discharge cycles, and thus cycle counters are only useful if they count coulombs. ~~Even~~ Momentary fluctuations in the ac power to the UPS may result in battery discharges of several seconds or more. However, ~~Frequent cycling of the~~ UPS batteries in locations with relatively high grid reliability should not cycle enough to significantly harm a battery. In places with lower grid reliability, or where UPS are used to interact with the grid as an energy storage system, life will be determined by depth and quantity of discharges, along with time spent on float (and the float voltage). battery, even for short durations, shortens battery life.

The relationship between depth-of-discharge (DOD) and number of cycles is exponential rather than linear (e.g., a given battery type may provide three to four times the number of cycles at 40% DOD than it would provide at 80% DOD).

The battery with the longest life may not necessarily be the best battery for the application, as other factors, such as cost, space, weight, safety, environment, regulatory requirements, and expected life of the application come into play as well.

4.4.2.2 VLA

The cycle life of VLA batteries depends on the design and chemistry. For example, designs with tubular grids, and/or antimony grid alloys may provide better cycling performance. Wrapped positive plates will also provide better cycling capability but limit the rate at which power can be drawn from the battery (see C.5).

VLA batteries in UPS applications often have accelerated aging factors (shorter lifetimes). These factors can include:

— Use of thinner plates for short discharge times

- Inverter feedback ripple (see Annex I)
- More frequent shallow cycling (see 4.4.2.1)

As a result, VLA cells designed for high-rate applications typically last 10 to 15 years in a UPS environment.

~~A VLA battery can be designed for extended cycle life either by placing retaining mats against the positive plates or by enveloping the positives in a perforated sleeve. This partial electrical isolation increases internal resistance, and may limit the rate at which power is withdrawn from the battery. (See Annex C.6.)~~

4.4.2.3 VRLA

VRLA batteries may be ~~Many~~ AGM or gel. AGM designs utilize separators that serve as retention mats, which inherently improves cycling ability. ~~can provide superior cycle service to vented cells with the same grid alloy, since the plate element is under compression and the glass fiber mat acts as a retainer. Manufacturers of~~ Gel designs may incorporate additives into the electrolyte that provide extended cycle service.

Under typical operating conditions, VRLA batteries tend to have shorter lifetimes in UPS applications for the same reasons given in 4.4.2.2. Individual 2 V VRLA cells typically have a useful life of about eight to 12 years in a UPS application but may exhibit a considerable shortening of run time over this period when sized for less than 15 min of discharge (Nispel [B36]) at UPS rated load unless proper aging factors are applied (see 6.4, as well as the discussion of 80% end-of-life conditions in 5.2.3). Smaller VRLA multi-cell units (typically 12 V, but 6 V and 16 V blocs are sometimes used in UPS applications) have typical UPS lifetimes ranging from two to eight years depending on the manufacturer, model, and design.

4.4.2.4 Ni-Cd

Ni-Cd cells can provide long-term cycle service for deep discharge applications. [The cycle life varies by plate type \(see D.2\) and active material additives.](#) To enhance cycle life and ~~to~~ reduce the adverse effect of high temperatures, various amounts of lithium hydroxide may be added to the potassium hydroxide electrolyte. The manufacturers specify the exact amount added during manufacturing.

[The typical life of Ni-Cd batteries in UPS applications is 20 to 25 years.](#)

4.4.2.5 Ni-Zn (nickel-zinc)

[Nickel-zinc can provide long-term cycle service for deep discharge applications. As with other chemistries, the number of cycles achieved is directly related to the rate and depth of discharge and the operating temperature. The majority of nickel-zinc batteries are designed for high-rate, short-duration discharges, but may be used in some general-purpose applications with good cycle ability. At high discharge rates, several hundred full discharges are possible. With shallower and/or shorter duration discharges, several thousand discharges are available. In discharge of less than 10% of the available capacity, over 20 000 discharges have been documented from nickel-zinc batteries.](#)

[While Ni-Zn has only recently been placed in UPS applications, testing has shown that the expected life is 10 to 15 years.](#)

4.4.2.6 Li-ion

[There is a wide variation in cycling ability among Li-ion chemistries and designs. For the commonly used chemistries for Li-ion in UPS applications, there are 1000 to 20 000 80% DOD cycles.](#)

[Expected Li-ion life in a UPS application ranges from 10 to 15 years, depending on chemistry, environment, etc.](#)

4.4.3 Calendar life versus capacity

4.4.3.1 VLA

VLA batteries for the UPS application typically ship from the manufacturer at 100% capacity. This should be verified prior to purchase. As the cells age, capacity drops off in a steadily increasing exponential curve, but there is a significant “knee-of-the-curve” around 80% capacity. After that point in time, capacity tends to fall relatively rapidly. For this reason, 80% capacity is typically considered to be the end of life (EOL) for lead- acid batteries, and they are often oversized considering this fact (an aging factor of 1.25—see 6.4).

4.4.3.2 VRLA

VRLA batteries typically ship from the manufacturer at 100% capacity. VRLA batteries are considered at end of life at approximately 80% capacity due to the knee-of-the-curve phenomenon. VRLA batteries should be sized with an aging factor of 1.25.

4.4.3.3 Ni-Cd

The active material of Ni-Cd ages gradually (approximately 1% per year) and there is no degradation of the plate structure, so there is no sudden fall-off in cell capacity. Ni-Cd batteries simply produce shorter backup time as they age and can sometimes be left in service until their remaining capacity declines to as low as 50% rating. The end-user can decide whether to use a larger aging factor during battery sizing to accommodate the lower capacity or to accept the shorter backup times.