ANSI/IEEE Std 535-1986
(Revision of ANSI/IEEE Std 535-1979)

An American National Standard

IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations

Sponsor
Power Generation Committee of the
IEEE Power Engineering Society

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IEEE Standards Board

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 535-1986, IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations.)

ANSI/IEEE Std 323-1983, Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, was developed to provide guidance for demonstrating and documenting the adequacy of electrical equipment used in all Class lE and interface systems. This standard, ANSI/IEEE Std 535-1986, was developed to provide specific methods and type test procedures for lead storage batteries in adherence to ANSI/IEEE Std 323-1983.

Adherence to this standard may not suffice for assuring public health and safety because it is the integrated performance of the electrical systems of the station that limits the consequence of accidents. Each applicant has the responsibility to assure himself and others that this document, if used, is pertinent to his application and that the integrated performance of his station is adequate.

This standard was prepared by the Working Group on Batteries of the Station Design Subcommittee of the Power Generation Committee. At the time this document was approved, the working group had the following members:

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An American National Standard

IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations

1. Scope

This document describes qualification methods for Class lE lead storage batteries and racks to be used in nuclear power generating stations outside of primary containment. Qualification required in ANSI/IEEE Std 308-1980 [2] can be demonstrated by using the procedures provided in this standard in accordance with ANSI/IEEE Std 323-1983 [3].

Battery sizing, maintenance, capacity testing, installation, charging equipment, and consideration of other type batteries are beyond the scope of this standard.

2. Definitions

cell type: Cells of identical design, for example, plate size, alloy, construction details, but that may have differences in the number of plates and spacers, quantity of electrolyte, or length of container.

For other definitions of terms contained in this standard, refer to Section 3. For all definitions not listed in the referenced documents ([2] through [9]), refer to ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms [1].[1]

3. References

This standard shall be used in conjunction with the following publications:

[1] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.[2]

[2] ANSI/IEEE Std 308-1980, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations.

[3] ANSI/IEEE Std 323-1983, IEEE Standard for Qualifying Class lE Equipment for Nuclear Power Generating Stations.

[1]The numbers in brackets correspond to those of the references listed in Section 3 of this standard.
[2]ANSI/IEEE publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

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[4] ANSI/IEEE Std 344-1975 (R1980), IEEE Recommended Practice for Seismic Qualification of Class lE Equipment for Nuclear Power Generating Stations.

[5] ANSI/IEEE Std 450-1980, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations.

[6] ANSI/IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations.

[7] IEEE Std 484-1981, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations.[3]

[8] IEEE Std 484a-1984 (Supplement to IEEE Std 484-1981).

[9] Specification for the Design, Fabrication and Erection of Structural Steel for Building, American Institute of Steel Construction (AISC), New York, 1978.[4]

4. Introduction

The users of Class lE lead storage batteries are required to provide assurance that such equipment will meet or exceed its design specifications throughout its installed life. This is accomplished through a quality assurance program that includes design, qualification, production, quality control, installation, maintenance, and periodic testing. This document will treat only the qualification portion of the program.

The objective of qualification is to demonstrate that the batteries and racks, as installed, will perform their required Class lE function throughout their qualified life. ANSI/IEEE Std 450-1980 [5] recommends that the batteries be replaced when their capacity drops below 80% of the manufacturer's rating. Therefore, aged cells that deliver at least 80% rated capacity in the post seismic (or final) capacity discharge test are qualified.

Qualification may be accomplished by type testing, operating experience, or analysis, and any of these may be used individually or in combination. Ongoing qualification may be used to extend qualified life. Each method requires justification.

This standard provides the detailed procedures for type testing. Mathematical analysis and other methods of qualification are described in general terms.

With all qualification methods, the end result is the documentation that demonstrates that the battery and rack are adequate to perform their required functions. The documentation shall be in a form that allows verification by competent personnel other than the qualifiers, and shall contain the design specifications, the qualification method, results, statement of qualified life at 25 °C (77 °F), and the justifications.

Qualification data for cell types or rack designs previously qualified may be used to qualify additional cells of the same type or racks of the same design as long as the severity of the environmental parameters with appropriate margin does not exceed that of the previously qualified items. General practice is to qualify one or more sizes of a cell type and interpolate or extrapolate to other size cells of that type.

Battery installations in nuclear generating stations will not normally subject the battery to vibration that will affect its life. Therefore, test procedures for this condition are not included. Any degradation resulting from abnormal vibration will be detected during periodic capacity discharge tests and inspections. Refer to ANSI/IEEE Std 450-1980 [5].

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, Piscataway, NJ 08854.
[4]This publication is available from the American Institute of Steel Construction, 400 North Michigan Avenue, Chicago, Illinois 60611.

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5. Principles and Methods of Qualification

The capability of Class lE lead storage batteries and racks, including interfaces, to perform their required functions shall be demonstrated. Principles and methods for demonstrating the qualification of Class lE equipment shall include:

1) Assurance that the severity of the qualification parameters are equal to the maximum anticipated service requirements and conditions with an appropriate margin (ANSI/IEEE Std 323-1983 [3], 6.3.1.5)
2) Assurance that any extrapolation or inference be justified by allowances for known potential failure modes and the mechanism leading to them
3) Documentation fries that provide the basis for qualification
4) Qualification of any interface utilized in demonstrating the adequacy of the battery and rack

5.1 Type Testing

A type test satisfies qualification only if the equipment to be tested is aged to an anticipated qualified life, subjected to all environmental influences known to affect performance, and operated under simulated conditions to provide assurance that all such equipment will be able to meet its design specifications.

5.2 Operating Experience

Batteries and racks that have operated successfully can be considered qualified for equal or less severe service. Operating experience can provide information on limits of extrapolation, failure modes, and failure rate. The validity of operating experience as a means of qualification shall be determined from the type and amount of documentation supporting the service conditions and the performance of the battery and rack during this time.

5.3 Analysis

Qualification of the battery or the rack, or both, by analysis shall require the construction of a valid mathematical model. The validity of the mathematical model shall be justified by test data, operating experience, or physical laws of nature. Qualification shall consist of a quantitative analysis of the mathematical model that shall logically prove that the battery or the rack, or both, meet or exceed the equipment design specifications when subjected to the design basis event. The data used to support the qualification of equipment by analysis shall be pertinent to the application and be in an auditable form.

CAUTION: At the present state of the art, mathematical modeling of an aged cell is not recommended because of its complexity.

5.4 Extension of Qualified Life

ANSI/IEEE Std 323-1983 [3], 6.9, describes several methods of extending qualified life. Some examples of applying these methods are described below:

1) After a period less than the previously qualified life, randomly selected cells from the qualified battery shall be removed and replaced with new, qualified cells. The removed cells shall be subjected to another qualification test (including accelerated aging). Successful qualification of the removed cells will extend the qualified life of the battery.
2) At the time of the initial installation of the qualified battery, additional qualified cells shall also be installed in locations where they will be subjected to service and environmental conditions at least as severe as those of the initial battery. After a period less than the qualified life, cells shall be subjected to a qualification test (including accelerated aging). The new qualified life is then applicable to the initial installation.
   NOTE — Exactly matching service and environmental conditions will be difficult to achieve.
3) Extension of qualified life by analysis should consider the service environment, battery condition as determined by maintenance, testing records, and manufacturer's recommendations.

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6. Qualification Information

The information required for the qualification of the battery or the rack, or both, shall include the following:

1) Identification of the battery or the rack, or both, being qualified.
2) The installation requirements including mounting method and configuration(s) and interfaces to the battery or the rack, or both (refer to IEEE Std 484-1981 [7] and IEEE Std 484a-1984 [8]).
3) The preventive maintenance schedule for the installed life of the battery or the rack, or both (refer to ANSI/IEEE Std 450-1980 [5]).
4) The range, type, and duration of environmental conditions including, but not necessarily limited to, temperature, radiation, and seismic spectra.
5) Electrical data including, but not necessarily limited to, ampere hour capacity, float voltage, minimum voltage, and specific gravity (refer to ANSI/IEEE Std 450-1980 [5]).
6) Complete description and expected frequency of discharges if they exceed the equivalent of two performance discharge tests annually.
7) Qualified life at 25 °C (77°F) electrolyte temperature. (This entry may be established during the qualification testing.) An adjustment to a battery's qualified life at other than 25 °C can be obtained from the manufacturer.

NOTE — The relationship between temperature and life is exponential. For example, life increase by operating one month at 20 °C does not completely offset life decrease by operating one month at 30 °C.

7. Qualification by Type Testing

7.1 Test Plan

The test plan for a lead storage battery or a rack, or both, will consist of qualification by subjecting them to radiation (when required), aging, and seismic vibration. Therefore, to qualify a battery, it shall be aged (by natural or accelerated means) by application of environmental factors that can act on it.

7.2 Test Sequence

The type tests shall be performed on the battery or the rack, or both, in a specific order, as follows, unless an alternate sequence can be justified:

1) Radiation exposure (as required) per 8.1
2) Aging per 8.2
3) Seismic qualification per 8.3

7.3 Acceptance Criteria

In the evaluation of the qualification test results, any sample equipment is considered to have passed when the test satisfies 8.3.1.4 and 8.3.3.3. If there is a failure, the failure shall be analyzed, the cause identified, and the designation of random or common mode justified.

If the failure is demonstrated to be of random nature, repeat the test with new equipment. If the failure is of common mode origin (for example, part of the design), the equipment is notqualified and the qualifier has two choices:

1) The equipment can be redesigned
2) New identical equipment can be tested to lesser qualification parameters

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8. Type Tests and Analysis Procedures

For all test procedures the following shall apply:

1) The cells to be used for determining qualified life shall be selected at random from production.
2) A minimum of three single cells or three multiple cell units shall be tested so that both middle and end of string cell connections can be simulated.
3) The electrolyte level shall be maintained between the high and the low level lines.

8.1 Radiation

Normal battery installations will be in locations subject only to low level background radiation exposure during normal service and postulated accidents. If the total integrated dosage over the life of the battery does not exceed 104 rad, no radiation exposure is required for qualification. If an installation is planned with a total integrated dose greater than 10(4) rad, it shall be specified and unless an analysis shows that it is not required, an accelerated exposure rate shall be applied prior to aging by temperature and the seismic testing. For naturally aged cells, exposure to radiation can be applied just prior to seismic testing. For further test details, see ANSI/IEEE Std 323-1983 [3], 6.3.4.

8.2 Aging Procedure

Naturally aged cells may be used for qualification testing. The following procedure shall be used for accelerated aging. This procedure will age the entire cell to the predominant aging failure mode, which is based on the failure of the positive plates. Other cell components with age-related failure mechanisms will be stressed to a life not less than the qualified life of the positive plates.

These components may be replaced during the aging procedures, if justification is provided that the replacement components have been aged to at least the proposed qualified life of the cell before the cell is subjected to the seismic test. When cell components are replaced, all other celltest conditions shall remain unchanged.

8.2.1 Accelerated Aging Conditions

1) Lead calcium cells shall be aged at one of two temperatures: 62.8°C (145°F) or 71°C (160 °F). Lead antimony pasted plates (Faurée) shall be aged only at 62.8 °C (145 °F).
2) The electrolyte shall be maintained at the selected aging temperature with a tolerance of –2 °F + 5 °F (–1.1 °C + 2.8 °C)
3) The walls of the cell may be supported to prevent excessive bulging that will occur due to the elevated temperatures throughout the aging procedure.
4) The length of the aging period in days shall be selected from Table 1.

8.2.2 Test Procedure

1) The test cells shall be brought to their full charged condition and a capacity test shall be performed at their three hour rate to 1.75 volts per cell (V/C) average and then recharged. This test shall be performed in accordance with ANSI/IEEE Std 450-1980 [5], Section 6 (6.1 (1) is optional). The three-hour rate shall be used because it provides a uniform basis for qualification by all manufacturers for all types.
2) The test cells shall be fully charged and placed on float to provide a positive plate potential of 50-100 mV above open circuit potential for the selected aging temperature.

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Table 1— Accelerated Thermal Aging Factors

Plate Type	Test Days at 62.8 °C (145 °F) to Equal 1 Yr at 25°C (77 °F)	Test Days at 71 °C (160 °F) to Equal 1 Yr at 25 °C (77 °F)
Lead calcium—pasted (Fauré)	20	10
Lead antimony—pasted (Fauré)	25	—

NOTE — The above table is based on results of tests performed by battery manufacturers on nominal 1.215 specific gravity cells. The test data is available from the manufacturers for verification.

3) The temperature of the electrolyte shall be elevated to the selected aging temperature and held at that temperature with a tolerance of–2 °F + 5 °F (–1.1 °C + 2.8 °C) for the duration of the aging period. The average temperature over the life of the test shall meet the criteria of Table 1.
4) The length of the aging period in days is determined by multiplying the expected qualified life in years by the factor listed in Table I for the appropriate temperature and positive plate type.
5) At the end of the aging period, the cells shall be cooled and maintained on float until a capacity test can be performed at the three-hour rate to 1.75 V/C average. The test is to be run in accordance with ANSI/IEEE Std 450-1980 [5], Section 6 (6.1 (1) is optional).
6) Life expectancy of batteries is not affected by two deep discharges per year. Therefore the above procedure will qualify the battery for the equivalent of two performance discharge tests per year, average, over the qualified life of the battery. If the expected service is more severe, the following procedure shall be followed:
   a) To simulate the additional discharge cycles, periodically cool the cells while still on float, then discharge the cells at the three hour discharge rate to 1.75 V/C average in accordance with ANSI/IEEE Std 450-1980 [5], Section 6 (6.1 (1) is optional), and then recharge. Repeat the procedure for the expected number of additional discharges. The number of discharges that are allowed at any one time shall be limited to the sum of the possible additional discharges that the battery would have experienced in actual service for the time represented by the preceding aging period.
   b) After the last recharge, return the test cells to the float condition, elevate the electrolyte temperature to the test value, and continue the aging procedure.
7) If the capacity test indicates less than 80% of rated capacity, the cells may be recharged, returned to float at ambient temperature for a minimum period of 72 h, and retested. If the cells fail the second capacity test, the cells shall have failed.
8) All test data shall be recorded.
9) If a cell is damaged as a result of accident or test equipment malfunction, its life test shall be considered void.

8.3 Seismic Vibration Procedure

For seismic vibration, qualification of a Class lE battery and its rack shall be in accordance with ANSI/IEEE Std 344-1975 [4]. The following is presented as a supplement for stationary type batteries. The recommended means for seismic qualification of the cell type to be used of the battery is by test. The battery or the rack, or both, shall be qualified by testing or by mathematical analysis.

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8.3.1 Cell Qualification by Test

8.3.1.1 Capacity Tests

After aging, the following discharge tests shall be performed to show that the aged cells are capable of performing before, during, and after a seismic event.

1) The cells shall be given in a pre-seismic capacity test in accordance with ANSI/IEEE Std 450-1980 [5], Section 6 (6.1 (1) is optional). The discharge rate shall be the three hour discharge rate to 1.75 V/C average. The discharge test performed after the aging portion of this program may be substituted for this pre-seismic capacity test. The cells shall then be recharged.
2) During a seismic test, the cells shall be placed on a fixed load discharge of a low current value of approximately 2% of the three-hour ampere discharge rating, and cells shah be monitored for current voltage fluctuations that could indicate circuit interruptions. If desired, a higher current may be used. This current or cell voltage shall be recorded during the seismic test. The cells can be recharged following the seismic test.
3) The cells shall be given a post-seismic capacity test as described in (1) of this 8.3.1.1.

8.3.1.2 Cell Qualification with Rack

The test rack shall be seismically representative of the full rack design to be used and its equivalency to a full-scale rack shall be demonstrated. It shall be erected on and fastened to the seismic table in accordance with the rack vendor’s instructions and shall simulate actual installed conditions. The aged cells shall be mounted on the rack and electrically connected in accordance with the manufacturer's instructions. The rack shall be fully loaded with cells (a minimum of three cells or three multiple-cell units) so that electrical connections of middle and end of row cells can be simulated.

NOTE — Three cells may not be adequate for a two-step or tier rack design.

The cells will be placed on a low-current discharge as described in 8.3.1.1(2). The assembly shall then be subjected to a seismic test to the specified floor response spectra and according to the test procedure in ANSI/IEEE 344-1975 [4], Section 6.

8.3.1.3 Cell Qualification without Rack

A minimum of three aged cells or three aged multiple-cell units shall be qualified in one seismic test so that electrical connections of middle and end of row cells can be simulated. The cells shall undergo the discharges described in 8.3.1.1. The cells shall be mounted on the seismic table using a fixture that is rigid and contacts the cells with the same material and in the same relative locations as found on the rack on which the cells are to be installed. The assembly shall then be subjected to a seismic test to the specified floor response spectra, taking into consideration the applicable rack amplification, if any, and according to the test procedure in ANSI/IEEE Std 344-1975 [4], Section 6.

8.3.1.4 Acceptance Criteria

Cells are qualified when there are no abrupt changes of more than 5% of the current or voltage of the discharge during the seismic test and when the post seismic discharge capacity is 80% or more of the cells' rated discharge capacity.

8.3.2 Cell Qualification by Analysis

8.3.2.1 Mathematical Analysis of Cell

A valid mathematical model of the cell that is to be qualified shall be presented. The mathematical model shall be based upon established principles, verifiable test data, or operating experience data. All components and physical characteristics of the cell, including aging, shall be included, and the damping action of the electrolyte shall be considered. For further guidelines on analysis procedures, refer to ANSI/IEEE Std 344-1975 [4], Section 5.

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8.3.2.2 Acceptance Criteria

When the cell is analyzed for the Operating Basis Earthquake (OBE), failure shall be assumed when the calculated stresses of a cell component, whose failure would cause loss or reduction of the allowable cell capacity, exceeds the material's allowable stress. When the cell is analyzed for the Safe Shutdown Earthquake (SSE), failure shall be assumed when the calculated stresses of a cell component, whose failure, would cause loss or reduction of the allowable cell capacity, exceed the material's minimum yield stress.

8.3.3 Rack Qualification by Test

8.3.3.1 Rack Qualification with Cells

(See 8.3.1.2.)

8.3.3.2 Rack Qualification without Cells

The rack description and erection procedure as described in 8.3.1.2 shall be used. In place of cells, the rack shall be fully loaded with dummy masses that approximate cell size and mass, and that have the same center of mass and mechanical stiffness as the cells for which the rack is designed. The dummy masses shall have simulated electrical connections and cell spacers similar to those used with actual cells. The assembly shall then be subjected to a seismic test to the specified floor response spectra and according to the test procedures in ANSI/IEEE Std 344-1975 [4], Section 6.

8.3.3.3 Acceptance Criteria

The rack shall suffer no structural failure that when analyzed would be detrimental to the intended function of the battery.

8.3.4 Rack Qualification by analysis

8.3.4.1 Mathematical Analysis of Rack

A valid mathematical model of the rack that is to be qualified shall be presented. The mathematical model shall be based upon established principles, verifiable test data, or operating experience data. The natural frequencies of the rack and battery assembly as a unit shall be determined. When this is determined, the applicable analysis method shall be selected from and performed according to ANSI/IEEE Std 344-1975 [4], Section 5.

8.3.4.2 Acceptance Criteria

When the rack is analyzed for the OBE, the calculated stresses shall not exceed the recommended values in the AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings [9]. When the rack is analyzed for the SSE, the calculated stresses shall not exceed the material's minimum yield stress. If rack materials other than steel are used, recognized industry design standards shall be used to determine recommended stress values.

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9. Documentation

9.1 General

The qualification documentation shall verify that the battery and rack are qualified for the application and meet specified performance requirements. The basis of qualification shall show the relationship of all facets of proof needed to support the design adequacy of the battery and rack. Data used to demonstrate the qualification of the battery and rack shall be pertinent to the application and organized in an auditable form.

9.2 Documentation Files

The user shall maintain a qualification file (not necessarily at the plant site). The file shall contain the information as listed in 9.3, 9.4, and 9.5, depending upon the qualification method used.

9.3 Type Test Data

The type test data shall contain:

1) The qualification information (Section 6)
2) Identification of the specific feature(s) to be demonstrated by the test
3) Test plan (refer to ANSI/IEEE Std 323-1983 [3], 6.3.1.1)
4) Report of test results. The report shall include:
   a) Objective
   b) Equipment tested
   c) Description of test facility (test set up) and instrumentation used, including calibration records reference
   d) Test procedure, frequency of readings, and input data (for example, seismic acceleration and spectra)
   e) Test data and accuracy (results)
   f) Signature of test personnel and date
   g) Summary, conclusions, and recommendations, including a statement of qualified life
   h) Supporting data
   i) Approval signature and date
   j) All malfunctions, action taken, and justification

9.4 Operating Experience Data

The operating experience data shall contain:

1) The qualification information (Section 6)
2) The interface or boundary conditions of the battery and rack
3) The specifications of the battery and rack for which operating experience is available
4) Identification of the specific features to be demonstrated by operating experience
5) Comparison of past applications and specifications with the new battery and rack specifications for each feature identified above
6) Summary and source of operating experience applicable to the battery and rack qualification
7) The basis on which the data has been determined to be suitable, including a statement of qualified life
8) Preparer's signature and date
9) Approval signature and date

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9.5 Analysis

The analysis data shall contain: (1) The qualification information (Section 6)

1) The qualification information (Section 6)
2) The interface or boundary conditions of the equipment
3) The specific features, postulated failure modes, or the failure effects to be analyzed
4) The assumptions, empirically derived values, and mathematical models used together with appropriate justification for their use
5) Description of analytical methods or computer programs used
6) A summary of analytically established performance characteristics and their acceptability,including a statement of qualified life
7) Analyst's signature and date
8) Approval signature and date

9.6 Other Information

Flammability and finish characteristics of battery and rack materials are not required for qualification but may be required for plant evaluation.

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