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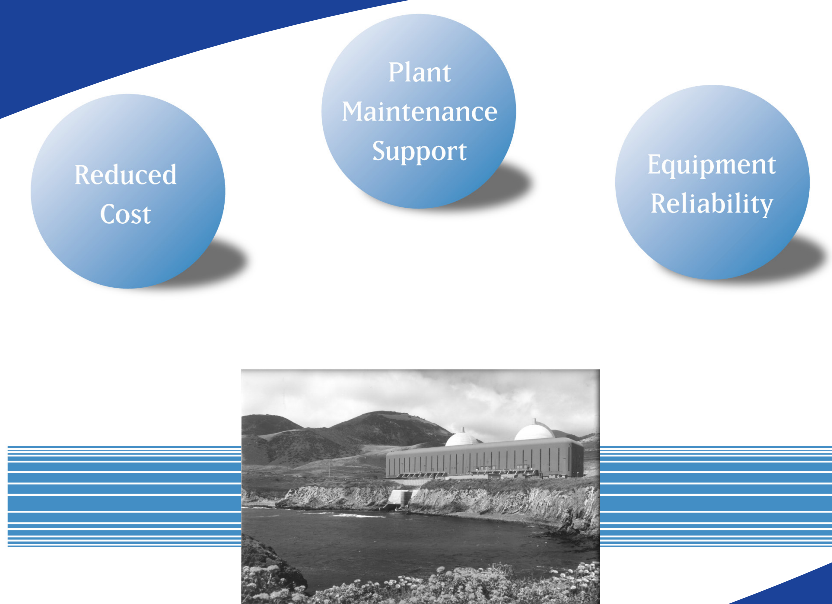
Nuclear Maintenance Applications Center: Motor Management Guide Supporting Plant License Renewal Including Environmental Qualification Considerations



Nuclear Maintenance Applications Center: Motor Management Guide Supporting Plant License Renewal Including Environmental Qualification Considerations

This document does NOT meet the requirements of 10CFR50 Appendix B, 10CFR Part 21, ANSI N45.2-1977 and/or the intent of ISO-9001 (1994)

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Report Summary

This report was developed by the Electric Power Research Institute's Large Electric Motor Users Group Information Working Group, which includes motor engineers, motor specialist consultants, and vendors. Environmental qualification (EQ) program owners were also involved in the development of this report. This report addresses the most important elements of a sound motor management program to support an informed decision on motor preservation and motor life extension. Motor life extensions of EQ motors are covered in accordance with options identified in IEEE Standard 323-1974.

Background

Many U.S. nuclear power plants are approaching their original design life of 40 years. Most plants have requested plant license renewal in accordance with Code of Federal Regulations 10CFR54 to allow them to operate up to 60 years. It is anticipated that many will seek plant license renewal up to 80 years during the next 20 years. Extending the plant life has required plant operators to evaluate the impact of extended operation on electrical and mechanical equipment. The challenges on motors at these plants must be addressed by a motor program that contains activities for motor preservation as well as continued EQ.

Plant license renewal requires that motors originally estimated to operate for 40 years be revaluated and the original qualified life extended for EQ motors, if practical, to allow for continued operation.

Motor life extension must be understood by the motor program owner and EQ program owner, or motor reliability can be decreased and/or EQ can be affected, rendering the motors inoperable.

Objectives

- To improve communications between the motor program owner and the EQ program owner
- To provide the elements of an effective motor program
- To present options for motor life extension to support plant license renewal

Approach

An effective electric motor program can pay great dividends when considering component reliability and plant license renewal. Typically, a motor program will include requirements for a long-range motor plan, maintenance activities for all motors, an understanding of motor preservation (including EQ motors), and the need for critical spare motors.

Results

This report provides information that requires understanding by the motor program owner for the preservation of motors and available options to extend motor life expectancy of EQ motors. Ultimately, the EQ life extension is the EQ program owner's responsibility.

Although motor life extension can be achieved by properly maintaining motors (which can include rewinds and core restack to reset life) and addressing EQ end-of-life calculations, it should be noted that, as motors age, failure mechanisms can change. Many age-related issues that have not been prevalent in motors of less than 30 years of age (for example, rotor laminations and cage loosening, weld fatigue, and shaft cracking) might have to be addressed as motors are operated beyond their originally perceived design life.

Keywords

Electric motor
Environmental qualification (EQ)
License renewal
Long-range planning
Motor management

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Section 1: Introduction

This report covers ac squirrel-cage induction motors and includes safety-related non-environmentally qualified and environmentally qualified (EQ) motors.

It is intended that this report be used as a basis for ensuring that motor preservation is performed to maximize life expectancy including EQ life. This report should be used in conjunction with original equipment manufacturer (OEM) recommended maintenance programs, additional Electric Power Research Institute (EPRI) reports pertaining to motor maintenance, refurbishment, rewinds, and procurement, IEEE standards for equipment qualification, and Nuclear Regulatory Commission (NRC) regulations. **Where the guidance of this report differs from those of standards, commitments, and/or NRC regulations, the requirements of the standards and regulations shall have precedence and govern.**

1.1 Purpose

This report provides the elements of a sound motor maintenance program and presents options for modifying the qualified life of some motors.

1.2 Scope

This report is applicable to ac squirrel cage induction motors used in nuclear power plants. Some information contained can also be used to assist fossil power plants in motor life extension. The following motors are included within this report:

- Commercial-grade motors
- Safety-related non-EQ motors
- Safety-related EQ motors
- Motors with a voltage range as follows:
  - Low voltage (<600 volts alternating current [Vac])
  - Medium voltage (2,300–15,000 Vac)

This report does not take precedence over the OEM qualification reports that reside in the EQ documentation (for example, binders) of the nuclear sites.

This report is not applicable for submersible, hermetically sealed, or canned pump motors because of their specialized and unique designs.

Section 2: Terms and Definitions

The following items are offered to assist in understanding, from a nuclear power plant perspective, terms that are used to present the ideas in this report.

bearings. An assembly of stationary and rotating members that support the motor rotor. These devices can take on various forms, such as rolling elements, plates, or sleeves.

Class 1E safety-related non-environmentally qualified (mild environment). Safety-related non-EQ motors are motors that are important to the safe operation and shutdown of the reactor, but their environment does not significantly change during a design basis event. According to Code of Federal Regulations 10CFR50.49 and IEEE Standard 323, qualified life or equipment qualification (that is, motorette testing) is not required for equipment located in a mild environment. However, some technical evaluation might be necessary to prove that the motor will perform its intended function in its installed location. The only design basis event of consequence for the specified end use application is considered to be seismic.

coil. A formed and insulated conductor with one or more turns.

design life. A period of time during which a motor is expected to function within acceptance criteria or the time during which satisfactory performance can be expected for a specific set of service conditions, based upon component selection and application.

environmentally qualified. A motor that has been qualified by type testing, operating experience, analysis, or a combination of these to function during and after a design basis event (if required by application), such as a loss-of-coolant accident or main steam line break, to safely shut down a reactor and to survive the resulting environment long enough to perform this task. Radiation harsh only environments also have to be included in the environmental qualification program. These motors are typically called *harsh environment motors*.

foreign material. Any material that is not part of the system or component as designed. Examples include dirt, debris, broken or missing parts, oil, slag, tools, rags, chemicals, machine tailings, lapping component, grinding or machining particles, paint chips, leak sealing components, and any other items that could adversely affect the intended operation, reliability, or function of the system.

foreign material exclusion. The processes and practices for preventing the introduction of foreign material into a motor or one of its components.

high-energy line break. Definition varies with plant licensing vintage but generally refers to breaks in systems with temperatures greater than 200°F (93°C) and/or pressures greater than 275 psig (2 MPa).

insulation. Materials used to provide electric separation between conductors, between conductors and ground, and between phases.

lubricant. Material such as oil or grease used to provide lubrication to motor bearings.

qualified life. Qualified life is formally defined by IEEE as the period of time, prior to the start of a design base event, during which a motor was demonstrated to meet the design requirements for the specified service conditions. Qualified life is generally specified in calendar time (for example, five years) at specified service conditions. Other values correlated with operating time (such as total radiation dose) or number of operating cycles can also be used. In practice, the qualified life of almost all electrical equipment located in harsh environments is limited by thermal aging with the thermal life determined by accelerated aging in the environmental qualification program and the use of the Arrhenius aging model.

rotor. The rotating element of a motor, which includes the rotor circuit (rotor bars and shorting rings), core, cooling air fans, and shaft.

service life. This is the period from initial operation to retirement of a motor from service.

stator. The stationary portion of a motor that includes a core and windings.

testing. Activities or methods used to check or determine a specific condition.

winding. A combination of electrically connected conductors used in a motor stator to generate the rotating electrical field while energized.

Section 3: Exceptions

When using this report, care should be taken to ensure that revisions to standards and/or regulations are evaluated for additional or different recommendations.

Although this report contains a sound methodology that can be used to extend a motor's life expectancy, for EQ motors, it does not supersede the recognized EQ program of a nuclear site. Any activity to extend the qualified life of a motor must be approved by the EQ program owner and meet established criteria to ensure that qualification is maintained throughout the life of the motor.

Section 4: Industry Documents

The following standards or documents are referred to in this report:

4.1 American Society of Mechanical Engineers

ASME NQA-1	Quality Assurance Program for Nuclear Facilities (also see American National Standards Institute [ANSI] N45.2)

4.2 Code of Federal Regulations

10CFR50, Appendix A	General Design Criteria for Nuclear Power Plants
10CFR50, Appendix B	Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants
10CFR50.49	Environmental qualification of electric equipment important to safety for nuclear power plants
10CFR51	Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions
10CFR54	Requirements for Renewal of Operating Licenses for Nuclear Power Plants

4.3 Electric Power Research Institute

EPRI NP-3887	*Life Expectancy of Motors in Mild Nuclear Plant Environments*
EPRI 1008034	*Joint Utility Task Group Commercial Grade Item Technical Evaluations*
EPRI 1009698	*Shipping and Storage of Electric Motors*
EPRI 1011894	*Guide for Determining Motor Repair Versus Motor Replacement*
EPRI 1008964	*Repair and Reconditioning Specification for AC Squirrel-Cage Motors with Voltage Ratings of up to 600*

EPRI 1016679	*Nuclear Maintenance Applications Center: Repair and Reconditioning Specification Guidance for AC Squirrel-Cage and Salient Pole Synchronous Motors with Voltage Ratings of 2.3 to 13.2 kV*
EPRI 1011892	*Guideline for the Specification of Replacement and Spare AC Squirrel-Cage Induction Motors having Voltage Ratings of 2,300V to 13,200V*
EPRI 1016680	*Nuclear Maintenance Applications Center: Guide for the Performance of On-Site and Vendor Shop Inspections of Electric Motors*
EPRI 1021067	*Plant Support Engineering: Nuclear Power Plant Equipment Qualification Reference Manual, Revision 1*
EPRI 1021428	*Nuclear Maintenance Applications Center: Recommended Practice for Evaluating Interchangeability for National Electric Manufacturers Association Frame Motor Replacement*
EPRI 3002000809	*Guide for the Specification of Replacement and Spare AC Squirrel-Cage Induction Motors Having Voltage Ratings up to 600V*

4.4 IEEE

IEEE 43-2000	Recommended Practice for Testing Insulation Resistance of Rotating Machinery
IEEE 95-2002	Insulation Testing of AC Electric Machinery with High Direct Voltage
IEEE 112-2006	Test Procedures for Polyphone Induction Motors and Generators
IEEE 117-1984	IEEE Standard Test Procedure for Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery
IEEE 323-1974	IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations (other revisions that may be applicable are 1983 and 2003)
IEEE 334- 1971	IEEE Standard for Qualifying Continuous Duty Class 1E Motors and NPG Stations (other revisions that may be applicable are 1974, 1987, 2004, and 2006)

IEEE 344-1975	IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations (other revision that may be applicable is 1987)
IEEE 522-2004	Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines
IEEE 841-2009	IEEE Standard for Petroleum and Chemical Industry-Severe Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp)

4.5 National Electrical Manufacturers Association

NEMA MG1-2009 (Rev. 1)	Motors and Generators

Section 5: Considerations for Motor Long-Range Plan

An important area that requires development to maintain motor reliability is a long-range plan. A long-range plan outlines activities and their performance frequencies necessary to detect weaknesses, restore degraded conditions, and change out components and complete motors at the appropriate time. This section covers activities that should be included in a long-range plan.

5.1 Motor Program

An effective motor program consists of several program elements. Figure 5-1 depicts the elements that make up an effective program for motors.

Figure 5-1
The elements of an effective motor program

5.1.1 Predictive Maintenance

Predictive maintenance is used to provide motor reliability between preventive maintenance (PM) activities (for example, refurbishments and rewinds). Predictive maintenance consists of monitoring and tests that are used to predict present health of the motor and provide trend data used to detect negative trends. Results of predictive maintenance are used as one of the tools to determine the most appropriate timeframe for performing PM. Predictive maintenance activities for motors typically consist of the following four categories:

- Monitoring
- Testing
- Inspections
- Audible inspections

5.1.1.1 Monitoring

The items listed in this section provide information to optimize service life and minimize maintenance cost through effective condition monitoring. The following items should be included as part of a good maintenance program:

- Supply voltage
- Running current
- Speed
- Bearing temperatures
- Winding temperatures
- Vibration
- Oil levels
- Oil color change
- Oil flow (force-fed lubrication system)
- Oil slinger ring operation

5.1.1.2 Testing

It might be prudent to establish a battery of tests that would possibly reveal the condition of various portions of a motor. Applying these tests on a routine basis and comparing the data to baseline information can provide detection of degraded conditions. The following are some of the tests that are currently used for electric motors:

- Winding resistance
- Insulation resistance (includes polarization index test)
- Partial discharge (must have coupling capacitor installed—typically on motors above 5000 Vac)
- High-potential testing
- Oil analysis

5.1.1.3 Inspections

Motor inspections can be external and/or internal. External inspections are typically performed while a motor is in operation; whereas, internal inspections are performed while a motor is not operating. More intrusive inspections can be performed if a motor is to be partially or fully disassembled. Inspections can reveal the presence of dirt, oil or moisture, damage from foreign material, broken or cracked components, loose winding ties, and abraded insulation.

The following inspections can reveal anomalies and could require immediate corrective actions:

- Visual inspections, considering the following:
  - Loose parts
  - Foreign material
  - Oil leaks
  - Water leaks
- Visible vibration
- Audible, considering the following:
  - Change in normal sound level
  - Odd or peculiar sound

5.1.2 Preventive Maintenance

PM activities are more intrusive and usually require the motor to be out of service and, in some cases, disassembled. These activities can be as simple as a borescope inspection or as complex as a full refurbishment and/or rewind. PM activities are performed to maximize the potential for finding and correcting degraded conditions. Many degraded conditions can be found only during disassembly because of the degraded condition or component being located inside the motor (that is, bearing babbitt smear, winding looseness, and so forth)

PM is performed when predictive maintenance indicates a need (condition-based) or at a predetermined interval (time-based).

5.1.2.1 Condition-Based

Condition-based programs are preventive programs that use monitoring and test results to determine when it is time to perform a particular maintenance activity (for example, oil analysis to determine oil change intervals). Condition-based maintenance provides information on a motor's operation and reliability between the time-based maintenance activities. Experience has indicated that a 100% condition-based maintenance program on motors without time-based maintenance **will not** provide the level of reliability that is expected from utility power plant motors, especially those that are installed in a nuclear power plant. A combination of condition-based and time-based programs is the best PM program for motors.

5.1.2.2 Time-Based

Time-based PM is maintenance performed at a set timeframe that can be performed on a time schedule directed by OEM requirements or by industry standards. Motor refurbishments are normally time-based because of the planning required to remove a motor from service and the timeframe needed for inspection and/or refurbishment activities. Rolling element bearing replacement is another good example of time-based PM if the bearings are scheduled to be changed out at the end of their L-10 calculated life. *L-10 life* is essentially a time interval for a particular bearing where 10% of the bearings will fail.

Typical timeframes for motor refurbishments are between 10 and 20 years, depending on the motor design, operational time, number of starts, and environment.

The frequencies of time-based tasks are usually related to knowledge of age and/or operational related degradation. As stated in Section 5.1.2 of this report, many degradation conditions can be found only during refurbishments.

Many gaskets, sealant, and O-rings have a limited life as a result of their organic materials. Failure to replace these at periodic intervals can result in oil leaks and possible bearing or motor failure.

The intervals are determined by the material used and the environment in which it is installed. However, most of these are replaced during a motor refurbishment. If the refurbishment intervals are adhered to, changeout of these materials will occur during the refurbishment and should provide material replacement before their end of installed life.

5.1.3 Corrective Maintenance

Corrective maintenance activities are performed to address degraded conditions. Babbitted bearing repouring, stator core restacking, and rewinding are a few examples of corrective maintenance. Typically, corrective maintenance is performed during refurbishment activities during discovery opportunities after motor disassembly. It should be noted that many corrective maintenance activities can require long out-of-service times, which can affect outage schedules, plant power conditions, and/or safety concerns.

5.2 The Need for Refurbishments

The goal of a predictive maintenance program is to ensure motor reliability. However, predictive maintenance alone will not provide long-term reliability without additional inspections, partial disassembly, and/or full refurbishments. There are many degraded conditions that can be detected only with visual and hands-on inspections during disassembly and refurbishment activities.

The following are examples of some of the degraded conditions:

- Loose windings, endbracing, or wedges
- Brittle or damaged insulation (physical damage, not dielectric damage)
- Dirty and/or oily windings (unless they affect winding temperature)
- Damaged motor lead insulation that is isolated from a ground path (swelling from oil contamination, abrasion wear, ring cracks in insulation, and splits in insulation)
- Surge ring damage or looseness
- Stator and rotor finger and vent duct looseness
- Stator frame and stator core weld cracks
- Scratched or damaged journals (root mean square finish not acceptable)
- Beginning stages of babbitt damage on guide or thrust bearings
- Embedded particles and shaft current static discharge damage to bearings
- Damaged bearing insulation
- Rotor bar or resistance ring damage or rotor hardware looseness (Online current analysis can detect rotor bar and/or resistance ring cracking if they are cracked all of the way through but will not detect beginning stages or cracks.)
- Manufacturing defects
- EQ features that can be inspected only during disassembly
- Loose hardware
- Foreign material internal to the motor

The preceding degraded conditions will lead to reduced reliability and potential in-service motor failures if they are not detected and corrective actions are not performed. Limited internal inspections on some motor designs can be achieved by the use of a borescope. Although a borescope inspection does not provide the same degree of internal inspection that can be seen during a disassembly, it can detect some indications of rotor and winding problems that need immediate attention.

To achieve maximum motor service life and reliability, it is recommended that power production (main process motors) and critical motors have a proven preventive and predictive maintenance program coupled with partial and/or complete refurbishments. Refurbishments for EQ motors should be scheduled in accordance with the requirements listed in the EQ documentation/files. For all others, refurbishments should be based on industry standards and recommendations. Examples of industry guidance can be found in the 1992 EPRI report, *Electric Motor Predictive and Preventive Maintenance Guide* (NP-7502), and in *Preventive Maintenance Basis Database* (1018758), which contains the EPRI PM templates for motors.

Examples of OEM refurbishment recommendations can be found in General Electric Service Instruction Letter 484, Item 4, and in Westinghouse TB-04-5, "Recommended 1, 5, and 10 year Reactor Coolant Pump Motor Inspection and Maintenance Plan."

All motors will require refurbishment sometime during their design life. This timeframe will vary based on several stressors that can degrade motors. Examples of these stressors are as follows:

- Age of motor (Typically, motor reliability decreases after 30 years of service.)
- Number of starts (Starting places significant magnetic, vibration, and centrifugal stresses on motors, especially on the endwindings and rotors.)
- Voltage spikes (Voltage spikes occur during breaker closure and system perturbations.)
- Environmental conditions (temperature extremes, salt water/moisture, dirty, steam, radiation, and so forth)
- Mechanical vibration during operation
- Speed of motor (3600-revolution-per-minute motors degrade at a faster rate because of the centrifugal forces placed on the rotor and bearings)

Typical industry- and EPRI-recommended timeframes for refurbishments are between 10 and 20 years. Experience by nuclear plant motor engineers has proven this timeframe to be acceptable.

5.2.1 Importance of Refurbishment Specifications

Refurbishments for motors are meant to find and eliminate degraded components found during disassembly and inspections. Mechanical components can be repaired, reworked, or replaced so that the motor is in like-new condition and maximize reliable operation between refurbishments. However, electrical components are made of metallic and organic materials and, therefore, usually will require replacement to achieve like-new condition. Control of refurbishment activities is required if you are to get the full benefit of a refurbishment. Refurbishment specifications are used for this control. A detailed refurbishment specification, including customer oversight, increases the chances of reliable motor operation after refurbishment and standardizes both mechanical and electrical component inspection, tests, repair, and replacement. EPRI has provided several detailed refurbishment reports that can be used as guidance for developing plant-specific motor refurbishment specifications.

If a refurbishment specification is not submitted with a motor to be refurbished, control of the refurbishment activities could be lost and motor reliability could suffer.

5.3 Rewinds

Rewinds are not part of a standard refurbishment. The motor winding is one of the most important components to maintain between refurbishments. A good quality winding will typically provide 30–40 years of reliable operation. A winding ages thermally and mechanically (vibration and movement) during operation; however, starting causes a significant amount of mechanical stress in the endwindings. Radiation and environmental conditions affect the winding regardless of whether the motor is running and play a role in the aging of the organic materials. Because windings do not have an infinite life, a rewind will most likely be required to provide motor reliability for plant license renewal if a motor replacement is not planned.

5.3.1 Importance of Rewind Specifications

Although windings for random wound motors are basic in construction, control of winding fabrication and installation is still required to obtain a well-built motor. In order to obtain a motor that will be reliable and provide a long operational life, high-quality materials should be used.

Form-wound motors have complex windings that can consist of many materials. Material selection is important to ensure that a rewound motor will be reliable for the remaining life of a plant. Skilled workmanship and process control are necessary and should be procedurally controlled in order to obtain the desired end product. The following items should be controlled to ensure that a robust winding is constructed and installed:

- Insulating materials
- Fabrication process
- In-process testing
- Installation techniques
- Winding blocking and tying techniques
- Winding resin treatment
- Sample coil quality checks

A winding specification is typically used to control these activities. EPRI has several reports that contain proven winding designs, material selection, fabrication processes, installation techniques, and testing that can be used for guidance when developing motor rewind specifications.

5.3.2 Guidance on When to Replace Insulation Systems

The decision process to replace an insulation system is not straightforward. There are various inputs required to make this determination. The following inputs should be considered:

- Condition of the insulation
- Time in service
- Test results, including the following:
  - Insulation tests indicating negative trends that do not improve with winding reconditioning during refurbishment
    - Low insulation resistance reading
    - High microamp leakage
  - High winding resistance imbalance
- Inspection by a knowledgeable individual, considering the following:
  - Winding looseness that is observed during winding inspections
  - Loose endwindings
  - Loose or missing wedges
  - Broken blocking and ties
  - Significant corona damage
  - Cracked or brittle insulating tapes
  - Damaged insulating tapes
  - Swollen or cracked motor leads insulation (although motor leads can be replaced on some non-EQ motors)
- Consideration of winding replacement between 30 and 40 years in service
- After winding failure and/or damage

If a motor refurbishment is time-based, the insulation system must be reliable until the next scheduled refurbishment because, in most cases, a motor winding cannot be adequately inspected unless the motor is disassembled.

5.3.3 Core Condition

A stator core should be tested and inspected prior to installation of a new winding.

A core should be tested for acceptable core loss results with no hot spots above acceptance criteria.

A core should be inspected for the following:

- Lamination smearing
- Tightness with no loose laminations
- Tight clamping fingers
- Tight vent ducts
- No loose through bolts (if applicable)
- No burrs or damaged laminations in the slots

A new winding installed in a marginal, bad, or damaged core will not last long in service because of stator core heating or hot spots. The refurbishment specification should provide stator core inspection and test criteria to ensure that the stator core is suitable to receive a new winding.

5.3.4 Failures Causes That Lead to Rewinds

When a motor experiences a winding failure, it is important to understand the failure cause(s). The following are common failure causes:

- Poor workmanship
- Winding design, including the following:
  - Insufficient dielectric strength
  - Improper connections
  - Inadequate blocking and tying
- Improper maintenance
- Foreign material
- Mechanical failure
- Improper operation
- Environmental conditions
- End of life

Without understanding the failure cause(s), failures could occur on additional installed motors of similar design. Also, if the failure cause(s) is not understood and is the result of winding design weaknesses, a new winding could contain the same design weaknesses if the new winding duplicates the original winding.

5.4 Availability of Critical Spares

Critical spare motors are essential in the motor long-range plan. Many large motors and some of the small motors are critical to plant operation, although some are important to reactor safety. Some motor failures are repairable, although more catastrophic failures require motor replacement. Regardless of the cause of the failure, the failed motor will have to be removed from service. If the motor is critical to plant production, plant operation will be affected. If the motor is critical for safe shutdown and operation of the reactor, the plant will enter into a limited condition of operation (LCO), which usually states that if the motor cannot be repaired or replaced in a limited time (typically not more than seven days—can be as short as 24 hours), reactor shutdown will be required.

It is well known in the industry that catastrophic failures usually require long repair times, winding and stator core replacement require long lead times, and new-motor procurement can take up to 24 months. To protect the plant from operating at reduced power or from a reactor shutdown, critical spare motors are required to allow motor replacement and sufficient time for motor repair, rewind, or new-motor procurement.

Recent industry reports that reviewed events impacting nuclear power production stated that plants are expected to have available critical spares as part of a nuclear site's motor program. The reports also stated that lack of critical spares has caused loss of power generation at U.S. nuclear power plants.

5.5 New-Motor Procurement Specifications

Because most originally installed motors in the nuclear power industry are 30-plus years in age, their design may be obsolete or the OEM may no longer be in business. New motors procured today can be designed with better materials, different insulation systems designs, and higher efficiencies. Although new motors can be an improvement over the original designs, changes in weight, frame design, and performance characteristics can create installation and operational problems. A motor procurement specification should be used to control new-motor manufacturing to ensure that the motor has the same form, fit, function, and performance characteristics as the original motor.

EPRI reports 1011892 (*Guideline for the Specification of Replacement and Spare AC Squirrel-Cage Induction Motors having Voltage Ratings of 2,300V to 13,200V*) and 3002000809 (*Guide for the Specification of Replacement and Spare AC Squirrel-Cage Induction Motors having Voltage Ratings up to 600V*) provide recommendations for new-motor procurement and can be used to develop on-site new-motor procurement specifications.

5.6 Challenges and Logistics for Removal/Installation of Motors

Some motors are more difficult than others to remove from a plant. Small low-voltage motors can be less difficult to remove; however, many considerations must be addressed when removing a large medium-voltage motor.

Many motors are installed in plant areas that make removal and installations difficult. These difficulties can be because of location of auxiliary equipment from original plant design or equipment that has been installed as a result of modifications.

5.6.1 Rigging

It is important that rigging plans, rigging points, lifting equipment load testing (slings, hoists, hooks, and so forth), trained rigging personnel, and crane or hoist operators be considered far enough in advance of a motor removal or installation to minimize delays and ensure the safety of the personnel and the plant equipment.

Motors can be large, heavy, difficult to move, and damaged if they are not rigged properly. Many areas in the plant where motors are located do not have a clear path or sufficient rigging points located to allow direct removal. Some motors require drifting, multiple rigging, and hoists to remove them from the plant.

Most plants require rigging permits and other documentation before a motor can be rigged. In some cases, lifting points for rigging, such as hooks, have to be welded at strategic locations above the motor to allow removal. When using I-beams and/or seismic supports, the load-carrying capability has to be addressed. Some motors will be located in radioactive contaminated areas, and rigging (especially Kevlar[1] slings) must be protected from contamination.

5.6.2 Motor Removal Plan—Motor Egress

To minimize delays in motor removal, a removal plan should be developed to ensure that all challenges and logistics are considered. In some cases, a floor loading analysis might be necessary. Some plants have installed motors in rooms that have sacrificial walls that can be removed to facilitate motor removal. The motor removal path is not always direct or unencumbered. Many egress paths are blocked by piping, seismic supports, ductwork, equipment installed during plant modifications, or other obstructions that must be removed or temporarily repositioned to allow a motor removal. Some motors have been installed in areas with a monorail and/or overhead hoist to allow removal (see Figure 5-2). However, most motors do not have these and must rely on a drift pull, a rolling transport cart, or both to accommodate removal. If a floor path is clear, a motor could be placed on a rolling cart (see Figure 5-3), and egress would be significantly easier than a drift pull. Figure 5-4 shows a motor transport cart. These carts can be fabricated to meet a motor's size, weight, and shaft configuration.

[1] *Kevlar* is a registered trademark of E. I. du Pont de Nemours and Company.

Figure 5-2
An overhead hoist for motor removal and installation

Figure 5-3
Motors staged on transport carts

Figure 5-4
A motor transport cart

5.6.2.1 Ingress of Replacement Motor Through the Plant

If a new or refurbished motor is to be installed, consideration should be given to keeping temporary rigging in place and not reinstalling any items removed or repositioned (ductwork, seismic supports, piping, and so forth) during motor removal until the new or refurbished motor is installed. This will save time and minimize duplication of rigging installation and equipment repositioning. As with the removal path, the installation path should be kept clear of any obstructions until the replacement motor is installed.

5.6.2.2 Challenges to Removal of Obstructions in Egress and/or Ingress Path

Most plants will have some form of obstruction that will make the removal and installation of motors challenging. If potential challenges are not considered and addressed prior to motor removal, delays can be expected. Some of the challenges to consider with these obstructions are as follows:

- Do the obstructions support an operating system?
- What permits are needed to remove or reposition the obstructions?
- Are the obstructions energized?
- Will hold orders be required?
- What additional personnel support is required to remove the obstruction?
- Will the plant's configuration control be affected with the obstruction removal?
- Will the obstruction removal be considered a design change (that is, cutting a seismic support)?
- What will be required to reinstall the obstruction that was removed (welding, fabrication of supports, pressure or leak tests, and so forth)?
- Does the obstruction removal place the plant into an LCO?
- What preplanning is required for the obstruction removal?
- Will the obstruction require storage or staging during motor removal and reinstallation?
- Does it violate design requirements (that is, cable bend radius)?

5.6.2.3 Staging of New or Refurbished Motors

It is preferable to stage a replacement motor at a location within a plant near the installation point. Staging the replacement motor will accommodate expedited motor installation, removal of temporary rigging, and equipment restoration.

5.6.3 Coupling Compatibility, Base Alignment, and Physical Dimensions

Replacement motors should couple, mount, and align properly with driven equipment. Mounting and alignment issues can be significant and cause major installation delays. If replacement motors are purchased or the spare that is available is not an exact duplicate of the originally installed motor, the following should be considered prior to installation:

- Ensure that mounting feet bolt hole size and location are the same for horizontal motors.
- Ensure that the flange bolt hole size and location are the same on vertical motors.
- Ensure that the flange boss or rabbet fit of the flange is the same size for vertical motors.
- Ensure that foot flatness and flange runouts are within design specifications.
- Verify that shaft diameters and keyway dimensions meet original coupling requirements.
- If motor shaft is not the same as the original motor, coupling modification might be required. If a new coupling half is required, bolt hole size and arrangement, as well as the flange dimensions, could require modifying to meet the coupling half on the driven equipment.
- If the shaft height of a horizontal motor does not have the same centerline dimension from the mounting feet, adapters might have to be fabricated.
- If the shaft extension does not extend the same length from the inboard end bracket, adjustments might be required.
- The location of the main junction box and auxiliary boxes on the replacement motor must be in the same location as the original motor design, or cable and wire splices may be required.
- The motor's overall dimensions need to be evaluated against the original motor's design to ensure that it will fit through the installation path and on the motor skid or base without interfering with adjacent structures or equipment.
- The motor's weight should be known to ensure that the mounting structure will adequately support the motor and, when necessary, will meet seismic requirements.

5.6.4 Coordination of Activities

Usually, there are multiple activities being performed in the same general area where a motor is to be removed (especially during outages). Activities such as scaffolding erection, pipe insulation removal, pipe inspections, driven equipment maintenance, and painting can cause major delays in motor removal and installation. It is necessary to ensure that all activities in the general area where a motor is being removed or installed be identified and coordinated with personnel performing these activities. Some of the activities can generate significant foreign material exclusion issues for a motor, which could lead to premature degradation and/or in-service failures.

Because each plant has limited resources to support many activities that are performed during an outage, it is necessary to ensure that scaffolding requesting and craft scheduling are pre-outage activities. This will minimize down time waiting for support personnel to complete a requested task during motor removal and installation.

5.6.5 Mounting Base Flange Preparation

After a motor is removed, the base should be inspected prior to installing a replacement motor. This surface could have pitting, rust, and other debris, which can cause alignment and soft foot conditions. Preparation of mounting surfaces can require cleaning, sanding, and or machining. Figures 5-5 and 5-6 show examples of a degraded motor base. Figure 5-7 is an example of a properly prepared motor base flange.

Figure 5-5
A degraded motor base
Used with permission from Pump & Motor Works, Inc.

Note: Mounting flange is free of rust, but the secondary flange is still rusty.

Figure 5-6
A rusted and pitted motor base flange
Used with permission from Pump & Motor Works, Inc.

Figure 5-7
A properly prepared motor base flange

5.6.6 Marking Magnetic Center on Horizontal Motors

Horizontal motors with sleeve bearings can have up to 0.5 in. (12.7 mm) shaft float between the mechanical shoulders of the bearings. During no-load running, the shaft should run between the mechanical shoulders of drive end and opposite drive end bearings (this keeps the shoulders on the shaft from running on the babbitt thrust shoulders of the sleeve bearings). This is the magnetic center of the rotor. Three marks should be placed on the drive end of the shaft during the no-load run (blueing can be used on the shaft to allow marking without scoring the shaft)—one mark for the drive end mechanical shoulder, one for the opposite drive end mechanical shoulder, and one for no-load magnetic center. This will assist in the alignment and coupling of the motor.

5.6.7 Alignment and Coupling

Vertical and horizontal motors require proper alignment to the driven equipment. Proper alignment should be within specifications (plant and/or OEM requirement), or increased vibration and premature bearing wear can be expected. Alignments should be performed by individuals trained in aligning machines. Laser alignment is typically more accurate but might not be feasible on certain motor configurations. Alignment takes time and must be factored into total installation time.

Note: If a horizontal motor with sleeve bearings does not run at magnetic center, ensure that the alignment is adjusted for mechanical center of the shaft float. This will provide proper alignment and minimize any hard contact between the thrust shoulders of the shaft and the babbitt thrust shoulders of the sleeve bearings.

After the alignment is complete, ensure that the motor is coupled to the driven equipment and properly torqued. Ensure that the correct type—and proper quantity—of grease is added to a geared coupling, if used, or premature coupling failure may occur.

5.6.8 Bump for Rotation and No-Load Run

Induction motors can operate in either direction if they do not contain the following design features:

- An anti-rotation device (ARD)
- Directional bearings
- Directional fan designs

A phasing meter should be used to identify phase rotation. After temporarily connecting the motor leads to the power cables, the motor should be bumped for proper rotation and visually verified to rotate in the correct direction. Ensure that motors with an ARD installed have the ARD disabled during the bump test, or the ARD could be damaged because most are not designed for full reverse torque.

In order to change direction of rotation of an induction motor, any two of the three phases can be swapped. Unfortunately, connecting a replacement motor to existing power cables with phasing labeled on the motor leads does not guarantee that the motor will run in the same direction as the originally installed motor.

Note: Listen for any unusual sound during the bump test that could indicate mechanical issues.

After the bump test has verified proper rotation, the motor leads should be connected and insulated to the power cables and the ARD restored to operational condition prior to the no-load run. A no-load run should be performed until stator and bearing thermal stabilization to determine whether any temperature anomalies are present and to ensure that the motor (after mounting to the base) does not have any abnormal vibration prior to coupling the motor to the driven equipment. If the coupling is not installed during the no-load run, install and secure a half key to minimize unbalance resulting from the keyway in the shaft.

5.6.9 Housekeeping

A motor removal and installation activity is not complete until the area around the motor is as clean as or better than before the motor was removed. This includes removal of rigging, scaffolding, rags, spilled oil, and so forth and generally requires assistance from laborers and other craft to complete.

5.7 Motor Management Program (Roles and Responsibilities)

Implementation of a motor management program is not just the responsibility of the motor program owner, especially when EQ motors are part of the program. The motor management program should be part of a company's integrated long-range plan.

With most plants seeking plant license renewal, motor life extension should be included in the motor management program. Life extension can be more complicated with EQ motors because their qualified life has to encompass the total life of the plant.

5.7.1 Long-Range Plan

Long-range planning is setting goals and developing plans to help an organization move in a focused direction while operating in an efficient and effective manner. Strategies or plans are then developed for moving the organization closer to its goals. Long-range plans usually pertain to goals that are expected to be met five or more years in the future.

Nuclear power plants were licensed for a specific operating period (typically, 40 years). Many motors and other components that were purchased as EQ were purchased with the plant life as a basis. However, with the advent of plant license renewal, qualified life of various components has to be evaluated. This evaluation must be factored into the long-range plans and the overall motor management program. A typical long-range plan should include the following:

- PM
- Scheduled refurbishments
- Critical spares
- Equipment replacement

Because maintenance activities or lack of required maintenance can affect a motor's reliability and service life as well as the qualification and qualified life of an EQ motor, many individuals or groups have a role to play in the preservation-life phase of motors. Each of these individual's or group's roles and responsibilities for the motor management program is covered in the following sections.

5.7.2 Motor Program Owner

The motor program owner has the responsibility to ensure that motors (including EQ motors) in its programs are being maintained to provide the expected reliability and life and to minimize in-service failures. This starts with procurement and continues until the end-of-life (non-EQ motors) or qualified life (EQ motors).

The motor program owner must ensure that the following activities are performed correctly to achieve maximum motor life expectancy.

- Proper procurement
- Proper shipping
- Proper storage
- Installation and post-installation testing
- PM programs
- Corrective maintenance
- Long-range motor plan (includes EQ life and EQ life extension coordination with EQ program owner)
- Coordination with driven equipment program owner(s) and interfacing organizations (as necessary) to implement the motor program

Note: Various organizations are involved in several of the preceding activities.

5.7.3 Engineering and EQ Program

Motor performance characteristics and any design changes are controlled by engineering with input from the motor program owner. Typically, the EQ program is part of the engineering program and controls all aspects of a motor's qualification and qualified life.

Typical engineering and EQ program owner responsibilities as related to motors will be in the following areas:

- Motor performance characteristics and any design changes (engineering, EQ program owner)
- Motor procurement/specifications (engineering)
- EQ documentation/files preparation and revisions (EQ program owner)
- Qualified life extension in accordance with IEEE Standard 323 (EQ program owner)

5.7.4 Project Management

Capital projects will have an assigned project manager who should work with the motor program owner and engineering to obtain critical spares and/or replacement motors.

Project management will typically be involved in the following motor activities:

- Motor budgetary activities
- Motor project planning
- New-motor procurement (capital projects)

5.7.5 Procurement

Procurement (which includes contract management) is primarily responsible for the procurement process of replacement and critical spare motors and parts. Its involvement in the motor management program includes the following:

- Generating request for proposal (RFP)
- Negotiating exceptions to the RFP
- Generating the contract for new-motor procurements
- Awarding new-motor contracts to successful bidder(s)
- Following contract implementation
- Accepting submittals from motor manufacturer(s) and coordinating internal review and approval

For EQ motor procurement(s), deviations from specifications must be approved by the EQ program owner.

5.7.6 Maintenance

Maintenance organizations will be responsible for conducting many of the activities pertaining to motor preservation. Maintenance and other activities required to maintain motor qualification are established by the EQ program owner; however, these activities are typically carried out by plant maintenance personnel. These activities can also include motor removal and installation.

Typical roles and responsibilities include the following:

- Performance of PM
- Maintaining PM programs
- Corrective maintenance
- Testing
- Condition monitoring
- Removal and installation activities
- Some on-site refurbishments

5.7.7 Outage Management and Scheduling

Outage management coordinates activities to conduct efficient and effective outages. This group supports the motor management program activities that are performed only during outages (that is, removal and installation of a motor). Coordination with outage management is required to ensure that the motor activities do not interfere with other outage activities. This will minimize the risk of motor activities extending outage schedules.

There are some motors that have major maintenance activities performed during plant operation. In these cases, maintenance or other assigned organizations control the activities with operations coordination.

5.7.8 Craft

Normally the appropriate craft will perform the hands-on work during motor preservation activities and motor removals and replacements. This will include the following:

- Testing
- Predictive maintenance
- Corrective maintenance
- Parts replacement
- Troubleshooting

- Motor removal, including the following:
  - Disconnection of motor terminations (determination)
  - Rigging
  - Scaffolding
  - Moving the motor through the plant
  - Installation
  - Reconnection of motor terminations (retermination)
  - Alignment
  - No-load test run
  - Final acceptance tests

5.7.9 Warehouse Personnel

Warehouse personnel are responsible for ensuring that the motors are correctly received, protected, and stored in the correct environment while in inventory. This is usually governed by American Society of Mechanical Engineers (ASME) NQA-1 (formerly American National Standards Institute [ANSI] N45.2.2) for safety-related motors. They are also responsible for coordination of required maintenance and testing activities with the appropriate on-site organizations.

5.7.10 Third Parties

Third parties can play an important role in motor preservation, motor procurement, and motor long-term storage. Depending on the nuclear sites resources, third parties can be used for the following:

- Staff augmentation
- Witnessing of inspections during motor refurbishment, rewinds, and procurement
- Nuclear Procurement Issues Committee audit support
- Off-site storage
- Maintenance during storage of motors

Section 6: Mild and Harsh Environment Motor Considerations

The differences between mild and harsh equipment qualification are related to the accident environment levels that the equipment is exposed to, in qualification methods, documentation, and different regulatory requirements. Harsh EQ is controlled by Code of Federal Regulations (CFR) 10CFR50.49 and has very prescriptive documentation requirements. Mild environment for existing plants is defined in 10CFR50.49 (c)(3) as "an environment that would at no time be significantly more severe than the environment that would occur during normal plant operation, including anticipated operational occurrences." However, mild environment equipment is excluded from the requirements of 10CFR50.49 and is addressed by 10CFR50 Appendix A, general design criterion 4:

> Criterion 4—Environmental and dynamic effects design bases.
>
> Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. These structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit. However, dynamic effects associated with postulated pipe ruptures in nuclear power units **may be excluded** from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.

Mild environment motors do not have to be qualified to provide their safety function after a postulated accident; however, these motors do have requirements related to their Class IE designation. This removes mild environment motors from the accident qualification and qualified life requirements that harsh environment motors must demonstrate. Utilities have PM programs and use equipment monitoring to assist in maintaining reliability and to detect degradation of mild environment motors. Some utilities may formally determine and document a mild environment motor's service life because of licensing basis requirements.

EPRI guidance on harsh and mild EQ is addressed in report 1021067 *Plant Support Engineering: Nuclear Power Plant Equipment Qualification Reference Manual, Revision 1*. Table 6-1 (Table 1-1 in the EPRI report) shows the differences between harsh and mild EQ programs.

Table 6-1
Harsh and mild environment differences

Equipment Type	Harsh Environments	Mild Environments
Electrical	• Special regulations and standards • Formal qualification program • Type testing most commonly used • Aging addressed by testing aged conditioned samples and by surveillance and maintenance	• Based on performance information developed during design and procurement • Formal program usually not required • Aging addressed by surveillance, maintenance, and failure trending
Mechanical	• Historical reliance on ASME Code and procurement process • Formal programs not required for older plants • Equipment for new plant designs will address aging and design basis event conditions	• Same as electrical in mild environments • Aging addressed by surveillance and maintenance

Section 5.3 of EPRI report 1021067 addresses a mild environment qualification program.

Motors operating at or below prescribed limits are considered mild environment. These limits are usually site-specific. Some typical limits used are as follows:

- Temperature: below 104°F (40°C) to 140°F (60°C).
- Pressure: atmospheric pressure
- Radiation: below 10^4 rads (1000 Gy) gamma
- Humidity: below 100% relative humidity

6.1 Qualified Life Requirements

Equipment purchased for installation in a mild environment does not require qualification documentation/files under the plant's EQ program. The documentation is captured in the quality assurance (QA) documentation system; however, it does not get placed into the EQ system and is not continuously updated and controlled.

Note: Although 10CFR50.49 does not require EQ files for mild environment equipment, the licensing basis for some existing post-Three Mile Island plants and new plants has mild environment qualification requirements.

This does not mean that the environment in which a device will be installed to operate should not be considered. Typically, the requirements are provided to the vendors at time of purchase, and they provide a certificate of conformance or other assurance that the devices supplied will operate to meet the requirements. Mild environment motors do not have a definitive life, and their ability to continue to perform their function relies on replacement of parts (including windings), periodic surveillance and testing, and trending of condition monitoring results to preclude a significant increase in failure rates. The following should be considered when evaluating and purchasing mild environment motors:

- Design/purchase specifications detailing service conditions and operating requirements
- Definition of life objective (for example, motor is required to operate cyclically for 40 years)
- Load horsepower
- Seismic condition extremes
- Normal and abnormal service conditions, such as the following:
  - Starting and running restrictions (for example, must start under defined degraded voltage conditions within defined time, must not stall nor overheat under minimum voltage)
  - Voltage extremes and durations (both high and low)
  - Intermittent duty and periodicity of cycling
  - Continuous duty
- Temperature and thermal cycling
- Vibration
- Radiation
- Humidity
- Chemical exposure and compatibility
- Flooding
- Expected equipment operating mode
- Seismic test report
- Purchasing from reputable manufacturer/remanufacturer/commercial dedicator with an accepted QA program, such as the following:
  - 10CFR50, Appendix B
  - ANSI N45.2 program

- ASME NQA-1
- Plant's umbrella QA program oversight

- Certificate of conformance from the commercial dedicator or manufacturer

6.2 Life Estimation

Life estimation for electric motor insulation is based on the endurance qualities of the materials that make up the insulation system. Insulation materials are typically affected by the following stressors:

- Thermal
- Electrical
- Mechanical
- Environmental

Although all of the stressors affect motor insulation materials, thermal degradation is the most significant and is used to determine motor insulation design life. Life estimation is typically based on thermal design life using the Arrhenius calculation illustrated in Figure 6-1.

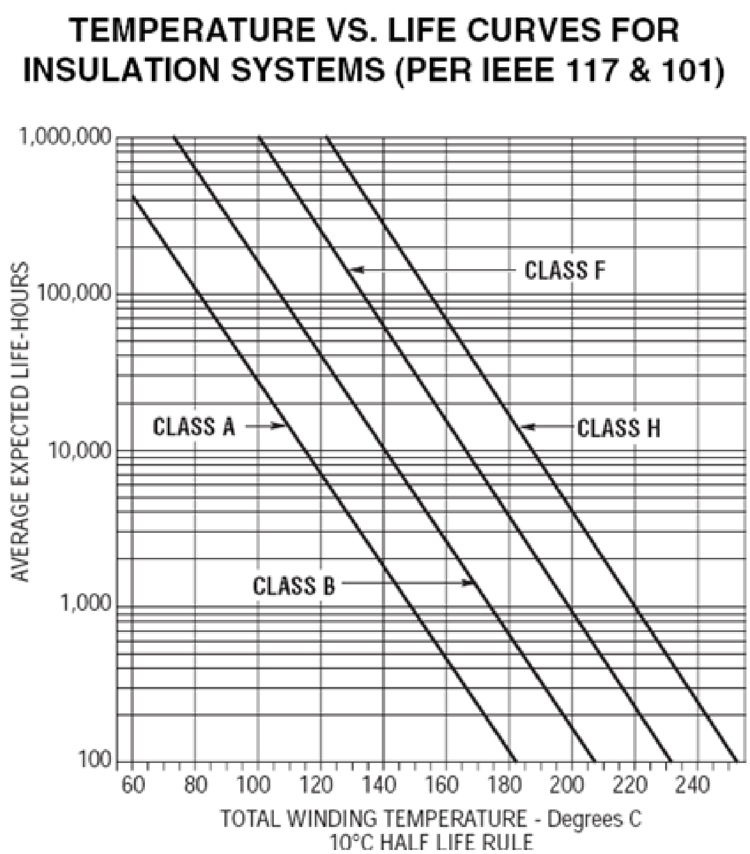

Figure 6-1
Motor insulation thermal life curve

The Arrhenius equation is a mathematical model for the rate of reaction of chemical processes that has been used by harsh EQ programs to evaluate the accelerated aging of organic compounds (for example, plastics, resins, and rubbers). For mild environmental equipment, it is not necessary to calculate a qualified life based upon aging mechanisms and models such as the Arrhenius equation; however, insights can be gained from understanding potential aging effects on organic components. Based on the Arrhenius equation, reducing the temperature by a factor such as 10°C (18°F) on organic materials such as those used in motor insulation systems, a doubling or more of the expected life occurs. Conservatively, if the temperature increases by 10°C (18°F) on organic materials, expected life can be reduced by half or more.

Identical motors used in identical environments can have significantly different post-accident requirements and life limitations. Mild environment motors are not required to withstand the severe environments of an accident; whereas, motors that are required to operate under harsh environment conditions must be able to withstand accident conditions and remain operable for a limited time period after the accident. Accident environments can have high temperature and radiation conditions for significant durations. Accordingly, harsh environment motors must have a significant amount of thermal and radiation withstanding capability for ensuring function during and following an accident exposure. During the development of EQ program for a motor, the qualified life is reduced to ensure accident function, and the motor is not subjected to accelerated aging that would bring it to the end of its functional capability. If a motor was aged to that condition, the likelihood of failure under accident simulation would be very high.

The role of environments as a potential common cause of failure comes into play when an environment either produces excessive aging degradation leading to common-mode failures during operation or accidentally and suddenly intensifies in certain plant areas (so-called harsh environments), which could thereby trigger failures of more than one component within an area.

It is important to note that ambient environmental conditions and changes in equipment operational conditions can induce common-cause failures even during normal plant operation. As with any good design, normal conditions should be considered in the design of equipment and/or features to reduce their impact.

EQ is addressed by IEEE Standard 323 with most EQ programs using the 1974 version endorsed by the NRC. Although no nuclear sites are licensed to IEEE Standard 323-1983, the guidance contained in the 1983 version provides clarifications to the requirements of the 1974 version. The 1983 version imposes no additional requirements for qualification documentation of equipment located in mild environment areas.

Typical documentation for existing nuclear power plants consists of the equipment specification, identification of safety function, required maintenance, and a certification of compliance. IEEE Standard 323-1983 states that, for mild environment components, seismic conditions are generally the only event with the potential for common-cause failures. For mild environment equipment, the failure rate is driven by the normal aging process (see Figure 8-1) where the end-of-life prediction is slowly reached, and failures occur more randomly than would be expected under the harsh conditions of an accident if the equipment were not EQ. Random early failures cannot be fully prevented, but, with proper maintenance and monitoring, their number can be reduced.

With few exceptions, aging for mild environment equipment can be addressed by normal maintenance, surveillance, and failure trending programs. For harsh environment EQ motors, EQ alone does not ensure that motors will achieve their qualified life without failure. EQ is a design verification process that is based on the premise that good maintenance practices will be applied and that the motor will be operated within the environmental and service conditions evaluated in the EQ documentation/files. The EQ analysis also requires that certain maintenance activities be performed at specific intervals. These activities must be performed to preserve EQ. Although the EQ analysis does not require other good maintenance practices, such as condition monitoring and inspections, these practices will help ensure that the qualified life can be achieved.

6.3 Critical Activities for Electric Motors

Electric motors can degrade overtime, and their ability to perform their function can be affected if certain critical activities are not performed correctly within specified intervals. The performance of these activities should increase motor reliability during its design life.

The activities described in the following sections are critical for maintaining motors designed for either harsh or mild environments.

6.3.1 Storage and Warehousing

The same storage and warehousing considerations apply to all critical motors whether they are EQ harsh or mild environment motors. Storage and layup recommendations are provided in vendor and industry documents. This guidance is covered in Section 10 of this report.

6.3.2 Preventive Maintenance

An electric motor PM program must employ the appropriate technical measures to identify and address degraded conditions prior to impact on motor operation and to prevent catastrophic failure.

Typical vendor recommendations cover subcomponent replacements and other PM activities that should be followed while a motor is stored. The periodicities at which these activities take place can vary based on an overall maintenance program. However, motors designed for harsh environments must follow required maintenance specified in EQ documentation. The following are examples of EQ maintenance requirements:

- Bearing lubrication
- Bearing replacement
- Seal replacements

6.3.3 Monitoring and Testing

Part of PM is the application of condition-monitoring techniques and certain tests that can provide early detection of anomalies. The data gathered from these techniques and tests, when trended, can be used to adjust or implement maintenance practices to minimize in-service failures.

Motors covered by 10CFR50.49 may have additional maintenance and testing requirements to maintain qualifications.

The following techniques and tests are the most commonly used for PM:

- Winding temperatures
- Bearing temperatures
- Vibration monitoring
- Oil analysis
- KW power usage
- Run time meters
- Insulation resistance testing of the windings
- Resistance testing of the winding (includes connections)
- Polarization index test for medium-voltage motors
- DC step potential test
- Current monitoring (transient and steady-state)
- Visual inspections

For equipment in mild or harsh environments, operability testing and failure trending are needed to demonstrate that equipment aging is under control and that unidentified aging mechanisms are not occurring. Inspection, surveillance, condition monitoring, and trending of key parameters for any installed safety-related equipment increase the understanding of aging effects and provide confidence in equipment reliability and performance.

6.4 Refurbishment, Repair, and Replacement Considerations

Various subcomponents of an electric motor (windings, bearings, gaskets, seals, O-rings, lubricant, and so forth) can be replaced, essentially making it like a new motor. Motor refurbishment and/or repair might not be practical if certain subcomponents have nonrepairable mechanical damage (that is, enclosure, stator core, rotor/shaft, or bearing housings).

Sometimes, it may appear that replacing a motor might be the most viable option; however, the option to refurbish or repair may be the better choice under the following circumstances:

- The motor is no longer manufactured or has a special design.
- A replacement motor will require significant plant modifications.
- Long lead times for new qualified replacement motors do not fit plant schedules.
- Rewinding is significantly less expensive than purchasing a new motor.
- Minor maintenance issues, such as bearing replacements, need to be addressed.

Additional guidance for repair versus replacement determinations is provided in EPRI report 1011894, *Guide for Determining Motor Repair Versus Motor Replacement*.

For mild environment National Electrical Manufacturers Association (NEMA) frame size motors, EPRI report 1008034 and motor reports Commercial-Grade Item—Motors (CGIM) 001, CGIM002, and CGIM003 can be used to upgrade commercial-grade industrial designed motors for use in mild environment applications. Use of the guidance in these reports and using a commercial dedicator or service shop with an accepted 10CFR50, Appendix B, N45.2 QA, or NQA-1 program should ensure acceptable form, fit, and function of the dedicated motor. Recent regulatory changes and consolidations in frame offerings could require addition review when considering the use of current NEMA energy efficient motors. EPRI report 1021428, *Nuclear Maintenance Applications Center: Recommended Practice for Evaluating Interchangeability for National Electric Manufacturers Association Frame Motor Replacement*, provides insight when comparing original NEMA frame motors with current NEMA T-frame motors.

6.5 EQ Motor Maintenance

Each nuclear site has an EQ program that identifies harsh environment equipment having life-limiting components or special maintenance requirements related to EQ. Safety-related electrical equipment that is located in a plant's harsh environment and that performs an accident and/or post-accident function to mitigate the consequences of a design base event is required to be qualified in accordance with 10CFR50.49. Conformance to this federal regulation also requires that qualification be preserved after initial qualification has been established. Preservation of EQ is intended to maintain the qualified status of the safety-related equipment through proper installation, configuration control, maintenance activities, and periodic component replacement.

Although mild and harsh environment motors have similar requirements for maintenance and documentation, harsh environment motors have significant constraints on the degree to which they may be allowed to degrade before they are replaced. Harsh environment motors must be able to function during and after being exposed to an accident environment and must have sufficient capability to withstand the accident effects at the end of its installed life. A motor must be replaced or rewound before the expiration of its qualified life; however, a replacement winding for an EQ motor may not have the same life as the original winding. Preservation of EQ also requires that any equipment or components whose demonstrated qualified life is less than the design life of the plant be replaced before the end of the qualified life to maintain qualification. Failure to maintain the qualified status of safety-related equipment defined in 10CFR50.49 in an operating plant is a violation of federal code and, upon discovery, may require declaring the equipment inoperable.

With regard to general motor maintenance and work scheduling under a site's motor program, an attempt is made to minimize critical equipment unavailability and reliability. Motor work is matched to safety trains, grouped with pump maintenance, performed collectively with other maintenance needs when the motor is accessible—such as with overhauls. Personnel responsible for the site PM, component, and equipment reliability programs inclusive of the site motors need to be knowledgeable of EQ requirements (parts replacement, PMs, surveillance instructions, and so forth and regulatory periodicity) to ensure that the program's EQ motor features are maintained.

Section 7: Four Life Phases of EQ Motors

All motors have different life phases as the plant ages. This section is primarily written for the discussion of the life phases of EQ motors. For commercial-grade and safety-related non-EQ motors, Phases 1, 3, and 4 would still apply with the exception of the EQ requirements.

EQ motors have four life phases. The first three phases were designed into the original qualification of the motor. The fourth life phase emerged with the movement in the nuclear industry for plant license renewal up to 60 years or more.

7.1 First Three Life Phases of EQ Motors (Original Qualification)

Life Phases 1, 2, and 3 are considerations used for original plant design. These phases cover activities related to initial design, qualification analysis, operation, and preservation of EQ motors.

7.1.1 Life Phase 1: Initial Design Inputs

EQ motors are procured, designed, and manufactured to design specifications for service and environmental conditions during normal operation and accident conditions. Margin and conservatisms have to be designed into these requirements for EQ motors to provide sufficient functional capability during an accident condition at the end of their qualified life. These margins and conservatisms are also helpful in the event that plant design changes occur during the construction or operation of the plant that would affect the environmental qualification of a motor (that is, environment in an area of the plant changes to a more severe accident condition resulting from a plant system or operating parameter change).

7.1.2 Life Phase 2: Establishing Environmental Qualification

This phase is the actual qualification of a motor either by testing, analysis, or both and implementing the motor's qualification into the plant's EQ program. Usually, one motor receives full EQ testing for a family of the same type of motors. The qualification of the tested motor is used to qualify motors that are manufactured with the same practices and materials as the tested motor. The qualification of the tested motor can also be used along with analysis by the OEM and/or third parties to qualify a motor of similar design.

7.1.3 Life Phase 3: Operational Phase and Preservation of Environmental Qualification

The operating phase of the plant is the period during which the motors are performing the normal function and the period through which the EQ status must be preserved. Preservation requires specific maintenance activities to be performed at the appropriate time as determined by the OEM and the EQ documentation for that motor. Not performing the required maintenance on EQ motors could affect their qualified lives and could invalidate their qualification, potentially rendering the motors inoperable.

Figure 7-1 illustrates of the three life phases of an EQ motor.

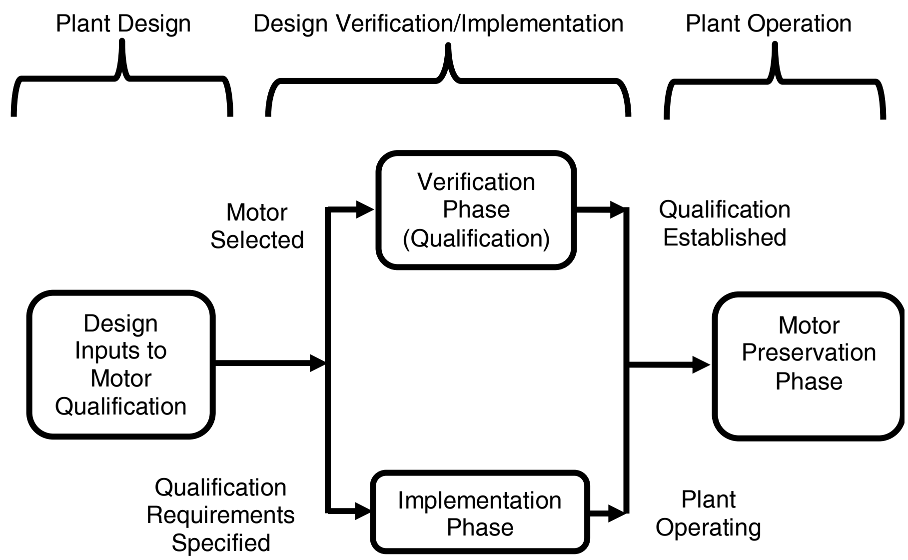

Figure 7-1
The three life phases of an EQ motor
Source: Figure 1-1 of EPRI report 1021067

Note: Figure 7-1 represents the three life phases of all EQ equipment.

The preservation phase consists of activities to ensure that the motor remains qualified during its installed life. If a motor is a rotational spare, qualification has to be based on total installed time (previous and existing).

These activities include the following:

- Plant, system, and licensing criteria modifications
- PM
- Inspections
- Surveillance testing
- Condition monitoring
- Corrective maintenance

EQ motors must be capable of performing their required functions throughout the plant life, in spite of equipment aging and extremely harsh environments created by events such as pipe breaks (for example, loss-of-coolant accidents) and seismic events, should they occur.

7.2 Fourth Life Phase of EQ Motors (Reassessment of Qualified Life)

The fourth life phase of an EQ motor is the reassessment of qualified life (including rewinding and condition assessment) or the resetting of qualified life by replacement to support plant license renewals. Most nuclear sites in the United States have obtained or have requested plant license renewal in accordance with the guidance of 10CFR51 and 54 to allow continued operation beyond the original 40-year license. These plant license renewals request an additional 20 years of operation; however, there is a potential for some plants to request an additional license renewal at the end of the first 20-year extension. The original qualification of the motors maintained a qualified life margin in excess of 40 years, but few motors have been evaluated for greater than 40 years of qualified life. This has placed challenges on the site motor and EQ engineers to plan for reevaluation of qualified life by the means identified in IEEE Standard 323 and IEEE Standard 334. This is covered in more detail in Section 9 of this report.

7.3 Qualified Life of an EQ Motor

Qualified life of an EQ motor is based on a motor design that has been tested to meet a specific accident profile for a given period of time. This qualified life can be less than or equal to a plant's design life. Typical qualified life for EQ motors can be 40 years or more. In order to achieve full qualified life, the motor must be properly maintained.

7.3.1 Maintenance Effects on Qualified Life

An unexpected or adverse reduction in qualified life can occur if proper maintenance and parts replacement are not performed at intervals as specified by the EQ program.

Figure 7-2 illustrates how maintenance affects the qualified life of an EQ motor. The illustration is typical for all EQ equipment but is used in this report to identify the need for proper maintenance.

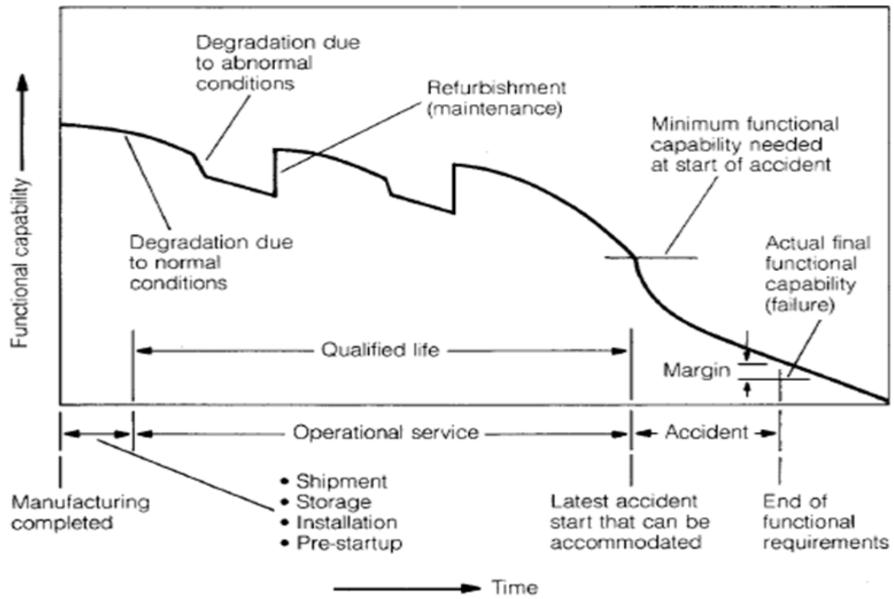

Figure 7-2
Maintenance and EQ life
Source: Figure 4-13 of EPRI report 1021067

Note: Without scheduled refurbishments (maintenance), the qualified life would be reduced. Although this illustration is used for EQ motors, operational life of commercial and safety-related non-EQ motors would follow the same example. Proper maintenance at the correct time equates into longer operational life.

7.3.2 Beginning of Qualified Life

In the absence of specific guidance from qualification standards and regulations, the most common practice has been to assume that qualified life begins when equipment is initially installed in the plant and declared operational. This assumes that negligible degradation takes place between the time the equipment is manufactured and the time it is placed in service. For motor winding materials, the environment during storage is likely to have little effect on the thermal life of the winding. However, other components such as seals and gaskets may age. Lubricants can dry out or degrade during storage. Motors that are stored for very long periods should be inspected and tested and possibly refurbished before being placed in service.

See Section 10 of this report for proper storage recommendations and guidance.

Section 8:EQ Motor Preservation

A typical failure rate curve, also known as a *bathtub curve*, is shown in Figure 8-1 but is used in this report to indicate the effect that proper and/or required maintenance has on aging/wear-out failures and to illustrate the preservation phase of a motor's life.

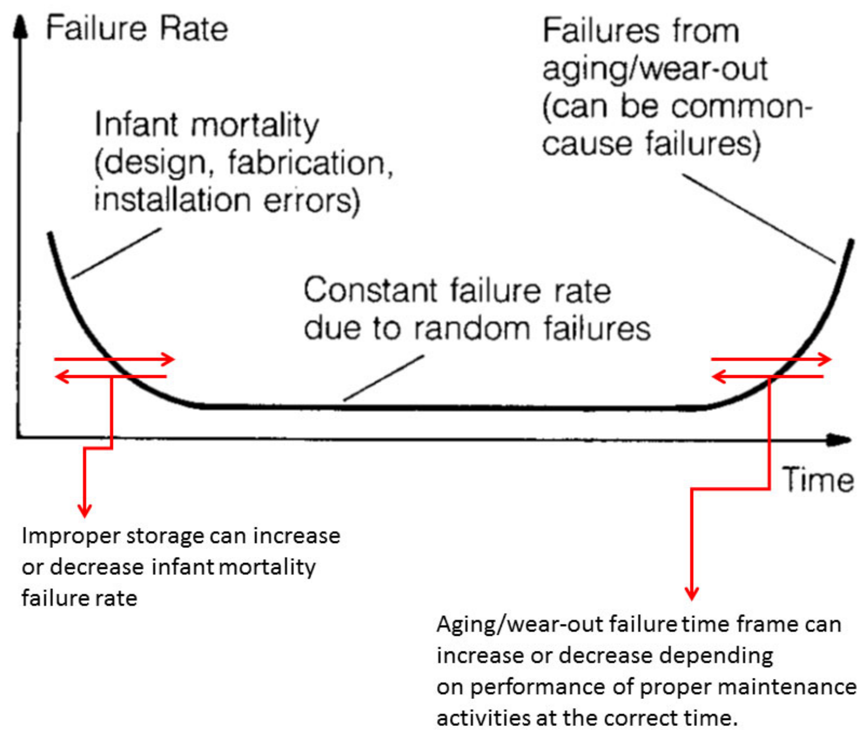

Figure 8-1
A typical failure rate curve

Note: Although Figure 8-1 is used to illustrate how aging/wear-out failures can be increased or decreased for EQ motors with performance of or lack of maintenance activities, it can also be applied to commercial and safety-related non-EQ motors.

The combinations of replacing or rewinding a motor at the end of its qualified life and the performance of maintenance during service are relied upon to prevent age-induced common-mode failures during normal and accident conditions.

As shown in Figure 8-1, infant mortality failures and aging/wear-out failures can increase or decrease depending on the actions performed during storage and the preservation phase. Under an effective maintenance program, cleaning, inspecting, and testing motors both reduces and detects aging before it adversely affects the motor and reduces the qualified life.

Maintenance helps preserve the condition of the installed motors within the boundaries of the EQ qualifications. Appropriate maintenance performed at scheduled intervals will improve the potential for a motor to achieve qualified life. Condition monitoring to detect degradation between maintenance intervals may provide early detection of anomalies that could cause decreased life or in-service failures. Some EQ motors have limited run times, which may not allow thermal stabilization of the insulation system and bearings. In these cases, readings should be taken near the end of the limited run time. Typically motor surveillance run test times are established by plant specifications and/or operation practices. Adjustments to run times can be evaluated on a case-by-case basis in order to obtain more useful performance data.

Other influences that can affect a motor's qualified life are run time and plant service/operating conditions (temperature, radiations, and so forth). If any of these conditions exceeds the anticipated or calculated values of the EQ documentation, the qualified life of the motor could be decreased.

PM (including refurbishments) will be required at some point in any motor's life. For an EQ motor, the PM must be performed in such a way as not to invalidate the motor's environmental and seismic qualification. Extended grace periods for maintenance activities that are allowed for non-EQ motors (that is, mild environment motors) are not allowed for EQ motors. All PM (including refurbishments) for motors should be controlled by an established motor maintenance program to provide consistency and expected motor reliability.

Failure trending is important to ensure that each failure is understood in order to limit the possibility of repeat failures. Failures should also be evaluated to ensure that common-mode failures are not likely to occur in similarly designed motors. Operating experience is a good source for evaluating similar motor failures at other nuclear sites that could affect installed motors.

8.1 Required Maintenance for EQ Motors

All motors require an effective PM program in order to achieve maximum service life. EQ motors may have additional maintenance activities listed in the EQ documentation/files that are required to preserve qualification. These required maintenance activities may include PM, inspection/surveillance, periodic testing, and certain component replacements. Failure to perform the required maintenance may invalidate the qualification of the motor and potentially render it inoperable.

Typical required maintenance activities are as follows:

- Inspections
- Electrical testing (which can include high-potential testing)
- Required component replacement, including the following:
  - Bearings (not EQ but are typically changed at L-10 life)
  - Gaskets
  - O-rings
  - Sealant
- Refurbishments, considering the following:
  - Typically between 10 and 20 years
  - May be extended by the OEM if proper PMs and inspections are being performed

8.2 Required Maintenance Frequency

EQ documentation/files list the required maintenance activities and their performance intervals. Motor design and installed operating environment are used as inputs when establishing these maintenance activities and their performance intervals. These intervals are part of the qualification and cannot be arbitrarily changed or extended. Any change requires a documented evaluation and analysis that has to be added to the EQ documentation/files before any change can be implemented.

Section 9: Plant License Renewal Considerations for EQ Motors

There are options available to extend the qualified life of motors located in a harsh environment. The bases of these options for qualification were established under IEEE Standard 323-1974 and IEEE Standard 334-2006, which are endorsed by the NRC.

Electric motors suppliers must maintain an approved QA program (10CFR50, Appendix B) that validates that the tested qualified specimens have the identical materials of construction that were initially provided and installed at the nuclear plants. The nuclear industry's preferred method of qualification is type testing, which is also the method recommended by IEEE Standard 323. Type testing can be done using an actual motor, a statorette, or a formette that is tested in simulated service conditions. The complexities of electrical equipment make it difficult to establish a baseline qualification by analysis alone for harsh environments. It is the basis of this section to use type testing reports located in the plant's equipment qualification files to apply to one of three options to extend the qualified life of motors.

To address motor qualified life to support license renewal for existing nuclear power plants, the following three options are available.

- Reevaluation of qualified life of EQ motors
- Rewinding with qualified EQ system (This is an EQ reset as aged parts are replaced, thereby resetting the qualified life, which may not be the same as the original qualified life.)
- Replacement—not a life extension

When the original baseline qualification was performed on EQ motors, type testing included the nuclear plants' design parameters of radiation and normal temperature values at the installed location. Excessive conservatisms may exist in the original basis for qualified life. If nuclear plants monitor the actual temperature and radiation of an installed location, these data can be compared against the original baseline qualification parameters. If the nuclear plant is operating at temperatures and radiation levels less than the original qualification parameters, the necessary calculations can be performed to determine whether the original qualified life can be extended. The original activation energy used to determine the qualified life during the baseline should remain fixed during the reevaluation.

9.1 Reevaluation of Qualified Life of EQ Motors

The following is an example of how temperature differences can be used to extend qualified life.

Normal temperature conditions coupled with time create an aging mechanism known as *time/temperature effects*. The exposure of nonmetallic materials to the influence of environmental factors over a period of time generally leads to deterioration in physical properties. Current industry practice allows acceleration of the time/temperature aging effects artificially by increasing the temperature. For many nonmetallic materials, it is known that the degradation process can be defined by a single temperature-dependent reaction that follows the Arrhenius equation.

$k = A \exp -(E_a/(k_B T))$

where

k	=	reaction rate
A	=	frequency factor
exp	=	exponent to base e
E_a	=	activation energy
k_B	=	Boltzmann's constant
T	=	*absolute* temperature (Kelvin)

For many reactions, the activation energy can be considered constant over the applicable temperature range. The preceding equation can be transformed into a form that yields an acceleration factor.

The acceleration factor is defined as t_2/t_1.

The equation is

$t_2/t_1 = \exp((E_a/k_B)(1 / T_2 - 1 / T_1))$

where

t_1	=	accelerated aging time in hours at temperature T_1
t_2	=	normal service time in hours at temperature T_2
exp	=	exponent to base e
E_a	=	activation energy (electronvolts [eV])

k_B	=	Boltzmann's constant (8.617×10^{-5} eV/K)
T_1	=	accelerated aging temperature (°K)
T_2	=	normal service temperature (°K)

The preceding equation can be used to calculate a qualified life (t_2) based on thermal aging data from a qualification-type test program. Solving for t_2 yields

$$t_2 = t_1 \exp((Ea/kB)(1 / T_2 - 1 / T_1))$$

Example

A test specimen motor was subjected to an IEEE Standard 323 qualification-type test program. The specified normal service temperature was 40°C, and the activation energy for the insulation system was 0.94 eV. The accelerated aging temperature was 130°C, and the accelerated aging time was 153 hours.

Solving for t_2

$$t_2 = (153) \exp((10908.66891)(.000712892))$$

$$t_2 = (153)\ (2384.3933)$$

t_2 = 364,812 hours

Using the preceding equation, the normal service time or qualified life is 41.6 years.

The qualified life of a motor installed in a power plant typically will have a qualified life based on a postulated normal service temperature (T_2). If it can be determined that the actual normal service temperature is lower, the qualified life of the motor can be extended by calculating a new qualified life.

After installing a temperature measurement system, it was determined that the actual normal service temperature at the motor's installed location was 36°C. Using the same equation and other parameters, the normal service time or qualified life is 65.3 years.

This example demonstrates a method for extending the qualified life of an installed motor (see EPRI report 1021067 for additional information).

9.2 Rewind with Qualified EQ System

If the decision is made to rewind an EQ motor, the insulation system chosen must meet the requirement of 10CFR50.49. In order for an insulation to be considered qualified, it must have successfully completed testing according to IEEE Standards 323 and 334. In addition to the insulation system meeting the requirements of 10CFR50.49, the system has to meet the EQ requirements at the installed location within the plant (that is, environmental profile, accident conditions, and seismic requirements). The documentation for a new or different insulation system will require acceptance by the EQ program owner and revision to a plant's EQ documentation/files prior to motor installation.

In order to exercise the rewind option, plants will typically have one of the following alternatives: to rewind the motor during an outage and place it back in service during the same outage, or to replace the motor with a qualified spare.

Under the first rewind alternative, the risk of extending an outage is possible. The logistics of motor removal, transport, refurbish/rewind, and reinstallation must all be considered. There are several additional items that can affect planned rewind activities, such as the following:

- Decontamination of a contaminated motor
- Special transportation permits, such as the following:
  - Oversize
  - Overweight
  - Radioactive or contaminated
- Unknown degraded conditions after motor disassembly in the following:
  - Stator core
  - Rotor core
  - Bearing oil coolers
  - Critical fits, such as the following:
    - Shaft journals
    - Seals
    - Bearing carriers
    - Bearing housings

These items are not all inclusive but are provided here to emphasize the effort that must be considered when pursuing an EQ rewind within an outage timeframe.

In order to pursue the second alternative, a qualified spare motor must be available and ready for installation. All of the considerations of the first alternative still apply to the removed motor with the exception of time restraints. The removed motor can be rewound at a more relaxed pace, and most degraded conditions can be addressed and the motor repaired. Often, the time and effort required to remove and replace a motor in some locations require the full outage schedule to complete.

With plant license renewals allowing plants to operate up to 60-plus years, qualified insulation system replacement is an option to reset the qualified life of a motor. A rewind resets the clock on the qualified life of an insulation system.

The qualified may not be the same as the original qualified life. Other organic components (gaskets, O-rings, and so forth) that can affect operation of a motor will require replacement during the qualified life of a motor. Mechanical parts (bearings, mechanical seals, and so forth) will typically be replaced for reliability purposes and may be required by some EQ documentation; however, metallic components are usually not considered to have the same aging issues as nonmetallic (organic) components.

9.3 Replacement Motor

When the presently installed qualified motor is nearing its end of qualified life, actions are required to maintain EQ operability. A viable option is a replacement motor under the following conditions:

- The motor cannot be repaired/rewound.
- The logistics of reworking multiple motors is too risky.
- The expense of rewinding is greater than purchasing a new motor.

The decision to replace is a business decision that each plant/fleet must make. When considering using this option, the engineering organization must determine whether the replacement motor meets the qualification requirements of 10CFR50.49 and all EQ files located at the plant. If the present location of the installed motor has changed in temperature and/or radiation levels due to a power uprate, these changes must also be considered.

9.4 Motor Degradation

EQ motors should have a continued monitoring function to evaluate any electrical or mechanical issues. The following sections explain conditions that must be monitored to assess potential impact on qualified life.

9.4.1 Electrical Issues

Electrical insulation degradation can be the result of electrical, mechanical, and environmental stresses. Electrical stress contributes to insulation under the following conditions:

- Voltage, including the following:
  - Surges
  - Unbalance
  - Over equipment operating limit
  - Under equipment operating limit
- Current, including the following:
  - Unbalance
  - Operating above equipment limit

Winding looseness and vibration are forms of mechanical stress that can contribute to insulation degradation.

Contamination can be any material that accumulates on a winding over time, which can limit heat transfer, increase leakage current, and degrade insulating materials.

Loss of dielectric strength is usually the result of these stresses. It is imperative that a nuclear site monitors the insulation condition of EQ motors to verify that the motors are operating within acceptable parameters.

9.4.2 Mechanical Issues

Mechanical stresses such as unbalance, vibration, and misalignment will generally provide gradual warning signs of mechanical degradation. Other issues are loss of lubricant and bearing and other mechanical component wear. These stresses and issues can typically be monitored and evaluated, and corrective actions can be taken before a motor failure occurs.

9.5 Power Uprates

As nuclear plants continue to increase their ability to generate more electricity, the motor engineer must be aware of the impact on installed EQ motors. Any increase in a plant's thermal power cycle that changes its energy content can impact equipment service conditions or accident exposure limits, such as steam generator replacements or license basis changes that allow increase in plant output (also known as *extended power uprates*). The EQ engineers and motor engineer must evaluate this type of uprate because the motors have the potential to be exposed to higher levels of radiation, greater temperatures, and operating demands under both normal and accident states. These demands may contribute to having an adverse effect on the original qualified life. The increases should be evaluated and addressed in the plant's EQ documentation/files.

9.6 Shared Utility Information on Same or Similar Motors

Some nuclear plants have successfully extended the qualified life of EQ motor by reevaluating the qualified life, as described in Section 9.1 of this report. Utilities may share information pertaining to the life extension of their EQ motors. By sharing information, plants can reduce the cost of EQ motor life extensions and maintain a consistency that the nuclear industry seeks, which is an approach approved by the NRC.

Section 10: Storage of Motors

Proper storage of a motor is vital to ensure the reliability of the motor when it is placed in service. The following sections provide guidance and best practices to ensure that a stored motor is kept in a ready condition and able to operate without premature or unexpected failures.

10.1 ASME NQA-1 (ANSI N45.2.2) Storage Requirements for Motors

The AMSE NQA-1 (ANSI 45.2.2-1978) standard was written to define the quality requirements related to the storage and handling of safety-related items for nuclear power plants. The requirements for activities covered by this standard are divided into four levels with respect to the measures needed to protect the item. These protective measures are intended to prevent damage, deterioration, and contamination of the items. These levels are based on important characteristics of the item and not based on the item's function. The manufacturer's recommended storage requirements should be followed as a minimum. The four levels are as follows:

- Level A
- Level B
- Level C
- Level D

Level A items are exceptionally sensitive to environmental conditions and require special protection measures. The special protection measures are from one or more of the following effects:

- Temperature outside required limits
- Sudden temperature changes
- Humidity and vapors
- Gravitational forces
- Physical damage
- Airborne contamination

Level B items are those sensitive to environmental conditions, and measures are required to protect the items from the following effects:

- Temperature extremes
- Humidity and vapors
- Acceleration forces
- Physical damage
- Airborne contamination

Most motors fall under Level B storage requirements. These items do not require the special protection required for Level A items.

Level C items are those that require protection from the following:

- Environmental exposure
- Airborne contamination
- Acceleration forces
- Physical damage

Protection from water vapor and condensation is not as important as Level B items.

Level D items are those less sensitive to the environment of Level C and require protection from the following:

- Weather
- Acceleration forces
- Airborne contamination
- Physical damage

Typically, all motors stored in accordance with the ASME NQA-1 (ANSI 45.2.2) standard, should be stored under Level B or Level C protection measures. A motor stored in Level C requires heaters to maintain the motor's internals (includes the winding) above the dew point.

10.2 Storage Time and Refurbishment Before Use

While in storage, a motor should have an appropriate PM program. By evaluating the PM data, a decision can be made about whether the motor should be sent out for refurbishment prior to installing it in the plant. Typically, if a motor has been in storage longer than 10 years, a refurbishment evaluation should be performed.

After a motor is selected for refurbishment, the motor can be fully inspected for possible degradation caused by improper motor storage. Refurbishing the motor also decreases the risk of unexpected failure and increases the motor's reliability.

10.3 EPRI Storage Guide

To assist the power industry in proper motor storage EPRI published report 1009698, *Shipping and Storage of Electric Motors*. Guidance on proper motor maintenance while in storage is provided in this report, along with the recommendations to store motors to Level B based on ASME NQA-1 (ANSI 45.2.2).

10.4 Alternatives to On-Site Storage

Because of numerous reasons (lack of adequate storage facility, on-site costs, salt water environment, and so forth), some sites are unable to properly store motors onsite. To fill the need of the power industry for storing critical spare motors, third-party companies have developed motor storage facilities that provide Level B storage (see Figure 10-1) in accordance with ASME NQA-1 (ANSI N45.2.2), as well as providing services for PM. Other benefits can include cost savings, decreased warehouse space, and reduction of maintenance resources to perform storage PM. Most of these companies can deliver the motor in storage to their customers within 24 hours.

Figure 10-1
Third-party Level B storage
Used with permission from EMC

10.5 Improper Storage and the Consequences

Motors that are improperly stored run a higher risk of failure when they are installed and placed into service. The two most common failures associated with improper storage are stator winding failures and bearing failures.

The stator winding failures are typically caused by moisture or foreign material/contamination in the windings of the motor. Moisture saturates the windings when the winding temperature is not maintained above the dew point and can create a ground path between the stator conductors and ground. If this moisture is not removed prior to placing the motor in service, winding fault to ground could occur. Foreign material (that is, dirt, sand, salt, wire, screws, bird nests, oil, or water) can lead to premature winding failure. A motor should never be stored in a location where foreign material can enter the winding as a result of a dirty environment, being driven in by wind and/or air flow, or being dropped into the motor from overhead storage. Figure 10-2 shows an example of improper motor storage.

Figure 10-2
Example of improper motor storage

Bearing degradation such as false brinelling (rolling element bearings), hardening of grease, babbitt smear (sleeve bearings), or rust from lack of lubricant can occur in stored motors with a poor storage maintenance program.

Internal rust on the carbon steel components can affect proper motor operation. This is especially true for bearing journals and close-fit seal surfaces on the shaft. Level B storage should eliminate the concern for internal rust issues.

Section 11: Summary

Power plants in the U.S. nuclear industry were originally licensed for 40 years. Most plants have sought or are seeking renewed licenses under 10CFR51 and 54 for 60 years of operation; a few plants have already passed 40 years of operation. As part of the license renewal process, equipment issues will have to be addressed to maintain plant reliability. The license renewal process has caused plants to revisit their EQ for equipment, especially electric motors.

Other industry events, such as power uprates, aging equipment, and equipment reliability initiatives, have brought focus to the need for an effective motor management program. Also, an aging work force and personnel turnover have led to a situation where some plant personnel do not have experience with managing all the elements related to electric motors in a nuclear power plant.

Implementation of a motor management program is not just the responsibility of the motor program owner, especially as related to managing EQ motors. The motor management program should be part of a company's integrated long-range plan.

This report presents the elements of an effective motor management program. Options as stated in IEEE Standard 323 for extending qualified life of EQ motors to support plant license renewal are covered in this report. It also covers the roles and responsibilities of individuals and/or groups that should be involved to ensure a successful program. However, as with any program, ownership is required to obtain maximum benefit and expected equipment reliability, and the motor management program is no exception.

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