

IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations

Sponsor

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Abstract: The guidelines are provided for assessing, monitoring, and mitigating degradation of Class 1E equipment used in nuclear power generating stations due to aging. The methods described can be used to identify the performance capability of Class 1E equipment beyond its qualified life. A discussion of stressors and aging mechanisms is included. If aging considerations have been satisfactorily addressed through other means (e.g., equipment qualification), then use of this guide may not be warranted. For some equipment, only partial application of this guide may be warranted.

Keywords: aging effects, degradation, Class 1E equipment, condition assessment, failure, life, life cycle assessment, life management, maintenance

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Introduction

(This introduction is not a part of IEEE Std 1205-1993, IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations.)

Class 1E equipment in nuclear power generating stations must meet its safety functional requirements throughout its service life. This is accomplished through a systematic and disciplined program of quality assurance covering design, qualification, manufacturing, storage, installation, operation, maintenance, periodic testing, and surveillance. As part of the maintenance, surveillance, and periodic testing programs, Class 1E equipment is maintained in a state of readiness by various methods which include, as appropriate, periodic refurbishment and/or replacement. Also, for some Class 1E equipment located in harsh environment areas in the plant, rigorous testing and/or analysis is employed to demonstrate a qualified life. For equipment located in mild environment areas, a qualified life demonstration is generally not required; an effective program of surveillance and maintenance is sufficient to identify and mitigate potential aging degradation. Continuation of these programs should ensure that Class 1E equipment is capable of performing its intended safety function during its service life.

It is not the intent of this guide to imply that new programs be established for the purpose of aging assessment. Aging assessments should not be directed toward an endless search for data and information, but rather should be an effort that is practical, cost-effective, and based on collecting and evaluating a minimum set of data and information collected preferably from existing programs using proven techniques to assess the condition of equipment.

The service life of some equipment may include operation beyond its design or qualified life and even beyond a plant's original license term. To accomplish this, a technical basis is necessary to demonstrate that the Class 1E equipment is capable of continued safe operation during any renewed license term of the plant. For equipment qualified to IEEE Std 323-1974 or IEEE Std 323-1983 (Reaff 1990), this technical basis exists for its original qualified life. One concern is that the potential for significant aging is effectively assessed such that necessary mitigating actions are taken to assure dependable and safe operation of the plant, including extension of qualified life.

The Nuclear Power Engineering Committee of IEEE recognized a need to supplement its existing body of standards to a) provide guidance in the areas of aging assessment, control, and mitigation, and b) promote uniformity in the methods used for developing the technical basis cited above. While it would have been possible to incorporate this guide into related standards, the decision was made to develop a stand-alone document for the following reasons: a) It would be expedient and promote consistency, by providing guidance that can be incorporated into future standards, and b) it would help disseminate the body of knowledge and promote uniformity in application methods while minimizing the confusion that could result due to the differences in the licensing bases of the various operating nuclear power plants.

This document is intended to provide general guidance for the assessment, monitoring, and mitigation of significant aging effects of Class 1E equipment used in nuclear power generating stations. The specific equipment that warrants attention using this guide will be determined by the user. It is not intended that the methods described herein be required to be applied to all Class 1E equipment. It supplements the existing IEEE nuclear standards and contains additional details that may assist in ensuring the use of a uniform and consistent approach to performing aging assessment evaluations for Class 1E equipment. Utilization of the guide can result in a) economic benefits from optimization of equipment service life, b) improvements of equipment failure evaluation and root cause analysis, c) recommendations for improving in-plant environmental monitoring, and d) optimization and focussing of inspection, condition monitoring and maintenance toward activities that can improve reliability/availability, and e) guidance for future standard revisions. The annexes to this guide provide examples of applications of aging assessments as described herein, for Class 1E equipment. This equipment was selected to provide a cross section of the types of equipment that can be found in a nuclear power generating station. However, the Working Group intends to extend annex C by pro-

viding additional examples on aging assessment of equipment that would be cost-effective and provide safety benefits.

Evaluation of equipment interactions may be significant for aging assessments. Therefore, the user should note that while this guide covers Class 1E equipment, other documents such as IEEE Std 603-1991 provide guidance on interacting systems and components. Appropriate attention should be given to equipment interactions to ensure their adequate performance in a system.

While the scope of this guide is limited to Class 1E equipment, the principles can be applied equally to non-Class 1E equipment also.

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IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations

1. Overview

1.1 Scope

This document provides the guidelines for assessing, monitoring, and mitigating aging degradation effects on Class 1E equipment used in nuclear power generating stations.

1.2 Purpose

The purpose of this document is to supplement existing IEEE nuclear standards in assessing aging degradation effects. The methods described herein can be used to identify the performance capability of Class 1E equipment beyond its qualified life.

1.3 Application

The specific equipment, which warrants attention using this guide, will be determined by the user. It is not intended that the methods described herein be required to be applied to all Class 1E equipment. For example, if aging considerations have been satisfactorily addressed through other means (e.g., equipment qualification), then use of this guide may not be warranted. Similarly, for some equipment, only partial application of this guide may be warranted.

2. References

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

IEEE Std 323-1983 (Reaff 1990), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations (ANSI).¹

IEEE Std 943-1986 (Reaff 1992), Guide for Aging Mechanisms and Diagnostic Procedures in Evaluating Electrical Insulation System (ANSI).

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3. Definitions

Most terms used in this standard are consistent with the recognized industry and IEEE standards. The following definitions are provided to establish the meanings of words in the context of their use in this standard. In annex D, [B43]² provides definitions for terms not commonly found in IEEE standards.

3.1 aging assessment: Evaluation of appropriate information for determining the effects of aging on the current and future ability of systems, structures, and components to function within acceptance criteria.

3.2 aging degradation: Gradual deterioration in the physical characteristics of a system, structure, or component, that is due to aging mechanisms, that occurs with time or use under preservice or service conditions, and could impair its ability to perform any of its design functions.

3.3 aging mechanism: A specific process that gradually changes the characteristics of a system, structure, or component with time or use.

3.4 residual life: The remaining period of time during which a system, structure, or component is expected to perform its intended function under specified service conditions.

3.5 service life: The actual period from initial operation to retirement of a system, structure, or component.

3.6 significant aging mechanism: An aging mechanism that, if in the normal and abnormal service environment, causes degradation during the installed life of the equipment that progressively and appreciably renders the equipment vulnerable to failure to perform its safety function(s) during design basis event conditions (DBE) (see [B27]).

3.7 stressor: An agent or stimulus that stems from fabrication or preservice and service conditions and can produce immediate degradation or aging degradation of a system, structure, or component.

4. Discussion

4.1 Need for an aging assessment

The first step in performing an aging assessment is to determine the need for it. Factors affecting the need for an assessment include a) evidence that a significant aging mechanism may exist, b) potential problems indicated by existing maintenance and surveillance programs, c) accessibility of components, and d) plant objectives in the areas of increased plant availability, extension of qualified life or determination of residual life, and increased confidence in lifetime evaluation methods. The description of the aging assessment process in this guide assumes that a judgment has already been made that an aging assessment is needed.

4.2 Desired objective and benefits

The purpose of performing an aging assessment is to establish the technical basis that demonstrates the continued safety and functional performance capability of Class 1E equipment. This requires an understanding of the type and nature of the aging mechanisms affecting the equipment and may involve establishing a qualitative or quantitative estimate of residual life.

²The numbers in brackets, when preceded by the letter B, correspond to those in the bibliography in annex D.

Beyond the purpose stated above, an aging assessment at a nuclear power plant is often performed in a larger context of a desire for improved safety and operation of the overall plant. For example, understanding the aging mechanisms that affect Class 1E equipment in a nuclear power generating station permits the identification, monitoring, and mitigation of aging degradation effects that are significant to the performance of safety function prior to failure. An aging assessment may provide the station with improved safety through fewer challenges to the safety systems and avoidance of forced outages.

The knowledge gained by understanding the significant aging mechanisms, and the potential for failures they can cause, could be integrated into the operational surveillance programs and preventive/corrective maintenance programs at nuclear power generating stations. With a knowledge of significant aging degradation, surveillance activities may be tailored to collect the necessary data to assess aging, and maintenance programs may be designed to identify the need for repair or replacement of age-degraded Class 1E equipment or components. For example, activities such as transformer oil analysis, equipment hot-spots mapping using infrared thermography, and root cause analysis of equipment failures, are existing plant activities which can be directed toward aging assessment. For some equipment, a combination of some of these programs should be all that is needed to assess aging degradation. For valve motor actuators, existing programs of preventive maintenance and root cause analysis of failures coupled with trending data from condition monitoring techniques or current signature analysis should yield sufficient data to perform an aging assessment.

4.3 Aging assessment elements

Aging assessments are performed at nuclear power plants on a routine basis, although they may not be identified as such. A brief discussion of typical elements of an aging assessment program follows.

The determination of aging mechanisms, such as fatigue, oxidation, corrosion, wear and others, and their causes (clause 5), is a requisite element in an aging assessment. This knowledge may be used to establish bases for aging assessments (clause 6), and for selecting actions such as inspection, surveillance, or maintenance to mitigate age-related effects where significant (clause 7). These assessments are made using data whose collection (clause 8) is an evolutionary process; that is, preliminary data needs are established for determining aging mechanisms, but additional data needs may surface when the aforementioned bases and mitigating actions are formulated. Figure 1 illustrates the elements of aging assessment and mitigation, and the sequence in which they would typically be performed.

When performing an aging assessment of Class 1E equipment, it is often necessary to consider the design function of the equipment, its operating mode (active or passive), and the actual versus the design conditions that will affect aging assessments. Also, aging assessments should be reduced in scope by considering the commonality of subcomponents and service conditions. Finally, aging mechanisms and degradations identified from environmental qualification should be used as a basis for, and comparison to, the results of aging assessments.

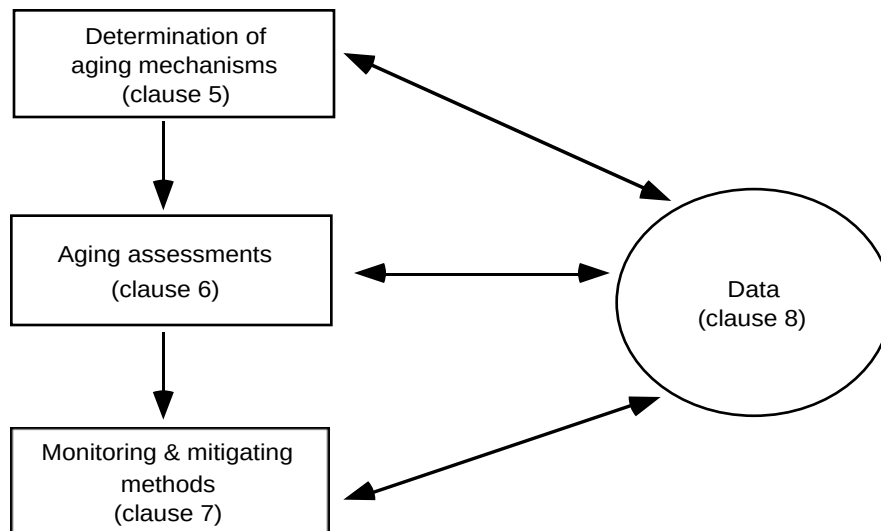


Figure 1—Aging mechanisms, assessment, and mitigation

5. Stressors and aging mechanisms

5.1 Stressors

A stressor that stems from fabrication, preservice or service conditions may produce aging mechanisms and effects or immediate degradation of Class 1E equipment. The following two types of stressors should be considered for aging:

- a) *Environmental*. These are stressors that exist continuously in the environment surrounding the equipment, whether it is operating or shut down. Examples include vibration, heat, radiation, and humidity. Annex A provides a representative listing of stressors and their effects, while annex B provides considerations for environmental monitoring.
- b) *Operational*. These are stressors arising from equipment operation. Examples are internal heating from electrical or mechanical loading, physical stresses from mechanical or electrical surges, vibration, and abrasive wearing of parts.

The aging degradation of electrical equipment will usually be a function of the duration, range, and intensity of stressors experienced by the equipment. Aging degradation due to a single stressor may usually be represented as a simple first-order relationship involving stressor intensity and time; however, aging degradation due to a combination of more than one aging mechanism may exceed the sum of the individual effects.

5.2 Aging mechanisms and effects

One method of determining the susceptibility of equipment to aging mechanisms, and consequent aging effects, is by understanding the behavior of the individual materials that make up the Class 1E equipment, when subjected to environmental and operational stressors. These mechanisms may apply to solid-state electronic components as well as electrical equipment. Some examples of aging mechanisms are provided below.

- a) High temperature environments can cause organic insulating materials to become brittle. Moisture or physical contact may result in a loss of dielectric integrity.
- b) High humidity environments can accelerate bearing wear in rotating machinery lacking special seals or pressure lubrication.
- c) High humidity can increase pitting and corrosion of contacts on relays and controllers.
- d) Vibration can loosen fasteners on linkages causing misalignment of components or loss of electrical contact integrity. Misalignment accelerates wear in moving parts; loose electrical contacts may lead to heat-related degradation.
- e) Support structures subject to high humidity or contact with water and/or chemicals may corrode if not protected by coatings or covers.
- f) Radiation can break down the anti-oxidation chemicals in organic insulation materials and produce embrittlement similar to that caused by high temperature.
- g) Continuous operation of certain electronic components (e.g., diodes, resistors) at high ambient temperatures, can cause operation outside of their performance specification or circuit drift.
- h) Excessive voltage cycling can result in premature failure of electrolytic capacitors.
- i) Exposure to moisture can result in delamination of insulated wires.

Tables A1, A2, and A3 in annex A provide, in summary form, a listing of typical aging mechanisms and their effects on metals, polymers, and lubricants.

Not all mechanisms may be operative; nor may they produce significant aging effects in equipment in a given service environment. In some cases, aging mechanisms may be readily judged to be of little or no importance because they are not significant relative to equipment function. For example, metals in electronic components (except at electrical contact points or other areas susceptible to corrosion) may not require aging assessment.

The information in tables A1, A2, and A3 may be supplemented by other information on aging effects such as operating experience, manufacturer's data, expert opinion, research and test data, and demonstrated performance capability from environmental qualifications.

6. Aging assessment

It is not the intent of this guide to imply that existing qualification or maintenance programs are inadequate, nor that the bases or data justifying qualified life or design life of equipment derived from these existing programs need to be regenerated. However, based on the continuing review of these existing programs and observation of the performance of equipment or on the need to extend qualified life, it may be determined that an aging assessment is necessary. For these cases, utilization of all, or a portion of, the elements in this guide will be useful. Note that in lieu of an aging assessment, qualification testing in accordance with IEEE Std 323-1983³ may be performed to extend qualified life.

One method of performing an aging assessment is to establish the underlying aging mechanisms and the most probable causes of potential failure in order to estimate residual life, including the present and expected equipment condition. Such assessments may take credit for data available from existing programs (e.g., environmental qualification, surveillance test and maintenance programs).

The aging assessment may use a structured evaluation method, such that the assessment is clear, objective, and well-documented. It may be quantitative or qualitative, in the form of a model, correlation, or rationale. The information or data that are used to support the conclusion of the aging assessment should be documented. The typical elements of an aging assessment include the following:

- a) Describing the equipment
- b) Identifying the aging components in the equipment
- c) Screening for obsolescence or replacement

³Information on references can be found in clause 2.

- d) Identifying aging mechanisms
- e) Determining significant age-related failure modes
- f) Determining limiting age-related critical characteristics
- g) Determining parameters to be observed
- h) Establishing residual life

The assessment will likely be an iterative process. Information developed or conclusions reached at a given point in the assessment may indicate that information or conclusions in a prior stage should be modified, or that more detail or information (e.g., design or historical) is necessary. Data-gathering and evaluation may occur in stages as development of the aging assessment indicates the need for more data. The planning of the initial description of the equipment should be facilitated at a level of detail commensurate with the aging mechanisms that are initially judged. This will greatly influence service life of the equipment. However, this initial judgment may be modified as the aging assessment proceeds.

6.1 Describing the equipment

The equipment should be described such that clear boundaries are defined between what is being assessed and what is not being assessed. The safety function(s) and operation of the equipment should be described in terms of design requirements. Equipment or subcomponents can have multiple functions, not all of which are safety. Functions can be active or passive.

Equipment interfaces with other equipment and systems (e.g., splices and terminal blocks) should be described relative to form, physical, functional and environmental factors.

The specific set of functional requirements and environmental and operational conditions of the equipment should also be described.

6.2 Identifying the aging components

The equipment may be broken down into aging components that simplify the task of identifying significant aging mechanisms and failure modes. The aging components are generally categorized as a) parts or subassemblies that have a similar identifiable subfunction important to the overall function of the equipment, or b) parts or subassemblies which react to stressors in a similar manner. For ease of expression, these groups or types of components will hereafter be referred to as “aging units.” The breakdown of the equipment into constituent aging units generally determines the level of complexity of the aging assessment. Generally, aging units are selected to make the assessment as simple as possible. In the simplest case, the equipment is viewed (or treated) as a single aging unit.

6.3 Screening for obsolescence or replacement

An initial screening of the equipment and aging units should be performed subsequent to generating a description of the assembly/system and aging units. If sufficient information is available beforehand, then this consideration can be made prior to initiating an aging assessment. The purpose of screening is to identify whether the equipment or aging units currently (or, are projected to) have significant obsolescence (e.g., spare parts unavailability, or lack of vendor support), or high maintenance related concerns. Though obsolescence solely is not cause for replacement, if the screening reveals obsolescence or maintenance problems, consideration should be given to replacement or refurbishment without further aging assessment. However, it should be noted that there may be sufficient residual life in the equipment, or an adequate station inventory of identical spare parts may exist. Note, however, that an aging assessment of the installed equipment or aging unit may be useful in determining aging mitigation actions for new or refurbished items.

The aging units should also be initially reviewed to determine equipment or components that are, or are expected to be, readily replaced through periodic or planned routine maintenance. Such items need not be included in an aging assessment, providing the replacement interval is short enough to ensure that aging degradation does not lead to loss-of-function.

6.4 Identifying significant aging mechanisms

For each aging unit, the aging mechanisms that are significant, i.e., those that could lead to loss-of-function should be identified. Identification may be made through examination of the equipment and its functions, pertinent aging mechanisms (see clause 5 and annex A), design, qualification, performance, maintenance, testing, and condition monitoring data (see clause 7 and annex B).

For equipment subject to harsh environment qualification, most or all of the necessary information should be available from existing qualification files. However, the sufficiency of this data may be determined based on a review of the operating and maintenance experience and actual service conditions. In some cases, the operating experience and/or service conditions may reveal aging mechanisms that may not have been fully identified and treated during the qualification process. On the other hand, actual service conditions may be found to be substantially less severe than those assumed in the original qualification.

Examples of some practical items for consideration in this regard include identification of equipment and cable installations that are a) in close proximity to hot piping or vessels (e.g., steam tunnel, main steam and feedwater valves or piping, pressurizer), b) installed in a high humidity environment, and c) subject to a high number of operating cycles (e.g., solenoid valves).

6.5 Determining significant age-related failure modes

The set of aging mechanisms leading to the most significant or limiting modes of loss-of-function should be selected. This is based on further evaluation (e.g., failure modes and effects) of candidate aging mechanisms. In this step the level of significance is a function of a) the relative importance of the aging mechanism to loss-of-function, and b) the rate of aging. Note that the selection of ongoing maintenance tasks [e.g., time/usage-directed (periodic) or condition-directed (predictive)] already in effect for the equipment may have been based on similar evaluations of the relative importance of the ways in which failure could occur. Trending of failures and evaluation of root cause(s) may aid in the determination of significant age-related failure modes. A well-designed equipment history program may provide the necessary data for performing such an evaluation.

6.6 Determining limiting age-related critical characteristics

For each of the aging units subject to significant aging, the limiting age-related critical characteristic(s) based on the failure modes identified in clause 6.5 should be determined.

A characteristic is an equipment or material property. A critical characteristic is the one associated with stressors and their aging effects having the most significant or limiting influence on loss-of-function. It may be direct or inferred. It may be measurable or observable through sensory tests. Examples of these characteristics include dielectric strength of insulation, contact thickness, contact resistance, moisture content in oil, accumulated fatigue cycles, changes in mechanical clearance, and structural strength.

6.7 Determining parameters to be observed

One or more observable parameters may be chosen to monitor each limiting age-related critical characteristic. The observable parameter may be the critical characteristic in many cases. If it is not practical to measure

the characteristic directly, the observable parameter (e.g., elongation conservatively correlated to dielectric properties, or accumulated fatigue cycles) should have been validated as adequately describing the progress of an aging unit to its point of loss-of-function. For equipment subject to harsh environment qualification, the necessary information should already be available.

In some cases, there may be no practical observable parameter. In such cases, it may be necessary to establish conservative replacement intervals based on known failure rates or testing results.

6.8 Establishing residual life

For each aging unit determined to have a significant aging mechanism, residual life can be estimated in the following three steps:

Step 1. First, the present condition of equipment or constituent aging units may be determined through consideration of

- a) Time in service (hours, days, etc.)
- b) Usage or operational history (e.g., number of cycles or modes of operation)
- c) Stressor history, or if not available, a conservative approximation which bounds expected extremes
- d) Failure history
- e) Maintenance and surveillance history

By evaluating the considerations listed above, it can be determined if time in service at the assumed or design service conditions is a realistic measure of equipment condition, or if it is necessary to account for past history which may lead to conclusions of below- or above-average equipment condition.

Step 2. Second, an estimate of design life or qualified life may be determined based on the previously established stressor history. For aging units with an existing qualified life basis, comparison of this basis should be made to the considerations determined above to ascertain whether an update of the qualified life basis is required (e.g., more realistic values of environmental stressors). For equipment where no previous qualified life determination exists, an approximate design life may be established through consideration of the identified aging mechanisms (see 6.4) and one or more of the following:

- a) Failure rates (mean time between failure)
- b) Comparison to equipment with a similar materials and environmental stressor history
- c) Arrhenius modelling

Step 3. Third, the residual life may be estimated by subtracting the time in service (modified as appropriate through present condition considerations in step 1) from either the qualified life (updated as necessary) or the estimated design life. The residual life of the significant aging unit will determine the residual life of the equipment being assessed.

In some cases, a residual life cannot be estimated due to insufficient data or lack of a practical observable parameter. In these cases, a conservative time frame should be established for periodic condition monitoring or aging unit replacement (see clause 7).

The determination of residual life should consider any excessive conservatism used, which may be applied in determining or extending the estimated time to exceed some performance criteria (time-to-loss-of-function would be an extreme bound). Excessive conservatism is the amount beyond that which has been determined to be necessary by existing standards in representing levels of uncertainty with regard to measured values and quantifiable parameters. The determination of an appropriate level of conservatism may consider the following factors:

- a) Duration required for replacement or refurbishment of equipment or aging units
- b) Overall confidence level of estimated time to loss-of-function
- c) Consequences of allowing loss-of-function to occur
- d) Frequency of monitoring limiting age-related critical characteristics based on time or usage
- e) Ability of equipment to function in its expected design basis event environments

A degree of uncertainty may exist from the determinations of the previous three steps. This degree of uncertainty may be addressed through the establishment, refinement, and/or continuation of condition monitoring programs to verify the accuracy of residual life approximations.

7. Methods for monitoring and mitigating aging degradation

Monitoring and timely initiation of appropriate mitigating actions are key elements for effective control of aging degradation. To assure effectiveness, monitoring and mitigating actions, when necessary, should verify the following:

- a) Performance satisfies safety functions.
- b) Monitoring methods provide early detection of aging degradation.
- c) Aging mechanisms are identified and addressed (see clause 5).
- d) The techniques used provide the necessary and sufficient basis for aging assessment.
- e) Mitigation methods (see 7.2) are scheduled on a frequency consistent with the equipment/component/material's degradation rate.

General methods for monitoring and mitigating aging degradation are described in the following subsections. Related examples of these applications are provided in annex C.

7.1 Monitoring methods

7.1.1 Monitoring

From an aging perspective, monitoring of components is an observation or measurement of observable parameters (condition indicators) to verify that the performance of equipment currently conforms to acceptance criteria. The prescribed observations may take the form of measurements, periodic tests or inspections designed to produce consistent, repeatable results. Observed values may then be compared with acceptance criteria or with the results of previous observation(s) on the same components.

Criteria can be established that require corrective action to be performed when monitored parameters deteriorate to a specific level or vary in a specified manner. These criteria can be established to assure component performance under all conditions (normal, abnormal and accident). Operating experience, equipment qualification or research results may provide the basis for establishing these criteria.

Observable parameters used for monitoring certain types of components may provide the basis for establishing predictive criteria. They should correlate with the type and frequency of preventive action. Examples of some of the common measurable indicators of degradation are voltage, current, load, response time, setpoint drift, and contact resistance change. Mechanical wear, erosion, binding or bent parts may be determined from sensory type parameters/visual inspections (e.g., noise, color change, or touch). Vibration monitoring of rotating equipment, monitoring motor current of motor-operated valves, transformer oil analysis, thermography and nondestructive examination techniques for pressure retaining components are additional examples of condition monitoring methods. Tables 1, 2, and 3 in annex A, provide in summary form, a list of typical monitoring methods of aging for several types of degradation effects.

7.1.2 Inspection

Certain types of degradation can be detected prior to equipment failure through routine inspections. These inspections can be designed to identify indications of equipment condition and potential abnormalities. Such indications include, but are not limited to the following:

- a) Dirt, dust, and contamination
- b) Moisture/water in grease and lube oil
- c) Inadequate or excessive lubrication
- d) Friction
- e) Excessive vibration
- f) Ambient environment variations
- g) Cracks/erosion
- h) Age and service wear
- i) Color change
- j) Embrittlement
- k) Overheating

Tables A1, A2, and A3 in annex A list typical aging degradation effects from the above indications.

7.1.3 Surveillance

Aging degradation may be detected prior to equipment failure through existing plant surveillance or diagnostic testing programs. Such programs include, but are not limited to the following:

- a) Technical specification surveillance tests
- b) In-service inspection tests
- c) Calibration of instrument sensors
- d) Vibration analysis tests
- e) Other signature analysis (e.g., motor current)

Plant set point monitoring programs also provide a method of monitoring the aging degradation of equipment. In this program, instrument drift is utilized as an indication of overall health of the equipment.

IEEE Std 943-1986 provides a listing of suggested tests for the detection of aging degradation in electrical insulating systems. These tests are categorized according to the affect on the equipment.

7.1.4 Trending

Trending of monitoring, inspection, or surveillance results (condition trending) provides an indication of aging degradation, and the current and future ability of equipment to function as designed. For example, trending of results from monitoring drift in meter and instrument setpoint readings provide information that can be used to determine calibration intervals. Should the trending indicate aging is significant, instruments and meters can be removed, and repaired or replaced. Trending special or periodic test results or inspections is another technique for monitoring of equipment condition and associated aging degradation. For example, for batteries, trending of performance test results, specific gravity measurements, electrolyte level, or plate inspection data should yield sufficient information to assess aging degradation. Examples of trending special or periodic test results follow. For battery chargers, these could include power factor, no-load current, measuring the limits on the current limiter, or measuring the increase in ripple in the dc output for sudden increases and decreases applied to the line voltage (which could be attributed to aging degradation of the dc electrolytic filter capacitor). For oil-filled transformers, these could include gas analysis, interfacial tension, hot spot temperature, or color test. For containment electrical penetrations, these could include leak rate tests. For temperature sensors, these could include repeatability, time constant, response time, and drift.

Condition trending does not always provide a reliable indication of aging degradation. Electronic equipment, for example, can fail catastrophically rather than provide easily detectable indications of degradation. For this type of equipment, trending failure rates may be an appropriate method of monitoring aging degradation. If statistical data are available, then surveillance, preventive maintenance, or replacement can be scheduled more effectively on the basis of failure trends. If the failure pattern of a component shows that the probability of failure increases significantly after a certain life span, then replacement of the equipment may be considered.

Failure trending requires a systematic collection and analysis of plant data (see clause 8). Equipment failures must be recorded in a specified, systematic manner to permit determination of the severity of failures, failure modes, and root causes of failures. Trends of failures and their causes may then be monitored and evaluated. Some examples of trending applications are provided in annex C.

7.2 Mitigation methods

7.2.1 Maintenance

7.2.1.1 General

Maintenance is the actions that detect, preclude, or mitigate degradation of equipment, or restore to an acceptable level the design functions of failed equipment. For purposes of this discussion, maintenance includes not only activities traditionally associated with identifying and correcting actual or potential degraded conditions, repair, surveillance, diagnostic examinations, and preventive measures, but extends to other supporting functions as discussed in the following subclauses.

Maintenance is most effective when performed on a timely basis. The following is an approach to determine when to perform maintenance:

- a) Identify observable parameters for aging unit or equipment, which would give an indication of its condition at the time of observation.
- b) Identify methods to detect aging degradation prior to failure.
- c) Perform condition/failure trending (see 7.1.4), as appropriate, for aging unit or equipment under observation.
- d) Determine minimum functional capability that defines the end of normal service life while being capable of performing its designated safety function.
- e) Analyze the data collected from the above process and decide the appropriate corrective action.

Detection and mitigation of significant aging degradation effects is accomplished through preventive maintenance, which includes those maintenance activities performed on a periodic, continuous, or predictive basis prior to failure.

Requirements to maintain the Environmental Qualification (EQ) of Class 1E equipment are integrated into maintenance/operational programs. Utilities have established an Environmental Qualification program for Class 1E equipment located in potentially harsh environments. Two techniques that are currently used for mitigating aging degradation in an EQ program are a) reconfiguration or operational changes to reduce aging environmental stressor (principally heat and radiation) levels, and b) replacement.

7.2.1.2 Replacement

Replacement is the substitution of a component, usually degraded or failed, with another that complies with the design requirements.

Components may be replaced prior to reaching the end of design or qualified life or prior to failure based on the results of monitoring. For instance, in equipment qualification programs, weak link components are replaced prior to the end of their qualified life such that the longer qualified life of the host equipment is maintained.

Replacement is also an option to use for equipment that has become obsolete (as noted in 6.3, obsolescence solely is not cause for replacement), equipment for which spare parts are no longer available, equipment that fails to meet acceptance criteria, or equipment for which increased reliability is desired.

7.2.1.3 Refurbishment

Refurbishment is the renovation or restoration of a degraded component to an acceptable state, not necessarily its original, nondegraded state. The equipment to be refurbished may have selected components or materials replaced. Examples of refurbishment of equipment are changing the contacts on a breaker, installing new bearings on a motor, or replacing insulation materials. It should be noted that environmental qualification requirements, when applicable, must still be satisfied for refurbished equipment.

7.2.2 Adjustments in operating environments and practices that reduce stresses

Environmental stressors such as heat and radiation are known to induce aging degradation, particularly in nonmetallic materials. Adjustment in the operating environment or operational practices is an effective method of mitigating aging degradation. Collection and evaluation of environmental data can provide the basis for making adjustments in the environmental or operating practices that can mitigate the aging degradation effects from these stressors. Examples of adjustments in the operating environment include adding thermal insulation, venting electrical enclosures, implementing HVAC upgrades, adding radiation shielding, minimizing location of aging sensitive equipment in a non-benign environment, and periodically decontaminating piping near Class 1E equipment. Annex B contains guidance on environmental monitoring of components. Examples of adjustments in operating practices include reducing the period of operation, reducing the number and rate of startups/shutdowns, and optimizing or improving testing practices.

7.2.3 Redesign of equipment

Equipment manufacturers and the nuclear industry routinely perform design enhancements based on operating experience and new technology/materials availability. These include changing to materials more resistant to aging stressors, reconfiguring for improved reliability or even relocating equipment. For example, research [B50] conducted on inverters recommended age-mitigating design improvements such as the use of higher ratings for voltage and temperature sensitive components in the inverter circuitry, and the addition of forced air cooling to reduce overheating problems. It should be noted that the environmental qualification requirement, when applicable, should still be satisfied for redesigned equipment.

8. Data

The compilation of relevant information on the Class 1E equipment under evaluation is a cornerstone activity of aging assessments. Relevant data should form the basis on which decisions concerning the suitability of electrical equipment for continued operation, can be made.

Since many kinds and types of records and data can be considered for review, a means to identify relevant data is helpful with respect to the goals of this guide. Relevant data can be identified or suggested by first identifying the aging mechanisms (clause 5) that are operative for the equipment or component under scrutiny. The relevant data should support the observable parameters (clause 6) determined for that equipment. If the aging assessment determines that additional data is required, then additional data will be identified by a more focussed selection of observable parameters. Specific data generated as a result of an aging assessment