

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

Sponsor

**Nuclear Power Engineering Committee
of the
IEEE Power Engineering Society**

Reaffirmed 21 March 2007

Approved 30 March 2000

IEEE-SA Standards Board

Abstract: Guidelines for assessing, monitoring, and mitigating aging degradation effects on Class 1E equipment used in nuclear power generating stations are provided. This guide also includes informative annexes on aging mechanisms, environmental monitoring, condition monitoring, aging program essential attributes, and example assessments for five types of equipment (including electric cable).

Keywords: activation energy, aging, aging assessment, aging effects, aging management, aging mechanisms, Arrhenius, condition monitoring, degradation, environmental monitoring, license renewal, radiation model, residual life, stressor, thermal model

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2000 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 20 December 2000. Printed in the United States of America.

Print: ISBN 0-7381-2494-X SH94856
PDF: ISBN 0-7381-2495-8 SS94856

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied “**AS IS**.”

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

IEEE is the sole entity that may authorize the use of certification marks, trademarks, or other designations to indicate compliance with the materials set forth herein.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (978) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

(This introduction is not part of IEEE Std 1205-2000, 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 that 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.

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, this technical basis exists for its original qualified life. The potential for significant aging needs to be effectively assessed so that necessary mitigating actions are taken to assure dependable and safe operation of the plant, including extension beyond original qualified life.

In 1988, the Nuclear Power Engineering Committee (NPEC) of IEEE recognized a need for and directed Working Group 3.4 to prepare a guide to supplement its existing body of standards. This guide was to

- Provide guidance in the areas of aging assessment, control, and mitigation.
- Promote uniformity in the methods used for developing the technical basis cited previously.

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:

- It would be expedient and promote consistency by providing guidance that can be incorporated into future standards.
- It would help disseminate the body of knowledge and promote uniformity in application methods while minimizing the confusion that could result from the differences in the licensing bases of the various operating nuclear power plants.

The Working Group's effort culminated in 1993 with the original issue of IEEE Std 1205.

At the time of original issue of IEEE Std 1205-1993, the industry focus for assessing and mitigating aging degradation was on identifying and addressing aging mechanisms. This approach derived from the rigorous aging analyses performed in support of earlier environmental qualification (EQ) programs. In 1991, 10 CFR 50.65 (Maintenance Rule) was published. In 1995 10 CFR 54 (License Renewal Rule) was amended. As a result of these two regulation changes and industry interactions in response [e.g., NEI 95-10 (Revision 1), Industry Guideline for Implementing the Requirements of 10 CFR Part 54 — The License Renewal Rule],

the emphasis for addressing aging degradation shifted from identifying aging mechanisms to identifying aging effects. Since the original issue of IEEE Std 1205-1993, the Working Group has also received feedback on a need to better integrate the various clauses of this guide in order to improve its usefulness.

In 1997, the NPEC authorized Working Group 3.4 to revise IEEE Std 1205-1993 to incorporate industry feedback and to bring the approaches discussed in the guide into closer conformance with present industry philosophy. To this end, the following changes to the guide have been adopted:

- Developed new block diagrams that update the aging assessment, monitoring, and mitigation process for consistency with current industry philosophy and better show and integrate the relationships between the process steps.
- Reversed the order of Clause 4 and Clause 5, and revised Clause 5, Clause 6, and Clause 7 for improved consistency with the new process block diagrams.
- Added a new Annex C on condition monitoring.
- Updated the example assessments now found in Annex D for consistency with the revised Clause 6, and added two new examples on electric cable and electric penetrations.
- Added a new Annex E on attributes of an effective aging management program.

The Working Group believes that this guide is useful in supporting EQ Program aging assessment updates, Maintenance Rule related failure evaluations, other root cause evaluations, License Renewal aging management reviews, as well as special case maintenance problem evaluations. While the scope of this guide is limited to Class 1E equipment, the principles can be applied equally well to non-Class 1E equipment.

A future activity of the Working Group is to extract candidate monitoring methods for aging effects from Table A1, evaluate continued viability, and incorporate into a future update of Annex C.

Attention is called to the possibility that implementation of this guide may require use of subject matter covered by patent rights. By publication of this guide, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

At the time this guide was balloted, Working Group 3.4 on Aging Assessment Guidelines had the following membership:

David A. Horvath, *Chair*
George Ballassi, *Vice Chair*
Paul C. Shemanski, *Secretary*

Brij M. Bhartey
R. Paul Colaanni
Lamis Q. Fleischer

Henry C. W. Leung
Robert J. Lofaro

Mansoor H. Sanwarwalla
Douglas E. Thomas
Carl Yoder

The Working Group would like to recognize the invaluable administrative and graphics contributions provided by Cynthia J. Wiktor.

At the time this guide was balloted, Subcommittee 3 on Operations, Surveillance and Testing had the following membership:

Sonny Kasturi, Chair
John H. Taylor, Secretary

Millard R. Allen
Brij M. Bharteey
R. Paul Colaianne

Lamis Q. Fleischer
David A. Horvath
Wayne Johnson
Steven Z. Parsons

Douglas E. Thomas
Jit P. Vora
Carl S. Weary

At the time this guide was balloted, the Nuclear Power Engine Committee had the following membership:

Britton P. Grim, Chair
Scott Malcolm, Vice Chair
Neil P. Smith, Secretary

Satish K. Aggarwal
Vincent P. Bacanskas
Farouk D. Baxter
Brij M. Bharteey
Wesley W. Bowers
David F. Brosnan
Aris S. Candris
Salvatore P. Carfagno
Robert C. Carruth
John P. Carter
Robert L. Copyak
John D. Disosway
Surin K. Dureja
Jay Forster

Joseph R. Fragola
Wilmer C. Gangloff
Lawrence R. Gradin
Kenneth Greene
Robert E. Hall
Gregory K. Henry
David A. Horvath
Paul R. Johnson
Sonny Kasturi
James T. Keiper
John MacDonald
Alexander Marion
Wolfgang Michel
Richard B. Miller

Roger D. Parker
Barry J. Skoras
Donald J. Spellman
Peter B. Stevens
James E. Stoner
Peter Szabados
James E. Thomas
Gary J. Toman
John Waclo
Carl S. Weary
Raymond Weronick
David J. Zaprazny
Mark S. Zar

The following members of the balloting committee voted on this standard:

Satish K. Aggarwal
Vincent P. Bacanskas
George Ballassi
Farouk D. Baxter
Brij M. Bharteey
Daniel F. Brosnan
John Carter
Raymond J. Christensen
Patrick M. Duggan
Jay Forster

John Kenneth Greene
Britton P. Grim
Robert E. Hall
Gregory K. Henry
David A. Horvath
Carl E. Kunkel, Jr.
Henry Leung
John E. Merando, Jr.
Richard B. Miller

Roger D. Parker
C. A. Petrizzo
Barry J. Skoras
Neil P. Smith
James E. Stoner
John H. Taylor
James E. Thomas
Gary Toman
David J. Zaprazny
Mark S. Zar

When the IEEE-SA Standards Board approved this standard on 30 March 2000, it had the following membership:

Donald N. Heirman, *Chair*
James T. Carlo, *Vice Chair*
Judith Gorman, *Secretary*

Satish K. Aggarwal
Mark D. Bowman
James T. Carlo
Gary R. Engmann
Harold E. Epstein
H. Landis Floyd
Jay Forster*
Howard M. Frazier
Ruben D. Garzon

James H. Gurney
Richard J. Holleman
Lowell G. Johnson
Robert J. Kennelly
Joseph L. Koepfinger*
Peter H. Lips
L. Bruce McClung
Daleep C. Mohla
James W. Moore

Robert F. Munzner
Ronald C. Petersen
Gerald H. Peterson
John B. Posey
Gary S. Robinson
Akio Tojo
Donald W. Zipse

*Member Emeritus

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Alan Cookson, *NIST Representative*
Donald R. Volzka, *TAB Representative*

Yvette Ho Sang
IEEE Standards Project Editor

National Electrical Code and NEC are both registered trademarks of the National Fire Protection Association, Inc.

Contents

1.	Overview.....	1
1.1	Scope.....	1
1.2	Purpose.....	1
1.3	Application.....	1
2.	References.....	2
3.	Definitions.....	2
4.	Stressors, aging mechanisms, and aging effects	3
4.1	Stressors	3
4.2	Aging mechanisms and aging effects	3
5.	Discussion	4
5.1	Need for an aging assessment	4
5.2	Desired objective and benefits	4
5.3	Aging assessment elements.....	6
6.	Aging assessment.....	6
6.1	Define evaluation boundaries	6
6.2	Identify equipment safety functions.....	7
6.3	Identify plant locations where the equipment is installed.....	7
6.4	Identify the electrical equipment service conditions	8
6.5	Identify the materials of construction	8
6.6	Identify and assess aging effects.....	9
7.	Monitoring and mitigating aging degradation	13
7.1	Maintenance.....	13
7.2	Replacement.....	13
7.3	Refurbishment.....	14
7.4	Redesign of equipment	14
7.5	Adjustments in operating environments and practices that reduce stresses	14
7.6	Environmental and operational stress monitoring	14
7.7	Inspection.....	14
7.8	Surveillance.....	15
7.9	Trending.....	15
8.	Data.....	16
8.1	Baseline data (original capability)	17
8.2	Historical data (operating history)	17
8.3	Diagnostic testing data.....	18

Annex A (informative) Aging effect tables	20
A.1 Introduction.....	20
A.2 Use of the equipment aging tables	20
Annex B (informative) Monitoring of environments	30
B.1 Introduction.....	30
B.2 Environmental stressors	30
B.3 Environmental monitoring program	31
Annex C (informative) Condition monitoring.....	34
C.1 Introduction.....	34
C.2 Condition monitoring considerations and characteristics	34
C.3 Available condition monitoring techniques	35
C.4 Conditioning monitoring bibliography	37
Annex D (informative) Equipment and system examples	39
D.1 Reactor protection system.....	39
D.2 Emergency diesel generator.....	45
D.3 Motor control centers	48
D.4 Insulated cables.....	55
D.5 Electrical penetration assemblies (EPAs)	70
Annex E (informative) Aging management program attributes.....	74
Annex F (informative) Bibliography	76

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 guide 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

It is intended that the user determine the specific equipment that warrants attention using this guide. 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.

Aging assessment may be pursued in response to a variety of factors, e.g., regulatory guidance, approaching obsolescence, reduced availability or reliability, or for life extension. For example, IEEE Std 323-1983¹ provides definitive guidance for the qualification of Class 1E equipment required to mitigate the consequences of a design basis event. Such factors plus economics also affect the method and extent of aging assessment actually performed. Monitoring and/or mitigating the aging of some equipment may be determined to be less cost effective than replacing the equipment. Running to failure may be an option under certain special situations.

¹Information on references can be found in Clause 2.

2. References

This guide should be used in conjunction with the following standards:

IEEE Std 323-1983 (Reaff 1996), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.²

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

3. Definitions

Most terms used in this guide 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 guide. EPRI RP-2927 [B15]³ 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 preserves or service conditions and could impair its ability to perform any of its design functions.

3.3 aging effects: Net changes in characteristics of a system, structure, or component that occur with time or use and are due to aging mechanisms.

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

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

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

3.7 significant aging mechanism: An aging mechanism that, 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 IEEE Std 649-1991 [B51]).

3.8 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.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

³The numbers in brackets correspond to those of the bibliography in Annex F.

4. Stressors, aging mechanisms, and aging effects

4.1 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 is 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 stressor may exceed the sum of the individual effects.

4.2 Aging mechanisms and aging 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 stressors, aging mechanisms, and aging effects are provided as follows:

- 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 antioxidation 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.

Table A.1, Table A.2, and Table A.3 provide, in summary form, a listing of typical aging mechanisms and their effects on polymers, lubricants, and metals.

All mechanisms may not be operative or produce significant aging effects in equipment in a given service environment for a given period of time. In some cases, aging mechanisms may be readily judged to be of little or no importance because they are not significant relative to the equipment safety 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 Table A.1, Table A.2, and Table A.3 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.

5. Discussion

5.1 Need for an aging assessment

The first step in performing an aging assessment is to establish the population to be addressed. The description of the aging assessment process in this guide assumes that a judgment has already been made that an aging assessment is needed. However, potential reasons for performing an aging assessment may include

- Industry-identified equipment problem evaluation
- Plant-specific equipment problem evaluation
- License renewal equipment review
- Maintenance rule equipment failure evaluation
- Equipment qualification aging-related problems

An aging assessment evaluation may not be necessary if the equipment is affected by

- Obsolescence (e.g., superseded technology, lack of vendor support)
- A lack of a viable source of spare parts
- IEEE Std 323-1983 requalification (e.g., a retest decision has been made)
- Replacement or attention for other reasons (e.g., regulatory requirements)

Figure 1 provides an overview of the aging assessment process by illustrating the main activities.

5.2 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. Such an aging assessment may require some understanding of the type of stressors, the nature of the aging mechanisms affecting the equipment, and the often more discernible resultant aging effects (refer to Annex A).

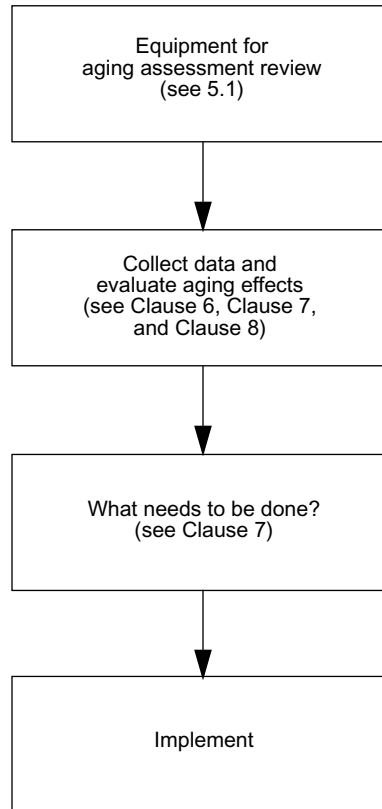


Figure 1—Overview of assessing, monitoring, and mitigating aging effects

Beyond the purpose stated previously, 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. Understanding the aging mechanisms that affect Class 1E equipment in a nuclear power generating station permits the identification, monitoring, and mitigation of aging effects (aging degradation) that can significantly effect the performance of a safety function. 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 effects, and the potential for failures they can cause, could be integrated into the operational surveillance programs and preventive maintenance programs at nuclear power generating stations. With a knowledge of significant aging effects, 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-spot mapping using infrared thermography, vibration monitoring of motors, and root cause analysis of equipment failures are existing plant activities that can be directed toward aging assessment. A combination of some of these programs should be all that is needed to assess aging degradation for some equipment. For example, 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.

5.3 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 process follows.

Clause 4 establishes the relationship between aging mechanisms and aging effects. The identification of known operational stressors, aging mechanisms, and the resultant aging effects can be useful elements in an aging assessment process. It should be understood that there is no intended order of performance with regard to investigating aging mechanisms and aging effects. Specific knowledge of the equipment and its service conditions (stressors) should be applied to determine if any significant aging effects are discernible or if aging mechanisms may be considered to provide insight to aging effects not yet apparent.

Once the equipment is selected for evaluation, several pieces of information are collected to form the technical basis for an aging effect assessment. The actions that should be performed are

- a) Define and determine the equipment boundaries relative to what is going to be included in the aging assessment process
- b) Identify the equipment's safety functions
- c) Identify the equipment's installed location
- d) Identify the stressors operating on the equipment
- e) Identify the parts and materials included in the equipment's assembly
- f) Identify and assess the aging effects on the equipment

An assessment of the aging effects on the equipment is done to determine if a reasonable correlation can be made with respect to the stressors that exist in the equipment's installed location, a material's sensitivity to the stressors, and a loss of equipment function. If a correlation is apparent, an aging mechanism may be identified. As a minimum, the assessment should be comprehensive enough to support and implement an effective aging management decision. Following implementation, the actions should be validated or refined as needed. Figure 2 defines the individual elements of the aging assessment process. The process shown in Figure 2 combined with the insight from Clause 4, Annex A, Annex C, and the existing environmental qualification (EQ) equipment documentation are integrated to obtain a sufficient technical basis to determine an aging mitigation solution.

NOTE—The process of implementing aging management would most likely be an iterative one. That is, the results of monitoring and mitigating aging effects would allow future refinement of the aging assessment.

6. Aging assessment

Clause 6 provides guidance for data collection (see Clause 8) in support of the aging assessment and also for performing the aging assessment. The level of detail selected for aging assessments should be determined prior to starting the evaluation. The level of detail selected in most cases need only provide reasonable assurance of equipment safety function.

6.1 Define evaluation boundaries

The boundaries of the evaluation should be defined for the purposes of the aging effect assessment and clearly define the parts or portion of the equipment to be examined. The need for a clear definition is especially true where equipment to be evaluated interfaces with field cables or other equipment. The boundary should determine inclusion or exclusion of equipment, parts, or connections external to the device being evaluated. A description of the equipment and its boundaries being evaluated, not discussed elsewhere in the evaluation, should be provided.

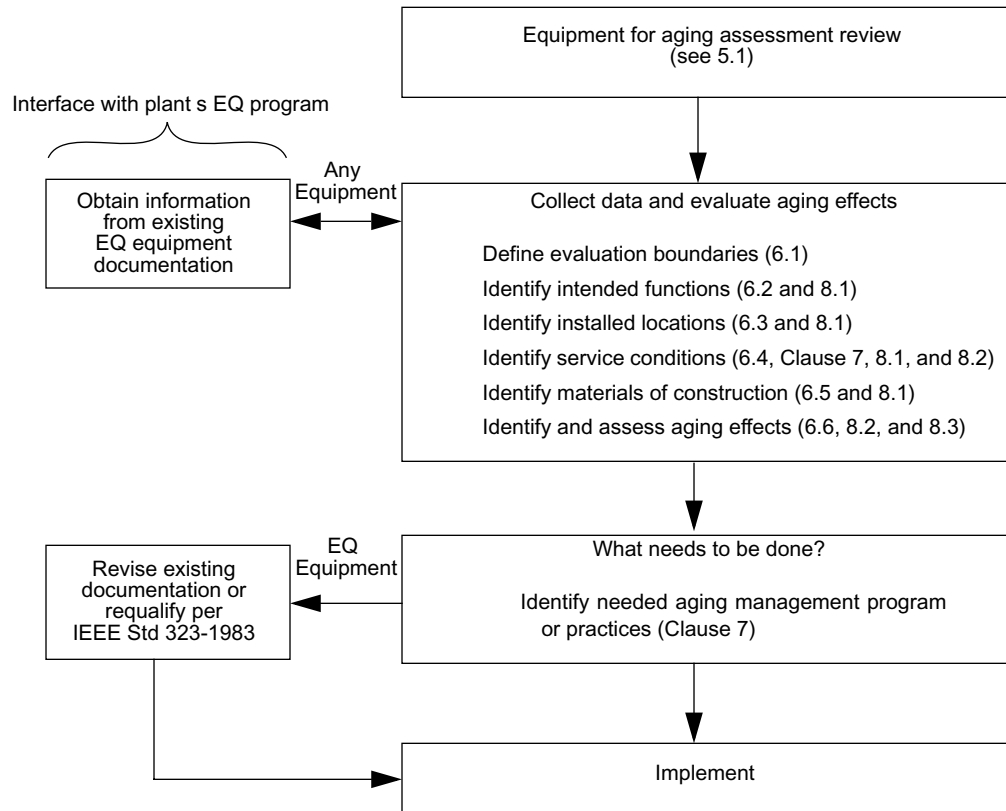


Figure 2—Process for assessing, monitoring, and mitigating aging effects

6.2 Identify equipment safety functions

Equipment safety functions are those that are essential to the system's safety function. For more complex pieces of equipment (e.g., emergency diesel generators), it would also be important to identify subassembly safety functions. For purposes of performing an aging assessment, the following functions should be identified:

- Equipment safety functions susceptible to known aging effects
- Subassembly safety functions susceptible to known aging effects
- Equipment and subassembly support functions whose degradation or failure could cause loss of a safety function (e.g., electrical penetration O-ring performing a pressure-retention function)

Typical sources of information pertaining to equipment safety functions are provided in 8.1.

6.3 Identify plant locations where the equipment is installed

It is important to identify the location where the equipment is installed in the plant. Location information is needed for determining service conditions. Typical sources of equipment locations are plant drawings, equipment databases, and plant walkdowns.

6.4 Identify the electrical equipment service conditions

The electrical equipment's service conditions are determined in order to assess the influences that can affect its service life. Service conditions include both environmental conditions (e.g., thermal, radiation, moisture) and, if applicable, equipment operational conditions (e.g., self-heating, vibration). These service conditions are the stressors that may cause aging of the electrical equipment. Annex A identifies other stressors that may be applicable to equipment.

Environmental temperatures for most plant areas are normally available in various heating, ventilation, and air conditioning (HVAC) design specifications, station safety analysis reports, or design basis documents. For areas in which equipment temperature data is not available or the existing data requires reevaluation, new temperature data should be gathered. In addition to the ambient thermal environment, temperature rise due to component self-heating can also contribute to equipment thermal aging and, where applicable, should be addressed in the evaluation. Equipment self-heating temperature rise information can be obtained from manufacturers' data, from equipment item specific analyses, or from tests. Self-heating temperature rise is added to the ambient temperature to determine the total temperature to be considered for thermal aging of the equipment and materials.

Radiation data, for plant areas where it is applicable, is normally available from the station safety analysis report or from the plant EQ program as radiation mapping is normally done to determine normal electrical equipment radiation doses in applicable plant areas. In those instances where no radiation data is available, it may be obtained from the plant surveys.

Humidity for plant areas, if needed, can be obtained from HVAC design specifications, station safety analysis report, or periodic plant monitoring, or can be conservatively established.

Cyclic stresses are an operative concern depending on the degree of the stress and the number of cycles. A cyclic stress service condition need only be identified for the aging assessment if there are known aging effects. Examples are mechanical and electrical cycling. See Annex A for additional information.

Sources of design and actual service condition data can be found in 8.1 and 8.2. Information on monitoring of environments is contained in Annex B. In addition, EPRI TR-109619 [B10] provides guidance for obtaining service condition data.

6.5 Identify the materials of construction

The equipment's parts and construction materials should be identified for evaluation under their service conditions. In cases where it is not possible to determine all materials or the exact materials of construction, the goal is to have reasonable assurance that age-sensitive materials have been identified.

Electrical component materials can be identified from various sources such as from design material lists, component manufacturer drawings, or spectrographic analysis. See 8.1 for additional sources of information. Where specific component information is lacking, industry aging management guidelines and other reports (e.g., NUREG-1377 [B65], NUREG/CR 3629 [B66], NUREG/CR 4156 [B67], NUREG/CR-4731 [B68], NUREG/CR-4715 [B69], NUREG/CR 4740 [B70], NUREG/CR-5051 [B71], NUREG/CR-5057 [B72], SAND96-0344 [B74]) may be sources of the most common materials used for specific component types installed in the nuclear power industry.

Electrical components are constructed with organic and inorganic materials. Depending on the type of component being evaluated, identification of the metals and other inorganic materials may not be necessary. For example, there are no significant aging effects for inorganic materials associated with cables (i.e., cable conductor, shielding, fillers and armor).

NOTE—Most metals and other inorganic parts in cables are covered by insulation or a jacket and are not exposed to environments that would cause the inorganic materials to degrade under normal circumstances. Although not typical, moisture can seep between various layers of cable construction and with oxygen introduced can cause corrosion and metal loss. Contacts, linkages, and bearings are inorganic parts of electrical equipment that may also be susceptible to aging.

6.6 Identify and assess aging effects

Aging effects are identified and assessed to determine whether any additional aging management efforts are needed to prevent the effects from becoming significant over time. Significant aging effects are those that can detrimentally affect the equipment safety function or functions identified in 6.2.

The following subclauses describe aging effect identification, other supportive information needed, and use of aging models and condition monitoring to perform aging assessments.

6.6.1 Identification of aging effects

Aging effects are identified from either plant-specific or industry failure or degradation experience with the specific equipment or its materials of construction (from 6.5) in a similar application. Alternatively, plant-specific service conditions (stressor values) and materials information may be used to determine applicable and potentially significant aging effects from the tables of Annex A.

6.6.2 Other supportive information needed

Next the following information should be researched or established as feasible or available:

- a) Evaluation period: Most materials degrade somewhat over time, even in fairly benign environments; it is useful to set a specific goal for the equipment's life to be evaluated. The evaluation period is normally selected on the basis of the plant's 40-year operating license, but can be selected for any other specific time period (e.g., outage to outage for specific equipment, time periods between tests as dictated by safety analysis, or 60 years for license renewal).

NOTE—For EQ Program equipment, it is necessary to include the mission (or postaccident required operating) time in the evaluation period to assure sufficient margin for postaccident operability beyond the normal life goal.

- b) Past and future service conditions (from 6.4) as a function of time or as enveloping values for the evaluation period.
- c) Degree of flexibility in controlling or limiting future service conditions.
- d) Aging mechanisms likely to cause the identified aging effects in the identified materials of construction (determined from Annex A or similar sources of information, such as EPRI NP-1558 [B12] and NUREG-1377 [B65], NUREG/CR-3629 [B66], NUREG/CR-4156 [B67], NUREG/CR-4731 [B68], NUREG/CR-4715 [B69], NUREG/CR-4740 [B70], NUREG/CR-5051 [B71], NUREG/CR-5057 [B72]).
- e) Dependence of the aging mechanism and resulting aging effects on the identified service conditions.
- f) Aging information, such as activation energy, accelerated aging test data (temperature and time), temperature rating or maximum continuous-use temperature, radiation dose threshold, and related information, for the equipment or its materials of construction.

To perform the aging assessment, the material's withstand capability is compared to the intensity of a service condition stressor. Results from tests of material properties, after being subjected to accelerated aging, are the best and most readily available sources of material aging information. Other sources include utility

experience and industry aging management guides such as those published by the Department of Energy and the Electric Power Research Institute (EPRI), e.g., EPRI EL-5885 [B11], EPRI NP-1558 [B12], NUREG-1377 [B65], NUREG/CR-3629 [B66], NUREG/CR-4156 [B67], NUREG/CR-4731 [B68], NUREG/CR-4715 [B69], NUREG/CR-4740 [B70], NUREG/CR-5051 [B71], NUREG/CR-5057 [B72], SAND96-0344 [B74], and NUREG/CR-6384 [B73].

The aging assessment can be performed to achieve either one or both of the following objectives, depending on information availability, expected or estimated remaining life margin, and whether specific equipment life goals have been established or are needed. The objectives of the aging assessment are to determine

- How long (years) a material will remain functional while exposed to its stressors, or
- A maximum stressor (heat, radiation) value that a material would be able to withstand for a specified period (years) and still remain functional.

Knowing the equipment materials and stressors, it is possible to assess the effects of aging on the material to date and to determine how in the future aging will affect the equipment safety function. For a given material, aging effects (some type of material degradation) can be directly related to a specific environmental or operational stressor. The intensity of the stressor normally determines the rate that the material degrades.

Next, one or a combination of methods is used to assess aging effects for the equipment's future service conditions. Two models, which extrapolate test results and condition monitoring, are discussed in the following subclause.

6.6.3 Use of a thermal aging model

Thermal aging is commonly assessed by using the Arrhenius model, which is described in EPRI NP-1558 [B12] and Nelson [B58]. The model establishes aging degradation as a function of temperature and allows an estimation of thermal life at a given temperature. It is also used to relate remaining life at one temperature to remaining life at another temperature. Alternatively, it can be used to determine a maximum continuous temperature for a specific length of time.

Thermal aging is a chemical reaction, and such reactions are a function of temperature. The reaction rate (dg/dt) according to Arrhenius from EPRI NP-1558 [B12] and Nelson [B58] is given in Equation (1).

$$\frac{dg}{dt} = A \exp(-\phi/kT) \quad (1)$$

Neglecting the effect of depletion of the reactants on the reaction rate to solve this differential equation gives Equation (2).

$$t = B \exp(\phi/kT) \quad (2)$$

where

- | | |
|--------|--|
| t | is the time to reach a specified end-of-qualified-life condition or lifetime, |
| A | is a constant of proportionality, |
| B | is a constant [related to the amount of degradation that will have occurred at end of time t or $B = g(t)/A$ where $g(t)$ is the amount of reactions occurring through time t], |
| ϕ | is the activation energy (eV) for a chemical reaction of concern and indicative of aging susceptibility, |
| k | is the Boltzmann's constant (0.817×10^{-4} eV/K), |
| T | is the absolute temperature (K) of the service condition. |

Equivalent degradation can be applied to the Arrhenius relationship to allow calculation of a lifetime t_2 at an actual (or expected) installed temperature T_2 , given a different test temperature T_1 and a test period t_1 [see Equation (3)].

$$t_2/t_1 = \exp \{(\phi/k)[(1/T_2) - (1/T_1)]\} \quad (3)$$

Equation (3) can be used in conjunction with appropriate testing results (to a marginal degradation condition) at a higher temperature to theoretically derive a maximum continuous-use lower temperature for a longer specified period of time. Alternatively, this expression can be used to approximate remaining life given a known exposure temperature history and a conservative expected future temperature. To facilitate such a determination, a series of i discrete “time at temperature” intervals can be used to derive an equivalent Arrhenius weighted average temperature T_n for the entire period of time t_n as shown in Equation (4).

$$g(t_n) = At_n[\exp(-\phi/kT_n)] = A[t_1 \exp(-\phi/kT_1) + t_2 \exp(-\phi/kT_2) + \dots + t_i \exp(-\phi/kT_i)] \quad (4)$$

$$T_n = (\phi/k)/\ln [t_n/\sum t_i \exp(-\phi/kT_i)]$$

where T_i is the temperature for time interval t_i and the summation is over all i discrete intervals.

It should be noted that Arrhenius thermal age modeling has the following assumptions, sensitivities, and limitations:

- a) A single stressor type, i.e., thermal aging is assumed at work throughout the life of the material. (Radiation exposure degradation and other forms of aging would need to be addressed separately.)
- b) One dominating chemical reaction corresponding to one dominating aging mechanism causing the identified aging effect (e.g., corrosion, embrittlement, etc.) is assumed. (Test temperatures should be selected to assure that the dominant aging reaction at the test conditions is also dominant and equivalent at the installed service condition temperature.)
- c) The coefficient A is assumed to be independent of temperature. According to gaseous reaction theory, A increases at approximately the square root of temperature.

NOTE—It is square root dependent when both reactants are gases; for solid material aging, only one of the reactants (oxygen) is normally gaseous and A would be less temperature dependent. This assumption could cause the reaction rate or amount of reactions to be calculated lower than actual, but the error is small—less than 5% for typical ambient and test temperatures—and this error would be offset by other conservative assumptions.

- d) The activation energy is considered to be constant with temperature and time. (The selected activation energy should be at the conservative end of the range of possible activation energies.)
- e) Equation (1), Equation (2), Equation (3), and Equation (4) are very sensitive to the accuracy of the selected activation energy. Because the activation energy is often available in only one or two significant digits, it should be selected carefully and the expression results interpreted judiciously. (That is, calculated results with accuracy beyond one or two significant digits are not considered credible.)
- f) The reaction rate is assumed to be not affected by depletion of the reactant concentration; in other words, the end of life (amount of degradation) is selected to be before depletion effects are noticeable.

NOTE—This assumption is conservative because reactant depletion reduces the aging reaction rate, which would give a longer predicted life given a life endpoint based on the same amount of degradation.

- g) Equation (3) assumes the same amount of degradation damage when converting from one set of time at temperature conditions to another set of conditions. (This amount of damage does not necessarily represent an end-of-life condition.)

Because of the limitations and assumptions stated previously, the Arrhenius model for thermal aging should be considered to provide only an approximation of the lifetime of the equipment. When feasible, condition monitoring or other means should be considered to validate remaining or residual life of equipment.

6.6.4 Use of a radiation aging model

Unlike thermal exposure, the radiation dosage or amount of energy deposited affecting a material's integrity and operability linearly increases with time for a constant field or dose rate. A conventional model for radiation aging assumes that material damage is directly related to the amount of energy deposited as a result of exposure in an ionizing radiation field. This model also assumes a principle of equivalent damage exists. This principle states that the amount of material damage resulting from exposure to a constant radiation dose rate field and a given duration is equivalent to that same exposure from any other combination of dose rates and exposure durations. The total integrated dose is the time integral of the dose rate as a function of time over the total exposure duration.

The value of total integrated dose that begins to detrimentally affect the material's functionality and, thereby, the equipment's ability to perform its safety function can be determined by test and has been tabulated for many materials. Therefore, an assessment of the effects of radiation aging would be a determination of remaining life to achievement of a detrimental-to-function dose at the expected service condition dose rate.

6.6.5 Condition monitoring

Condition monitoring can be used to determine and predict the physical and operating status of equipment. The condition of a limiting weak link part is normally used as an indicator to determine the overall condition of the equipment. The condition of the weak link material or part is ascertained by comparing some age-dependent or trendable material property or other observable parameter to a baseline value (usually the value when new) or an end condition (determined from the acceptance criteria).

Appropriate condition monitoring techniques should be identified and data should be collected at various stages in the life of the equipment to establish a performance history. This history can then be used to identify trends, which would provide insights for determining current equipment condition, as well as predicting equipment future performance and residual life.

Annex C contains additional information on condition monitoring techniques, which may be used to perform or support the aging assessment. In addition, many IEEE standards provide guidance for evaluating, testing, and maintaining electrical insulation systems [see the relevant examples of IEEE standards in Annex F ([B16], [B20], [B21], [B22], [B23], [B53], [B54], [B55], [B56], [B50], [B17], [B18], [B19], [B25], [B26], [B27], [B30], [B40], [B41], [B42], [B43], [B45], [B48], and [B57])].

6.6.6 Summary

An aging assessment approach can be summarized as follows:

- a) Identify aging effects that may become significant based on site-specific or industry-available degradation data.
- b) Determine the specific duration and end-of-qualified-life condition of the aging effect assessment. Collect aging information for materials identified as being part of the electrical equipment as it relates to applicable environmental stressors.
- c) Use an aging model to determine maximum stressor values (normal and accident conditions) that each material would be able to withstand for the evaluation period and still remain functional.
- d) Compare the actual service condition stressor values with each material maximum stressor value. The actual service condition stressor values are expected to be less than the maximum stressor value.

for each material or a result of the margin provided by the original design basis. If an actual service condition stressor value is greater than a material maximum stressor value, aging management may be required to preserve the material or equipment safety function. If so, determine how long a material would remain functional while being exposed to its actual service conditions.

- e) Obtain and review condition monitoring data to perform or validate the aging analyses.

7. Monitoring and mitigating aging degradation

Clause 6 defines the process for performing an aging assessment and for collecting data in support of this process. The assessment determines those aging effects that require further or continuing monitoring and mitigative action. These actions consist of maintaining, improving, or replacing the equipment (7.1 through 7.4); reducing environmental or operating stressors (7.5); or collecting more data (7.6 through 7.9) in support of future actions to maintain, improve, or replace the equipment. Annex C contains additional guidance on condition monitoring techniques, which could be used in support of mitigative actions.

7.1 Maintenance

Maintenance consists of the actions that detect, preclude, or mitigate degradation of equipment. Maintenance is most effective when performed on a timely basis. The following is an approach to determine when to perform maintenance:

- a) Identify methods to detect aging degradation prior to failure.
- b) Perform condition/failure trending (see 7.9), as appropriate, for equipment under observation.
- c) Determine minimum functional capability that defines the end of normal service life while being capable of performing its safety function.
- d) Analyze the data collected from the previous 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 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 post-accident 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 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 or operating history of similar equipment. For instance, in equipment qualification programs, weak link components are replaced prior to the end of their qualified life so that the longer qualified life of the host equipment is maintained.

Replacement is also an option to use for equipment that has become obsolete (obsolescence alone 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.

7.3 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, should be satisfied for refurbished equipment.

7.4 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, and even relocating equipment. For example, research NUREG/CR-5051 [B71] 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 requirements, when applicable, should still be satisfied for redesigned equipment.

7.5 Adjustments in operating environments and practices that reduce stresses

Environmental stressors such as heat and radiation are known to induce aging degradation, particularly in organic 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 nonbenign 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 start-ups / shutdowns and optimizing or improving testing practices. In addition, EPRI TR-109619 [B10] provides guidance for management of adverse operating environments.

7.6 Environmental and operational stress monitoring

Monitoring can be used to obtain additional data for a future aging assessment or to modify actions from a prior assessment. Monitoring includes, but is not limited to, the following:

- a) Environmental monitoring (e.g., temperature, radiation)
- b) Power system monitoring (e.g., system voltage, current, load, response time, setpoint drift, contact resistance change)
- c) Process monitoring (e.g., operating cycle / frequency)

7.7 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) Ambient environment variations
- b) Bent parts

- c) Color change
- d) Corrosion
- e) Cracks
- f) Dirt, dust, and contamination
- g) Embrittlement
- h) Erosion
- i) Excessive heat
- j) Excessive lubrication
- k) Excessive vibration
- l) Mechanical wear
- m) Noise
- n) Water in grease and lube oil

In addition, EPRI TR-109619 [B10] provides guidance for performing walkdowns and inspections. Table A.1, Table A.2, and Table A.3 list typical aging degradation effects from the previous indications.

7.8 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 setpoint 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 effect on the equipment.

7.9 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 measuring power factor, no-load current, the limits on the current limiter, or 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 planned periodic replacement of the equipment may be considered.

Failure trending requires a systematic collection and analysis of plant data (see Clause 8 and 10 CFR 50.49 [B7]). Equipment failures should 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.

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 effects (Clause 4) 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 should be identified by a more focused selection of observable parameters. Specific data generated as a result of an aging assessment (Clause 5 and Clause 6) should obviously be included as a part of this data set. Records or relevant data should be retained in accordance with plant requirements. EPRI TR-109619 [B10] provides additional guidance for data research.

The process of identifying relevant data and aging effects would most likely be an iterative one. That is, an initial level of awareness concerning the operative significant aging effects would steer the collection of the relevant data. As the data is reviewed, awareness or understanding of the aging effects may become more specific and refined. The increased understanding may warrant additional data collection. Thus, the cycle can continue until the significant aging effects are identified.

Data may be organized into three major groups:

- a) Baseline data (original capability)
- b) Historical data (operating history)
- c) Inspections and diagnostic testing data

Essentially, the data groups emphasize a logical progression of fact finding and attempt to answer the following basic questions:

- What was the equipment's original design basis?
- How well did it perform in service?
- What is its present condition with respect to its safety function?

8.1 Baseline data (original capability)

The evaluation of any set of relevant historical data begins with a comparison to a reference or baseline data. The baseline data describe, in detail, the original design features and capability that the Class 1E equipment had at the time of initial operation. Baseline data can be found in the following sources:

- a) *Equipment specifications.* Contain the characteristics of the equipment (e.g., capacity, voltage, horsepower).
- b) *Purchase orders.* List and describe the specific deliverables concerning the equipment order. Deliverables of hardware and important literature / software (e.g., certificate of conformance) should be noted as well as any special terms or conditions or options concerning the equipment.
- c) *Manufacturer's information.* Can range from catalog data, application recommendations, and bulletins to very detailed reports and comprehensive test results.
- d) *Equipment qualification reports.* Contain data required by various IEEE standards, which clearly show that the equipment's performance satisfies or exceeds the standards and criteria noted in the equipment's specification and purchase order. This type of data emphasizes environmental concerns related to equipment performance during a design basis accident.
- e) *System preoperational or acceptance tests.* Performed after equipment installation, these tests verify that the equipment performs satisfactorily, as an individual component and within its respective system. These test records contain actual performance parameters (e.g., power consumption, temperature rise, rated output, and time response), which can then be compared to more current performance data.
- f) *Equipment technical manuals.* Can contain information and explanations of the equipment's performance and maintenance requirements.
- g) *Equipment nameplate.* In many cases, the information noted on the nameplate may simply confirm specification and purchase order information. In other cases, the nameplate may be one of the few available sources where information can be obtained.
- h) *Final safety analysis reports (FSARs and updated FSARs).* Contain specific design information for systems including seismic and environmental data. The plant FSAR should be a very convenient and useful source to establish a comprehensive overview prior to investigating specific details.

The preceding data sources should, in general, be available for use at any nuclear power generating station. However, this list is not intended to be all-inclusive, and other data sources may be available. It should also be noted that some data sources are more appropriate for certain kinds of data than others. This observation is made because the data suggesting the operative aging effects specific to the equipment would not be addressed in every data source. For example, while the FSAR describes the equipment's environmental design requirements, the most likely source for complete details is the equipment qualification reports prepared by the equipment manufacturer and / or the utility or industry groups. The other sources may be of assistance, but to a lesser degree. A good working knowledge of the available data sources and insights to the most likely aging effects can serve to expedite the required research.

8.2 Historical data (operating history)

A review of the equipment's performance in actual service under various types of service conditions establishes the next relevant data necessary to support the aging assessment goal. The major sources of this data set can be found, by and large, in the records kept by the plant.

- a) *Equipment operating records.* Contain records that may specify / quantify when equipment is energized / de-energized (number or cycles or indications of duty cycle) or an abnormal equipment response (failure). Data from operating logs can reveal actual equipment responses to real plant

conditions. Such information can help identify various stressors (Clause 5 and Annex A) such as overload conditions or frequent cycling of a breaker.

- b) *Service condition records.* These records can reveal the specific stressors that may be significant to the aging assessment of the equipment, such as temperature, radiation, humidity, or cleanliness. (See Annex B for environmental monitoring considerations.)
- c) *Event records.* These records may be used to review when a particular sequence of events is significant such as an automatic equipment actuation to a defined event (e.g., turbine or reactor trip). Event records can also show response times and highlight out-of-tolerance indications.
- d) *Maintenance records.* These records may indicate routine and corrective maintenance that the equipment has received and the frequency of the maintenance performed. “As-found” and “as-left” conditions may also be noted within the records, which may provide additional insight to the operative aging effects. Maintenance records can be a very significant resource for supporting a trend analysis because they may contain information that is attainable only when the equipment is de-energized. The off-line condition provides for more detailed observations that are not feasible with the equipment online (e.g., insulation resistance, detailed visual inspections of equipment interior areas, linearity and accuracy verifications).
- e) *Surveillance testing records.* These records often contain the results of observations and / or measurements of the equipment’s physical condition or performance. The data confirms that the equipment conforms to the identified acceptance criteria. These records can be used to trend equipment performance and permit measured data to be routinely compared.
- f) *Outage inspections.* The extended off-line equipment status presented by the normal plant outage schedule provides the opportunity to examine Class 1E equipment in even greater detail. For example, normal surveillance testing can verify that the processing circuitry of an instrument is performing within limits. However, the outage condition allows for the additional testing of the transmitter and cabling, provided that the equipment can be de-energized.
- g) *Equipment failure records.* Equipment operational failure can be an obvious indication of aging effects. The analysis of failure data can
 - 1) Validate the application of the equipment and its maintenance requirements
 - 2) Reveal inadequacies of the equipment design or maintenance
 - 3) Reveal conditions that subjected the equipment to stressors not accounted for in the original design
 - 4) Predict failures through trending

Failure data collected at any plant can be supplemented by data existent in databases such as the Nuclear Plant Reliability Data System, NRC bulletins and notices, and the Government Industry Data Exchange Program. Analysis of equipment failures can be made by a review of information from these databases, since their sample size is more extensive.

Equipment failure records may also contain data that describes the results of detailed investigations on the failed components. Such investigations may concern material analysis, and destructive and nondestructive physical testing. Table 1 of IEEE Std 943-1986 shows how a component can be examined before and after failure (e.g., insulation resistance, hardness, chemical properties).

8.3 Diagnostic testing data

Diagnostic testing is performed to establish the operating status or condition of the equipment. The purpose of diagnostic testing is threefold. First, diagnostic testing establishes the present operating condition of the equipment. Second, it provides supplemental information with respect to the historical operation data. Third, it provides information useful to assess future performance.

In its simplest form, diagnostic testing may involve routine calibration procedures, such as that of an instrument channel. A more complex test may require evaluation of subassemblies such as individual circuit boards. The extent of the testing is heavily influenced by the materials and construction of the equipment and the identified stressors that act on it over time (see Annex A). It is noted for emphasis that testing may become iterative as the operative stressors become better defined.

Included in this effort is testing or inspections of the equipment that may be included in any of the historical data. Additional testing and inspection can be performed when historical data is insufficient to support an aging assessment.

Diagnostic testing may also be useful in establishing that the actual operating mode of the equipment is less stressful than anticipated in design (e.g., operating temperatures are lower than originally specified), which tends to suggest a longer service life as the stressor may not be as significant as originally expected.