3D Attach B Aging Evaluation Program

B.1 Introduction

An important concept in equipment qualification is the recognition that significant degradation could be caused by aging mechanisms occurring from the environments during the service life. Significant aging mechanisms are those that, under normal and abnormal service conditions, cause degradation of equipment that progressively and appreciably renders the equipment vulnerable to failure to perform its safety functions during design basis events. Therefore, safety-related electric equipment should be aged to a state of degradation prior to simulating design basis events.

B.2 Objectives

The objective of the U.S. EPR aging evaluation program is to verify, for safety-related electrical equipment with an established qualified life (QL) or condition, that the significant aging mechanisms have been identified and addressed. This provides reasonable assurance that the safety-related electrical equipment can perform its safety functions without experiencing common-cause failures before, during, and after applicable design basis events.

B.3 Basic Approach

The aging evaluation program addresses the effects of significant aging mechanisms through operating experience, testing, analysis, inservice surveillance, condition monitoring, and maintenance activities, as noted in IEEE Std 323-2003[1].

Safety-related electrical equipment that is located in a harsh environment, and for which significant aging mechanisms have been identified, is classified in the harsh location category. The aging mechanisms for this equipment are accounted for in the qualification program.

Safety-related electrical equipment that is located in a mild environment, and for which significant aging mechanisms have been identified, is classified in the mild location category. The aging mechanisms for this equipment are accounted for in the design and purchase specification.

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[1] Section 3.11 provides the justification for the use of the latest version of the IEEE standards referenced in this section that have not been endorsed by existing Regulatory Guides. AREVA NP maintains the option to use current NRC-endorsed versions of the IEEE standards.

B.4 Safety Related Electrical Equipment Located in a Harsh Location

B.4.1 Scope

The equipment in this scope is tabulated in Table 3.11-1—List of Environmentally Qualified Electrical/I&C Equipment.

B.4.2 Aging Mechanisms

The assessment of equipment aging effects in connection with a type test program is required to determine if aging has a significant effect on operability. Types of aging include thermal, radiation, wear (e.g., mechanical and electrical cycling), and vibration. Where significant aging mechanisms are identified, suitable age conditioning is included in the type test.

B.4.3 Time

For safety-related electrical equipment located in a harsh environment, the beginning of life is the date that the plant initially achieved criticality; for replacement components, it is the date the component is turned over to operations. This is the baseline from which QL is measured in order to establish a replacement due date. Typically, thermal aging life is the limiting factor when determining replacement frequencies, although there may be cases where other aging mechanisms (e.g., radiation, cycling) are the dominant factor. The replacement due date is selected, so that replacement occurs before exceeding the QL.

The shelf storage of a component usually does not affect its inservice QL. That is, when it is installed, the item is "like new." Per EPRI TR-100516 (Reference 1), this assumption is acceptable provided proper storage conditions are used and conservative shelf-life limitations are specified.

As an alternative to replacement, the actual service conditions can be evaluated to determine if the QL was conservative and if the replacement due date can be adjusted.

B.4.4 Operational Stresses

Operational stresses include surge voltages, mechanical, and electrical cycling, and self heating; these parameters are factored into the aging evaluation as applicable.

B.4.5 External Stresses

External stresses include radiation, nonseismic vibration, EMI and RFI susceptibility, and thermal; these parameters are factored into the aging evaluation as applicable. Because earthquakes falls under the category of design basis events, seismic stresses are not considered external stresses.

B.4.6 Synergism

In accordance with Regulatory Guide 1.89, if synergistic effects have been identified prior to the initiation of qualification, they should be accounted for in the qualification program. Synergistic effects known at this time are dose and dose rate effects resulting from different sequences of applying radiation and elevated temperature.

B.4.7 Design Basis Event Testing

A type test subjects a representative sample of equipment, including its interfaces, to a series of tests that simulate the effects of significant aging mechanisms during normal operation. The sample is subsequently subjected to design basis event testing that simulates, and therefore, establishes the tested configuration for installed equipment service and expected environments.

B.4.8 Aging Sequence

The sequence of aging should consider sequential, simultaneous, and synergistic effects in order to achieve the worst case of degradation.

B.4.9 Performance Criteria

The equipment being qualified will perform the intended safety-related functions for the required operating time before, during, and following the design basis event.

B.4.10 Failure Treatment

Any failure to meet the acceptance criteria is analyzed to determine the cause of failure. Modifications needed to the equipment are made and the equipment is retested. If necessary, use limitations on the equipment are identified and imposed.

B.5 Safety Related Electrical Equipment Located in a Mild Location

B.5.1 Scope

This section pertains to safety-related electrical equipment located in a mild environment, as identified in the U.S. EPR Master Equipment Database.

B.5.2 Performance Criteria

The functional acceptance requirements during normal environmental conditions and anticipated operational occurrences are specified in the design and purchase specifications.

B.5.3 Failure Treatment

Failures are documented and investigated to determine their nature. Failures determined to be random are tracked for trending purposes. Failures determined to have a common mode cause are also documented and the components are replaced. Consideration is given to the impact on the maintenance and surveillance program, including establishing or adjusting the replacement frequencies, as appropriate.

B.5.4 References

1. EPRI TR-100516, "Nuclear Power Plant Equipment Qualification Reference Manual," Electric Power Research Institute, 1992.

3D Attach C Effects of Gamma Radiation Doses Below 10^4 Rads on the Mechanical Properties of Materials

C.1 Introduction

The purpose of this section is to provide an evaluation to substantiate the radiation qualification of electronic components used in safety systems (e.g., the TXS system) in a mild environment, to levels not exceeding 10^3 R, total integrated dose (TID).

C.2 Scope

The scope includes the electronic equipment and components used in the various safety and non-safety systems located in a mild environment.

C.3 Discussion

The service conditions for this type of equipment is specified as mild environment, including radiation, to levels not exceeding 10^3 R, TID. This evaluation provides confidence that none of the system components become degraded by exposure to radiation.

The equipment that will be qualified under this program is known to be located in a mild environment, and is also known not to possess any significant aging mechanisms. Thus, a qualified life is not required, nor is it necessary to perform any pre-aging, including radiation aging, of the equipment prior to any seismic tests, or to include aging effects in the analyses.

This evaluation provides confidence, in lieu of testing, that none of the system components become degraded by exposure to radiation.

Studies of raw materials such as EPRI NP-2129, “Radiation Effects on Organic materials in Nuclear Plants,” (Reference 1) and EPRI NP-1558, “A Review of Equipment Aging Theory and Technology,” (Reference 2) have shown that nearly any organic material could withstand a radiation environment up to about 10^3 R, TID, measured against a damage threshold based on some particular property, including physical and chemical.

As noted in RG 1.89, Rev. 1 and Reference 1, these criteria are misleading because the primary concern is the ability of the equipment to perform specific functions, rather than the point at which damage is detected. Thus, equipment testing was conducted to determine the difference, if any, between the threshold values and actual degradation of performance, with subsequent loss of function.

Subsequent equipment tests by EPRI, Sandia Labs, and others (e.g., References 1 and 2) found that nearly all types of electronic equipment could withstand at least an order of magnitude more radiation exposure before performance degradation became a concern. Also, Regulatory Guide 1.89 and IEEE Std 323-2003 (Reference 3) suggested that the operability threshold was near 1 x10^4 R TID before noticeable degradation of performance, and in some cases, levels ≥1 x10^5 R TID could be tolerated.

In addition, for current-generation operating reactors, the NRC definition of a mild radiation environment for electronic components (e.g., semiconductors or any electronic component containing organic materials) differs from the definition of a mild radiation environment for other equipment. NUREG-1793 (Reference 4) defines a mild radiation environment for such electronic equipment as a total integrated dose of less than 10 gray (Gy) (1 x10^3 R). For other equipment, it is less than 100 Gy (1 x10^4 R).

C.4 Results

The ability of equipment to withstand radiation is based on performance degradation and not just a threshold value of susceptibility. A reasonable level of radiation tolerance would be in the range of 1 x10^4 R to 1 x10^5 R TID.

On the basis of investigations and evaluations of similar equipment exposed to similar radiation environments, the TXS system is qualified to a radiation exposure of at least 1 x 10^3 R TID.

C.5 References

1. EPRI NP-2129, "Radiation Effects on Organic Materials in Nuclear Plants," Georgia Institute of Technology, 1981.
2. EPRI NP-1558, "A Review of Equipment Aging Theory and Technology," Franklin Research Center, 1980.
3. IEEE Std 323-2003, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers, Inc., 2004.
4. NUREG-1793, "Final SER AP1000, Chapter 3, Design of Structures, Components, Equipment, and Systems," September 2004.

3D Attach D Accelerated Thermal Aging Parameters

D.1 Introduction

Thermal aging is an integral part of qualification testing, and accelerated thermal aging is used to simulate QL duration before subjecting equipment to design basis event testing. Because of practical limits on test duration, this is accomplished by subjecting the test specimen to temperatures higher than the service temperature but for a duration shorter than the service time.

D.2 Arrhenius Equation

The Arrhenius equation provides a method of equating thermal aging data to the equivalent duration at temperatures other than the aging temperature. EPRI TR-100516 (Reference 1) identifies the following Arrhenius equation most suited to this analysis:

$$t_s = t_a\, e^{N(1/Ts - 1/Ta)/k}$$

Where:

t_s = service time being simulated (same unit as aging time)

t_a = accelerated aging time (typically in hours)

e = exponential function

N = activation energy (eV)

T_s = service temperature (°Kelvin)

T_a = aging temperature (°Kelvin)

K = Boltzman's constant = 8.617 E-5 eV/K

The Arrhenius equation can be used to establish any of the four time or temperature parameters (i.e., t_s, t_a, T_s, or T_a) when the other three are specified.

D.3 Activation Energy

The activation energy is a material characteristic that is a measure of the sensitivity to thermal aging. It is the energy that must be delivered to a given quantity of the material, usually one mole, to cause the entire quantity to complete the dominant chemical reaction and causing thermal degradation.

The Arrhenius equation relates the rate of aging process to temperature. Activation energy generally depends on both the type of physical parameter (e.g., elongation or tensile strength) used as a measure of condition, and on the end point value of that parameter.

An assumption of this model is that material thermal degradation is dominated by a single chemical reaction whose rate is determined by the temperature of the material and the material activation energy. At a given temperature, a reaction with a high value of N proceeds more slowly than one with a lower value.

Arrhenius parameters are typically derived by testing a population of material samples for a range of durations. Measurements of the relevant parameter (e.g., compressions set or elongation-at-break) are made, statistically averaged, and plotted. Using such data, an appropriate endpoint is selected and a regression analysis performed mathematically or using Arrhenius graph paper. The slope of this regression line is the activation energy (N), see, Figure 3D.D-1—Sample Arrhenius Plot for Material Activation Energy Based on 30% Retention of Elongation.

The activation energy values should always be conservatively selected. For equipment containing more than one material, it is conservative practice to use the lowest material activation energy as a basis for equipment thermal aging calculations. In addition, the following four guidelines aid in proper activation energy selection:

1. The activation energy is based on the specific compound used in the equipment.
2. The activation energy is based on the most relevant material property and property endpoint. Compression set is the most appropriate property for gaskets and O-rings. Elongation-at-break is applicable for cables because electrical failure has been found to correlate closely with cracking of cable insulation in low-voltage applications.
3. Potential nonlinearities and data extrapolation should be minimized by using activation energy values based on material test data obtained within the temperature range of interest.
4. The activation energy should exhibit a good fit to the Arrhenius relationship. IEEE Std 101-1987 (R2004) (Reference 2) provides guidance for determining Arrhenius coefficients.

When precise activation energy for the application is not available, the following approaches may be used:

1. An activation energy is selected based on the most representative of the material, material property, and temperature range of interest. Apply a factor of conservatism, such as decreasing the activation energy by a few percent or reducing the resulting QL by a percentage.

2. When similarity is difficult to determine and a number of reference activation energies are available for a generically similar material, select the lowest published value.

3. When little information is available, a conservative activation energy is selected that represents the lower bound of available data for most materials and properties (e.g., 0.75 eV).

4. Activation energies are available from such sources as the Equipment Qualification Data Bank, vendor environmental qualification reports, as well as EPRI TR-100516 (Reference 1) and EPRI NP-1558 (Reference 3).

D.4 Thermal Aging (Normal/Abnormal Operating Conditions)

Thermal aging evaluations consider the normal operating conditions and anticipated abnormal operating conditions.

D.4.1 Normal Operating Temperature

Normal equipment operating temperatures are based on several factors, including: ambient temperature, time equipment is energized, time equipment is de-energized, internal enclosure heat rise, and self-heating effects, as applicable.

D.4.2 Accelerated Aging Temperature

Accelerated aging is artificial aging that simulates, in a short time, the natural aging effects of long-term service conditions.

D.4.3 Example of Arrhenius Calculations

A transmitter has a lowest activation energy of 0.78 eV, and it was thermally aged for 135 days at 208°F. To determine the QL at 120°F:

Using equation (1) $t_s = t_a\, e^{N(1/Ts - 1/Ta)/k}$ substituting yields:

$t_{s\,=}$ 135 days $e^{0.78eV[(1/(48.88 + 273.16) - 1/(97.77 + 273.16)]/8.617\ E\text{-}5)}$ = 5486 days = 15.0 years.

D.4.4 Post-Accident Thermal Aging

In certain cases, the accident profile may only have been administered for several days. However, the tested temperature profile may be used in the Arrhenius equation to determine the equivalent time at the actual expected post-accident temperature.

D.4.5 Post-Accident Operating Temperatures

Refer to Appendix 3D, Figure 3D-1—Typical Combined LOCA/SLB Inside Containment Temperature Service Conditions Envelope.

D.4.6 Accelerated Thermal Aging Parameters for Post-Accident Conditions

Example: A transmitter (See Section D.4.3 above) is required to operate for four months after an accident. The test profile shows a constant value of 270°F that was applied from 100,000–235,000 seconds. The required profile shows that from 100,000 seconds to four months the containment temperature is at or below 150°F.

Substituting into the Arrhenius equation yields:

t_s = (235,000 - 100,000) seconds $e^{0.78\mathrm{eV}[(1/(65.55 + 273.16) - 1/(132.22 + 273.16)]/8.617\ \mathrm{E}\text{-}5)}$ = 126.6 days = 4.08 months. Thus, the device is thermally qualified for four months for the postulated post-accident temperature of 150°F.

D.5 References

1. EPRI TR-100516, “Nuclear Power Plant Equipment Qualification Reference Manual,” Electric Power Research Institute, 1992.

2. IEEE Std 101-1987 (R2004), “IEEE Guide for the Statistical Analysis of Thermal Life Test Data,” Reaffirmed June 24, 2004.

3. EPRI NP-1558, “A Review of Equipment Aging Theory and Technology,” Electric Power Research Institute, September 1980.

Figure 3D.D-1—Time Retention versus Temperature