ELECTRIC POWER RESEARCH INSTITUTE

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EPRI

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Reg. Guide

October 16, 1979

Secretary of the Commission
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

ATTENTION: Docketing and Service Branch

SUBJECT: Proposed Revision 1 to Regulatory Guide 1.131, "Qualification Tests of Electric Cables and Field Splices for Light-Water-Cooled Nuclear Power Plants," August 1979

Dear Sir:

The purpose of this letter is to comment on the first paragraph of Regulatory Position 5 of the subject document.

Equipment Aging Technology

The first requirement of this paragraph, that "Aging data shall be developed to establish long-term performance of the insulation," is in keeping with the fact that the effects of ambient and operational environmental stresses may degrade the performance of insulation during service. This requirement is met in current design practice by carrying out the provisions of Section 6.3 of IEEE Std. 323-1974 (Ref.1), which is endorsed by USNRC Reg. Guide 1.89 (Ref.3). The accelerated aging methods used to satisfy these provisions for cable have been developed on the basis of a half century of research and testing by the electrical insulation industry (Ref.3). Nevertheless, it is well known that the state-of-the-art of insulation aging has important limitations (Ref.3). These limitations have led to wide debate on the extent to which accelerated aging can actually simulate natural aging. Recognition of the limited state-of-the-art prompted IEEE to issue a supplement (Ref.4) to IEEE 323-1974, in which it was stated that, "It is expected that known technology will be utilized in any aging program."

Motivated by a desire to assist the nuclear power industry in meeting the requirements for qualification of safety system equipment, the Electric Power Research Institute (EPRI) initiated in 1977 a comprehensive state-of-the-art study on equipment aging technology. The study was performed by Franklin Research Center (FRC), a leader in qualification testing since its inception in the nuclear power industry ten years ago. It is anticipated that the final report on this study (Ref.5) will be available early in 1980. Because the conclusions of the report are so pertinent to the issue at hand, a draft copy of the EPRI Perspective and FRC Summary of the report are attached. The main conclusion is that at the present time there is no comprehensive, rigorously scientific solution to the problem of accelerating the aging of equipment. This conclusion is based on an in-depth examination

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of the fundamental theory of equipment aging, applications of the theory, and a compendium of information on the degradation of materials and components, all of which are documented in the report.

The next requirement of the subject paragraph is that "Synergistic effects (Ref. 6) on aging due to simultaneous application of environmental conditions shall be considered in the accelerated aging program." Such consideration is warranted since, in a few instances, testing has shown that simultaneous heating and radiation apparently produced more degradation in certain insulation materials than sequential application of heating following radiation (Ref. 7, 8).

The evidence of this effect, however, is extremely tenuous because of several factors. In the Sandia tests of two materials (Ref. 7), the difference between simultaneous and sequential application of heat and radiation was examined by means of only one sequential test for each material. Furthermore, for both materials the comparison was made at levels of degraded elongation substantially below that normally used as a failure criterion in qualification testing. Even at these severely degraded levels, the tests indicated a difference in elongation from the two types of tests of only about 15 percent of virgin elongation to break. A more convincing demonstration of alleged synergistic effects would involve measurements at degradation levels on the order of 50 percent of virgin elongation. The Sandia tests did, however, demonstrate the importance of the order of sequential stress application. To produce degradation close to that produced by simultaneous tests it was necessary to apply radiation first and then heating.

In the U.S. Naval Research Laboratory tests (Ref.8) several magnet wire insulations were tested with both radiation followed by heating and under the combined environment. Of the five materials examined in this way, four materials exposed to the combined environment displayed an increased average life as determined from electrical tests on ten specimens of each material. One material (polyester) displayed more degradation under simultaneous testing than under sequential testing.

Therefore, although the evidence for strong synergisms is sparse, it is prudent to be aware of potential synergistic effects in developing an accelerated aging program. This can be done by (1) avoiding whenever possible the use of any material that ongoing research-laboratory testing has identified as displaying strong synergisms (whenever the use of such material is necessary, an ongoing qualification program may be adopted) and (2) continuing to apply the sequential aging procedures allowed by IEEE Std 323-1974, with special care that

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the sequence of accelerated environments and the margins over those expected in service life are selected judiciously to account for potential synergistic effects. The above two steps meet the second requirement of Regulatory Position 5 in a manner consistent with the current known aging technology. Continued advancement of the state-of-the-art in synergistic aging effects by means of well-conceived research should be encouraged by all sectors of the industry.

Requirement for Combined Environment Testing

The third requirement of the subject paragraph is that "Investigation shall be performed to determine if there are synergistic effects and, where identified, they shall be accounted for in the qualification program." The intent of this statement is not clear. One possible interpretation would parallel the understood intent of the previous statement so closely that its inclusion in the regulatory position would be redundant. On the other hand, an interpretation that appears more likely to agree with the true intent of the statement is that the phrase "Investigation shall be performed" requires comparison of results from simultaneous and sequential tests for every insulation material proposed for use with Class 1E equipment and, if significant effects are identified, utilization of combined effects testing in the qualification program. The following comments are made on the assumption that Regulatory Position 5 calls for general use of combined-environment accelerated-aging testing.

The goal of accelerated aging is to put a cable sample in its true end-of-qualified-life condition. In light of the purely technical considerations revealed by the EPRI/FRC equipment aging study (Ref. 5), the performance of combined-environment accelerated-aging testing would not improve the accuracy of qualified-life predictions. The principal supporting fact for this statement is that the uncertainties involved in simulating the aging effects of single stresses such as ambient temperature, operating temperature, mechanical and electrical cycling, radiation, and corrosion are, in general, greater than any uncertainties expected from synergistic effects. The former uncertainties result mainly from questions concerning the actual history of service conditions, the validity of theoretical aging models such as the Arrhenius Law, and the accuracy of degradation model parameters that apply under true service conditions. Present practice accounts for these uncertainties by making use of conservative measures such as enveloping or putting margins on actual service conditions.

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A related reason for not adopting thespecifics of "combined-environment" testing for qualification purposes is that there is at present no valid method for determining the acceleration factors that should be applied in accelerated tests. Current work at Sandia (Ref. 9) is attempting to develop an approach for specifying such factors, but the approach to date is purely empirical and is not yet quantitatively coupled to a known physical process (e.g. the Arrhenius Law is coupled to known chemical reaction rate behavior). Research on a well-founded combined-effect accelerated-aging method should continue. It is anticipated that a physical model which is a variant of the Eyring rate model can ultimately be devised. Until such time as a first-principles model is established, the technology does not appear to exist for accelerated aging under a combined stress environment.

Impact

The impact of the proposed Regulatory Position 5 appears to be much greater than that indicated in Section 2.2.2 of the subject document. The only known test laboratories capable of performing simultaneous thermal/radiation testing on a limited basis are Sandia Laboratories and the Naval Research Laboratory. Neither are chartered to carry out testing on a commercial basis. Therefore, before any testing in response to the proposed revision could be performed, facilities would have to be installed in commercial test laboratories. The high costs of such facilities would be passed along to the eventual users.

Closure

In summary, a requirement to include simultaneous combined-environment testing in cable qualification programs is not technically justifiable at the present time and would be difficult and costly to implement. An alternative is to allow an option. Sequential testing with radiation exposure prior to thermal aging is permitted provided a margin is added to aging time, temperature, or radiation dose to account for those instances where synergistic effects may produce a non-conservative result. The margin specified in the Regulatory Guide should take into account the latest research on synergistic effects for particular classes of equipment. Meanwhile, research should continue to develop combined-effect aging methods based on improved understanding of the coupled molecular mechanisms involved.

Respectfully submitted,

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Enclosure

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REFERENCES

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A REVIEW OF EQUIPMENT AGING THEORY AND TECHNOLOGY

(Reference 5)

EPRI PERSPECTIVE

Project Description

An important element in the design of nuclear plants is the demonstration that safety-related electrical equipment can function under design basis environments (such as heat, humidity, radiation, and seismic motion), not only in an "as-new" condition, but also after the degrading effects of in-service aging have occurred. The requirements of "IEEE Standard (323-1974) for Qualifying Class IE Equipment for Nuclear Power Generating Stations" calls for aging in a time-correlatable fashion such that a "qualified life" be demonstrated. Since the issuance of this standard there has been debate as to the technical feasibility of conducting accelerated aging on this basis. The study in this report is intended to steer the debate towards the development useful and realistic qualification procedures that are consistent with the state-of-the-art.

Project Objective

The objective of the project is to investigate the adequacy of accelerated aging technologies in sufficient detail to discriminate what can be accomplished in a technically supportable manner from that which cannot. The information is presented in a manner to be useful to engineers in utilities, architect-engineering firms, equipment manufacturing firms, and test laboratories engaged in developing and applying accelerated aging/qualification programs.

Conclusions and Recommendations

The main conclusion of this work is that, except for certain simple materials, the prediction of a qualified life through accelerated aging is generally not feasible at the present time. This conclusion must be interpreted very carefully: It is not the usefulness of aging in qualification that is challenged;

rather it is the notion of demonstrated qualified life. Accelerated testing is useful for the identification of dominant failure modes in advance of field applications and for comparative analysis of alternative materials and component designs. However, except for the limited materials for which aging effects are well characterized, the state-of-the-art of accelerated aging does not justify prediction of future equipment performance in terms of a qualified life. (This conclusion is supported by a fairly substantial military effort in the 1960's to assess accelerated testing).

Rather than abandoning current accelerated aging practices, which often rely on "simplistic" approaches, their continued use should be encouraged with the objective of determining whether equipment is vulnerable to aging. This, in combination with alternative measures such as (1) locating safety equipment outside of the containment or away from potential steam line break environments or (2) periodic removal and testing as part of an on-going qualification program, can provide an adequate level of protection that is technically supportable. This could best be undertaken as a cooperative industry venture, geared towards classes of equipment whose aging properties are poorly understood or whose function in a safety system is critically important under adverse environmental conditions. A productive avenue for future research may be to establish in-service surveillance procedures geared to monitor equipment degradation in terms of specific degradations mechanisms where they can be identified.

It is not suggested that accelerated aging be abandoned as an element of equipment qualification; rather, it is hoped that a better understanding of equipment aging technology will help eliminate the use of questionable practices and encourage the development of more meaningful aging procedures. Also, it is hoped that an appreciation of the limitations of accelerated aging technology will lead to more realistic determination of qualified life estimates.

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A REVIEW OF EQUIPMENT AGING THEORY AND TECHNOLOGY

(Reference 5)

SUMMARY

The objective of this report is to document the status of aging technology as it relates to the qualification of safety-related electrical equipment in nuclear power plants. The requirements for accounting for the effects of aging on the functional capability of equipment are specified by IEE Std 323-1974, which is endorsed with minor exceptions by USNRC Reg. Guide 1.89. This report attempts to delineate the present state-of-the-art as a background for addressing the aging requirements in the standard. In addition, an effort is made to establish a fundamental, theoretical basis for further development of aging procedures.

The dominant picture that results from the study is that there is no comprehensive, scientifically rigorous solution to the problem of accelerating the aging of equipment. This is not a surprising outcome, but the documentation provided in this report should facilitate the acceptance of the fact, which will in turn allow the reconciliation of qualification requirements with practical means of meeting them.

Aging that can be accelerated in ways that yield verifiable correlation between real and simulated aging is an exception rather than the rule. Degradation due to aging is a very complex process.

Several environmental and operational stresses may cause degradation. The degradation depends on stress level, time, changes in stress level, and the sequence of such changes. Defining the service stresses as a function of real time presents a problem because it is difficult to predict the stress history that a material or component will experience in service; for some stresses in particular (e.g., in-service vibration), there is scant historical data on which to base predictions.

To accelerate the degradation, it is essential to have models relating it to the causative factors. There are a number of theoretical models available

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for consideration, but the applicability of any chosen model must be verified in each case. The known models, including those of considerable mathematical sophistication, are rather simple approximations to the real-life problem; sufficient correlation with observed real-time aging to substantiate their validity for long periods of time is lacking. Furthermore, the models all require the experimental determination of certain parameters. Such experimental determinations have been made for very few materials and components, and then only for relatively simple stress histories (e.g., constant elevated temperature). Therefore, it is necessary to undertake substantial experimental programs just to evaluate the parameters or to make conservative approximations.

Major advances in equipment aging technology are not expected within the foreseeable future. The huge diversity in the kinds of materials, components (combinations of materials), and assemblies (combinations of components) makes the dimensions of the problem quite large. An enormous effort is needed simply to discover, accumulate, and catalog the appropriate physical constants for even a respectable percentage of these items. New materials, modifications to old materials, new components, and new combinations of old and new materials and components make this a never-ending undertaking.

Although equipment aging on a rigorous scientific basis is beyond the current state of technology, it is nonetheless possible to satisfy the purpose of aging in equipment qualification. This is true only so long as the intent of aging is to qualitatively assess vulnerability with respect to aging effects and not to achieve aging in the strict sense. While it was beyond the scope of this study to develop accelerated aging procedures consistent with the status of technology, the following considerations indicate how the problem can be simplified and brought within the limits of what is feasible:

1. It is not essential to simulate the degradation caused by an aging mechanism that is not coupled to the kinds of failures that can be induced by design basis accidents; e.g., thermal aging of a capacitor may not be essential if the capacitor is part of a system subject only to a seismic event (not to a steam-line break or loss-of-coolant accident) and thermal aging does not affect the capacitor's vulnerability to the vibratory mechanical stresses imposed by the seismic event.

2. When it is possible to identify <u>weak</u> elements that are responsible for all, except freak, potential failures of a system, it may be possible to limit the aging program to these <u>weak</u> elements.

3. Much of the evidence on the synergistic effects of simultaneous application of aging stresses indicates that they do not usually produce degradation dramatically different from that which occurs when the stresses are applied sequentially. An approach is to apply stresses in a sequence intended to produce at least as much degradation of functional capability as would occur with combined stressing. The use of conservatism is necessary to compensate for lack of knowledge concerning possible synergistic effects.

4. Surveillance keyed to the known degradation/failure mechanisms of equipment is a potential complement to, if not a substitute for, accelerated aging.

The conclusions summarized above are based on the content of this report which falls into three major categories: the basic theory of equipment aging, applications of the theory, and a compendium of information on the degradation of materials and components. The report begins with a discussion of the common failure problem, which is the main concern addressed by equipment aging; adequate aging procedures guard against common failures in redundant safety systems, which in turn protect against random failures.

The fundamental theory of aging is reviewed including the statistical nature of degradation processes, the application of reliability theory to the acceleration of equipment aging, and the most common theoretical and empirical models of aging (the Arrhenius, Eyring, and Inverse Power Laws, and the so-called 10-degree rule). Assumptions and approximations are examined for their contribution to uncertainty in the determination of parameters necessary to apply these theories. The difficulties encountered in applying the models to the accelerated aging of semiconductors and assemblies of two or more elements are demonstrated. These difficulties are compounded if one attempts to account for the synergistic effects of combined environmental stresses, also discussed in this report.

A compendium of aging data for many materials and components, including degradation mechanisms, failure modes, and activation energies is given. These data can assist equipment qualification engineers in meeting today's requirements with known technology, but at the same time, the limited nature of the data is a contributing factor to the substantial limitations of that technology.

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