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Results of a Literature Review on the Environmental Qualification of Low-Voltage Electric Cables[1]

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INTRODUCTION

In the design of nuclear power plants in the U.S., safety-related electric equipment must be qualified to provide reasonable assurance it can withstand the effects of a design basis event (DBE) and still be able to perform its prescribed safety function, even if the accident were to occur at the end of its service life. The requirement for environmental qualification (EQ) originates from the General Design Criteria in the Code of Federal Regulations, Title 10, Part 50 (10 CFR 50). The acceptable method of performing the qualification of this equipment has evolved over the years, starting with the NRC Division of Operating Reactors (DOR) Guidelines, which were issued in Bulletin 79-01B [1], and NUREG-0588 [2] requirements and ending with the current EQ Rule, 10 CFR 50.49 [3]. While the EQ methods described in these documents have the same overall objective, there are some notable differences for which a clear technical basis has not been established. One difference is the preaging requirement for equipment prior to LOCA testing.

In addition, specific issues related to current EQ practices have been raised by the U.S. NRC which need to be addressed. These issues, which are discussed in detail later in this paper, are related to the sources of conservatism and uncertainty in IEEE Standard 323-1974 [4], which is the qualification standard currently endorsed by the NRC. To address these issues, the NRC Office of Nuclear Reactor Regulation (NRR) implemented a Task Action Plan (TAP) [5], and the Office of Nuclear Reactor Research (RES) initiated a complementary research program. The current focus of this program is on the qualification of low-voltage instrumentation and control cables. These cables were selected since they are not typically replaced on a routine basis, and their degradation could impact plant safety.

As the first step in developing a research approach, NRC/RES sponsored a public workshop on EQ in November 1993. Panels of experts from across the country attended and participated in individual meetings to provide input in four major areas related to EQ; 1) preaging techniques, 2) operating experience, 3) condition monitoring (CM), and 4) LOCA testing. One of the main conclusions drawn from the workshop is that a great deal of work has already been performed in the area of EQ, and it should be reviewed before any new work is initiated. The information gathered at these meetings was published in NUREG/CP-0135 [6], and subsequently used by NRC/RES to define specific details of a Research Program Plan [7]. In response to the workshop, the RES Research Program Plan includes a literature review and analysis as the first objective.

[1]Work performed under the auspices of the U.S. Nuclear Regulatory Commission.

Brookhaven National Laboratory (BNL) is the lead laboratory assisting NRC/RES in the EQ Research Program. BNL performed a literature review to consolidate and assess the vast body of research work that has been completed related to the qualification of electric cables, operating experience and other relevant information. The objective of this review was to determine which of the EQ related issues identified could be fully or partially resolved by past or ongoing work, and which required additional study. The results of the review are being used as input to optimize the scope of future EQ research.

EQ ISSUES

To properly focus the review, the issues to be addressed in this research program were first clearly identified and documented using input from the 1993 EQ Public Workshop [6], as well as from discussions with NRC staff and EQ experts. The issues identified are consistent with both the NRR TAP [5] and the RES Research Program Plan [7].

The EQ issues identified are important for the current licensed plants and for extended life consideration. The issues identified can be categorized into seven major issues, which are presented as broad questions in the first column of Table 1.

The first issue is related to the preaging techniques used in the qualification process. As part of current EQ requirements (10CFR50.49, Regulatory Guide 1.89), prior to LOCA testing, the equipment to be qualified must first be preaged to simulate its expected condition at the end of its qualified life. The issue of preaging was identified for evaluation due to the many questions raised related to the accelerated aging practices used on the cable specimens. The questions focus on the methods used to calculate the exposure times and temperatures for accelerated thermal aging (Arrhenius), the dose rates used for accelerated radiation aging, and the synergistic effects of thermal and radiation aging. Also, there are other environmental and service conditions, in addition to heat and radiation, which can degrade the functional capability of safety-related equipment and which are not always simulated accurately in the preaging process. Uncertainties in preaging can affect the overall result of the qualification process.

Conservatism in the qualification process is the subject of the second issue. The large number of variables that influence cable degradation make it impossible for the qualification process to exactly duplicate actual in-service conditions for a specific cable. In addition, since only one sample of new cable is required to be tested, no statistical base for the qualification test results is established. Therefore, to provide an acceptable level of confidence that installed cables will perform their intended safety function under a DBE, a number of conservatisms are included in the qualification process. An example is the addition of a second temperature/pressure transient to the LOCA profile the cable is tested to, even though an actual DBE may include just one. Also, the peak temperature and pressure expected during the DBE are increased for the qualification test. Based on the many years of qualification experience obtained since these requirements were developed, it is felt that these conservatisms should now be reviewed to determine if they are acceptable, or if they need to be modified.

Issue 3 relates to the variations in cable manufacture that are found in the industry. In the manufacturing process, variations occur in the different additives and the vulcanization system used in the cables. Differences may also occur over the years due to changes in resin and additive suppliers. Variations also exist in the construction of the cable itself; for example, multiple conductors versus single conductor, or bonded jacket versus un-bonded jacket. These variations can potentially affect the aging characteristics of the cable, however, details are incomplete as to methods used to account for cable variations in the qualification process. Typically, one sample of a particular cable type is qualified, and similarity criteria are used to qualify other "similar" cables, therefore, not all cable constructions are tested. Since the implications of this are unknown, this was included as the third issue to be addressed.

When cables are installed, there are many localized field conditions that can arise which may affect the degradation rate of the cable. An example is areas of unusually high temperature or radiation, commonly called "hot spots." Another example is areas where the cable is mechanically stressed, such as at bends and support locations, or where installation or maintenance damage has occurred. These are commonly referred to as "weak-links". Some of the stresses imposed by these field conditions are accounted for by simulated mounting configurations, and others are not specifically addressed. To address the questions related to installed field conditions, this fourth issue was identified for evaluation in the program.

One of the most important issues to be addressed in this research effort is related to the evaluation of cable condition monitoring (CM) methods. If the condition of the cables can be accurately determined in the plant, this would provide an increased level of confidence that plant safety is not compromised by cable degradation. Currently, elongation-at-break is the best laboratory indicator to assess embrittlement and cable degradation. However, this method has limitations since it is destructive, it requires relatively large samples, and its effectiveness at predicting accident survivability is unknown. The fifth issue was identified to include the evaluation of other potentially more versatile CM methods in this program.

As part of the current EQ requirements, a qualified life is assigned to the equipment being qualified. This qualified life is a time-based value which typically has a maximum value equal to the current licensed life of the plant (40 years), but can be less. As plants approach the end of their license and anticipate extended life operation, an important question which must be addressed is whether it is possible to extend the qualified life of the electrical equipment. The sixth issue identified for evaluation in this program addresses that question by considering the technical basis for maintaining and extending the existing qualification requirements.

The seventh issue addresses the graded approach to EQ that currently exists. Since different vintages of plants used different qualification requirements, depending on when they were licensed, questions have been raised as to the technical basis for considering these different approaches to qualification acceptable. This issue addresses those questions by examining the various differences in the qualification requirements and their impact on plant safety.

For each of the seven major issues, a number of specific sub-issues were identified, and individual analyses, hereafter called dossiers, were prepared for each sub-issue. The dossiers are the means used to document the results of the literature review and analysis. They provide background information on the sub-issue, a listing of the specific questions to be answered for the sub-issue, and the results of the literature review related to that sub-issue. The dossiers developed are identified in the second column of Table 1. For each sub-issue, specific topics that need to be addressed were identified. There are a total of 43 topics identified. These are shown in the third column of Table 1. The dossiers will be discussed in more detail later in this paper.

LITERATURE REVIEW APPROACH

In conducting the literature review, BNL searched a variety of library sources. In addition, NRC placed a request for information in the Federal Register. To date, over 400 reports have been obtained and reviewed by BNL. This includes technical reports and papers related to cable qualification and polymer research performed by Sandia National Laboratories (SNL), Electric Power Research Institute (EPRI), and others. Also, actual cable manufacturer qualification test reports were obtained and reviewed. EQ experts were consulted and their input was obtained. In addition, the Nuclear Utility Services (NUS) EQ database and the Idaho National Engineering Laboratory (INEL) EQ database were reviewed to identify the information in them and evaluate their usefulness. Research from other countries was also reviewed, including France, Japan, Canada, Germany, and the United Kingdom.

The literature reviewed was grouped into three basic areas; aging characterization, design basis accident testing, and condition monitoring methods. The first two areas are directly related to the EQ process for cables in nuclear applications. The third involves methods for assessing the level of degradation of cable insulation and jacket materials with respect to expected service life.

In reviewing the documents obtained, a number of them were not relevant to the seven major issues, and were not considered further. The documents that were relevant were reviewed in detail and summarized in an interim report. The interim report provides a technical basis for resolving several of the sub-issue topics identified, and for recommending additional research for others. As the program progresses and new documents are obtained, they are reviewed and added to the interim report, if they are relevant and provide new information. Current plans are to publish the final results of the literature review in NUREG/CR-6384 [8].

ANALYSIS OF THE LITERATURE

The information and data collected during BNL's literature search and review were categorized according to the seven major EQ issues to facilitate their analysis. The primary source of information for the review and categorization process was the literature identified and described in BNL's interim literature review report [8]. Other sources of information reviewed include the results of the 1993 EQ Public Workshop [6], along with some additional literature and documentation obtained and reviewed subsequent to the interim literature review report.

Drawing upon the information gleaned from the entire body of research and literature reviewed, an analysis of each sub-issue and its related topics was conducted. The approach taken was to assign an individual reviewer to study each sub-issue in detail, review the applicable literature, and determine the status of the research with respect to resolution of the topics related to that sub-issue. Upon completing the analysis, the individual reviewer prepared a draft dossier describing the review, analysis, and recommendations for resolution. A total of thirteen dossiers, designated as A through M, were developed to cover the seven major issues, as described in Table 1.

The draft dossiers were initially reviewed and commented upon by all members of the BNL EQ Research Team, and then by an outside panel of EQ experts. Finally, the NRC provided their review comments and guidance on the draft dossiers. By following this approach to the analysis of the EQ issues, BNL was able to systematically apply the information and research results identified in the literature review to the resolution of several sub-issue topics. The recommendations in these dossiers represent a consensus between BNL staff, and a panel of EQ experts, and were submitted to the NRC program manager for review.

The final dossiers document the analysis results, and the direction to be taken in the present research work toward resolution of outstanding issues. The dossiers provide the background and evolution of each topic, describe the significant problem areas associated with the topics, and summarize the outstanding issues and questions that must be resolved.

Based on the literature analysis, each sub-issue topic was grouped into one of three resolution categories: 1) resolved by past work, 2) unresolved but further research under this program is not warranted, and 3) unresolved, warrants further research at this time. It should be noted that these recommendations apply only to the performance of this EQ research program and do not imply that no further research should be conducted in any specific area. The recommendations simply reflect the priority of the sub-issue topics as they relate to the objectives of this program.

Unresolved topics were prioritized to avoid duplication of previous efforts and to address the most significant issues, particularly those areas that have not yet been studied extensively. The review process described above provided confidence that the most pressing issues had been properly identified and prioritized.

RESULTS

As previously mentioned, each of the seven major issues was broken down into specific sub-issues and related topics which need to be addressed to completely resolve the major issue. From the literature analysis, each topic was categorized according to its resolution based on past work. Figure 1 shows the resolution categories for the 43 sub-issue topics, which are listed in Table 1. As shown in this figure, 18 topics are categorized as Category 1, resolved by past work; 6 topics as Category 2, unresolved but does not warrant further research in this program; and 19 topics as Category 3, unresolved and warrants further research in this program. As shown by these numbers, a total of 24 issues out of 43 were eliminated from this program based on past research identified in the literature review.

Of the 18 topics in Category 1 (resolved), three are in the area of preaging techniques, eight are related to issues on LOCA testing, two are in the area of cable manufacturing, one is in the area of condition monitoring, and four are related to the graded approach to EQ. For these topics, sufficient information was available from past work to answer the questions of concern, and no additional effort is needed in this program to pursue these issues.

Six topics are categorized as Category 2, unresolved but do not warrant further research. Many of these topics have had prior research or have been addressed in methods common to qualification. Additionally, prior research and procedures have suggested that these topics may have minimal impact on the cable qualification process and, although research to fully understand the topic is incomplete, they are judged to not warrant further research at this time. The topics listed below are assigned to this category:

- Oxygen diffusion limitations during thermal aging
- Dose rate effects for radiation preaging
- The effects of electrical surges on aging
- Preaging synergistic/sequence effects
- The effects of oxygen in LOCA simulation
- The effects of manufacturing processes on aging

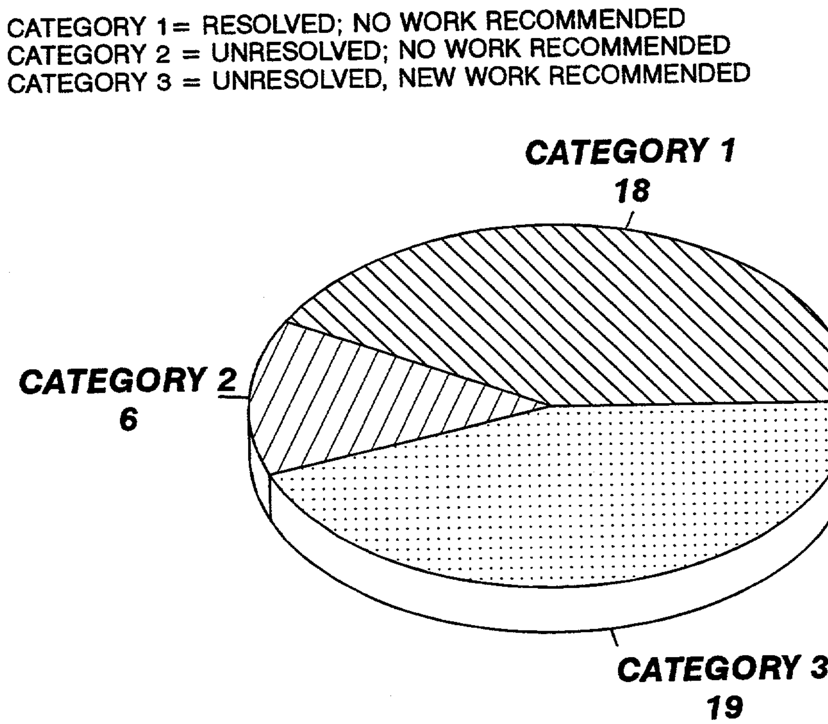

Figure 1 Distribution of EQ topic resolution categories

A total of 19 topics are categorized as unresolved, and further research on them is recommended in this program. As indicated in Table 1, three of the Category 3 topics are related to the issue of preaging methods and two are related to cable manufacturing processes. Eight of the Category 3 topics are related to the effects of installed conditions on the cable aging processes. Two topics are identified under the issue of condition monitoring for further research. Four topics, related to the overall EQ philosophy and how it applies to current and extended life operation, are recommended for further evaluation in this program. Each of the topics for which additional study is recommended is discussed in more detail in the following paragraphs.

Thermal Aging (Dossier A)

Of primary interest in the area of thermal aging is a comparison of the condition of cables naturally aged in a plant environment with the condition of cables artificially aged to the same service life using Arrhenius methods. This comparison would provide a measure of how well artificial aging simulates actual aging conditions, and what degree of conservatism is built into the process. The literature analysis shows that work related to this type of comparison is limited, and has not been able to completely resolve this issue. Since a direct comparison is the most effective way to determine the acceptability of current artificial aging methods, it is recommended that this be included in the program. These tests will involve measurement of material properties using the CM techniques recommended for study (see discussion on CM research). These tests will also be useful for evaluating the phenomenon of decreased degradation at elevated aging temperatures for some cable materials, which was reported in the literature.

Another unresolved issue related to thermal aging is the subject of activation energies, which still has some uncertainties. Concern has been raised with respect to the accuracy of activation energies used in the past since they have a significant effect on the qualified life of a component. Determination of these values requires a great deal of effort, and it is not recommended that this be done for any significant number of materials. However, it is recommended that activation energies for the four cable materials (XLPE, EPR, Hypalon, Neoprene) to be studied in this program be verified. This will provide a basis for determining the validity of this issue, and can be done in support of the previously discussed comparison of naturally aged and artificially aged cables.

Effects of Humidity on Aging (Dossier C)

The literature analysis shows that the effects of humidity have not been adequately addressed in past work. Humidity can be a problem if present on cable degraded by other mechanisms, such as heat, radiation, mechanical stress, or inadvertent damage. Additional tests evaluating the synergistic effects of humidity, radiation and thermal stresses are recommended as a first approach, to see if the most common insulation and jacket materials are susceptible. Comparison with samples exposed to combined radiation and thermal stresses in a dry environment will be performed to help address this issue.

Effect of Cable Construction on Aging (Dossier H)

In past work [9], some multiconductor cables with EPR insulation were found to have a higher propensity for failure during a LOCA compared to a single conductor cable insulated with the same EPR compound. Even though several hypotheses have been suggested to explain this result, sufficient information was not available to draw a definitive conclusion. Therefore, it is recommended that LOCA tests be performed on multiconductor and single conductor cable samples to study this phenomenon.

In addition, past work raised questions on the behavior of bonded jacket cables. Cables with EPR insulation and bonded CSPE jackets developed cracks much earlier compared with unbonded jacket cables. Since the reasons for this difference are not clearly understood, this issue remains unresolved and it is recommended that additional research be performed. The research should use the same cable materials, and the degradation should be monitored during the preaging process so that the failure mechanism may be determined.

Effects of Installed Environment and Installed Configuration on Aging (Dossiers I and J)

Past work and experience show that some of the environments and configurations in which cables are installed expose them to higher levels of stress. The environmental "hot-spots" are areas of elevated temperature and/or radiation above levels that are normally expected. In addition, bends, vertical runs, and other installation configurations can produce "weak links" in the cable. While these hot-spots and weak-links are known to exist in the plants, the degree to which they accelerate the degradation and failure rate of cables is very plant specific and cannot be generically quantified. Testing has not, and can not completely resolve this issue. Therefore, it is not recommended that any specific new research be performed in an attempt to resolve this issue since no generic answer is feasible. Rather, this is best addressed at individual plants by surveying suspected areas to identify and characterize hot-spots and weak links. Once these have been identified, condition monitoring methods can be used to evaluate cable condition and predict residual life. It is believed that the research on CM will provide useful information for addressing this issue and should be a major focus of this program. BNL is currently in the process of obtaining naturally aged cable samples from various types of hot spots and high-stress configurations, and it is recommended that they be tested to characterize the degradation due to these conditions. This could provide some insights into understanding how these unique installation conditions affect cable degradation.

Condition Monitoring (Dossier K)

From a review of the literature and discussions with experts in the field, it was determined that one of the most promising areas of research for this program could be in the area of condition monitoring. If cable condition can be measured in situ in the plant, and its accident survivability established, many of the concerns regarding the qualification process would be resolved. While a great deal of work has been performed on CM in the past, the effectiveness of the various CM techniques has not been completely determined, and acceptance criteria have not been established. Therefore, a primary focus of this research program will be to evaluate various CM techniques. These will include techniques that show promise for in situ use, as well as several inexpensive, simple to perform techniques. It is recommended that the following CM methods be evaluated for their effectiveness in monitoring cable condition and predicting LOCA survivability. These methods were identified from the literature analysis, as well as discussion with NRC and EQ experts:

1. Chemical Property Measurements
    - Fourier Transform Infra-Red (FTIR) Spectroscopy
    - Oxidation Induction Time

2. Physical Property Measurements
    - Indenter Modulus
    - Elongation at break

3. Electrical Property Measurements
    - AC Impedance
    - Time Domain Reflectometry

4. Simple/Inexpensive to Perform Measurements
    - Current Signature
    - EMF Measurement
    - Hardness
    - Insulation Resistance
    - Thermography
    - Visual Examination

Elongation-at-break will be performed as a baseline method for correlation of results. Also, functional testing, voltage withstand, and leakage current measurements will be performed for those samples undergoing LOCA testing.

It is recommended that the CM research include an evaluation of the various CM methods for determining current cable condition, as well as predicting accident survivability. The data required for this research include preaging and LOCA testing on both naturally and artificially aged cable samples. CM measurements will be taken periodically throughout the preaging process, and both before and after exposure to accident conditions.

EQ for Present and Extended Life (Dossier L)

One significant issue which will have to be addressed as plants consider extended life operation is how to address continued qualification of electric equipment. Currently, a time-based qualified life is assigned to the equipment based on the preaging performed. Once the qualified life has expired, the component must be replaced or requalified. Typically, the qualified life does not extend beyond the licensed life of the plant. An alternative is to consider modifying the EQ philosophy to incorporate a condition-based qualified life, for which the qualified life is determined solely by the condition of the equipment and not its age. This would allow equipment to continue operating as long as its condition is above a predetermined acceptable level. As a parallel effort to the aforementioned research discussed, it is recommended that insights gained from this project be used to evaluate the feasibility of the change in philosophy.

CONCLUSIONS

This literature review has shown that a great deal of work has been performed in the area of EQ of electric cables. The related subject areas are varied and range from polymer research to actual qualification test reports. Much of this work is directly applicable to the resolution of issues raised recently by the NRC. Of the 43 specific topics identified for resolution, 18 have been resolved by the analysis of past work. This will result in a significant savings in time and effort for this research program.

In addition, the literature review also helped to focus recommendations for future work to areas that can immediately benefit from additional research. It was determined that six specific areas would not immediately benefit from additional research in this program since an extensive amount of work had already been done and its impact appears to be minimal. The areas for which additional research is recommended in this program are those in which the issue is important enough to merit further research and resolution is promising.

Table 1 Recommendations from the EQ Literature Review

EQ MAJOR ISSUES	SUB-ISSUES/ DOSSIER TITLE	TOPICS FOR SPECIFIC QUESTIONS TO BE ADDRESSED IN DOSSIER	RESOLUTION CATEGORY*	RECOMMENDED WORK			COMMENTS
				CM	LOCA	OTHER	
Q1: Are existing preaging techniques, based upon the accelerated thermal and radiation aging methodology, adequate to account conservatively for natural age-related degradation?	A. Thermal Aging	A.1 Arrhenius application	3	X			Compare natural with accelerated aged cables.
		A.2 Oxygen diffusion limitations	2				
		A.3 High accelerated aging temperatures	1				
		A.4 Activation energy estimates	3	X			Verify activation energy for cables to be studied.
	B. Radiation Aging	B.1 Dose rate effects	2				
		B.2 Types of radiation used	1				
	C. Other Aging Factors	C.1 Humidity effects	3	X	X		Compare samples aged in a dry environment to those aged in a humid one.
		C.2 Electrical surges	2				
		C.3 Preaging synergistic/sequence effects	2				
		C.4 Use of slab samples for preaging research	1				

Table 1 (Cont'd)

EQ MAJOR ISSUES	SUB-ISSUES/ DOSSIER TITLE	TOPICS FOR SPECIFIC QUESTIONS TO BE ADDRESSED IN DOSSIER	RESOLUTION CATEGORY[*]	RECOMMENDED WORK			COMMENTS
				CM	LOCA	OTHER	
Q2: What is the overall level of conservatism in EQ LOCA testing, and post-LOCA testing?	D. LOCA Profiles	D.1 Temperature/pressure margins	1				
		D.2 Single versus double peak	1				
		D.3 Superheated versus saturated steam	1				
	E. LOCA Simulation Methods	E.1 Presence of oxygen	2				
		E.2 Effect of chemical sprays	1				
		E.3 LOCA synergistic/sequence effects	1				
		E.4 Accident total radiation dose (source term)	1				
	F. Cable Monitoring During LOCA	F.1 Functional test performance (actual loads, leakage current) and LOCA acceptance criteria	1				
		F.2 Mandrel bend (voltage withstand/submergence)	1				
Q3. What is the effect of variations in cable manufacture on the aging process and how should they be handled?	G. Manufacturing Processes	G.1 Fire retardant additives effect on aging, coloring agents, antioxidants and fillers, variations in base polymer materials, variations in curing	2				
	H. Cable Construction	H.1 Multiple versus single conductor designs	3		X		Multiconductor cable to be LOCA tested to study past results.
		H.2 Bonded jacket cables	3		X		Bonded jacket cable to be LOCA tested to study past results.
		H.3 Specialty cables (e.g., Kapton)	1				
		H.4 Similarity criteria	1				

Table 1 (Cont'd)

EQ MAJOR ISSUES	SUB-ISSUES/ DOSSIER TITLE	TOPICS FOR SPECIFIC QUESTIONS TO BE ADDRESSED IN DOSSIER	RESOLUTION CATEGORY*	RECOMMENDED WORK			COMMENTS
				CM	LOCA	OTHER	
Q4: Degradation from typically encountered field conditions is not usually accounted for in the aging simulation process. Does this impact the qualification of cable?	I. Installed Environment	I.1 Hot spots (temperature, radiation, humidity)	3	X	X		CM and LOCA tests will be performed on representative naturally aged samples, if available.
		I.2 Excessive vibration	3	X	X		(Same as I.1)
		I.3 Water/steam/liquid impingement	3	X	X		(Same as I.1)
		I.4 Maintenance activity damage	3	X	X		(Same as I.1)
	J. Installed Configuration	J.1 Bends, vertical runs, overhangs	3	X	X		(Same as I.1)
		J.2 Cable trays, conduits	3	X	X		(Same as I.1)
		J.3 Fire protection coatings	3	X	X		(Same as I.1)
		J.4 Installation damage	3	X	X		(Same as I.1)
Q5: What in situ inspections and condition monitoring techniques or methods are effective in determining (non-destructively) the state of installed cables, and what are the relevant indicators of cable degradation?	K. Condition Monitoring	K.1 Identification of existing and promising methods	1				
		K.2 Link to LOCA survivability	3	X	X		Cables will be preaged and LOCA tested with CM performed periodically.
		K.3 Measure of effectiveness	3	X	X		(Same as K.2)

Table 1 (Cont'd)

EQ MAJOR ISSUES	SUB-ISSUES/ DOSSIER TITLE	TOPICS FOR SPECIFIC QUESTIONS TO BE ADDRESSED IN DOSSIER	RESOLUTION CATEGORY*	RECOMMENDED WORK			COMMENTS
				CM	LOCA	OTHER	
Q6: Based on current knowledge, what technical basis can be developed to demonstrate continued validity of EQ?	L. Maintaining and Extending EQ	L.1 Re-qualification options	3			X	As a parallel effort, insights gained will be used to evaluate the feasibility of a condition-based qualified life.
		L.2 Definition of qualified life	3			X	(Same as L.1)
		L.3 Use of operating experience	3			X	(Same as L.1)
		L.4 Extension of qualified life	3			X	(Same as L.1)
Q7: What is the technical basis for considering the graded approach to EQ (DOR vs. NUREG Cat. I&II) acceptable?	M. EQ Graded Approach	M.1 Effect of preaging variations	1				
		M.2 Effect of test parameter margins	1				
		M.3 Effect of test sequence variations	1				
		M.4 Effect of accident profile variations	1				

* Categories:
1. Resolved by past work.
2. Unresolved; does not warrant further research.
3. Unresolved; warrants further research.

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