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Literature Review of Environmental Qualification of Safety-Related Electric Cables

Literature Analysis and Appendices

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ABSTRACT

In support of the U.S. NRC Environmental Qualification (EQ) Research Program, a literature review was performed to identify past relevant work that could be used to help fully or partially resolve issues of interest related to the qualification of low-voltage electric cable. A summary of the literature reviewed is documented in Volume 1 of this report. In this, Volume 2 of the report, dossiers are presented which document the issues selected for investigation in this program, along with recommendations for future work to resolve the issues, when necessary. The dossiers are based on an analysis of the literature reviewed, as well as expert opinions. This analysis includes a critical review of the information available from past and ongoing work in thirteen specific areas related to EQ. The analysis for each area focuses on one or more questions which must be answered to consider a particular issue resolved. Results of the analysis are presented, along with recommendations for future work. The analysis is documented in the form of a dossier for each of the areas analyzed.

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PREFACE

This work was performed in support of the NRC Environmental Qualification Research program to address issues raised related to the environmental qualification of electric cables. Prior to initiating any new research, a decision was made to perform a thorough review of past relevant work. The purpose of this review was to determine if any results from past work could be used to partially or fully resolve issues currently of interest to the NRC. The results of this review are published in this NUREG/CR report, which contains two volumes.

Volume 1 contains a summary of all the past work reviewed related to the environmental qualification of electric cables. It is a comprehensive summary of many different studies, both domestic and foreign, which was developed by obtaining and carefully reviewing numerous publications, then summarizing the salient portions of them for inclusion in this NUREG/CR. The views expressed in Volume 1 with respect to the conclusions that can be drawn from the work reviewed are those of the individual reviewer.

In Volume 2, a concerted effort was made to analyze the results reported in Volume 1 in relation to the specific issues being addressed in this research program. The purpose of this analysis was to determine if any of the issues could be resolved by past work, and, if not, what additional research is warranted to attempt to resolve them. To accomplish this, an expert panel was established to discuss and evaluate the findings from past work in relation to each specific issue. The expert panel consisted of BNL engineers and scientists, as well as three recognized experts in the area of EQ. Each issue was assigned to an individual reviewer to analyze. Volume 1 was used as a basis for the analysis, however, additional information, such as past experience and discussions with experts in the field, were also considered in the analysis. The analysis results were then presented to the expert panel for discussion, and a consensus was obtained on the final results reported in Volume 2. The Volume 2 findings were used in the development of the research program test plans.

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ACRONYMS

BNL	Brookhaven National Laboratory
BWR	Boiling Water Reactor
CM	Condition Monitoring
CSPE	Chloro Sulfonated Poly Ethylene
DBA	Design Basis Accident
DOR	Division of Operating Reactors
EPR	Ethylene Propylene Rubber
EPRI	Electric Power Research Institute
EQ	Environmental Qualification
JAERI	Japan Atomic Energy Research Institute
LOCA	Loss of Coolant Accident
LWR	Light Water Reactor
MOV	Motor Operated Valve
MSLB	Main Steam Line Break
NRC	Nuclear Regulatory Commission
PE	Poly Ethylene
PRA	Probabilistic Risk Assessment
PVC	Polyvinyl Chloride
PWR	Pressurized Water Reactor
SNL	Sandia National Laboratory
SOV	Solenoid Operated Valve
TID	Total Integrated Dose
TMI	Three Mile Island
UL	Underwriters Laboratory
XLPE	Cross-Linked Poly Ethylene
XLPO	Cross-Linked Polyolefin

1. INTRODUCTION

1.1 Background

Recent activities in the area of Environmental Qualification (EQ) of electric equipment used in commercial nuclear power plants have raised questions related to the techniques used in the qualification process. These questions resulted in the U.S. Nuclear Regulatory Commission (NRC) Staff identifying EQ as a generic issue that should be evaluated for backfit during the current license term (SECY-93-049), (1). To address these questions, the U.S. NRC, Office of Nuclear Regulatory Research (RES) initiated the EQ Research Program. Brookhaven National Laboratory (BNL) was selected as the lead lab to assist NRC/RES in performing this research.

As a first step in developing a Research Plan, NRC/RES sponsored a public workshop on environmental qualification of electric equipment (NUREG/CP-0135), (2) in November 1993 to obtain input for formulating the EQ research plan. Panels of EQ experts from the nuclear industry were convened to discuss technical issues related to four major research areas: preaging, operating experience, condition monitoring, and LOCA testing. From the information gathered at these meetings, specific details on the evaluation of EQ requirements for electric cables were identified. A review of the existing literature on the subject was deemed to be necessary to consolidate and assess the vast body of research work that has been completed regarding the environmental qualification of electric cables. It was felt the literature review could be used to fully or partially resolve many of the questions and concerns in this area, and identify the need for additional research work in specific areas.

In support of the NRC/RES EQ Research Program, BNL developed a Research Program Plan (3) which identifies the issues to be resolved, the scope of the program, and the approach to be taken in resolving the various issues. The BNL Research Program Plan is consistent with the NRC/RES Research Plan, structuring the research activities into four main areas: 1) a review and documentation of past work in this area, 2) the identification and acquisition of cable samples for testing, 3) the evaluation of condition monitoring techniques for cables, and 4) preaging and design basis accident testing of selected cable samples.

1.2 Overview of Literature Review

Following the workshop, BNL began a literature search and review of significant research and testing related to the EQ process for electric cables. The studies that were reviewed were grouped into three basic areas: 1) aging characterization, 2) design basis accident testing (referred to simply as LOCA testing in this report), and 3) 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 the expected service life. The interim results of the BNL literature review and analysis are described and summarized in BNL Technical Report TR-6168-1/95 (4). This NUREG/CR includes all literature reviewed for the interim report, as well as new literature reviewed subsequently.

A preliminary review of the literature showed that, since 1975, significant studies related to various aspects of EQ requirements have been performed. Many were performed at Sandia National Laboratories under sponsorship of the NRC. Other countries, particularly France, Japan, Canada, Germany, and the United Kingdom, have also carried out research to understand the effects of EQ requirements on their cables. Studies on the aging of polymers used in cable insulation and jacket materials have received most of the attention in the United States and in other countries compared to research related to LOCA simulation testing.

During the last decade, electric utilities and affiliated industries have expressed interest in research on the condition monitoring of cables. Thus, the Electric Power Research Institute (EPRI), sponsored several significant programs at universities, power plants, and within the cable industry. Cooperative programs among individual utilities, foreign agencies (specifically Ontario Hydro in Canada), and the NRC have formed to identify the most effective monitoring methods. Recently, Japan, the United Kingdom, and Sweden have become involved in developing condition monitoring methods for nuclear power plants. Despite this activity, an effective method has yet to be developed, and research is continuing.

In addition to the published literature, many proprietary studies have been performed by the cable manufacturers on their own products. These companies have the distinct advantage of knowing the actual composition and formulation of the polymeric materials used to construct their cables. Due to the proprietary nature of this information, these results do not include polymer data, and as a result, it is difficult to analyze the influence of different formulations on the results of preaging and LOCA tests for materials identified only by the base polymer. For this reason, such studies performed in the United Kingdom and Germany were not readily available for this literature review.

1.3 Overview of the Literature Analysis

The information and data collected during BNL's literature search and review were categorized according to the major EQ issues to facilitate their analyses. Each of the major issues was further broken down into relevant subissues and topics, identifying specific questions and concerns that must be addressed in order to resolve the major issues. The categorization of the major issues and related topics is summarized in Table 1.

Drawing upon the information gleaned from the entire body of research and literature that was reviewed, an analysis of each subissue and its related questions was conducted. The analysis consisted of a critical review by a BNL analyst of all relevant literature for a specific subissue. After reviewing the literature, the analyst drafted a dossier to document the findings from past and ongoing work that could help in resolving that specific subissue, and categorized the subissue topics as resolved or not resolved. If not resolved, recommendations for future work were also included. The draft dossier was then reviewed by an expert panel. Subsequently, a meeting was held with the expert panel and the analyst to discuss and resolve comments on the dossiers. While total agreement was not obtained, a consensus was obtained on the resolution of the subissue topics and recommendations for future work.

The dossiers were then presented and discussed with the NRC staff to solicit their insights, and obtain their concurrence on the findings. The dossiers included in Section 2 of this report are the product of the aforementioned process. The results of these analyses are summarized and described in individual dossiers, designated A through M, which are identified in the second column of Table 1.

The dossiers provide the background and evolution of each subissue topic, describe the significant problem areas associated with the topics, and summarize the questions of interest that must be resolved. An analysis of the issues is presented in the dossiers based upon all of the literature, research, and testing that have been reviewed related to that subject. Selected documents are referenced in the dossiers as examples to highlight the analysis, but all the literature has been considered in the development of the

Table 1 Environmental Qualification Issues List

EQ MAJOR ISSUES	SUBISSUES/ DOSSIER TITLE	TOPICS FOR SPECIFIC QUESTIONS TO BE ADDRESSED IN DOSSIER	RESOLUTION CATEGORY (See Note)	RECOMMENDED WORK		
				CM	LOCA	OTHER
Q1: Are existing preconditioning 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		
		A.2 Oxygen diffusion limitations	2			
		A.3 High accelerated aging temperatures	1			
		A.4 Activation energy estimates	3	X		
	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	
		C.2 Electrical surges	2			
		C.3 Preaging synergistic/sequence effects	2			
		C.4 Use of slab samples for preaging research	1			
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	
		H.2 Bonded jacket cables	3		X	
		H.3 Specialty cables (e.g., Kapton)	1			
		H.4 Similarity criteria	1			

Table 1 (Cont'd)

EQ MAJOR ISSUES	SUBISSUES/ DOSSIER TITLE	TOPICS FOR SPECIFIC QUESTIONS TO BE ADDRESSED IN DOSSIER	RESOLUTION CATEGORY (See Note)	RECOMMENDED WORK		
				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	
		I.2 Excessive vibration	3	X	X	
		I.3 Water/steam/liquid impingement	3	X	X	
		I.4 Maintenance activity damage	3	X	X	
	J. Installed Configuration	J.1 Bends, vertical runs, overhangs	3	X	X	
		J.2 Cable trays, conduits	3	X	X	
		J.3 Fire protection coatings	3	X	X	
		J.4 Installation damage	3	X	X	
Q5: What insitu 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 Measure of effectiveness	3	X	X	
		K.3 Link to LOCA survivability	3	X	X	
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
		L.2 Definition of qualified life	3			X
		L.3 Use of operating experience	3			X
		L.4 Extension of qualified life	3			X
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			

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

analysis for each topic. The discussions developed in the dossiers are intended to be as precise as possible in order to thoroughly address and resolve each topic, or clearly focus upon the actions required to bring the topic to resolution. Finally, recommendations for the present EQ research program are made based on the literature analysis of all the work previously performed.

1.4 Recommendations for EQ Research Program

The literature analysis dossier for each subissue describes the recommended actions with respect to the present EQ research program for electric cables, and determines the resolution status of topics related to that subissue. Based on the literature analysis, each topic has been 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. Note 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 subject areas. The recommendations simply reflect the priorities of the issues as they relate to the objectives of this program and the limitations of the resources available to perform the work.

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 of the topics. Unresolved topics were prioritized to avoid duplication of previous efforts and to address the most significant, particularly those areas that have not yet been studied extensively. Recommendations for further research fall into one or more of the following areas: condition monitoring research, design basis accident simulation (LOCA) testing, and/or other work including analysis of test data, analysis of previous research, application of PRA, effect of new source term, and other comparative analyses. The last three columns of Table 1 indicate the recommended work to be conducted under this program.

A tabulation of the topics identified and addressed in the EQ literature analysis dossiers is given below. The totals of resolved and unresolved topics are provided along with the quantities of topics that will be studied by means of condition monitoring research, LOCA simulation testing, or analytical research.

Total Number of EQ Topics Identified	43
Number Resolved by Literature Analysis	18
Number Unresolved, No Further Research Warranted	6
Number Unresolved, Warrants Further Research	19
Number Involving LOCA Only	2
Number Involving CM Research Only	2
Number Involving CM and LOCA Testing Research	11
Number Involving Other Research	4

The work recommended from this analysis will concentrate on low voltage instrumentation and control cables constructed from the following insulation/jacket material combinations: EPR/Hypalon, XLPE (an important member of the polyolefin family)/Neoprene, and single conductor Okonite EPR cable with bonded Hypalon jacket.

Section 2 includes the individual dossiers that were developed to document the literature analysis results.

2. LITERATURE ANALYSIS DOSSIERS

This section includes the individual dossiers developed to document the results of the literature analysis. The references cited in the dossiers refer to the literature reviewed and summarized in Volume 1 of the report. That reference list is duplicated in Section 3 of this report.

The format developed for the dossiers is to first present background information that will help understand the evolution of the topics to be addressed in that specific subissue. Following the background, the specific questions to be answered are listed. Relevant work is then discussed in relation to the questions posed. Finally, recommendations for resolution of the specific questions and future work, if any, are made.

2.1 Dossier A: Thermal Aging

Background:

Prolonged thermal exposure of cables inside nuclear power plants can cause significant degradation (or embrittlement) of their insulating polymers. These changes in the elastic properties of cable insulation and jacket materials can be considered a precursor to eventual cable failure. To account for this in the qualification process, cable samples are thermally preaged prior to accident testing to simulate their expected condition at the end of their service life.

To simulate thermal aging for a 40-year service life, cable specimens are typically subjected to elevated temperature conditions in ovens. Since it would not be practical to preage the cables for extended time periods, the aging time is accelerated by using oven temperatures higher than the expected service temperature. The aging oven temperatures are calculated based on the Arrhenius methodology using an estimated activation energy.

The Arrhenius equation has been used by test facilities to estimate oven conditions (temperature and time) for a set of actual plant conditions, and by analysts to extrapolate the qualified life for an assumed constant thermal environment from the accelerated aging conditions. This methodology is widely applied in the qualification process, and assumes that a single chemical reaction occurs under both actual and accelerated conditions. However, this methodology has limitations. First, the assumption that a constant thermal environment exists in a nuclear power plant is erroneous. Temperature changes occur, both with time and location. The more significant concern here is with areas in the plant where temperatures routinely exceed that assumed in establishing a qualified service life. Second, studies have shown that for certain polymers, high temperature conditions may not induce the same single chemical reaction that occurs under actual plant conditions. Also, the elevated temperatures can sometimes cause multiple degradation mechanisms which result in nonlinear Arrhenius behavior. This nonlinear behavior can lead to erroneous results if linear extrapolations are made.

Another concern with accelerated aging is that it may cause heterogeneous degradation of the cable polymer material. One of the main degradation mechanisms for polymers is reaction with oxygen. During cable service life, oxygen inside the bulk of the insulation material is consumed during oxidation, and is replenished by the diffusion process. During accelerated aging at higher temperatures, if the polymer oxidation rate is faster than the oxygen diffusion rate, then the oxidation reaction in the interior of the polymer decreases because of the lack of oxygen. This results in heterogeneous degradation, with the surface more degraded (oxidized or embrittled) than the interior.

Elevated oven temperatures are an additional concern with accelerated aging. Oven temperatures of up to 150°C (302°F) have been used for cable testing in the EQ process. Most cable polymers have melting temperatures ranging from 130°C to 250°C (266°F to 482°F). Since the presence of a crystalline phase in the insulation renders the material sensitive to changes in temperature, oven conditions well beyond these melting temperatures may bring large uncertainties compared to the linear extrapolation of chemical degradation behavior at lower temperature. Oven temperatures that are too high can lead to erroneous qualification results.

Another limitation with the use of the Arrhenius method is the estimated activation energy used in the calculations. Typically, the activation energy for a particular cable material is determined experimentally by obtaining three data points. These points are then used to estimate an activation energy for the material. However, if the Arrhenius behavior of the material is non-linear, three data points may not be sufficient to identify this nonlinearity. If linear extrapolations are made, the use of the Arrhenius methodology could produce erroneous results and either underestimate or even overestimate the actual degradation in a plant environment, and thus the qualified life of the cable.

The estimated qualified life of a polymer is very sensitive to the value used for the activation energy in the Arrhenius equation. For example, a change in activation energy from 1.0 to 1.3 eV increases the predicted qualified life from 12 to 87 years. A lower activation energy predicts a shorter qualified life, and vice versa. Multiple reactions or a phase change within the temperature range tested will result in the calculation of erroneous activation energy values. This uncertainty raises questions as to the application of this approach to the accelerated aging of cable materials.

Questions:

Based on the discussion presented above, the following questions have been identified:

A.1 How accurately does the Arrhenius equation predict actual service life for electric cables?

A.2 Does the fact that accelerated aging reduces the allowable diffusion time for oxygen within the polymer affect the results of qualification tests using accelerated aging?

A.3 What is the highest oven temperature one should use in accelerated aging simulation to avoid departing from the linear (Arrhenius) degradation behavior?

A.4 What are the limitations in using an estimated value of the activation energy to predict the chemical degradation during thermal aging?

Past Work:

The Arrhenius methodology has been studied extensively over the past few decades and has been shown to be a valid means of modeling thermal degradation in polymers, for example, polyolefins and EPR (4.17). However, it does have limitations which must be considered in its application in order to obtain meaningful results. While the validity of Arrhenius has been proven, only limited work has been done to compare natural aging with artificial aging predictions for materials used in the construction of cables.

In examining the limitations of the Arrhenius method, it was found that a number of studies have been performed on various materials which show that some materials exhibit linear behavior, while others do not. In studies on XLPO (4.17), chloroprene (4.18), Hypalon (4.21) and nitrile rubber (4.24), these materials were found to exhibit linearity when the temperature dependence of their elongation loss is analyzed using the Arrhenius methodology. However, in studies on EPR (4.22) and SBR (4.16), these materials were found to exhibit non-linear behavior for elongation loss. Interestingly, the nitrile rubber exhibits non-linear behavior in its ultimate tensile strength properties.

For some materials, high temperature conditions, specifically those well above the material phase change temperatures, can induce different degradation reactions. This was demonstrated in work by Gillen and Clough (4.16) which showed that at elevated temperatures, degradation of polymeric materials can be dominated by phenomena that may be unimportant at lower temperatures. This would indicate that high temperature aging may not be representative of actual aging conditions. Gillen also found that, in some cases, aging at lower temperatures can cause more degradation than elevated temperatures.

Work by Gillen and Mead (4.18) described some of the data analysis techniques necessary to correctly apply the Arrhenius methodology to thermal aging studies. Some of the major uncertainties are also discussed, including competing reactions, material transitions, oxygen diffusion, and sorption effects. Since these uncertainties can lead to changes in activation energy, it was concluded that long-term exposures should be used to minimize extrapolation. A recent Swedish study (3.3) presented a methodology for estimating activation energy values based on tests of more than one physical parameter. Gillen and Clough also critiqued the Arrhenius method, and developed an empirical method (4.47) for predicting polymer life under combined thermal and radiation aging effects.

In selecting aging temperatures for cable materials, industry practice is to limit the aging temperature to values for which data exist. Since many materials have a Temperature Index established by testing to Underwriter's Laboratory (UL) Standard 746B, or IEEE Standard 101-1987, common practice is to utilize the UL Temperature Index of the material for the aging temperature. The Temperature Index of a material is established by interpolation of tests, which have demonstrated the Arrhenius relationship of the material. The Temperature Index is a temperature less than the maximum utilized for the testing, and, therefore, is within a known use range.

When more than one degradation mechanism is active, the Arrhenius methodology is not applicable. This was demonstrated by Gillen and Clough (4.22) when non-Arrhenius behavior was seen for EPR at temperatures of 100°C to 170°C (212°F to 338°F). This was attributed to the presence of two degradation mechanisms; normal thermal degradation, and copper-catalyzed oxidation. The latter mechanism increased the degradation rate at the inside of the insulation, where copper poisoning from the conductors had occurred.

The effects of oxygen diffusion have also been studied to understand heterogeneous oxidation. In work by Gillen and Clough (4.23), material profiling techniques were used to identify heterogeneous degradation mechanisms. Profiling of EPR samples aged at 100° C (212° F) showed that oxidation near the surface of the sample was significant while no measurable changes were found further inside the material. This was attributed to diffusion-limited oxidation. Similar results were found for neoprene rubber and styrene-butadiene rubber (4.16), and in nitrile rubber (4.24). The modulus profiling work showed that at elevated temperatures, diffusion-limited oxidation can be important, while at lower temperatures this effect is less important.

Oxidation diffusion and its effect on the qualification process have been studied (6, 5.21, 5.22, 5.23). It has been shown that 12 cable types without oxidation diffusion and with oxidation diffusion had no difference in performance when subjected to LOCA testing. Japanese researchers (4.39, 4.40) have shown that using higher pressures of oxygen, up to 0.5 MPa (5 atm) reduces radiation dose rate effects attributable to oxygen diffusion. In work performed by Stonkus (6.17), no difference was found in elongation-at-break measurements when homogeneous or heterogeneous diffusion occurred.

Differences in activation energy estimates have also been studied. In work by Gillen and Clough, (4.24) the differences in activation energies measured by mechanical and chemical test methods were reported for EPR and CSPE. The conclusion was that material degradation (loss of elongation) was not directly related to chemical oxidation (as measured by differential scanning calorimetry).

The extensive amount of work performed on the Arrhenius methodology has shown that this equation provides reasonable results as long as it is applied properly. Improper application, such as estimating qualified life for conditions outside the linear range, may over- or under-predict the actual results.

Recommendations:

Based on the literature reviewed, the following recommendations are made:

A.1 Extensive research has already been conducted evaluating the validity of the Arrhenius equation, and no further research in this area is recommended. However, only limited work has been done to evaluate the application of Arrhenius, which is the issue of interest here. Comparisons of Arrhenius predictions to naturally aged materials have been limited. Therefore, it is recommended that a study comparing naturally aged cables with cables aged under accelerated conditions be performed. These tests should include measurement of material properties using the CM techniques being researched (see Dossier K). Testing will be consistent with test conditions used by the original manufacturers during qualification.

A.2 Past work on oxygen diffusion has shown that accelerated aging can limit the amount of diffusion that takes place leading to heterogeneous material conditions. Research has not shown a difference in LOCA performance for cables with and without oxidation diffusion. This issue is not resolved, however, no further research on oxygen diffusion limitation is recommended.

A.3 No work was found in this literature review which addressed high accelerated aging temperatures, however, if activation energies are properly determined and Arrhenius is properly applied, the issue of excessive temperature limits should not be a problem. Guidance on the application of the Arrhenius method is available in standards such as IEEE Std 101-1987. Additional work in this area is not recommended, because the issue is resolved.

A.4 The issue of activation energies is not resolved since there is uncertainty in the process used and the values obtained. It would be extremely cost and time intensive to embark on a comprehensive research program to accurately determine activation energies, and this is not recommended. The activation energies reported by the vendor will be used for the artificial aging in this program. However, it is recommended that tests be included in the program to verify activation energies for the cable materials to be studied. This will be done in support of the CM phase of this program, in which accelerated aged materials will be compared with naturally aged materials. Measuring activation energies of these materials will provide the data needed to validate the life-service predictions of the Arrhenius model.

2.2 Dossier B: Radiation Aging

Background:

The principal source of radiation in a nuclear power plant is the fission products contained in the reactor fuel. There are four types of radiation in a nuclear power plant: alpha, beta, gamma, and neutron. While cables in general may be exposed to any combination of the above types of radiation inside reactor containment, gamma is the principal type of radiation used in environmental qualification.

Radiation changes the molecular structure of materials through processes such as excitation, ionization, cross-linking, and scission. The photons or particles emitted from a radiation source travel through a material and deposit energy. The dose absorbed by the material varies with the thickness of the material, and its absorption cross-section.

During normal service, some areas of the reactor containment are exposed to radiation from the reactor. The dose rates are a function of spatial location in the containment and are typically small. However, certain specific locations can be exposed to relatively high dose rates; for example, areas that are very close to the reactor vessel or steam lines carrying radioactive steam. These are sometimes referred to as radiation "hot-spots." Any cables in these areas can be exposed to significant radiation doses. Depending on the dose rate and the amount of time the cable is in service, the total integrated dose received by the cable over its life can lead to degradation that may impair its performance. In addition, in the event of an accident which releases radiation from the reactor, the cables could be exposed to additional significant radiation sources which could further degrade them. Therefore, to accurately test a cable's ability to survive an accident and still be able to perform its safety function, the potential degradation caused by these radiation exposures should be accounted for in the qualification process.

As specified in IEEE Std 383-1974, accelerated radiation aging of cables for environmental qualification can be performed using Cobalt 60 sources for gamma radiation in air at a dose rate not greater than 10 k Gy/hr (1 Mrad/hr). Typically, for a 40-year life of a nuclear power plant, a total integrated dose (TID) of 500 kGy (50 Mrad) is accounted for in radiation aging, and a TID of 1500 kGy (150 Mrads) is typically used to simulate accident radiation exposure. The concept of "equal dose - equal damage" is employed in which the radiation effect is assumed to depend only on total absorbed dose and to be independent of dose rate. However, experiments have shown this model may not be conservative for certain materials in certain configurations that are sensitive to the radiation dose rate. Furthermore, similar to thermal-aging effects, radiation exposure in different environments (e.g., vacuum, nitrogen, oxygen, or air) can affect both the type and magnitude of degradation.

Questions:

Based on the above discussion, the following questions have been identified:

B.1 Do dose rate effects influence the qualification of cable materials?

B.2 Can actual cable degradation due to radiation exposure during its service life be accurately simulated for the qualification process using gamma radiation only?

Past Work:

A review of the literature shows that a great deal of work has been done in the area of material irradiation. In a joint effort by the U.S. and French (4.25), it was found that beta and gamma radiation induced damage in thin samples (less than 4 mm) of polymer base rubber materials may be correlated on the basis of average absorbed radiation dose. Therefore, gamma radiation causes aging effects in cable polymers very similar to beta (electron) radiation.

Neutron radiation is strongest close to the source and is rapidly attenuated with distance. Cables near the reactor used for its instrumentation are typically exposed to high neutron radiation, and are therefore replaced at specific intervals prior to their end of life.

Dose rate effects on cable insulation and jacket materials have been studied extensively during the last decade. It has been shown that jacket materials, including neoprene, Hypalon, and PVC are more sensitive to radiation aging than all types of insulation materials (4.26, 4.29, 4.30), and they have exhibited dose rate effects, i.e., more severe degradation at lower dose rates. Work by the Germans has also demonstrated dose rate effects (6). Studies of insulation polymers, including XLPE, EPR and SR, indicate moderate to very low or no dose rate effect (4.22, 4.23). A model of dose rate effects has been developed and combined with an Arrhenius type thermal degradation model and applied to Hypalon and neoprene (4.47).

Although dose rate effects have been noted for certain materials, this must be viewed in relation to the impact on the qualification process. It is possible that the degradation from the radiation dose received by the cable samples during the preaging process is insignificant in comparison to that received for the design basis accident simulation used in the qualification process. If this is the case, the dose rate effects are unimportant. In work at Sandia (6.7, 6.8, 6.9) a variety of cable materials were exposed to low dose rates in the preaging process. Approximately 50% of the cable insulation and jackets had lost all elongation ($e/e_o \approx 0$) at 300 kGy (30 MRad). These materials were then exposed to accident TID and LOCA testing, and 96% of the cable materials passed the qualification tests. From these results it may be concluded that the low dose rate synergism during preaging has no significant effect on cable qualification. This is more apparent when the TID for the test sequences are compared. In the qualification process, a preaging TID of 500 kGy (50 MRad) is applied, while the TID for a design basis accident is 1,500 kGy (150 MRad). No evidence was found in the literature that dose rate effects have impacted cable qualification results.

Recommendations:

Based on the literature reviewed, the following recommendations are made:

B.1 While the influence of dose rate effects has not been resolved completely, a great deal of research has already been performed on this subject and has shown it to be a secondary effect when compared to the accident radiation dose. Therefore, additional study is not recommended. The overall influence of this factor in a qualification program which involves DBA radiation and LOCA conditions prior to functional testing is believed to be minimal. Should radiation testing be required to resolve other issues, the radiation dose will be applied consistent with previous qualification of cables under test. No further research on this issue is recommended.

B.2 From past work, the use of gamma radiation appears to be appropriate for simulating aging effects. Therefore, this issue is resolved, and no further work is recommended.

2.3 Dossier C: Other Aging Factors

Background:

The effects of all environmental stresses must be considered in any qualification test program. Prior knowledge of a materials behavior may eliminate the need to include a full range of tests, however, elimination of any parameters from a test program must be based on the mechanisms known to degrade the material under consideration. For most polymeric materials used for cable insulation and jacket, the environmental stresses causing the greatest damage have been identified as radiation and heat. While these are the predominant stresses of concern, other stresses are of potential concern, including humidity and stresses due to intermittent electrical surges. In addition, the synergistic effects due to combinations of these stresses should also be considered in simulating material aging.

For electric cables in power plants, the environment to which they are exposed can include high levels of humidity. Over long periods of time, this exposure can affect the degradation rate of some materials. However, current accelerated aging practices do not typically include humidity exposure in simulating service conditions. This could affect the accuracy of the simulation. Similarly, electrical surges are not accounted for, but can affect cable degradation.

During their service life, electrical cable insulation and jackets will be exposed to various stresses, some of which may change in magnitude, but will be present continuously and simultaneously. The effects of environmental stresses are best evaluated singly for research purposes, and are typically simulated in this manner for qualification purposes. However, qualification testing should consider whether more severe degradation occurs when stresses are applied simultaneously, as in actual service.

If more severe degradation occurs with combined stresses due to synergisms, or if more severe degradation can occur when different test sequences are used, then usually the test program in which the more severe degradation occurs is recommended.

In much of the past research performed, samples of material were used which were of a different geometry than actual cables. For example, slab samples were used in various research work by Sandia. While the material properties may be identical to those used in actual cables, the geometry could influence the degradation rate for some mechanisms. This has raised questions on the applicability of research performed on different geometries to cables.

Questions:

Based on the above discussion, the following questions have been identified:

C.1 Are the effects of humidity during aging significant enough to affect qualification results?

C.2 Are the effects of electrical surges during aging significant enough to affect qualification results?

C.3 Are the effects of synergisms during aging significant enough to affect qualification results?

C.4 Are research results obtained from tests on one material geometry (e.g., slabs) applicable to another geometry (e.g., cables)?

Past Work:

The effects of dry air vs. air at 70% relative humidity on samples aged by irradiation at various dose rates were reported in 1978 (4.38). The polymers evaluated were CP, CSPE, silicone, Tefzel, EPR, and XLPE. Nearly identical losses in elongation after irradiation at various dose rates were observed for both dry and humid conditions (EPR did exhibit a dose rate effect). This study did not evaluate combined heat, radiation and humid environments. Humidity in combination with heat stress has been found to be a significant factor in polyimide based materials (Kapton, for example). Kapton is commonly used in cable penetrations and equipment seals. In an extended LOCA test study (6.7, 6.8, 6.9) two failures occurred involving Kapton; however, both were attributed to damage during handling.

The literature surveyed to date have not evaluated the effects of electrical cyclic stresses or power surges on cable performance. Information on electrical surges has shown that voltage densities are at least 20 times higher when electric circuits are cycled. Thus, cable qualification tests at nominal voltage may underestimate the voltage density to which cables are exposed in cycled circuits, such as motors, MOVs, and SOVs. The effects due to self-heating are considered negligible (4.12).

Many evaluations of multiple stresses on cable performance have been reported, and many focus on establishing whether more damage to cable materials occurs when the stresses are applied in sequence or together. The two experimental parameters investigated most are radiation and temperature. PE and PVC (4.26, 4.27) show the most severe degradation as measured by elongation loss when exposed to radiation and thermal aging environments simultaneously. Sequential tests of radiation exposure followed by thermal treatment resulted in more severe degradation than the reverse sequence, but not as severe as the simultaneous exposures. EPR shows more complex behavior; some formulations tested (4.36) are degraded (in terms of loss of elongation) approximately equally by simultaneous radiation and thermal environments and by radiation followed by thermal treatment. Some EPR based materials showed approximately equal loss of elongation no matter what sequence was used. CSPE and CPE (4.37) both exhibit more severe degradation when thermal treatment follows radiation compared to the reverse sequence, and the worst degradation results from simultaneous exposures. Two XLPO materials (4.37) exhibited differing sensitivity to test sequence, as was the case with EPR. One XLPO formulation showed the greatest loss of elongation with a simultaneous exposure, while the other showed no significant dependence on test sequence.

Sample size and geometry are important considerations in aging simulations. The use of cable insulation and jacketing may involve some experimental difficulties, while samples better suited for ASTM mechanical (tensile) tests may not undergo the same degree of degradation because they are thicker than the installed cable insulation and jacket materials. Slab samples exposed to electron beam and gamma irradiation have exhibited differing effects, particularly from lower energy electron irradiation, if the samples tested exceeded 4 mm thickness (4.25). However, the overall conclusion was that radiation effects could be adequately and conservatively simulated on slab samples if gamma radiation is used. Comparisons between cylindrical samples and slab samples showed that damage correlated well with absorbed radiation dose. Sample thickness is also associated with dose rate effects which can be attributed to oxygen diffusion limited reactions which cause the observed degradation (4.29).

Recommendations:

Based on a review of past work, the following recommendations are made:

C.1 Humidity has been shown to be a factor for Kapton in a heated environment. In combination with a radiation environment, humidity has no added effects for several common cable materials. However, the combined effects of humidity, thermal stresses and radiation have not been addressed in aging programs. Additional tests evaluating the potential 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.

C.2 Limited work has been performed to address the effects of electric surges, however, past experience indicates that its effect is minor compared to thermal and radiation effects. Therefore, additional research in this area is not recommended.

C.3 Past work has shown that, in general, more severe degradation results from radiation exposures first, followed by thermal aging. However, with the perspective that preaging sequences cause only a small portion of the damage induced in a DBA simulation, the sequence in which the preaging is performed would be inconsequential and the question should be considered moot. Although the issue is not resolved, further work is not recommended. Should radiation aging be required to resolve other issues, the aging sequence simulated will be consistent with previous qualification for the cables being tested.

C.4 Sample size and geometry are a significant consideration in a qualification program if the degradation mechanisms of the materials are known. To date, oxygen diffusion limited degradation, exhibited in dose rate effects in polymers, is the one mechanism identified for which sample thickness must be considered. Other degradation mechanisms may exist where test results are significantly affected by sample size and geometry. However, past work has not shown any conclusive evidence that these effects would significantly affect qualification results. Therefore, no further studies are recommended in this area. While no specific tests will be developed to study mechanisms such as oxygen diffusion limited degradation, data will be obtained from the various other tests to be performed.

2.4 Dossier D: LOCA Profiles

Background:

As part of the qualification process, representative samples of cable to be qualified are subjected to design basis accident (DBA) conditions, which typically consist of exposure to steam and chemical sprays representative of a loss of coolant accident (LOCA) and/or main steam line break (MSLB). The accident profiles include an initial transient, which involves a rapid increase of steam temperature and pressure simulating the initiation of the accident, followed by a decrease in the temperature and pressure to steady-state conditions. During the DBA tests, the cables are functionally tested to verify performance of their safety related function during an actual accident. The DBA tests performed on cables by the cable manufacturers, the utility industry, and the research facilities use test profiles for steam temperature and pressure conditions which specify the conditions to be simulated and envelope the LOCA and MSLB profiles anticipated for the cable application.

When generic qualification tests were performed, the temperature/pressure profile used may have been similar to that given in the Appendix A to IEEE Std 323-1974. IEEE Std 323-1974, Appendix A profiles note that the values for test conditions may vary from plant to plant and may or may not contain adequate margin.

Alternatively, qualification tests may have been performed to plant specific temperature/pressure profiles. Even plant specific profiles may be enveloping profiles, representing all of the postulated line breaks analyzed for the harsh environment area under consideration. In some instances, plant specific profiles exceed the IEEE Std 323-1974 profiles and in this case the plant specific profile would form the requirements for qualification.

To ensure that the qualification process provides an adequate level of confidence that the qualified equipment will survive an accident, IEEE Std 323-1974 includes requirements for margin to be added to the test conditions. IEEE Std 323-1974 stated "Margin is the difference between the most severe specified service conditions of the plant and the conditions used in type testing to account for normal variations in commercial production of equipment and reasonable errors in defining satisfactory performance." IEEE Std 323-1974 identifies the following suggested factors to be applied to service conditions for type testing : +8°C (+15 °F) temperature; +10% of gauge pressure, but not more than 0.703 kg/cm^2 (10 psi); +10% Accident Radiation dose; ±10% voltage; ±5% Hz; +10% operational time following DBE; and Environmental Transients. The initial transient and the dwell at peak temperature shall be applied at least twice. These recommendations are based on expert opinion and are not linked to a quantitative increase in the level of assurance provided by the qualification process.

A second transient provides additional conservatism to the test. This second transient is not representative of expected accident conditions, but is meant to increase the DBA test severity to provide an additional level of assurance. Although it is recognized to be more severe than expected conditions, the second transient does not provide a quantifiable margin in the test. This is based on the definition of margin being the difference between the peak test temperature and the highest expected accident temperature.

When plants were required to perform reviews in support of NRC IE Bulletin 79-01B, it was necessary to document the quantifiable margin in DBA tests. The quantifiable margin was determined by subtracting the peak temperature condition of the DBA requirements from the documented qualification report. The DBA requirements came from plant specific temperature/pressure profiles.

The IEEE Std 323-1974 temperature and pressure profiles show a superheated steam condition for the initial transient portion and saturated steam later in the profile. This is based on the expected accident profiles. However, in simulating this, some qualification tests were performed using only saturated steam conditions. The superheated steam conditions were addressed using thermal delay analysis. It was believed that this was acceptable since the saturated steam provided a more severe condition, and thus a more conservative test.

The post-transient portion of the temperature/pressure profiles can vary from short periods of time (measured in hours) to many months, depending on the specific plant design and the accident conditions. Accepted practice is the performance of qualification tests for a specific enveloping post-transient duration, with time margin, and the utilization of analysis, i.e. Arrhenius techniques, to demonstrate longer post-transient operating durations, including time margin.

Questions:

Based on the above discussion, the following questions have been identified:

D.1 Are the safety margins used in the temperature/pressure profiles adequate to ensure a high level of confidence in the qualification process?

D.2 Does the use of a single peak accident profile provide a sufficient level of conservatism?

D.3 Are cable qualification tests performed using only saturated steam conditions adequate?

Past Work:

Since qualification is part of the quality assurance process to assure that safety-related equipment used in the plant will operate as required, only one sample of an item needs to successfully pass qualification. The purpose of margin in qualification was to account for normal expected variations in products between the test specimen and the items to be used in the nuclear plant, and account for inaccuracies in test equipment and defining requirements.

The temperature/pressure margin of +8°C (+15 °F)/+10% of gauge pressure, and the double peak test profile originated from IEEE Std 323-1974. The intent of adding margin to the test parameters and performing the transient twice was to add a higher level of assurance to the qualification process by over testing. Since qualification requires only one sample to be subjected to DBA testing, it was thought that there was greater assurance that an item indeed has the capability to perform its safety function under severe environments, if these conservatisms were added.

Because of NRC IE Bulletin 79-01B, utilities were required to document plant specific line break profiles for all postulated line breaks, and demonstrate that equipment was qualified to the plant specific line breaks. Safety Component Evaluation Worksheets (SCEW), in which qualification levels were documented next to requirements, and the excess of the requirements shown as margin, were utilized to summarize significant qualification information. Many, if not all, utilities generated a version of the SCEW sheet to document margin. Even though IEEE Std 323-1974 stated that double transient peaks were a form of margin, no quantitative margin could be demonstrated for temperature and or pressure unless the test documentation exceeded the requirements.

Additionally, since the temperature/pressure transient is an enveloping profile, which envelopes many line break scenarios, it already has considerable margin in the requirements. An enveloping DBA inherently exceeds the requirements of all line breaks that it envelopes.

Margin was demonstrated by test results exceeding postulated requirements. Thus, a one transient test which exceeded postulated requirements was determined to be an acceptable method of providing margin. Therefore, since the early 1980's, many DBA tests were performed with one peak DBA testing. Additionally, if margin wasn't specifically identified in plant enveloping requirements, then margin per IEEE Std 323-1974 was added during testing.

Although no specific research is known to have been performed to compare two peak transients to one peak transients, much actual data exists. First, it was not uncommon for DBA tests to start, then have to be stopped, due to early anomalies with test facilities, and then restarted. This caused many multiple transient tests to be performed because of testing artifacts. Additionally, Sandia (5.21, 5.22, 5.23) tested some cables in a two transient DBA simulation. Some of these cable specimens were then tested to a third high temperature steam testing sequence to failure (5.25), to establish maximum temperature margin.

As noted in Table D.1, various cables were exposed to a two transient DBA in NUREG/CR-5772, DBA number AT3. Some of the cables were then further tested in NUREG/CR-5655. The purpose of NUREG/CR-5655's high temperature DBA testing, DBA number HTS3, was to determine the maximum temperature at which cables would fail. The HTS3 DBA was intended to increase the temperature by about 10 °C (18°F) every 15 minutes until all cables failed. Due to steam system problems, a double peak test was actually performed. During the first transient of HTS3, saturated steam was used to attain a temperature of 165°C (329°F). Superheated steam was then used to attain a temperature of 216°C (420°F), at which time the test was stopped due to steam system problems. The chamber was allowed to cool and testing restarted the next day. The peak conditions attained during the second attempt were 400°C (752 °F) at 8.225 kg/cm^2 gauge (117 psig). These findings indicated that a margin of several hundred degrees was available for the cable types tested. The margin for pressure is more than twice the typical requirements. The cable types tested represent a significant cross section of cable materials and types. As noted in Table D.1, each cable material, except for the multiconductor Dekoron, did not fail until significantly higher DBA temperatures were reached. Failure here-in is defined as the point that the insulation resistance fell below 0.1 kΩ-100m.

The Sandia work in NUREG/CR-5772 was performed without chemical sprays, however each cable type was tested for long term chemical spray submergence in other testing in NUREG/CR-5655.

Typical plant qualification pressure requirements are in the range of 3.515 kg/cm^2 to 4.218 kg/cm^2 gauge (50 to 60 psig). During HTS3, pressures reached 8.225 kg/cm^2 gauge (117 psig) and no failures were caused by the high pressure. Thus, the 10% margin on pressure poses no significant issue for cables.

From these results it is seen that cable materials have several hundred degrees margin before peak temperature caused failure. Since the failure level is so much higher, the temperature margin defined in IEEE Std 323-1974 is adequate. Additionally, since the cables tested to two transients in NUREG/CR 5655, had already been exposed to an IEEE Std 323-1974 two transient profile test, the number of peaks and duration at peaks exceeded typical requirements. Since the temperature margin for the cables tested were significant, at least 93°C (200 °F), LOCA tests utilizing one peak are acceptable and additional peaks may be superfluous.

IEEE Std 323-1974 and plant specific DBA profiles postulate line breaks to cause a superheated steam portion followed by a saturated steam portion. This occurs because when a line break occurs, the steam is hotter than the saturated temperature in containment or area near the line break. If the area is small enough, and the pressure is allowed to build up, the steam conditions will become saturated. For in-containment breaks, chemical and water sprays will cause the superheated steam conditions to become saturated.

During DBA testing, superheated requirements are met by most facilities, then the simulation achieves saturated steam conditions when sprays are turned on or temperatures cool. Thus, most cable tests have been achieved with superheated and saturated steam during the simulation, or just saturated steam. When steam conditions become saturated, cables are subjected to more conductive steam, or steam and sprays.

Table D.1: Peak Temperature Test Conditions of Cable Types Tested in NUREG/CR-5772 then NUREG/CR-5655, DBA Temperature at which Failure Occurred

	Supplier	Material	NUREG/CR-5772 Peak Transient 1 Temp °C (°F)	NUREG/CR-5772 Peak Transient 2 Temp °C (°F)	NUREG/CR-5655 DBA Temperature {Failure @ 0.1 kΩ-100m} °C (°F)
1	Brand Rex	XLPE w/CSPE Jacket	175 (347)	172 (341)	385 (725)
2	Rockbestos	Firewall III, XLPE w/Neoprene Jacket	175 (347)	172 (341)	320 (608)
3	Raychem	Flamtrol XLPE	175 (347)	172 (341)	386 (726)
4	Samuel Moore	Dekoron Polyset, XLPO, w/CSPE jacket	175 (347)	172 (341)	298 (569)
5	Anaconda	Y-Flame-Guard FR-EP, EPR w/CPE jacket	175 (347)	172 (341)	394 (742)
5a	Anaconda	Flame-Guard EP, EPR, w/individual CSPE jacket and overall CSPE jacket	175 (347)	172 (341)	381 (717)
6	Okonite	Okolon, EPR w/CSPE jacket	175 (347)	172 (341)	387 (729)
7	Samuel Moore (Single Conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE jacket	175 (347)	172 (341)	370 (698)
7	Samuel Moore (Multi-conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE and overall CSPE jackets	175 (347)	172 (341)	Failed in NUREG/CR-5772
8	Kerite	FR w/FR jacket	175 (347)	172 (341)	372 (702)
8a	Kerite	FR w/FR jacket	175 (347)	172 (341)	372 (702)
9	Rockbestos	RSS-6-104/LE Coax	175 (347)	172 (341)	378 (712)
10	Rockbestos	Firewall Silicone	175 (347)	172 (341)	396 (744)
11	Champlain	Polyimide, Kapton	175 (347)	172 (341)	399 (751)
12	BIW	Bostrad 7E, EPR	175 (347)	172 (341)	375 (707)

Two studies, one by JAERI (5.12), and another by SNL (5.11) have been reviewed on this issue. Tests were conducted using saturated and superheated steam conditions. The tests focused on measuring changes in leakage current and insulation resistance during and after the respective tests. Particularly in SNL (5.11), EPR cable DBA tests in superheated steam were compared to similar EPR cable in a saturated steam DBA (5.4). Specific cable leakage currents showed that for 600 Volt applied voltage, the leakage current was 180 to 750 mA in saturated conditions and 2 mA during superheated conditions. It was noted that using superheated steam had little effect on ultimate ability to survive DBA, but did have an effect on leakage currents. Leakage currents were higher during the saturated steam portion of testing. The tests show that the DBA, which has a superheated transient, eventually becomes saturated as the DBA progresses and temperature decreases. During saturated portions of the two tests, there is negligible difference in insulation resistance and leakage current values. DBA simulations with initial superheated transients had the effect of delaying time to failure until saturated conditions occurred.

SNL studies (5.21, 5.22, 5.23) have shown that for cables, superheated steam, being less conductive than saturated conditions, allows insulation resistance to stay higher and leakage currents to stay lower. At the time that saturated conditions are achieved, insulation resistance will decrease and leakage currents will increase because of the more conductive atmosphere. Based on this work it is seen that testing using saturated steam is more severe than superheated steam, and should provide an acceptable alternative test condition.

LOCA temperature/pressure profiles can be divided into two periods: the transient period and the post-transient period. The initial transient period of a LOCA profile includes the start of LOCA and the high temperature/pressure conditions. The post-transient period is a long period of time at temperatures approximating pre-transient conditions. It has been common to require the postulation of long post-transient conditions, especially because of the lessons learned from the TMI accident. Reg Guide 1.97 requires that the post-transient needs for post accident monitoring equipment be established, therefore, some equipment has been designated for long duration post-transient operation. Since almost all safety-related equipment would require cables for post-transient, long duration post-transient qualification of cables has been standard.

Accepted practice has been to perform real time testing for long post-transient durations or to accelerate post-transient conditions artificially, using the Arrhenius methodology.

Recommendations:

Based on the analysis presented above, the following recommendations are made:

D.1 While the level of conservatism added by the recommended margins in IEEE Std 323-1974 has not been quantified, sufficient work has been done to show that the typical cable materials have a large degree of margin available before failure. Therefore, the IEEE 323-1974 margins should be considered acceptable and this issue is resolved. LOCA testing, which may be performed during continued research into EQ, will utilize the previously documented qualification test parameters for test parameters. No additional margin will be added.

D.2 Sufficient work has been done to show that single transient DBA testing is acceptable, and double transient DBA testing may be superfluous. This issue is resolved and no further research is required. However, if additional LOCA testing is performed during continued research into EQ, the previously documented qualification test parameters of cables undergoing testing, including number of transients, will form the basis for test parameters. If previous LOCA testing was performed solely with single transients, then a single transient will be utilized. However, if multiple transients were utilized in previous qualification, then the same multiple transients will be performed.

D.3 Sufficient work has been done to show that DBA simulations using superheated steam, followed by saturated steam conditions are acceptable. Also, utilizing superheated steam testing only for simulation of postulated DBA's characterized by saturated steam are not acceptable. Therefore, this issue is resolved. However, if additional LOCA testing is performed during continued research into EQ, the previously documented qualification test parameters of cables undergoing testing, including use of superheated steam, followed by saturated steam or saturated steam only, will form the basis for test parameters. If previous LOCA testing was performed solely with saturated steam, then saturated steam will be utilized. However, if superheated steam followed by saturated steam was utilized in previous qualification, then the same superheated steam followed by saturated steam testing will be performed.

2.5 Dossier E: LOCA Simulation Methods

Background:

As part of the qualification process, representative samples of cable to be qualified are first artificially aged to simulate their expected condition at the end of their expected service life, then subjected to conditions simulating a design basis accident (DBA), which could involve a loss of coolant accident (LOCA) and/or a main steam line break (MSLB). Throughout this DBA test, the cables are functionally tested to verify their safety related function. An actual accident could subject the cables to varying levels and rates of radiation exposure, along with steam at elevated temperatures and pressures, and chemical or water sprays. These exposures would occur simultaneously, and their severity would depend on the nature of the accident.

Due to time and cost constraints in performing qualification tests, a number of simplifying assumptions are typically made in simulating DBA conditions. The most significant one involves the use of sequenced radiation/steam exposures instead of simultaneous exposure. Others include the use or non-use of chemical sprays during testing, and the use or non-use of air injection to maintain oxygen levels. In addition, estimated radiation doses are used based on calculated radiation releases, and accelerated radiation dose rates are used to reduce test time. Each of these conditions has some uncertainty associated with it that could add uncertainty to the qualification process.

The vast majority of industry cable qualification programs have used a sequential sequence of accident radiation followed by steam testing. This allows the cables to be irradiated at a separate facility, thus eliminating the need for the irradiation capabilities at the steam facility. This greatly reduces the complexity and cost of the LOCA testing.

Another uncertainty is the level of oxygen present during the accident simulation. Since many cable materials have been shown to have oxygen dependent degradation mechanisms, the absence of oxygen could limit degradation processes and cause non-conservative test results.

LWR's utilize chemical (PWR) or deionized water (BWR) sprays in the event of a LOCA to help remove contamination from the containment atmosphere. Therefore, DBA simulations used in the qualification process include the use of chemical or deionized water sprays. The chemical sprays typically consist of 0.28 molar boric acid, 0.064 molar sodium thiosulfate, and sodium hydroxide added to obtain a pH between 10 and 11 at 77°C (171°F).

Another potential conservatism is the total integrated dose used to represent the radiation expected during an accident. Utilizing existing source term requirements, the accident Total Integrated Dose may be on the order of 1.5×10^6 Gy (150 Mrads) for some plants. However, the 79 kGy (7.9 Mrads) TID on cables at TMI were significantly less than 1.5×10^6 Gy (150 Mrads).

Questions:

Based on the above discussion, the following questions have been identified:

E.1 Does the presence of oxygen affect LOCA results?

E.2 What are the effects of sprays on cable materials during accidents, and should they be required during LOCA testing?

E.3 Does the sequence in which the LOCA radiation/steam exposure is performed affect qualification results?

E.4 Is the total integrated radiation dose from current requirements overly conservative?

Past Work:

Some plants have air atmospheres and some have inerted atmospheres in containment. NUREG/CR-4091 (5.6) investigated the use of oxygen versus nitrogen in LOCA simulations. The conclusions were that EPR and Tefzel were more degraded when oxygen was present. Oxygen was not important for XLPE, XLPO, CSPE and CPE. An additional test by the French (5.17) showed that EPR was more degraded during accident simulations with oxygen. PVC, which is not as common in US plants, degraded more without oxygen present. These results show that the effect of oxygen varies with different materials, and can be an important factor in the cable degradation rate.

No research was found which measured the amount of oxygen during LOCA simulations and no information was located relative to the amount of oxygen in containment during accidents. Since very low leak rates are designed into containment, it appears that the original oxygen content in the air is largely trapped inside containment during an accident. The oxygen concentration might decrease as the accident progresses due to both leakage and its reaction with materials in containment. Additionally, the use of nitrogen inerted containments may make cable less susceptible to damage during LOCA. Since many common cable materials degrade more in atmosphere containing oxygen, it is accepted practice to add oxygen or air during LOCA simulations to avoid oxygen depletion.

Chemical sprays and/or deionized water sprays (i.e., plant sprays) add to the conductivity of the surroundings of cables exposed to DBAs. Both deionized water and chemical sprays create a more conductive environment. The chemical sprays, since they contain chemicals, could attack polymers and cause more rapid degradation. However, the primary effect of sprays is to create a saturated steam condition, which causes cables to be more thoroughly immersed in this conductive medium. When sprays are applied in DBA simulations, cable insulation resistance drops. When sprays are performed at the same time that the pressure is at its maximum, the lowest insulation resistance and highest leakage occurs. Pressure forces sprays to intrude on items undergoing testing, and thus sprays should be applied at the maximum postulated pressure. The addition of a spray will cause saturated steam conditions, because of the significant moisture increase. Plant sprays normally are applied for 24 hours in a DBA simulation. Plant spray requirements are normally much less than 24 hours, therefore, the qualification requirement is a conservative approach.

Sandia did not utilize chemical sprays in many of their DBA simulations. However, in NUREG/CR-5655 (5.25), several cable types were subjected to chemical spray submergence. In this work, cables that had already undergone and passed the equivalent of 40 year aging and LOCA testing in NUREG/CR-5772, were further subjected to 1,000 hours at 95 °C (203°F) of a PWR chemical spray. Most XLPO, EP, Silicone and XLPE insulated cables performed acceptably during and after the submergence. Both Dekorad and Kapton had high failure rates.

Since chemical sprays, or deionized water sprays, are part of the postulated environment during a DBA, they are required to be demonstrated during the cable qualification at the highest pressure. Accepted practice has been that cables qualified by exposures to chemical sprays during the DBA simulation would be considered qualified to deionized water sprays also. The corollary has not been accepted practice.

LOCA requirements include an accident radiation dose and high temperature steam conditions. LOCA simulations are typically performed in the sequence of accident radiation prior to the steam testing. This is a conservatism, since large radiation doses have to occur after a line break and not before.

The effects of sequential accident radiation followed by steam LOCA testing versus simultaneous accident radiation and steam exposure were investigated by Sandia. It was reported (5.4) that in 6 out of 7 tests, the sequential (accident radiation before steam testing) sequence caused greater loss of tensile strength in EPR cables. This indicates that sequential testing is more conservative than simultaneous testing for the cables tested.

In regard to the radiation dose expected during an accident, a review of TMI experience (5.27) showed the highest accident radiation dose on a cable was 0.079×10^6 Gy (7.9 Mrads), which is significantly less than the 1.5×10^6 Gy (150 Mrads) assumed for most qualifications. TMI experience also showed that the steam exposure preceded the radiation dose.

Tests by Sandia (5.21, 5.22, 5.23, 5.25) were performed with accident radiation followed by steam testing. Cables were shown to have significant margin, Table E1, by surviving a DBA steam test, DBA number AT3 of NUREG/CR-5772, and then being tested to failure in DBA number HTS3 of NUREG/CR-5655. The radiation exposure was between 1.0×10^6 Gy and 1.3×10^6 Gy (100 and 130 Mrads).

The nuclear industry provided information on cable qualification parameters through the NUS EQDB, NUS EQ Database for Cables dated 9/23/94. Table E2 summarizes this information for the same cable types noted in Table E1. The significance of Tables E1 and E2 is to show that out of the twelve cable types tested, 11 have been qualified to a total integrated dose of greater than 2×10^6 Gy (200 Mrads) and one to 1.4×10^6 (140 Mrads).

Therefore, the conservatisms arising from the source term requirements and the application of the accident dose prior to DBA steam testing, have not precluded the cable types represented in Tables E1 and E2 from performing successfully and being qualified.

It is now recognized that the total integrated dose and the application of accident radiation prior to steam testing are conservatisms. Accepted practice is to utilize the required source term and to apply the accident radiation dose prior to steam testing in the qualification process.

Recommendations:

Based on the literature reviewed, the following recommendations are made:

E.1 Past work has shown that the effects of oxygen on accident degradation are material specific. Cables, for which oxidation is a significant failure mechanism, should be DBA tested so as not to eliminate oxygen. However, actual oxygen concentrations during an accident are not well

Table E.1: Radiation and Peak Temperature Test Conditions of Cable Types Tested in NUREG/CR-5772 then NUREG/CR-5655, DBA Temperature at which Failure Occurred

	Supplier	Material	Total Average Integrated Dose $x10^6$ Gy (Mrads)	NUREG/CR-5772 Peak Temp °C (°F)	NUREG/CR-5655 DBA Temperature {Failure @ 0.1 kΩ-100m} °C (°F)
1	Brand Rex	XLPE w/CSPE Jacket	1.19 (119)	175 (347)	385 (725)
2	Rockbestos	Firewall III, XLPE w/Neoprene Jacket	1.29 (129)	175 (247)	320 (608)
3	Raychem	Flamtrol XLPE	1.29 (129)	175 (347)	386 (726)
4	Samuel Moore	Dekoron Polyset, XLPO, w/CSPE jacket	1.13 (113)	175 (347)	298 (569)
5	Anaconda	Y-Flame-Guard FR-EP, EPR w/CPE jacket	1.28 (128)	175 (347)	394 (742)
5a	Anaconda	Flame-Guard EP, EPR, w/individual CSPE jacket and overall CSPE jacket	1.26 (126)	175 (347)	381 (717)
6	Okonite	Okolon, EPR w/CSPE jacket	1.26 (126)	175 (347)	387 (729)
7	Samuel Moore (Single Conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE jacket	1.20 (120)	175 (347)	370 (698)
7	Samuel Moore (Multi-conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE and overall CSPE jackets	1.20 (120)	175 (347)	Failed in NUREG/CR-5772
8	Kerite	FR w/FR jacket	1.13 (113)	175 (347)	372 (702)
8a	Kerite	FR w/FR jacket	1.17 (117)	175 (347)	372 (702)
9	Rockbestos	RSS-6-104/LE Coax	1 (100)	175 (347)	378 (712)
10	Rockbestos	Firewall Silicone	1.15 (115)	175 (347)	396 (744)
11	Champlain	Polyimide, Kapton	1.23 (123)	175 (347)	399 (751)
12	BIW	Bostrad 7E, EPR	1.3 (130)	175 (347)	375 (707)

E.2: Qualification Levels of Radiation and Peak Temperature of Various Cable Types from NUS EQDB

	Supplier	Material	Total Integrated Dose x 10^6 Gy (MRads)	DBA Peak Temp °C (°F)	Referenced Report
1	Brand Rex	XLPE w/CSPE Jacket	2 (200)	196 (385)	FIRL F-C5120
2	Rockbestos	Firewall III, XLPE w/Neoprene Jacket	2 (200)	172 (341)	ROCK 5804 R3 7/2/87
3	Raychem	Flamtrol XLPE	2 (200)	181 (357)	FIRL F-C4033-1
4	Samuel Moore	Dekoron Polyset, XLPO, w/CSPE jacket	2 (200)	191 (375)	EQ-CBL-017
5	Anaconda	Y-Flame-Guard FR-EP, EPR w/CPE jacket	2 (200)	196 (385)	FIRL F-C4836-2 1/78
5a	Anaconda	Flame-Guard EP, EPR, w/individual CSPE jacket and overall CSPE jacket	2 (200)	174 (346)	FIRL F-C4350-2
6	Okonite	Okolon, EPR w/CSPE jacket	2 (200)	171 (340)	OKONITE RPT 266R-1
7	Samuel Moore (Single Conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE jacket	2 (200)	191 (375)	NTS 558-1088
7	Samuel Moore (Multi-conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE and overall CSPE jackets	2 (200)	191 (375)	NTS-558-1088
8	Kerite	FR w/FR jacket	2 (200)	163 (325)	FIRL F-C2737 041570
8a	Kerite	FR w/FR jacket	2 (200)	163 (325)	FIRL F-C2737 041570
9	Rockbestos	RSS-6-104/LE Coax	2 (200)	174 (345)	ROCK QR-6802 R1
10	Rockbestos	Firewall Silicone	2 (200)	171 (340)	ROCK QR-7801 3/2/78
11	Champlain	Polyimide, Kapton	1.4 (140)	171 (340)	Note 1
12	BIW	Bostrad 7E, EPR	2 (200)	171 (340)	BIW TR# B915 REV 1

Note 1. No record located in NUS EQDB for Champlain Kapton, so Haveg Kapton, Report West TR CWAPP-332 was used.

quantified. While this issue is not resolved, no further work is recommended in this program. If additional LOCA testing is performed during continued research into EQ, air will be added during LOCA testing.

E.2 For the cables reviewed, chemical sprays and deionized water sprays have not precluded successful functional performance of cables during accident conditions. These sprays increase the conductivity during LOCA testing. Chemical sprays should be utilized in LOCA simulations, if included in plant requirements, and they should be applied at the peak accident pressure conditions to assure maximum penetration of sprays. This issue is resolved and no further work is recommended. If additional LOCA testing is performed during continued research into EQ, the previously documented qualification test parameters of the cables undergoing testing, including type of chemical spray, will form the basis for test parameters. If previous LOCA testing was performed solely with deionized water, then deionized water will be utilized. However, if chemical spray was utilized in previous qualification, then the same chemical spray will be performed.

E.3 DBA testing with accident radiation followed by steam testing is concluded to be conservative. This issue is resolved and no further research is recommended.

E.4 The required source term results in accident radiation doses which are conservative. This issue is resolved and no further research is recommended. If additional LOCA testing is performed during continued research into EQ, the previously documented qualification test parameters of cables undergoing testing, including type of accident radiation dose and dose rate, will form the basis for test parameters.

2.6 Dossier F: Cable Monitoring During LOCA

Background:

As part of the qualification process, cables are subjected to accident conditions and their performance is monitored to determine if their safety function can be accomplished. However, the manner in which the cables have been monitored, and the acceptance criteria used to evaluate their performance in past qualification tests has varied. Some cable qualification tests have been performed utilizing the application of a constant voltage and constant current. The constant voltage value may be the maximum voltage potential of the cable, the maximum expected voltage of the application, or a volts per mil rating. The current passed through the cable has varied from little current, to expected loads, to assumed worst case loads. Other monitoring has utilized insulation resistance methods and current leakage methods. Insulation resistance may have been applied continuously or periodically. Leakage current has been monitored using a fixed fuse and more sophisticated data recording.

The primary safety functions of a cable are 1) provide continuity for current, 2) provide insulation between adjacent conductors and ground, and 3) maintain a voltage potential.

Additionally, IEEE Std 383-1974 requires that new cables be mounted on mandrels and mechanically stressed using a 20 times diameter bend stress prior to being LOCA tested. This is followed by removing the cable from its mandrel, straightening and recoiling on a 40 times the overall cable diameter mandrel after the LOCA test, but prior to a submerged dielectric test. The dielectric test is performed with tap water and a voltage potential of 80 V/mil ac or 240 V/mil dc is applied for 5 minutes.

Questions:

Based on the above discussion, the following questions have been identified:

F.1 What functional tests and acceptance criteria should be used on cables during LOCA testing to evaluate performance?

F.2 Is the post LOCA straightening and recoiling on a 40 times diameter mandrel bend/voltage withstand test excessively severe?

Past Work:

The safety function of a cable is to maintain the applied voltage and provide a continuous circuit. The manner in which functional performance has been demonstrated has varied.

In some early qualification tests, cable qualification performance was measured by applying maximum rated voltage, typically 600 Vac, for instrument and control cable, and adding a fuse in the leakage current path. The acceptance criterion was the blowing of the fuse or a loss of voltage.

Some cables were qualified to IEEE Std 383-1974, which requires that cables undergoing LOCA simulation be operated under rated voltage and load, while simultaneously being exposed to the pressure, temperature, humidity and chemical spray of a LOCA event.

During reviews of qualification records per NRC IE Bulletin-79-01B, it was apparent that the contribution of a cable's performance to circuit performance in determining loop accuracy was enhanced with additional monitoring of leakage current and/or insulation resistance.

Additionally, since cables are used in a variety of different power, control and instrumentation applications, functional performance could more closely mirror actual requirements. Thus, instead of one enveloping voltage being used, some cables were tested at the voltage of actual circuit conditions. This allowed more accurate determination of cable performance and acceptance. For instance, if cable was being used in low voltage circuits, then testing at low voltage obtained more meaningful leakage currents and insulation resistance values. With more meaningful information, the cable's effect on loop accuracy could be better determined.

The applied voltage during IR tests was not standardized and its impact on cable functional performance was studied. In NUREG/CR-5772 (5.21, 5.22, 5.23), Insulation Resistance (IR) was used as the acceptance criterion. IR was measured at 50V, 100V, and 250 V. The IR values obtained were reasonably similar. The five times change in applied voltage showed substantially the same IR. The conclusion was made that IR's were generally independent of test voltage in this range. The difference in IR between unaged and aged cable during accident testing was about three orders of magnitude. In NUREG/CR-6095 (5.34), Sandia measured IR at applied test voltages of 100 V and 250 V, and utilized a continuous IR technique during the accident steam exposure to measure the performance of intentionally damaged cables. No significant differences in continuously monitored IR or periodically monitored IR were noted.

By having the appropriate applied voltage and periodically measuring IR, the cable performance can be measured, for most applications. Thus, monitoring voltage, current, and leakage current, along with periodic IR's would provide a good performance indicator of the cables during DBA conditions.

IEEE Std 383-1974 requires the mounting of cables on a 20 times diameter mandrel during LOCA simulation. This adds some mechanical stress to cables during LOCA simulations and enhances contact with a ground plane. In actual plant applications, cables may be in conduits or cable trays where portions of the cable may or may not be under significant mechanical stress. The use of a ground plane is accepted practice. Additionally, the use of mandrels to apply mechanical stress and enhance contact with a ground plane has been accepted practice.

Also, IEEE Std 383-1974 requires removing the cable from its mandrel, straightening and recoiling on a 40 times the overall cable diameter mandrel after the LOCA test but prior to a submerged dielectric test. The dielectric test is performed with tap water and a voltage potential of 80 V/mil ac or 240 V/mil dc is applied for 5 minutes. The effect of this "post LOCA mandrel bend" has been studied.

In NUREG/CR-5655 (5.25), cables that had already undergone and passed the equivalent of 40 year aging and LOCA testing in NUREG/CR-5772, were further subjected to a PWR chemical spray for 1,000 hours at 95 °C (203°F), while mounted to a mandrel. Most XLPO, EP, silicone, and XLPE insulated cables performed acceptably during and after the submergence. Both Dekorad and Kapton had high failure rates. Following the submergence test, a dielectric withstand test in tap water was performed with the cables still wrapped on the mandrel. The cables that passed the dielectric test were subjected to a post LOCA mandrel bend test. The cables were removed from the original mandrel, straightened, and recoiled around a mandrel with a diameter 40 times that of the cable and then subjected to a dielectric withstand test in tap water. The results of the post LOCA mandrel bend were that only 1 of 11 XLPO insulated cables failed, while 17 of 20 EPR insulated cables failed the dielectric test. It was concluded in both NUREG/CR-5772 and NUREG/CR-5655 that the post-LOCA mandrel bend test does induce failures in otherwise functional cables.

Recommendations:

Based on the review of past work, the following recommendations are made:

F.1 Sufficient past work has been performed to determine that effective functional performance of cable should consist of applying voltage and load current, consistent with the application or at cable rated conditions, and that the additional performance indicators of leakage current, or insulation resistance be applied. Acceptance criteria can be established based on the application. While voltage, current, leakage current and IR requirements based on the application can be developed for use as acceptance criteria, it is the responsibility of the utility to establish application criteria and to verify that LOCA test results demonstrate compliance with those criteria. Therefore, this issue is resolved and no further research is recommended. However, if additional LOCA testing is performed during continued research into EQ, the previously documented qualification test parameters of cables undergoing testing, including applied voltage and applied load, will form the basis for test parameters. Additionally, leakage current and IR monitoring will be performed.

F.2 Attaching cables to mandrels during LOCA testing simulates mechanical stress and provides the opportunity for more contact with a ground path. Thus, mandrel bend testing of new cable prior to accident testing is a good practice. Post LOCA submerged dielectric withstand testing is accepted practice. However, the post LOCA mandrel bend test, i.e., removing cable from a mandrel, straightening and recoiling on a mandrel of 40 X diameter, imparts an unrealistic stress on the cable which induces failures of good cables. Therefore, post LOCA mandrel bending is not necessary. This issue is resolved and no further research is recommended. However, if additional LOCA testing is performed during continued research into EQ, naturally aged cables undergoing testing will be attached to ground planes, which attempt to replicate the installed condition; and new, unaged, and artificially aged cables will be coiled on mandrels which are 20 times the diameter of the cable. Post LOCA dielectric testing in tap water will be performed with the cables still attached to the same mandrel (for artificially aged cables) or ground plane (for naturally aged cables) utilized in the LOCA simulation.

2.7 Dossier G: Manufacturing Processes

Background:

There are approximately three dozen manufacturers in the United States who have supplied safety-related electric cables to nuclear power plants. While the materials used in cables from these different manufacturers may be of the same generic polymer, they can have different aging characteristics due to variations in the manufacturing process used. These variations can occur not only among manufacturers, but also among cables from the same manufacturer. Variations can be caused by differences in the chemical composition of materials supplied to the manufacturer, or by differences in the curing process used in manufacturing the material. They can also be caused by the use of different additives in the material formulation.

The material formulations used by a particular manufacturer are typically proprietary. These formulations can include the use of various additives, such as fire retardants, coloring agents, antioxidants, and fillers, to achieve different material characteristics for specific applications. The amounts and types of additives used can differ not only among manufacturers, but also for materials from the same manufacturer. Since different additive manufacturers or suppliers may be used, it is unlikely that exactly the same chemical composition for the raw materials will be supplied each time. In addition to variations caused by the additives, differences in the base polymer materials can occur for the same reasons. Each of these variations in the material formulation can have an effect on the aging characteristics of the final cable. The degree to which they affect the cable properties is uncertain.

Qualification of electric cables is typically performed by type testing, in which a representative sample of the cable to be qualified is tested according to currently accepted standards. If the sample passes, similarity criteria are used to qualify other similar cables. Since samples are not required to be qualified from every batch of cable manufactured, the effects of variations in the manufacturing process may not be detected.

Questions:

Based on the above discussion, the following question has been identified:

G.1 How do variations in the manufacturing process, such as the use of different additives, variations in base materials, and variations in curing, affect the aging characteristics of electric cables, and how do these variations affect the qualification of cables?

Past Work:

Studies on the effects of fire-retardant additives by Sandia (4.41) concluded that these additives have a negligible influence on the degradation of EPR and CSPE materials under different thermal and radiation environments. Also, studies on EPR (4.42) show that radiation does not appreciably affect the rate of fire-retardant loss. Based on the loss rates noted in this work, it was concluded that within a 40 year service life, the loss of fire retardants due to aging should not be significant. This work also showed that Hypalon formulations become markedly less flammable on aging. This behavior appeared to be associated with the loss of flammable, volatile additives from the polymer.

A study on the effects of antioxidants by the University of Virginia (4.43) found that antioxidants were effective in providing material stability during thermal and radiation aging. No particular antioxidant was found to be superior to another in terms of the stability imparted to the material. This work shows that the presence of antioxidants in the material formulation affects the aging characteristics of the cable polymers. Therefore, variations in the amount used may affect the degree of stability provided. This work did not address the effect of variations in amounts, therefore, this remains an open issue.

In a study by Sandia (4.27) it was found that the aging characteristics of PE insulation had a color dependency. Black was found to be more stable than red, which, in turn, was more stable than white. It was theorized that the black insulation probably is more stable due to the use of carbon black in the formulation, which acts as an antioxidant.

While this literature review found only a limited number of studies related to variations in the manufacturing process, the work that was reviewed shows that these variations can have an effect on material aging characteristics. While the available information is not adequate to completely characterize the effect of these variations, limited evidence does exist to show that these variations can cause changes in material properties that are significant enough to affect qualification. Discussions with experts in the field indicate that although these variations are known to occur, the manufacturers do perform their own tests to ensure that the material formulations are acceptable to meet the design specifications of the cable. In addition, the cables must be manufactured according to industry standards, which provide a reasonable level of quality assurance.

Recommendations:

Based on the review of past work and discussions with experts in the field, the following recommendation is made:

G.1 Variations in the manufacturing process can lead to differences in the aging characteristics of cables; however, no work has been found that quantifies these differences or indicates that they can be significant enough to affect the qualification of the cables. This issue is unresolved; however, it is not recommended that specific additional research be performed to resolve it since manufacturer's tests and industrial standards provide a reasonable level of assurance that these variations are not significant. While no work is recommended, data obtained from other research performed in this program will be evaluated to gain insights into this issue. To make this feasible, the cables to be tested in this program should be "finger printed" using FTIR before any testing is done to determine the degree of variations in the cable material formulations. As they are tested, changes in physical appearance should be observed and noted for use in correlating visual attributes, such as color changes, with cable degradation.

2.8 Dossier H: Cable Construction

Background:

Low-voltage cables can be grouped into three basic categories; instrumentation cables, control cables, and power cables. Each of these cables has unique design specifications based on its intended application and can be constructed very differently. They vary in the number and size of conductors they contain, the type of materials used for the jacket and insulation, and the actual configuration of the cable itself. For example, instrumentation cables are typically constructed of shielded #14 AWG (American Wire Gauge) or smaller conductors, and are supplied as twisted pairs or triples, or coaxial and triaxial cables. Control cables typically contain #12-14 AWG conductors and may be single or multi-conductor cables, while power cables are typically #12 AWG or larger conductors. The number of conductors can influence the failure mechanisms of the cable due to the greater self heating effects with increased conductors. Damage due to insulation flow over long periods of time can occur in areas where one conductor is crossed over and pressed tightly against another conductor inside the cable during installation. Such insulation flow can continue during service in installed configurations that place high stress on the insulation, e.g., tight bends and long overhangs.

In addition to the number and size of conductors, the materials used to construct the cables also vary. For cables intended for applications where both temperature and radiation are expected to be high, special materials may be used. As examples, inorganic mineral insulation (MI) or polyimide film (trade name Kapton) typically are used. MI contains magnesium oxide, aluminum oxide or quartz insulation, which are hygroscopic and will absorb moisture in a humid environment. Therefore, these cables require a metallic watertight sheath. If the insulation is unprotected, possibly due to damage or degradation of the shield, the insulation resistance of the cable could be severely degraded causing the cable to fail. Also, the metallic sheaths used for protection (e.g., copper-bronze, stainless steel) cause the cable to be relatively stiff, which makes installation difficult and the cable more susceptible to installation damage.

Most cable insulations are manufactured by extruding and curing or vulcanizing the material blends directly onto the wire conductors. Kapton insulation cannot be extruded, but is manufactured in thin sheets precoated with Teflon-type copolymer that is an adhesive. The sheets are spirally wrapped in multiple layers around the wire conductors and the adhesive is fused at high temperatures. Although the capabilities of Kapton to withstand temperature and radiation may exceed 262°C (504°F) and 10^{11} Gy (10^7 Mrads), it is expensive and not as flexible as other materials, such as EPR or XLPE. Its elongation to break is relatively low ($\sim$70%) when new compared with other rubbery insulation materials (200% to 400%). Also, steam and sodium hydroxide tend to degrade Kapton. Therefore, it is susceptible to damage from humidity and must be protected from direct exposure to LOCA sprays.

Another variation in cable construction involves the jacket. The jacket protects the cable's insulation from mechanical damage, chemical attack, and fire. The principal jacket materials include Neoprene, CSPE (commonly called Hypalon), and PVC (polyvinyl chloride). Special braids or compositions of asbestos, glass, or cross-linked polyolefins are used as jackets for cables intended for applications in high temperature or radiation areas. In bonded jacket cables, the insulation and jacket are fused together and form a composite insulation. In this type of construction, the jacket and insulation cannot be easily separated and do not move relative to each other, as in unbonded jacket cables. This could have an effect on failure mechanisms. Often during the aging process, initially unbonded jackets may become effectively bonded.

Due to the large number of variations in cable construction, a cable manufacturer typically performs qualification testing on a particular insulation material (e.g., Rockbestos Firewall III) with several different cable constructions. This may include different conductor sizes, insulation thicknesses, jacket materials and/or configurations, or voltage/current ratings. Once the subject material is qualified for a set of generic plant conditions, all other cables manufactured with this material are qualified based on similarity criteria. These could include cables with construction variations, such as insulation thicknesses or configurations, that were not included in the original qualification tests, even though they could possibly have different failure mechanisms.

Questions:

Based on the above discussion, the following questions have been identified:

H.1 Do multi-conductor cables have different failure mechanisms than single conductor cables, and, if so, are they properly accounted for in the qualification process?

H.2 Do bonded jacket cables have different failure mechanisms than unbonded jacket cables, and, if so, are they properly accounted for in the qualification process?

H.3 Are specialty cables such as Kapton more susceptible to certain aging factors, and, if so, are they properly accounted for in the qualification process?

H.4 If failure mechanisms differ based on cable construction, under what conditions can qualification of one cable type be extended to another?

Past Work:

A significant amount of work has been done to investigate the various types of materials used in the construction of electric cables, however, few studies have addressed the issue of cable construction itself. For the issue of multiconductor cables, in work performed by Sandia (5.4) multiconductor cables constructed of EPR were found to have a higher propensity to failure during a LOCA compared to identical single conductor cable. This was attributed to severe dimensional swelling, specifically under simultaneous radiation and steam exposure, and raised a question of whether this is a generic problem with multiconductor cables. Several hypotheses were provided to explain why the multiconductor cables failed; these ranged from chemical interaction between the insulation and the jacket materials as they deteriorate, to stress buildup from the dimensional swelling and helicity construction of individual conductors in the multiconductor geometry. However, sufficient information was not available to draw a definitive conclusion. One view of this work indicates that the increased propensity to failure for multiconductor cables could be an artifact of the test methods used by Sandia. In particular, the penetrations used in the LOCA chamber could have caused differential pressures to develop between the inside and the outside of the cable during LOCA testing. This remains an open question.

On the issue of bonded jackets, recent Sandia testing (5.21, 5.22, 5.23, 5.25) has found that cables with bonded CSPE jackets cracked through to the conductor and subsequently failed during the post LOCA mandrel bend voltage withstand tests. Also, it was noted that after exposure to 2×10^5 Gy (20 Mrad) of radiation, the residual elongation of the cable, which included EPR insulation with a bonded CSPE jacket, approached zero. It was concluded that the cause of the bonded jacket cracking during aging was due to surface cracks which developed in the Hypalon jacket and, due to its integral bonding with the insulation, propagated into the insulation material. Although some cables with essentially zero elongation remaining after accelerated aging did show acceptable performance in subsequent LOCA tests, the observed degradation in the bonded jacket cables remains a concern. In subsequent work on damaged cables (5.34), similar bonded jacket EPR/CSPE cables developed cracks through to the conductor after radiation/thermal preaging and exposure to accident radiation, but prior to exposure to LOCA steam conditions. The exact cause is unknown, however, it was attributed to thermal aging of the bonded jacket material, which was thought to result in jacket cracking and propagation to the insulation, as discussed previously. Review of this work by others raised the possibility that the failures could have been due to the fact that the preaging sequence used was too severe since the cables were first exposed to full aging/accident radiation before being thermally aged. This is believed to be unrealistic. Based on this work, a definitive characterization of the behavior of bonded jacket cables remains to be determined.

Specialty cables, such as those with insulation using polyimide films (e.g., Kapton) or mineral insulation (MI) do have special characteristics under aging and LOCA conditions. In most cases, the use of specialty cable is limited; for example, Kapton is typically used for lead wires and mineral insulation cable is typically used for acoustic monitors. The most popular specialty cable is Kapton. A number of studies have been performed, including one by EPRI (4.46), to identify potential weaknesses of Kapton. This work showed that, if properly maintained, this specialty material can perform its intended safety function without premature failure. However, field experience has shown that this cable is very susceptible to nicks and other installation damage. The EPRI work also showed that if specialty cables using MI included a metallic water-tight sheath to protect them from moisture, they can provide acceptable performance. The main concern with this type of cable is at the interface with other cable or equipment where improper sealing can cause moisture intrusion problems. This information indicates that questions still exist concerning the use of specialty cable.

From the above discussion of multiconductor and bonded jacket cables, it is apparent that differences in cable construction could lead to different failure mechanisms. This would indicate that the use of similarity criteria for qualification of untested cables could be non-justifiable.

Recommendations:

Based on the analyses presented above, the following recommendations are made:

H.1 Since a question still remains as to why the multiconductor cables failed in the Sandia tests, this issue remains unresolved and it is recommended that additional research be performed. The research should include the preaging and LOCA testing of multiconductor and single conductor cable samples. Only one brand of cable needs to be tested; preferably that tested by Sandia. The LOCA tests should be performed first using the Sandia method; then repeated with test method anomalies corrected, such as using a different type of LOCA chamber penetration, to investigate the possibility of the cable failures being an artifact of the test method. In addition, the cable should be filmed or video taped during the LOCA test to provide visual evidence of the failure mode.

H.2 Since the reasons for the failure of cables with bonded jackets in the Sandia tests were not clearly understood, this issue remains unresolved and it is recommended that additional research be performed. The research should repeat the Sandia tests using the same cable materials to verify the previous results. The cable samples should be preaged both using the Sandia method and using a method typically used in a qualification program. The degradation should be monitored during aging, so that the failure mechanism attributed to this failure can be understood.

H.3 The use of specialty cables is very limited, and studies have been performed to identify and document the characteristics of the insulation types, however, a number of questions still exist. Many of the problems associated with this class of cable materials can be alleviated by implementing proper installation and maintenance activities, and also by not exposing them to hostile environments. This can be achieved by appropriate actions on the part of the utility industry. Therefore, no further work is recommended.

H.4 Since past work has shown that variations in cable construction and materials can cause differences in failure mechanisms, the issue of using similarity criteria to qualify cables is resolved. The aging characteristics and LOCA exposure performance of cables may be quite different despite similarities in their basic materials. Therefore, it is not recommended that qualification data be extrapolated based solely on similarity criteria without further demonstration of the similarities in chemical composition, construction, and other manufacturing details. This issue is considered resolved.

2.9 Dossier I: Installed Environment

Background:

One of the most important elements affecting the degradation rate of cables is the environment in which they operate. Cables installed in a relatively mild environment would be expected to produce a lower aging rate than cables in a harsh environment. The cables can be exposed to a number of different adverse conditions, such as elevated temperatures and/or radiation fields, or high humidity. They can also be exposed to physical stresses, such as liquid impingement or adverse handling during activities such as maintenance and testing. Each of these stresses can affect the rate at which cables degrade. Therefore, the environmental qualification of cables must account for the environment in which the cables are expected to perform during their service life.

As part of the qualification process for cables, the environments they are expected to operate in must first be determined. This is usually done using information from plant design specifications and analyses, which provide a reasonable estimate of the global conditions in a certain area of the plant. However, they typically do not account for localized areas of high stress, such as extreme temperature or radiation, which can occur, for example, in the vicinity of a steam line, or close to the reactor core. If cables are routed through these "hot-spots" they could be exposed to stresses higher than originally anticipated, and their degradation rate could be accelerated. This could lead to "weak-links" in the cable that are susceptible to failure. Current qualification requirements do not account for these weak-links.

Other sources of weak-links include areas of high vibration, such as near rotating machines, and areas of high humidity or liquid impingement, such as near leaky pipes, valves, or other equipment which could expose cables to steam, water, oil, or chemical leaks. Weak-links can also be caused by accidental physical abuse, such as by maintenance activities in the area. Workers may accidentally cause cuts or gouges in the cable jacket or insulation by walking on them, dropping tools on them, etc. Also, these activities could accidentally cause high mechanical stresses or structural failure of cable supports due to stepping on them, inadvertent exposure of the cable to heating equipment, or a variety of other abnormal stresses. Clearly, since some of these are unpredictable events, they cannot all be accounted for in the qualification process.

Questions:

Based on the background discussion provided, the following questions have been identified:

I.1. To what degree do hot-spots occurring in the plants affect the degradation rate of a cable, and how does this affect the qualification of the cable?

I.2. To what degree do areas of excessive vibration occurring in the plants affect the degradation rate of a cable, and how does this affect the qualification of the cable?

I.3. To what degree do areas of water/steam/liquid impingement occurring in the plants affect the degradation rate of a cable, and how does this affect the qualification of the cable?

I.4. To what degree does accidental physical abuse due to work in the area, such as maintenance activities occurring in the plants, affect the degradation rate of a cable, and how does this affect the qualification of the cable?

Past Work:

At the 1993 EPRI Workshop on Cable Condition Monitoring, McGuire (4.5) described the polymer degradation program at the Perry Nuclear Power Plant. After five years exposure of cable samples to the plant environment, the average temperature and total integrated dose readings at five locations were presented showing temperature variations from 29°C to 60°C (85°F to 140°F), and radiation fields from 5×10^{-6} Gy/hr. to 1.6 Gy/hr. (0.0005 rads/hr. to 160 rads/hr). Participants at the NRC's EQ Workshop (4.6) expressed different opinions on defining the worst possible temperature and radiation levels inside the containment. Ceiling areas of the drywell at Riverbend, cable vaults and reactor cavities at the Yankee plants, and other hot spot areas were reported to have higher than normal temperatures and radiation levels (i.e., as high as 113°C (235°F) and 3 Gy/hr. (300 rad/hr)). These studies, along with discussions with experts in the field confirm that hot-spots exist.

In NRC Information Notice (IN) 86-49, degraded cable condition was discussed related to a local hot spot near a feedwater line where the thermal insulation had been removed for maintenance and never replaced. Also, IN 89-30 describes instances of excessive temperatures in PWRs and BWRs which could result in cable degradation. These reports support the concern related to hot-spots.

While hot-spots and other high stress areas have the potential to cause significantly accelerated degradation rates under certain conditions, very little operating data is available showing cable failures (not including splices, terminal ends, and other cable appurtenances). However, this may be because there are no reporting requirements, or the cables were replaced. There have been instances of cables in hot spot areas being replaced before the end of their qualified life. This lack of failure data may also indicate that these failures are not being detected due to the lack of effective condition monitoring methods, or the cables have not yet aged enough to fail, or the failures will not be detectable until the cables are exposed to accident conditions. No clear answer could be obtained from the literature reviewed.

Ongoing efforts by EPRI (4.49) in conjunction with the University of Connecticut and several member utilities may provide useful results in defining these hot-spots. In this program, artificially aged cables will be compared with cables that are being naturally aged by placing them in an actual plant environment. No results have been obtained yet since the program began in 1985 and cable specimens have not had sufficient time to age significantly.

A number of cables accidentally damaged during maintenance activities have been reported in LERs (2.4). Sandia performed studies (5.34, 5.35) on artificially damaged cables to investigate the effects of cuts and gouges on cable performance. In this work, various sizes of insulation damage were artificially simulated on cable samples, then the samples were aged and/or LOCA tested. It was found that there is a minimum thickness of insulation required for the cable to successfully perform its design function. If the insulation thickness is below this minimum level, the cable could fail. These findings show that, if the damage is severe enough in terms of the amount of insulation removed, accidental damage can increase the susceptibility of a cable to failure.

In a study performed by Sandia (5.25), XLPE and EPR cable samples that had successfully passed a LOCA test were subsequently tested to failure by increasing the temperature. The results indicated that the cables had a margin of several hundred degrees above the highest expected operating temperature before they failed. In addition, plants have postulated operating and design basis accident conditions that are significantly less severe than simulated in qualification standards, including aging radiation doses on the order of 5×10^4 to 10×10^4 Gy (5 to 10 Mrads) instead of 50×10^4 Gy (50 Mrads). This may indicate that sufficient margin is built into the qualification requirements to account for these hot-spots, however, this could not be confirmed from past work.

Recommendations:

Based on a review of past work performed on this subject, and discussions with experts in the field, the following recommendations are made for each of the issues identified:

I.1 Past work and experience show that hot-spots and other weak links exist; however, the degree to which they accelerate the degradation rate of cables is very plant specific. Past work has not, and can not completely resolve this issue, therefore, it remains unresolved. 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, it would be better for individual plants to survey suspected areas of the plant to identify and characterize hot-spots and weak links. Once these have been identified, the use of Condition Monitoring techniques should be used to evaluate cable condition and predict residual life. Therefore, the research on CM will provide useful findings to address this issue and should be a major focus of this program. Current plans are to obtain naturally aged cable samples and artificially aged cable samples, and perform comparative CMtests on them. Some samples will then be LOCA tested. This will provide data which can be used to evaluate the effectiveness of the CM technique for monitoring cable condition and predicting LOCA survivability.

I.2 Same as 1.

I.3 Same as 1.

I.4 Same as 1.

2.10 Dossier J: Installed Configuration

Background:

The manner in which electrical cables are installed can play an important role in determining the degradation mechanisms that the cable is exposed to. Mechanical stresses imposed during installation of the cable may damage it. Also, the configuration in which the cable is installed can lead to degradation that takes place over long periods of time. Cable runs must sometimes cover large distances in nuclear plants. This typically requires that the cables be routed through a variety of different configurations which include not only straight, horizontal runs, but also bends and vertical runs. The cable runs can be supported in a number of ways, including installation in cable trays or inside conduit. Each of these configurations can induce different mechanical stresses on the cable which can influence the degradation rate of the cable.

When cable is installed inside conduit, it is typically pulled through the conduit using a pull cord. If not done properly, this can cause mechanical damage not only to the cable being pulled, but also to any cable already inside the conduit due to abrasion, cutting, or gouging as the cable is pulled through. Also, if too much force is used to pull the cable through long runs or through tight bends, damage can occur due to stretching of the insulation/jacket materials.

For cables installed in cable trays, several different stresses may be imposed. First, cables on the bottom of the tray could be exposed to compressive stresses due to cables piled on top of them. This could cause crushing damage if the weight is large enough. Secondly, excessive packing of the cables in the tray could limit heat dissipation causing overheating of the cables due to self-heating. Other potential problems with cable trays are that cables can overhang sharp tray edges, and improper installation of trays between different elevations can cause exposure of the cables to sharp tray edges.

Another concern associated with cables in trays is that they are typically sprayed with fire protection coatings to protect them from external sources of fire or extreme heat. This can prevent cables from dissipating the heat developed from internal heating, thus causing them to be exposed to temperatures in excess of design conditions. Also, fire protective coatings absorb moisture, which could keep cables wet and accelerate their degradation.

An additional potential problem with installation configurations are bends and unsupported vertical runs. If bend curvatures are too great, high mechanical stresses can be developed which can squeeze the conductors inside the cable together. Over time, the conductors can move through the soft polymeric insulation material causing a short. This is known as creep short circuit. If the cable is run vertically after a bend, the weight of the cable itself can cause high pressure at the bend, if it is not properly supported. In addition to creep short circuit, the residual stresses imparted to the cable can lead to cracking as the cable ages and the material becomes embrittled. These cracks can be potential sources of failure if moisture is present to create a short circuit to the exposed conductor. Another potential problem is the pressure point at cable supports or cable ties for vertical rise cables.

The extent to which these installation concerns impact the degradation rate of electric cables is variable and depends on the specific installation. As such, qualification requirements cannot explicitly account for each of these potential problems.

Questions:

From the background information discussed above, the following questions have been identified:

J.1 Do installation configurations such as bends, vertical runs, and overhangs impose additional stresses on the cables that are significant enough to affect the cable degradation rate, and, if so, are current qualification requirements sufficient to ensure that accident survivability is not compromised by these stresses?

J.2 Are the stresses imposed on cable due to installation in cable trays or conduits significant enough to affect the cable degradation rate, and, if so, are current qualification requirements sufficient to ensure that accident survivability is not compromised by these stresses?

J.3 Are the stresses imposed on cable due to fire protective coatings significant enough to affect the cable degradation rate, and, if so, are current qualification requirements sufficient to ensure that accident survivability is not compromised by these stresses?

J.4 Are the stresses imposed on cable due to improper installation significant enough to affect the cable degradation rate, and, if so, are current qualification requirements sufficient to ensure that accident survivability is not compromised by these stresses?

Past Work:

Cable damage due to improper installation is a known problem which received increased attention in the mid-1980s when concerns were raised that cable at two plants were damaged due to installation pulling, unsupported vertical runs, and crushing (2.1). This was felt to be caused in part by the fact that no standards for cable installation good practices were available in the early years of plant construction. This led to concerns that damaged cable might not be capable of performing its safety function. Subsequent to this, industry efforts were made to develop guidelines for installation good practices (2.1). Additionally, a number of studies were performed to investigate installation damage at several plants. These studies showed that the worst damage conditions were typically detected during the first few years of plant operation. Cables with less severe overstress, however, might not exhibit problems until later stages of plant operation. Furthermore, absence of problems during normal service is no guarantee that overstressed sections will not encounter problems during a DBA.

While installation damage has occurred, there exists very little operating experience indicating that cable bends, vertical runs, overhangs, cables inside conduits, or cables covered with fire protection coatings are exhibiting higher failure rates than expected. A review of LERs shows that cable failures due to installation damage have been reported (2.4). These failures are considered to be random and no aging trend was observed by industry (2.4). However, no evidence was found to show the percentage of currently installed cables with installation damage that are currently operating, but would fail under accident conditions. Also, as plants continue to age and the degradation mechanisms introduced by improper installation are given additional time to propagate, cable failures caused by installation damage could become more frequent.

In work performed at Sandia, cable degradation due to bends and vertical runs was examined (4.44, 4.45). In this work, a literature review was performed that showed when cables are not mechanically stressed or handled after installation, direct electrical-field breakdown, as well as thermal runaway is very unlikely, even after long-term exposure to high temperatures and radiation. Based on this, the highest potential for cable failure was determined to be cable that was mechanically stressed, such as due to installation damage or severe bends. Single-conductor, 600 volt power cables with EPR insulation and Hypalon jacket were subsequently tested to investigate two cable failure mechanisms: creep short-circuit and cracking induced by mechanical stress.

This work (4.44, 4.45) found that creep short-circuit was observed to occur in a relatively short period of time (hours or days) under conditions of high temperature (greater than 175° C (347°F)) and high pressure (greater than 35 kg/cm^2 (500 psi)). The high pressure could be caused by the weight of the cable itself in unsupported vertical runs, if the run is long enough. Using the critical stress of 35 kg/cm^2 (500 psi), critical overhang lengths for different cable sizes were calculated. Under less severe conditions, long term temperature and radiation hardening were found to slow down creeping and tend to decrease the likelihood of creep short-circuit. Two other phenomena were also found to decrease the likelihood of creep short-circuit over time. First, the strands will position themselves so that the effective support areas increase. Second, plastic bending of the wire further increases the effective support area. With this, the effective stress decreases and creep slows down.

The investigation of crack failure (4.44, 4.45) focused on two important cracking scenarios; cracking of undisturbed cables in (long) conduits, and cracking of cables due to bending during maintenance. It was found that in both cases, the appearance of cracks correlates well with the polymers reaching a certain critical strain-to-break factor (e.g., $e/e_o \sim 0.02$). However, if cables are bent during maintenance after being heated then cooled, the time for cracking to occur can be accelerated. It was also noted that, for materials exposed to very high temperatures (greater than 204° C (400°F)) for even a few days, cracks will develop without any other stress being applied. This work indicates that bending during maintenance and high temperatures can accelerate cable degradation.

Sandia performed studies (5.34, 5.35) on artificially damaged cables to investigate the effects of cuts and gouges on cable performance. In this work, various sizes of insulation damage were artificially simulated on cable samples, then the samples were aged and/or LOCA tested. It was found that there is a minimum thickness of insulation required for the cable to successfully perform its design function. If the insulation thickness is below this minimum level, the cable could fail. These findings show that, if the damage is severe enough in terms of the amount of insulation removed, accidental damage can increase the susceptibility of a cable to failure. This type of damage could be caused by improper installation.

On the issue of fire protective coatings, a great deal of work has been performed to investigate concerns related to its use. This work indicated that fire protective coatings are not a problem in terms of accelerating the degradation rate of low-voltage cables.

No other work related to the investigation of installation configurations was found in this literature review. However, the reports cited indicate that this can induce failure mechanisms that would not normally be present. Since this is very installation specific, the qualification requirements cannot address them explicitly.

Recommendations:

Based on the review of available literature and discussions with experts in the field, the following recommendations are made:

J.1 The literature shows that certain high-stress installation configurations, such as bends, vertical runs and overhangs can impose additional mechanical stress on the cables and potentially contribute to cable failure. While some work has been done to investigate these phenomena, questions still remain as to the severity of this problem; therefore, this issue is unresolved. It is recommended that additional testing on naturally aged cable specimens be performed to assist in the resolution of this issue. Naturally aged cable samples that are representative of the types of installation damage of concern should be obtained and LOCA tested to determine if their accident survivability has been compromised. Alternatively, existing test reports should be solicited which document testing of cables subjected to these stresses. If past tests can demonstrate that those installed configurations are not a concern, this issue can be resolved without additional testing.

J.2 Same as 1.

J.3 A sufficient amount of work has been done studying the use of fire protective coatings on cable trays. This work indicated that these coatings are not a concern for low-voltage electric cables. However, if samples are available, it is recommended that they be obtained and tested as a means of verification of past work.

J.4 Studies performed related to the influence of installation damage on the accident performance of cables indicate that this type of damage is typically detected during the first few years of operation. However, questions still remain as to the extent and severity of installation damage and its potential affect on accident performance. Therefore, this issue is unresolved. While no specific new work is recommended, if samples are available, it is recommended that they be obtained and tested as a means of providing insights into this issue.

2.11 Dossier K: Condition Monitoring

Background:

As discussed in relation to the other issues, there is a wide variation in the construction of electric cables; including the materials used, the number of conductors, the thickness of insulation and jackets, and the configuration in which the cable is put together. These variations, together with the environment in which the cables are installed, will affect the rate and degree to which the cables will degrade. The degradation of the various components of the cable will, in turn, affect the performance of the cable. To ensure the cable will perform its safety function when needed, it is desirable to monitor the condition of its various components. Various condition monitoring (CM) techniques are used for this purpose.

Since electric cables have a qualified life of 40 years, and are not routinely replaced in nuclear plant applications, it is highly desirable to be able to determine the condition of those cables that are currently in service. This information is important from a safety standpoint, with the ultimate goal of performing CM being to provide a means of predicting accident survivability for the cable. Also, it would be valuable input for deciding whether existing cables can remain in service throughout the licensed period, and possibly through an extended license period, or whether they need to be replaced. The high cost of replacement is another factor that makes effective condition monitoring desirable since casual replacement of cables is not a realistic option for utilities.

The type of CM technique used depends on the component to be monitored and material property being measured. Some techniques measure cable degradation by monitoring the chemical or mechanical properties of the polymeric materials used in the jacket or insulation. Other CM techniques may measure the electrical properties of the cable. No matter what property is measured, a correlation must be available to relate the measurement to cable performance degradation. From the previous discussion it is apparent that the variations in cable materials make it inherently difficult to find one technique that can effectively monitor the conditions of all types of cables.

There are many factors which must be considered in determining the effectiveness of a CM technique. Not only must it be able to measure a cable property that can be correlated to performance degradation, ideally it should also have the following characteristics:

- non-destructive/non-intrusive
- does not require disconnection of equipment
- can be related to an identifiable failure criteria
- applicable to a wide variety of materials
- reproducible and trendable
- able to detect "hot-spots" or "weak links"
- less expensive to implement than replacement
- not too complex or difficult to perform under field conditions

It is not expected that any one technique will satisfy all of these criteria, however, the more it does meet, the more attractive it will be.

Questions:

Based on the discussion presented above, the following questions have been identified:

K.1 What existing and promising new CM techniques are available to monitor the condition of electric cables?

K.2 How effective are the various CM techniques identified in (1) at determining cable condition?

K.3 Can the CM techniques identified in (1) be used to predict accident (e.g., LOCA, MSLB) survivability?

Past Work:

A great deal of research work has been conducted investigating various CM techniques as they apply to common cable insulation materials. Polymers used in cable insulation systems undergo changes in the chemical structure due to thermal oxidation, radiation induced oxidation, and other chemical reactions. These involve both physical and chemical property changes. Researchers have been studying the effectiveness of various test methods to detect these changes. In work performed by Sandia on cables made of XLPE (5.21) and EPR (5.22), elongation-at-break was found to be the best CM technique for EPR materials. Elongation measurements have been used by many researchers as a benchmark for comparison of other techniques. Hardness measurements and density measurements look promising for some materials.

Indenter measurements were also found to be useful at trending aging degradation. This is a relatively new technique being used by the industry to trend cable degradation. The indenter is a non-destructive device that measures the compressive modulus of cable jacket and insulation materials. In work performed by EPRI (6.26, 6.27), this method was found to be useful to measure the degradation of EPR, CSPE, PVC, Neoprene, Butyl Rubber, and Silicone Rubber. It was not found to be very useful for XLPE, however, a subsequent Swedish Study (6.28) showed good results for XLPE, as well as EPR. This technique shows potential for monitoring cable condition, and is desirable since it can be performed insitu without damaging the cables.

As polymers age, changes occur in the infra-red spectrum of the material, primarily in functional groups such as carbonyl, hydroxyl, and carboxyl groupings. A technique known as Fourier Transform Infra-Red (FTIR) spectroscopy measures these changes in the spectrum. In work presented to the IAEA (6.17), this technique was used successfully on fire retardant XLPE material that was aged by irradiation. Other work (6.18) showed successful use of this technique on thermally aged XLPE. While it has not been demonstrated on all common cable materials, past work has shown that the FTIR technique is a potentially effective means of predicting residual life.

For cable materials containing antioxidants, such as XLPE and EPR, the amount remaining can be determined by measuring the time taken for the onset of exothermic oxidation as a small sample of material is heated. This technique is known as Oxidation Induction Time (OIT) measurement. As an alternative, the temperature at which the onset of oxidation takes place can also be measured. Work performed by Stonkus (6.18) has shown this to be a useful technique for monitoring the condition of thermally aged specimens of XLPE and EPR. As the samples aged, the induction time decreased. Similar results were found for samples aged by irradiation. This work indicates that Oxidation Induction Time/Temperature are also potentially effective means of predicting residual life.

There are a number of different electrical tests that can be performed to obtain cable electrical parameters. However, the usefulness of these measurements for detecting degradation and their destructiveness need to be evaluated. Some of the more simple electrical tests are insulation resistance and polarization index. Other more complicated techniques include partial discharge testing, high potential testing, ac impedance measurements, and dielectric loss measurements.

Some of these electrical tests, including insulation resistance, polarization index, and high potential test, showed no consistent trend with age, and they were determined to be of little use in predicting residual life. Ontario Hydro used the insulation resistance and polarization index measurements on aged samples of SBR, PVC, butyl rubber, PE, and EPR (6.21). It was concluded that both of these techniques are insensitive to the advanced deterioration of aged cables. Similar findings were obtained in work by Sandia (6.32 and 6.33). These results were also confirmed in a joint U.S./French research effort (4.50).

While not shown to provide trendable data, insulation resistance has been shown to be useful for identifying gross damage in cable insulation due to grounding or moisture intrusion. Also, it was shown that insulation resistance measurement is an effective way to monitor the condition of the cables during the steam and chemical exposure in the LOCA simulation.

The research conducted by Sandia showed that capacitance and dissipation factor change noticeably as a function of insulation degradation for some materials (5.21, 5.22). Ontario Hydro also performed work on the use of ac impedance measurements on samples of butyl rubber naturally aged for 25 years in a thermal plant. The results of this work indicate that this technique can be used to detect partial discharge sites, which are potential sites of degradation. Consistent results between laboratory and insitu tests were obtained indicating that this technique may have potential as an effective CM technique.

Time domain reflectometry is a relatively sophisticated technique that is based on sending a low-voltage waveform with a fast transition time down a cable and measuring the time differential between the initial and reflected pulse. Reflections are generated by discontinuities in the cable, which could be sites of degradation. This technique was used to assess cable condition inside the reactor after the TMI accident (6.42) and was found to be a useful troubleshooting tool for locating potential failure sites.

Many other CM techniques have been and continue to be evaluated. BNL performed a review of the most promising ones, and identified their strengths and weaknesses (6.48). While no single method has yet been found that satisfies all attributes of an ideal CM method, a general consensus among researchers is that a combination of several test methods may provide the necessary information to effectively assess the condition of electric cable and predict accident survivability.

In addition to the techniques discussed above, a number of low cost, "common sense" techniques have been identified. These techniques are relatively easy to perform, are non-intrusive, and are inexpensive. While their effectiveness at predicting accident survivability is uncertain, they deserve evaluation due to their other desirable attributes, as previously discussed. The suggested techniques are the following:

- visual inspection
- simple hardness test
- current signature
- infrared thermography
- gamma radiation survey
- electro-magnetic field measurement
- functional test (same as, but in addition to that performed during LOCA)

Recommendations:

Significant research is needed to develop an effective means of monitoring cable condition in nuclear power plants. Based on this analysis, the following recommendations are made:

K.1 In a review performed by BNL, existing and promising new CM techniques that should be evaluated as part of the EQ research program have been identified. The strengths and weaknesses of each have been identified and recommendations made for inclusion in the program. This issue is resolved.

K.2 The effectiveness of the various CM techniques has not been completely determined in past work, therefore, this issue is unresolved. It is recommended that a research effort be initiated for a select group of techniques to be evaluated for their effectiveness. BNL has developed a CM Research Plan which outlines the approach to be taken in performing this research. It is also recommended that selected low cost monitoring methods based on a common sense approach be evaluated in the CM research program.

K.3 The use of the various CM methods for predicting accident survivability has not been adequately addressed in past work and needs to be researched, therefore, this issue is not resolved. It is recommended that the Condition Monitoring Research include an evaluation of the various CM techniques for 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. The detailed research approach is described in the BNL CM research plan (6.48).

The research efforts recommended in K.2 and K.3 should be designed to include the generation of data to resolve the issues for the following dossiers:

A.1	Arrhenius application
A.4	Activation energy estimates
I.1	Hot spots
I.2	Excessive vibration
I.3	Water/steam liquid impingement
J.1	Bends, vertical runs, overhangs
J.2	Cable trays, conduits
J.3	Fire protection coatings
J.4	Installation damage.

Of these, the issue resolutions for dossiers I and J may be limited by the availability of the naturally aged cables with the conditions of interests.

2.12 Dossier L: EQ for Present and Extended Life

Background:

The EQ rule, 10CFR50.49, established the current EQ requirements and allowed equipment that was already qualified by DOR Guidelines, NUREG-0588 Category I, or Category II to be considered as qualified. The discussion of this graded approach is in Dossier M.

Plants have demonstrated qualification of cables to DOR Guidelines, NUREG-0588 Category I, and Category II. Research testing has confirmed the successful performance of some similar cables, when exposed to similar qualification testing.

10 CFR 50.49 requires that equipment with significant age related degradation mechanisms be pre-aged prior to DBA testing. Emphasis is placed on establishing a qualified life for EQ equipment and verifying that as equipment ages, that assumptions regarding environments are verified in order for the qualification to remain valid. At the end of qualified life, equipment is replaced.

Qualified life has been established through type testing, experience, analysis, or a combination of these methods. Modifications to the qualified life, including extending and decreasing, are made if: 1) the service conditions, performance requirements, or accelerated aging models used during the original qualification process are demonstrated to be significantly different than was originally assumed, or 2) additional testing is performed.

Qualified life is the demonstrated period of time, prior to an accident that safety related equipment can remain in service. Qualified life is an estimate of time, based on a series of assumptions. Some of the significant assumptions are : normal operating temperature, heat rise, Arrhenius failure criterion (e.g., 50% elongation), Arrhenius relationship, normal radiation environment and primary stresses causing degradation (such as temperature and radiation). Qualified life has typically been established based on artificial aging techniques. EPRI is studying natural aging versus artificial accelerated aging. Limited results thus far, for common cable materials, indicate that natural aging may be conservatively predicted by artificial aging.

To account for the uncertainties in accelerated aging, type testing, and estimation of plant operating conditions, conservatisms are incorporated into the EQ process. However, anomalous degradation can occur during plant service, such as physical damage, misapplication, thermal or radiation hot spots, and installation, that can have an impact on qualified life estimates. Plants perform surveillance tests, inspections, and monitoring on systems and this provides some level of assurance that electric cables are performing as specified. In some cases it has identified unexpected degradation or other damage. There is no generally accepted insitu method for quantifying the level of degradation of electric cable insulation or predicting its remaining useful life.

There are several options available for consideration when electric cable has reached the end of its qualified life. Some options are:

1. Replacement with new cable
2. Requalification - type testing of similar cable that has been naturally aged, with additional artificial aging.
3. Requalification - type testing of similar cable that has been artificially aged.
4. Re-evaluation of initial assumptions.

Replacement is the most straightforward alternative, and, depending on the quantity of cable involved, may be the most costly option. Requalification utilizing naturally aged cable may be jeopardized since removal of cable may be traumatic and may add damage to test specimens. Requalification of artificially aged cables depends on the ability to locate sufficiently similar cables. Both of the previous methods assume that test cables are sufficiently representative of all similar plant cables. Re-evaluation of initial assumptions requires knowledge of general cable conditions and all assumptions, and may not be as straightforward as is commonly assumed, with additional conservatisms utilized when all assumptions are not verified.

There have been instances where cable in operating plants was unable to successfully perform its safety function for the period of time defined by the qualified life. Some of these instances were the cause of differences between assumptions and actual conditions. Some may be caused by differences in Arrhenius parameters and some have been caused by environmental factors originally considered insignificant.

The existing EQ process has focused on qualified life being a measure of time. The implication is that equipment is good for the qualified life, without any scrutiny, and at the end of qualified life, that it is no good and needs to be replaced. This ignores the realization that random failures continue to occur, that even redundant equipment could degrade at different rates and age related degradation may be insignificant for much equipment.

Questions:

Based on the above discussion, the following questions have been identified:

L.1 What are acceptable requalification options to extend the qualified life of electric cables?

L.2 Is the current definition of qualified life acceptable, or should it be modified?

L.3 How can operating experience be used to maintain or extend the qualified life of electric cable?

L.4 How can extension of qualified life be supported with the current qualification process?

Past Work:

Historically, EQ requirements have consistently favored the demonstration that safety related equipment is qualified for the DBA by testing. Thus, differences among EQ requirements have mainly focused on how and to what extent aging has been addressed. The integrity of DBA tests used as the qualification basis has been reviewed in past research. Research, such as NUREG/CR-5772 and NUREG /CR-5655, have tested a variety of cables, originally qualified to DOR, NUREG-0588 Category I or Category II. The cables that passed show that there is little difference in performance between the requirements and that significant margin still exists. Additionally, NUS EQDB has summarized qualification documents for a variety of cable. Review of this summary notes that some cable materials have been qualified to DOR Guidelines and NUREG-0588 Category I. This doesn't indicate that all cables originally qualified to DOR Guidelines could be qualified to NUREG-0588 Category I. However, the aforementioned research and the NUS data did not find any evidence that there was any difference in performance for cables qualified to DOR Guidelines, when tested to IEEE Std 323-74 requirements.

Most of the research applicable to maintaining and extending EQ centers upon verification and refinement of the accelerated aging models, particularly, the Arrhenius equation for thermal aging and the equal dose/equal damage assumptions for radiation. These efforts regarding accelerated aging models are described in Dossiers A, B, and C.

Among the parameters that have been difficult to quantify in the original qualification of electric cable are the plant environments and the actual performance requirements during normal service. Many utilities monitor plant environments and operating conditions, and have accumulated a substantial amount of operating experience data. This data provides a more precise measure of normal service conditions, the expected variations that may be encountered over several years of operation, and information on extreme conditions or "hot spots." This data may be useful to maintain current qualification programs, as well as to support extended life.

Re-qualification options include continuing with the requirements as is and allowing only 10 CFR 50.49 qualification. Research to date has not identified a technical need to discard DOR Guidelines.

In NUREG/CR-5772, cables were aged to the equivalent of 20, 40 and 60 years and, except for Dekorad cable materials, there was little difference in performance of cables. It was concluded that the cables tested should be able to survive a 60 year life and LOCA. Thus, some testing has shown that certain cables may be capable of extended life. Additionally, testing has not identified a definite life limit for a variety of cable materials. All of this testing has relied on artificial aging techniques using Arrhenius theory.

The status of aging research is characterized as having:

a) Considerable successful performance of cable when artificially aged, through the original qualification,

b) Confirmatory research that many cable types can operate for longer periods of time, when judged by artificial aging methods,
c) Limited studies using naturally aged cables,
d) Knowledge that some cables have failed in service before reaching the end of their qualified life,
e) Inferred in service performance information,
f) Little direct cable condition information.

Thus, significant information is as yet unknown on the performance characteristics of naturally aged cable. Research, which is proposed, will add significant information on naturally aged cable and the performance capability of naturally aged cable in LOCA conditions. Performance testing of naturally aged cable during LOCA is proposed, as well as CM tests to characterize the naturally aged degradation and the degradation from further testing. The results of this effort will provide a significant amount of the remainder of the technical basis to evaluate the re-qualification options.

Some previous research has focused on an attempt to characterize the aging model. Guillen and Clough have conducted research in models for predicting aging degradation of various cable insulation materials. Their time-temperature superposition model (4.17) was later expanded to become a time-temperature-dose rate superposition model to combine the effects of thermal and radiation environments (4.47 and 4.48). They emphasize caution in extrapolation for life prediction due to uncertainties in determination of activation energies, dose rate effects at low to medium dose rates, and complex relationships between time and temperature for polymers. There is some evidence that the model is overly complex.

Sandia has performed some long term aging degradation studies and research type testing of electric cables for specimens pre-aged by accelerated thermal and radiation techniques to an equivalent of as long as 60 years of service (5.21, 5.22, and 5.23). The research found that, when properly installed, most of the cable products tested (which included XLPO, EPR, and XLPE insulated cables from several major cable suppliers) should be able to survive an accident after 60 years of service for total aging doses of at least 150 kGy (15 Mrads) or higher (depending upon the material) and for moderate ambient temperatures (46-54 °C, 115-130°F). To assess what additional qualification requirements might be needed beyond the current nominal 40-year qualified life, the accident performance of cables aged to three different lifetimes were compared.

More recently, Sandia has conducted research on the accident performance and electrical performance of damaged cables. This work included preaging to equivalent lifetimes of as long as 60 years (5.34). Insulation thickness was less a factor in performance of low voltage cables than configuration. Failures in bonded CSPE jacket material propagated into the insulation material on certain cables.

In the absence of accidents, operating experience applies essentially to normal service. A key element is the identification of weak links and hot spots. Where the service environment has been adequately monitored and shown to be less severe than the service environment assumed in qualification, it is argued that operating experience can be used to justify a longer period of normal service than the period established initially. Conversely, if the actual service environment is more severe than was assumed, the allowable service period needs to be reduced - or other corrective action needs to be taken. Operating experience may also reveal unforeseen degradation and failure modes.

The current practice is to define qualified life in terms of time, with caveats that all assumptions are valid. It appears that research and experiences have shown that the reliance on a strict "time" based qualified life should be evaluated. It is apparent that the term qualified life should be broadened to include the concept of qualified condition. What is important is that the condition of safety related equipment remain high. As long as equipment condition is high, it is within its qualified life. When equipment condition trends toward unacceptable limits, then action needs to be taken to correct the degradation or replace the equipment. This concept is known as "Condition Based Life" (5).

"Condition Based Life" (CBL) recognizes from experience that the same equipment may age at different rates and experience different degradation due to location near hot spots, differences in manufacturing, differences in date of manufacture, maintenance, etc. It also recognizes that knowledge of the conservatism in Arrhenius accelerated aging methodology will not be fully understood until the completion of decades of natural aging. Knowing the condition of each piece of safety-related equipment is preferable to just knowing the time at which it should be replaced. Modern maintenance tools, such as Infrared Thermography, Current Signature Analysis, Vibration Signature Analysis were not in existence when EQ philosophy was generated. An opportunity now exists to review the EQ philosophy in light of existing technology and utilize the experiences to date. When maintenance obtains equipment condition information, the condition would be used as part of CBL. When no condition information is possible, the qualified life time would still apply.

Until now, the role of operating experience in EQ was largely undefined and thus not utilized. Operating experience which only documents that a piece of equipment has been inservice for a specific period of time and has operated properly, appears to be insufficient evidence to utilize it in EQ. What is missing is 1) some effective measure of equipment condition/performance, and 2) a relationship between the condition/performance and DBA performance. The CM and DBA testing proposed in current research will establish the condition and relationship for cables and thus show the method to allow operating experience in EQ.

The use of operating experience and CBL applies to EQ extended life. The research testing to date, including NUREG/CR-5772 and NUREG/CR-5655 show that there were no systematic differences in cables qualified for DOR Guidelines than NUREG-0588 Cat I, for artificially aged cables. The completion of CM and DBA testing on naturally aged cables and resolution of the multi-conductor versus single conductor issues will provide needed technical input to resolve this issue.

Recommendations:

Based on the review of past work, the following recommendations are made:

L.1 Previous confirmatory EQ research has identified no technical limitation on requalification options. However, the research has concentrated on artificial accelerated aging of test specimens. Since natural aging information is lacking, the issue is not resolved. Specific information from CM and LOCA testing is needed on naturally aged cables to resolve this issue. It is recommended that naturally aged cables be tested in naturally aged condition to provide the additional technical information to resolve this issue.

L.2 The current definition of Qualified Life is based on time only. This has significant consequences in relation to license renewal which would be difficult, if not costly to address. Little work has been done to explore the possibility of using a Condition-Based Qualified Life. Therefore, it is recommended that a demonstration technical position be generated for the cables undergoing testing from other issues in this program to broaden the definition of qualified life to include condition based life concepts.

L.3 Since little work has been performed related to assessing the methods for use of operating experience in EQ, this issue is not resolved. It is recommended that a demonstration technical position be generated, for the cables undergoing testing from other issues, to identify methods for the use of operating experience and the types of operating experience that can be utilized in EQ.

L.4 Previous confirmatory EQ research has identified that qualified life could be extended through the use of artificial aging methods, similar to those originally utilized for cables that had been artificially aged. However, the same limitations on assumptions that were made in the original artificial aging are still important factors and have not been significantly improved upon in research to date. Therefore this issue is not resolved. It is recommended that a demonstration technical position be generated, for the cables undergoing testing from other issues, to identify methods for extending qualified life.

2.13 Dossier M: EQ Graded Approach

Background:

The requirements for environmental qualification (EQ) of electric equipment originate from the General Design Criteria (GDC) 4 and 23. These criteria state, in part, that systems and equipment important-to-safety must be designed to withstand, without loss of function, the environmental effects of normal, abnormal and postulated design basis accident environments.

In May 1978, NRC issued Circular 78-08 highlighting licensees responsibility for Equipment Qualification. In NRC Bulletin 79-01 (February 1979) and 79-01B (January 1980), licensees were required to provide specific information on the qualification basis of their equipment important-to-safety. Issued with 79-01B, was "Guidelines for Evaluating Qualification of Class 1E Electrical Equipment in Operating Reactors," dated November 13, 1979, now known as the "DOR Guidelines." These guidelines were intended for existing equipment in a particular class of plants, i.e., operating reactors including Systematic Evaluation Program (SEP) plants, at the time of issue. The DOR Guidelines noted that equipment in other classes of plants, which had not yet been licensed to operate at the time, or replacement equipment for operating reactors, may be subject to different requirements such as those set forth in NUREG-0588, "Interim Staff Position on Environmental Qualification of Safety Related Electrical Equipment." NUREG 0588 was issued in December 1979.

The Division of Operating Reactors generated the DOR Guidelines to establish the guidance for EQ of operating plants. NUREG-0588 established Category II requirements for plants with construction permits before July 1, 1974 and Category I for plants with construction permits after July 1, 1974.

In 1980, NRC's Memorandum and Order CLI-80-21 (May 1980) clarified the licensing basis for EQ as follows: it designated operating reactors to meet the DOR Guidelines for EQ; it designated plants under licensing review to meet NUREG-0588; and it established NUREG-0588 Category I for replacement parts. When the EQ rule, 10CFR50.49, was issued in January 1983, it established the current requirements: to meet 10CFR50.49 for EQ and allowed equipment that was already qualified by DOR Guidelines, NUREG-0588 Category I, or Category II to be acceptable qualification methods. 10CFR50.49 does require new equipment to be qualified to 10CFR50.49. Thus, there is a graded approach to EQ, with the DOR Guidelines being the least stringent and NUREG-0588 Category I/10CFR50.49 being the most.

The DOR Guidelines and NUREG-0588, Category II expand EQ requirements beyond IEEE Std 323-71, while 10CFR50.49 and NUREG-0588 Category I are in general agreement with IEEE Std 323-74. Although the requirements of DOR Guidelines and NUREG 0588 Category I are very similar, there are some differences, such as the preaging required before the equipment is subjected to accident testing, the margins required, test sequence variations, and performance documentation. These variations have raised questions as to the acceptability of allowing equipment qualified under the old standards to be considered acceptable.

Questions:

Based on the above discussion the following questions have been identified:

M.1 Are preaging procedures based on DOR and NUREG 0588/Category II requirements acceptable in view of the (apparently) more severe requirements of NUREG 0588/Category I?

M.2 Are the differences in test parameter margins based on DOR and NUREG-0588/Category II versus those in NUREG-0588/Category I and 10CFR50.49 significant enough to affect the acceptability of past qualification results?

M.3 Are the differences in test sequence requirements based on DOR and NUREG-0588/Category II versus those in NUREG-0588/Category I and 10CFR50.49 significant enough to affect the acceptability of past qualification results?

M.4 Are the differences in accident profile variations based on DOR and NUREG-0588/Category II versus those in NUREG-0588/Category I and 10CFR50.49 significant enough to affect the acceptability of past qualification results?

Past Work:

The DOR Guidelines do not require preaging. A list of known short lived materials was included in the DOR Guidelines and plants were required to establish maintenance and surveillance programs for suspected short lived items. NUREG-0588/Category II also does not require preaging, except for valve operators committed to IEEE Std 382-1972 and motors committed to IEEE Std 334-1971, which must meet Category I. NUREG-0588/Category I does require aging, but only if a significant aging mechanism exists, which it does for cables. NUREG-0588/Category I is essentially the same requirement as 10CFR50.49.

NUREG-0588 Category I testing (5.21, 5.22, 5.23, 5.25) was performed on a variety of cables. Tests were performed with simultaneous radiation and thermal aging, followed by accident radiation, followed by steam testing. Cables were shown to have significant margin. The margin was demonstrated by testing cables to failure, by increasing steam temperatures, after they had already been aged and subjected to a two transient LOCA. Table M1 shows the cables tested, the radiation exposure and the peak temperature of the DBA steam test. The DBA was number AT3 of NUREG/CR-5772. The cables were further tested to failure in DBA number HTS3 of NUREG/CR-5655. The radiation exposure had been between 100 to 130 MRads.

The previous qualification of these cables is presented in Table M.2. The nuclear industry provided information on cable qualification parameters through the NUS EQDB, NUS EQ Database for Cables dated 9/23/94. Table M2 summarizes this information for the same cable types noted in Table M1.

Table M.3 compares the peak DBA temperature for each of these cable types and shows the DBA temperature margin, which is the difference between the original qualification peak DBA temperature and the DBA peak temperature at which failure occurred. Additionally noted is the original qualification basis: DOR Guidelines, NUREG-0588 Category II and NUREG-0588 Category I.

The significance of Tables M.1, M.2 and M.3 is to show that:

1) Out of the twelve cable types, 11 out of 12 have been qualified to a total integrated dose of greater than 200 MRads and one to 140 MRads;

2) Out of the eleven cable types which passed the AT3 Aging and LOCA sequence, eleven out of eleven were shown to have additional temperature margin of 222 °F to 404 °F over AT3 and; the five DOR Guideline cables tested were shown to have additional temperature margin of 357 °F to 404 °F over original qualification.

3) Out of the twelve cable types tested to a NUREG-0588 Category I test in AT3, five had been previously qualified to DOR Guidelines, one had been previously qualified to NUREG-0588 Category II and six had been previously qualified to NUREG-0588 Category I;

4) Five out of five of the previously qualified DOR Guideline cables passed the NUREG-0588 Category I testing.

In NUREG/CR-5772 (5.21, 5.22, 5.23), cables were aged to the equivalent of 20, 40 and 60 years. With the exception of the Dekorad cable materials, there was little difference in performance of cables and it was concluded that for the cables tested, they should be able to survive a 60 year life and LOCA. Since DOR Guideline plants and NUREG-0588/Category II plants are licensed for up to 40 years, the effect of the difference in preaging requirements appears to be moot.

NUREG-0588/Category I margins are the same as IEEE Std 323-74 and include a 10% time margin. 10CFR50.49 added a one hour time margin during LOCA for all equipment with operating requirements less than ten hours. The temperature margin is +15 °F, the accident radiation dose margin is + 10% and the accident pressure margin is ∓10%.

In NUREG/CR-5655 (5.25), cables which had already been preaged (thermal and radiation), and passed LOCA in NUREG/CR-5772 testing were subjected to a high temperature LOCA to establish ultimate capability. All cables which had not previously experienced problems were shown to have at least 200 °F temperature margin. These cables had experienced two LOCA transients successfully, until tested to failure. The peak conditions attained during this testing were 752 °F at 117 psig. These findings indicated that a margin of several hundred degrees was available for the cable types tested. The margin for pressure is more than twice the typical requirements. The cable types tested represent a significant cross section of cable materials and types. As noted in Table M.1, each cable material, except for the multiconductor Dekoron, did not fail until significantly higher DBA temperatures were reached. Failure here-in is defined as the point that the insulation resistance fell below 0.1 kΩ-100m.

Table M.1 Radiation and Peak Temperature Test Conditions of Cable types tested in NUREG/CR-5772 then NUREG/CR-5655, DBA Temperature at which Failure Occurred

	Supplier	Material	Total Average Integrated Dose (MRads)	NUREG/CR-5772 Peak Temp (°F)	NUREG/CR-5655 DBA Temperature {Failure @ 0.1 kΩ-100m} (°F)
1	Brand Rex	XLPE w/CSPE Jacket	119	347	725
2	Rockbestos	Firewall III, XLPE w/Neoprene Jacket	129	347	608
3	Raychem	Flamtrol XLPE	129	347	726
4	Samuel Moore	Dekoron Polyset, XLPO, w/CSPE jacket	113	347	569
5	Anaconda	Y-Flame-Guard FR-EP, EPR w/CPE jacket	128	347	742
5a	Anaconda	Flame-Guard EP, EPR, w/individual CSPE jacket and overall CSPE jacket	126	347	717
6	Okonite	Okolon, EPR w/CSPE jacket	126	347	729
7	Samuel Moore (Single Conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE jacket	120	347	698
7	Samuel Moore (Multi-conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE and overall CSPE jackets	120	347	Failed in NUREG/CR-5772
8	Kerite	FR w/FR jacket	113	347	702
8a	Kerite	FR w/FR jacket	117	347	702
9	Rockbestos	RSS-6-104/LE Coax	100	347	712
10	Rockbestos	Firewall Silicone	115	347	744
11	Champlain	Polyimide, Kapton	123	347	751
12	BIW	Bostrad 7E, EPR	130	347	707

Table M.2 Qualification Levels of Radiation and Peak Temperature of Various Cable Types from NUS EQDB

	Supplier	Material	Total Integrated Dose (MRads)	DBA Peak Temp (°F)	Qual Level	Referenced Report
1	Brand Rex	XLPE w/CSPE Jacket	200	385	CAT I	FIRL F-C5120
2	Rockbestos	Firewall III, XLPE w/Neoprene Jacket	200	341	CAT I	ROCK 5804 R3 7/2/87
3	Raychem	Flamtrol XLPE	200	357	DOR	FIRL F-C4033-1
4	Samuel Moore	Dekoron Polyset, XLPO, w/CSPE jacket	200	375	CAT I	EQ-CBL-017
5	Anaconda	Y-Flame-Guard FR-EP, EPR w/CPE jacket	200	385	DOR	FIRL F-C4836-2 1/78
5a	Anaconda	Flame-Guard EP, EPR, w/individual CSPE jacket and overall CSPE jacket	200	346	DOR	FIRL F-C4350-2
6	Okonite	Okolon, EPR w/CSPE jacket	200	340	CAT I	OKONITE RPT 266R-1
7	Samuel Moore (Single Conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE jacket	200	375	CAT I	NTS 558-1088
7	Samuel Moore (Multi-conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE and overall CSPE jackets	200	375	CAT I	NTS-558-1088
8	Kerite	FR w/FR jacket	200	325	DOR	FIRL F-C2737 041570
8a	Kerite	FR w/FR jacket	200	325	DOR	FIRL F-C2737 041570
9	Rockbestos	RSS-6-104/LE Coax	200	345	CAT I	ROCK QR-6802 R1
10	Rockbestos	Firewall Silicone	200	340	DOR	ROCK QR-7801 3/2/78
11	Champlain	Polyimide, Kapton	140	340		Note 1
12	BIW	Bostrad 7E, EPR	200	340	CAT II	BIW TR# B915 REV 1

Note 1: No record located in NUS EQDB for Champlain Kapton, so Haveg Kapton, Report West TR CWAPP-332 was used.

Table M.3 Comparison of DBA Peak Temperature Test Margin and Original Qualification

	Supplier	Material	DBA Temperature Margin (°F)	Original DBA Qualification Peak Temp (°F)	NUREG/CR-5655 DBA Temperature {Failure @ 0.1 kΩ-100m} (°F)	Qual Level
1	Brand Rex	XLPE w/CSPE Jacket	340	385	725	CAT I
2	Rockbestos	Firewall III, XLPE w/Neoprene Jacket	267	341	608	CAT I
3	Raychem	Flamtrol XLPE	369	357	726	DOR
4	Samuel Moore	Dekoron Polyset, XLPO, w/CSPE jacket	194	375	569	CAT I
5	Anaconda	Y-Flame-Guard FR-EP, EPR w/CPE jacket	357	385	742	DOR
5a	Anaconda	Flame-Guard EP, EPR, w/individual CSPE jacket and overall CSPE jacket	371	346	717	DOR
6	Okonite	Okolon, EPR w/CSPE jacket	389	340	729	CAT I
7	Samuel Moore (Single Conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE jacket	323	375	698	CAT I
7	Samuel Moore (Multi-conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE and overall CSPE jackets		375	Failed in NUREG/CR-5772	CAT I
8	Kerite	FR w/FR jacket	377	325	702	DOR
8a	Kerite	FR w/FR jacket	377	325	702	DOR
9	Rockbestos	RSS-6-104/LE Coax	367	345	712	CAT I
10	Rockbestos	Firewall Silicone	404	340	744	DOR
11	Champlain	Polyimide, Kapton	411	340	751	N/A
12	BIW	Bostrad 7E, EPR	367	340	707	CAT II

Since such wide margin exists between the ultimate capability of the cables and the requirements, the temperature margin of +15 °F, required of NUREG-0588 Category I cables is not an issue. All cables were required to have radiation tests in the DOR and NUREG requirements.

NUREG-0588/Category I and 10CFR50.49 require that the most significant sequence be utilized in qualification. DOR Guidelines and NUREG-0588/Category II require that known synergisms be addressed. The known synergisms were that thermal aging prior to radiation testing caused less or the same degradation as simultaneous radiation and thermal aging or radiation followed by thermal aging. A second synergism, low dose rate effects were also noted in Sandia testing.

In NUREG/CR-5772, cables were simultaneously aged (radiation and thermal) for the equivalent of 20, 40 and 60 years, using lower than typical dose rates. The data showed that for many cables the elongation was essentially zero at the time of the LOCA testing and they still passed the LOCA. Since simultaneous radiation and thermal testing were performed, a lower than normal dose rate was utilized, and cables that had previously been qualified to DOR Guidelines and NUREG-0588 Category II passed, this indicates that the effect of the synergisms for sequence and low dose rate effects are of little consequence to whether cables will operate properly during LOCA and prior qualification pre-aging differences had no significant effect on cable performance.

Recommendations:

Based on the review of past work, the following recommendations are made:

M.1 Past work has shown, for a sample of cables, that cables previously qualified to DOR Guidelines and NUREG-0588 Category II have passed qualification requirements which meet the most demanding and latest qualification requirements. Thus, no evidence exists that differences in preaging procedures between DOR Guidelines qualified cables and NUREG-0588 Category II qualified cables versus NUREG-0588 Category I requirements impact qualification results. Therefore, this issue is resolved and no further testing is recommended.

M.2 Past work has shown, for a sample of cables, that cables previously qualified to DOR Guidelines and NUREG-0588 Category II have passed qualification requirements which meet the latest qualification requirements. Additionally, the demonstrated DBA temperature margin has been shown to be at least 180 °C (357 °F) over DOR Guideline qualified cable. Thus, no evidence exists that differences in test parameter margin between DOR Guidelines qualified cables and NUREG-0588 Category II qualified cables versus NUREG-0588 Category I requirements affect the acceptability of past qualification results. Therefore, this issue is resolved and no further testing is recommended.

M.3 Past work has shown, for a sample of cables, that cables previously qualified to DOR Guidelines and NUREG-0588 Category II have passed qualification requirements which meet the latest qualification requirements, including simultaneous radiation and thermal aging and low dose rate effects. Eleven out of twelve cable types operated properly during testing to the latest qualification requirements. The one cable that had some samples pass and some samples fail is being recommended for further testing. Thus, significant evidence exists that differences in test sequence requirements between DOR Guidelines qualified cables and NUREG-0588 Category II qualified cables versus NUREG-0588 Category I requirements do not affect the acceptability of past qualification results. Therefore, this issue is resolved and no further testing is recommended, except as noted for the multiconductor bonded jacket cable.

M.4 Past work has shown, for a sample of cables, that cables previously qualified to DOR Guidelines and NUREG-0588 Category II have passed accident profiles which meet the latest qualification requirements. Additionally, the demonstrated DBA temperature margin has been shown to be at least 180 °C (357 °F) over DOR Guideline qualified cable, and the demonstrated DBA pressure margin has been shown to be at least 100% over DOR Guideline qualified cable. Thus, no evidence exists that differences in accident profile variations between DOR Guidelines qualified cables and NUREG-0588 Category II qualified cables versus NUREG-0588 Category I requirements affect the acceptability of past qualification results. Therefore, this issue is resolved and no further testing is recommended.

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APPENDIX A

COMPARISON OF EQ REQUIREMENTS IN SEVERAL COUNTRIES

CONTENTS

LIST OF TABLES

ACRONYMS

BSR	Basic Safety Rules
DBE	Design Basis Event
DBA	Design Basis Accident
EC	European Community
EQ	Environmental Qualification
GDC	General Design Criteria
HELB	High Energy Line Break
KTA	Kerntechnischer Ausschuss
LOCA	Loss of Coolant Accident
NSSS	Nuclear Steam Supply System
QL	Qualified Life
SAP	Safety Assessment Principles

A1.0 INTRODUCTION

Brookhaven National Laboratory is the prime contractor to the US Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES) for the Environmental Qualification (EQ) Research program. The principle objective of this program is to perform research on equipment within the scope of the NRC Rule 10 CFR 50.49 (1), with special emphasis on cables to seek answers to certain questions raised recently. These questions pertain to:

- the adequacy of the qualification established in older nuclear plants under the graded application of the qualification requirements as permitted by the Rule,
- the acceptability of qualification by similarity of several types of cable constructions based on qualification tests performed on certain types of cable construction,
- the adequacy of the qualification test methodologies employed until the early 1980s (which constitutes the bulk of the qualifications demonstrated in several of the currently operating plants) in light of the results from research conducted during the 1980s and since then, and
- the adequacy of the qualification demonstrated for the initial license term to address qualification during the license renewal period.

As a part of this effort, the NRC requested BNL to perform a comparative assessment of the EQ requirements and practices employed in other countries. This Appendix summarizes the results of this assessment. This Appendix begins (Section A2) with a brief overview of the EQ requirements and practices in the US. Sections A3 through A7 provide an overview of the EQ requirements and practices in UK, Sweden, Spain, Holland, Germany, France, Finland, Canada, and Belgium. For ease of reference, the contents of these sections are numbered in the same manner as that in section A2. Section A8 presents a comparison of the requirements and practices in all the countries reviewed in a tabular form. Section A9 presents the conclusions from this comparative assessment. Section A10 contains a list of references used and bibliography. Section A11 provides a glossary of terms used in the countries reviewed grouped by their general application context.

The scope of this assessment is limited to the US NRC's EQ Rule 10 CFR 50.49, i.e., electrical equipment important to safety located in harsh environment areas.

A2.0 EQ REQUIREMENTS AND PRACTICES IN USA

This section is divided into two subsections, first to discuss the regulations and standards that form the basis for EQ requirements in the US, and the second to present a discussion of the significant elements of EQ practices in the US nuclear industry.

A2.1 Regulations and Industry Standards

A2.1.1 Regulations

The requirements for environmental qualification of safety-related[1] electric equipment originate from the General Design Criteria (GDC) 2 and 4 (2). These criteria state, in part, that systems and equipment important-to-safety must be designed to withstand without loss of function, the environmental effects of normal, abnormal and postulated design basis accident environments. The Environmental Qualification Rule 10 CFR 50.49 was issued on January 21, 1983 to amplify the GDC requirements, and became effective on February 22, 1983.

A2.1.1.1 Scope of Applicability

The EQ Rule applies to safety-related electric equipment, non-safety related equipment whose failure could prevent satisfactory completion of its safety function, and certain post accident monitoring equipment that are located in harsh environment areas in a nuclear plant.

A2.1.1.2 What the Regulation Requires

The Rule requires licensees to establish a program for qualifying electric equipment covered by the above scope. Such a program must include the following key elements:

Equipment List

- A list of equipment to be qualified must be developed and maintained.

Environmental Conditions

- The environmental conditions must address the most severe Design Basis Event (DBE) during and/or following which the equipment must remain functional. The environmental conditions must include the applicable temperature, radiation, pressure, humidity, chemical sprays, and submergence conditions.

  Other NRC documents such as the DOR Guidelines (3), NUREG 0588 (4) and Regulatory Guide 1.89 (5) also contain requirements and guidance regarding the methods to be used for establishing the environmental conditions, particularly temperature and radiation for DBEs.

Qualification Methods

- Qualification must be demonstrated using tests, analysis, operating experience, or a combination thereof.
- Significant aging degradation affecting equipment performance must be addressed.
- Synergistic effects must be considered if they are expected to affect the safety-functional performance capability of the equipment.

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[1] Safety-related equipment (also referred to as Class 1E equipment in National consensus standards) is a subset of electric equipment important to safety.

- Margins must be applied to the test environmental parameters to account for uncertainties, such as those caused by production variations and test instrument inaccuracies.

Documentation

- Documentation demonstrating qualification must be auditable and traceable to the plant-specific equipment. Such documentation must contain information on the equipment performance requirements, and the environmental conditions under which such performance is expected. This document must be maintained in an auditable form for the entire period during which the covered item is installed in the plant, or is stored for future use.

Replacement of Equipment

- Replacement equipment must be qualified to the requirements of the Rule unless sound reasons to the contrary can be demonstrated. Examples of acceptable sound reasons to the contrary can be found in regulatory guide 1.89.

Grandfathering

- Existing equipment qualified to previous NRC requirements, such as the DOR Guidelines, or NUREG-0588, Category II, need not be requalified to the Rule's requirements. This provision of the Rule applies to those plants that were either in operation, or were close to receiving an operating license at the time the Commission Memorandum and Order CLI 80-20 (6) on environmental qualification was issued.

This provision of the Rule set the framework for the graded application of EQ requirements in US nuclear plants as shown in Table A1.1:

Table A1.1 EQ Requirements by Plant Vintage

Plant Vintage	EQ Requirements Applicable
Licensed to operate before May 1980	DOR Guidelines
Plants licensed to operate after 1980, but originally committed to IEEE Std. 323-1971.	NUREG 0588 Category II requirements
Licensed to operate after 1980 and committed to IEEE Std. 323-1974	NUREG 0588 Category I and full 10 CFR 50.49

A2.1.2 Industry Standards

The primary industry standard that addresses qualification of safety-related electric equipment, (also known as "the mother document"), is IEEE Standard 323-1974 (7). This standard is supplemented by a number of daughter standards, such as IEEE Std. 383-1980 for cables, that provide guidance on implementing EQ to specific equipment categories. The 1974 issue of IEEE Std. 323 forms the basis for the EQ requirements contained in the EQ Rule. The 1971 issue of the standard forms the basis for the qualification requirements contained in the DOR Guidelines and NUREG-0588 Category II. The significant differences between the two versions of the standard lie in their treatment of pre-aging of equipment prior to a DBE test, addition of margins to the test parameters and the sequence of performing the various tests.

A2.1.2.1 Scope of Applicability

As issued in 1974, the standard applies to *Class 1E electric equipment and interfaces*, which is a subset of equipment important-to-safety. It does not explicitly limit its applicability to equipment located in harsh environment areas in a nuclear plant and thus, it applies to all class 1E equipment in all plant areas.

A2.1.2.2 What the Standard Requires

The standard provides the principles and methods to achieve and maintain qualification. Key elements addressed in this standard include the following:

Equipment List

The standard does not address this topic. It is within the purview of other standards such as IEEE Std. 308, 627, 279, and 497. (9-14).

Environmental Conditions

- The environmental conditions must address the normal, abnormal, containment test, design basis event including the most severe DBA, and post-design basis event conditions during and/or following which the equipment must remain functional. The environmental conditions must include the applicable temperature, radiation, pressure, humidity, chemical sprays, and submergence conditions. The standard also contains appendices that provide examples of representative test environments for DBE tests.

Qualification Methods

- Qualification must be demonstrated using test, analysis, operating experience, or a combination thereof. The standard does state preference for demonstration by type tests on the actual equipment.

- Significant aging degradation affecting equipment performance must be addressed.

- Synergistic effects must be considered if they are expected to affect safety-functional performance capability of the equipment.

- Margins must be applied to the test environmental parameters to account for the uncertainties such as those caused by production variations and test instrument inaccuracies.

Documentation

- Documentation demonstrating qualification must be maintained in an auditable form, and be traceable to the plant-specific equipment. Such documentation must contain information on:

the equipment performance requirements,
the environmental conditions during and following design basis events (DBEs),
the method(s) chosen to establish qualification,
the applicability of the test analysis and/or operating experience data to demonstrate qualification,
the acceptance criteria for qualification, and
the qualified life objective.

Replacement of Equipment

The Standard does not address this area.

Grandfathering

The Standard does not address this area.

A2.2 EQ Practices

Environmental qualification programs implemented at US nuclear power plants generally consist of the following five elements:

- EQ Listing
- Qualification Specification
- Demonstration of Qualification
- EQ Documentation
- EQ Preservation

A2.2.1 EQ Listing

A list of equipment to be included in the qualification program is first established through a disciplined review of the postulated design basis events, and the plant systems and equipment. For all plants, this list also includes electrical and I&C equipment[2] located in areas that could experience environmental extremes during and following a DBA. The number of equipment included in this list varies (400 to 2000) with plant vintage reflecting the complexities of the plant systems. This list is maintained current.

A2.2.2 Qualification Specification

Environmental conditions are established for each area where safety-related equipment are located, taking into account the applicable design basis events including design basis accidents, such as loss-of-coolant accident and high energy line breaks. The plant environmental conditions are usually documented in a controlled document, such as a drawing or environmental design criteria specification.

Performance requirements for each equipment item are established as a part of developing the equipment functional and technical requirements specifications.

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[2] In some plants licensed to operate since 1980, the EQ list may also include other equipment important to safety such as certain mild environment equipment, active mechanical equipment, and certain passive mechanical equipment. It should be recognized that they are not within the scope of the EQ Rule.

For each category or group of equipment, a qualification specification outlining its performance requirements, environmental service conditions and acceptance criteria is generally developed and issued to the supplier. While this is true for the recent vintage plants, older plants generally may not have such a document.

These documents are generally part of the lifetime records for the plant.

A2.2.3 Demonstration of Qualification

Qualification demonstration is performed through a systematic review of data from type tests, analysis and/or operating experience for each plant item or group of items. This review takes into account the specific location of the equipment, associated environmental conditions, and equipment performance requirements. The review is documented in the form of qualification files developed for each item or group of items, as required. When necessary, additional tests and analysis are performed to supplement the test, analyses and operating experience data. A qualified life (QL)[3] is assigned to each qualified item. In addition, a field walkdown is performed to verify that the installed configuration matches that which is qualified. Deviations are addressed by either correcting the installation, or by justification with supplementary analysis.

A2.2.4 EQ Documentation

EQ documentation usually consists of the qualification files developed when establishing qualification as described before. These files consist of equipment specifications, qualification test reports, engineering reviews, calculations, and analysis. They are usually assembled for groups of similar items, make and/or location in the plant (e.g., Rockbestos cables used inside containment). For items in the scope of the EQ Rule, EQ files are maintained as part of the plant records.

A2.2.5 EQ Preservation

EQ preservation activities consist of the following:

- performing the contingent maintenance and periodic parts replacements
- extending the qualified life for limited QL items
- reviewing facility modifications and changes in design basis
- performing plant environment (temperature and radiation) surveys to verify original assumptions
- training of maintenance, engineering and QA/QC personnel involved in the EQ process
- Performing or participating in the root cause evaluation of equipment failures

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[3] Assignment of a qualified life is required only for items within the scope of the EQ Rule. However, it is common practice to use the same process for addressing the qualification of other items (e.g., mild environment or mechanical equipment) if they are included in the EQ program. The rationale is that this process makes it easier and perhaps cost effective to control EQ preservation activities.

- reviewing the replacement item procurement specifications
- maintaining the EQ documentation current.

These activities are integrated into the applicable plant programs and procedures.

A3.0 EQ REQUIREMENTS AND PRACTICES IN UNITED KINGDOM (UK)

EQ requirements and practices in the UK are similar to those in the US, although there are some variations. This section provides an overview of the UK requirements and practices, and also indicates where they differ.

A3.1 Regulations and Industry Standards

A3.1.1 Regulations

The requirements for environmental qualification of electric equipment categorized as Safety Category 1, originate from the Safety Assessment Principles (SAP) 139 and 140 (15). They state that "A qualification procedure should be in place to confirm that all safety systems and safety-related equipment will perform their required safety functions throughout their lives, under operational, environmental and specified (usually design basis) accident conditions. ...." The Nuclear Inspectorate (NII) staff is guided by these principles[4] when performing the safety assessment of an individual licensee program to verify qualification. The process of verification is similar to that used by the USNRC.

A3.1.1.1 Scope of Applicability

The EQ requirements apply to all (electrical, I&C and mechanical) Safety Category 1 equipment. Although the US EQ Rule applies only to harsh-environment electrical equipment important to safety, the General Design Criteria 2 and 4 (2), which are similar to the cited SAPs in the UK, do contain general requirements to address the qualification of all safety-related equipment.

A3.1.1.2 What the Regulation Requires

Unlike the US EQ Rule, there are no prescriptive requirements addressing environmental qualification in UK regulations. The SAPs cited above are construed to establish the framework for the following requirements:

Equipment List

- A list of equipment to be qualified should be developed and maintained.

Documentation

- SAP 140 states that "The equipment qualification procedure should ensure that adequate arrangements should exist for recording and retrieval of lifetime data from the manufacture,

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[4] Recent personal communications between S. Kasturi and David Andersen of UK-NII.

testing, inspection and maintenance of safety systems, and safety-related structures and components to demonstrate that any relevant assumptions made in the safety case remain valid throughout the design life of the plant." This is similar to a requirement found in the US EQ Rule, but is somewhat specific about the nature of the documentation required.

- Inspectorate staff verify that the documentation demonstrating qualification:
  - is auditable and traceable to the plant-specific equipment,
  - contains information on the equipment performance requirements, and environmental conditions during and following design basis accidents (DBAs), and
  - is maintained in an auditable form for the entire period during which the covered item is installed in the plant or is stored for future use.

Environmental Conditions

- The environmental conditions should address the most severe DBA during and/or following which the equipment must remain functional. The environmental conditions should include the applicable temperature, radiation, pressure, humidity, chemical sprays, and submergence conditions.
- No specific guidance or requirement is provided regarding the methods for establishing the environmental conditions.

Qualification Methods

- The regulations contain no specific requirements in this area. However, because the inspectors and licensees use the IEEE standards as the basis for demonstrating qualification, the general SAPs may be (indeed have been) interpreted to require the following:

Qualification should be demonstrated using tests, analysis, operating experience, or a combination thereof.

Significant aging degradation affecting equipment performance should be addressed.

Synergistic effects should be considered if they are expected to affect safety-functional performance capability of the equipment.

Margins should be applied to the test environmental parameters to account for uncertainties, such as those caused by production variations and test instrument inaccuracies.

Replacement of Equipment

- There are no specific requirements on this topic in UK regulations. The requirement regarding replacement items in the US EQ Rule was necessitated by the graded application of the EQ requirements based on plant vintage. Therefore, this may not be applicable since the cited SAPs are not generally applied retroactively to older plants.

Grandfathering

- Present regulations are silent on this topic. Again, this consideration may be moot if the EQ regulations are not applied retroactively.

A3.1.2 Industry Standards

UK NII and the industry use the IEEE Std 323 as the primary standard for addressing qualification of Safety Category 1 electrical equipment. This standard is supplemented by a number of daughter standards (e.g., IEEE Std. 383 for cables) that provide guidance on implementation to specific equipment categories. Therefore the discussion on the standards presented in sections A2.1.2 applies.

A3.2 EQ Practices

The implementation model for EQ programs in the UK is similar to that in the US and generally consists of the following five elements:

- EQ Listing
- Qualification Specification
- Demonstration of Qualification
- EQ Documentation
- EQ Preservation

Although there are some variations in the details, the program elements are implemented much like in the US and hence the discussion presented in section A2.2 applies. The concept of a qualified life is used for harsh-environment Safety Category 1 electrical equipment as well as certain mild environment and mechanical equipment included in their EQ List, again similar to the late vintage plants in the US.

A4.0 EQ REQUIREMENTS AND PRACTICES IN CANADA

EQ requirements and practices in Canada are similar to those in the US, although there are some variations. This section provides an overview of the Canadian requirements and practices, and also indicates where they differ.

A4.1 Regulations and Industry Standards

A4.1.1 Regulations

The requirements for environmental qualification originate from the Regulatory Documents R-7, R-8 and R-9 (26-28). Collectively, they state that qualification is required for all safe shutdown, ECCS, and containment equipment which may be required to operate, or to continue operating following exposure to the severe environmental conditions resulting from certain postulated events specified in these regulations. Qualification shall consist of tests and/or analysis.

A4.1.1.1 Scope of Applicability

The EQ requirements apply to all (electrical, I&C and mechanical) equipment in systems designated as special safety systems. Although the US EQ Rule applies only to harsh-environment electrical equipment important to safety, the General Design Criteria 2 and 4 (2), which are similar to the cited regulations in Canada, do contain general requirements to address the qualification of all safety-related equipment.

A4.1.1.2 What the Regulation Requires

Unlike the US EQ Rule, there are no prescriptive requirements addressing environmental qualification in the regulations. The regulations cited above are construed to establish the framework for the following requirements:

Equipment List

- A list of equipment to be qualified should be developed and maintained.

Documentation

- Documentation demonstrating qualification:

  should be auditable and traceable to the plant-specific equipment,

  should contain information on equipment performance requirements, and environmental conditions during and following design basis accidents (DBAs), and

  should be maintained in an auditable form for the entire period during which the covered item is installed in the plant or is stored for future use.

Environmental Conditions

- The environmental conditions should address the most severe DBA during and/or following which the equipment must remain functional. The environmental conditions should include the applicable effects of debris, steam, water, temperature, radiation, pressure, humidity, chemical sprays, and submergence conditions.

- No specific guidance or requirement is provided regarding the methods for establishing the environmental conditions.

Qualification Methods

- The regulations state that qualification shall be demonstrated using tests, or analysis, but contain no other detailed requirements similar to the US EQ Rule. However, because the inspectors and licensees use the IEEE standards as the basis for demonstrating qualification, in general, the regulations have been interpreted to require the following:

  Significant aging degradation affecting equipment performance should be addressed.

  Synergistic effects should be considered, if they are expected to affect safety-functional performance capability of the equipment.

Margins should be applied to the test environmental parameters to account for uncertainties, such as those caused by production variations and test instrument inaccuracies.

Replacement of Equipment

- There are no specific requirements on this topic in Canadian regulations. The requirement regarding replacement items in the US EQ Rule was necessitated by the graded application of the EQ requirements based on plant vintage.

Grandfathering

- Present regulations are silent on this topic. Discussions with Canadian utility staff indicate that backfits of the older plants are currently underway, and that they are likely to follow practices similar to those in the US. A graded approach to implementing EQ requirements to the older plants is being adopted.

A4.1.2 Industry Standards

The Canadian regulators and the industry use the IEEE Std 323-1974 as the primary standard for addressing qualification of Safety Category 1 electrical equipment. This standard is supplemented by a number of daughter standards (e.g., IEEE 383-1974 for cables) that provide guidance on implementation to specific equipment categories. Therefore the discussion on the standards presented in section A2.1.2 applies.

It should also be noted that a Canadian Standard on EQ is under development. Discussions with personnel involved in this development effort indicate that the standard will be quite similar to IEEE 323, except for minor variations to incorporate some of the practices unique to their nuclear industry.

A4.2 EQ Practices

The implementation model for EQ programs in Canada is similar to that in the US and generally consists of the following five elements:

- EQ Listing
- Qualification Specification
- Demonstration of Qualification
- EQ Documentation
- EQ Preservation

Although there are some variations in the details, the program elements are implemented much like in the US and hence the discussion presented in section A2.2 applies. The concept of a qualified life is used for harsh-environment electrical equipment as well as certain mild environment and mechanical equipment included in their EQ List similar to the late vintage plants in the US. Older plants may limit application of qualified life concept to harsh-environment electrical equipment only.

A5.0 EQ REQUIREMENTS AND PRACTICES IN FRANCE

EQ requirements and practices in France are comparable to those in the US, although there are some significant variations in the scope of applicability and qualification methodology. This section provides an overview of the French EQ requirements and practices and highlights the significant differences.

A5.1 Regulations and Industry Standards

A5.1.1 Regulations

The requirements for environmental qualification of electrical equipment important to safety originate from the Basic Safety Rules (BSR) IV.2.b, IV.1.a, and V.2.d (16-18). Collectively, these rules require that electrical systems and equipment important to safety, and required to function under harsh environments resulting from a DBA be:

- classified as Category k1[5], and
- designed and qualified[6] accordingly.

In other words, they must be designed to withstand without loss of function, the environmental effects of normal, abnormal and postulated design basis accident environments.

A5.1.1.1 Scope of Applicability

The Basic Safety Rules apply to *all electrical, I&C, and mechanical equipment important to safety.* However, the harsh environment qualification requirements are applicable only to those electrical and I&C (Category k1) equipment located inside the containment and required to perform their intended safety functions during and/or following a DBA.

A5.1.1.2 What the Regulation Requires

The BSRs *(although not explicitly)* require the licensees to establish a program for qualifying the electric equipment covered by the above scope. Such a program must include the following key elements:

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[5] Class 1E electrical systems are those that perform ECCS functions, or otherwise help prevent accidents or limit their radiological consequences. Equipment within the electrical systems are subdivided into three Categories, k1, k2 and k3.
k1 are those items installed in the containment which must perform their functions under environmental conditions corresponding to normal, accident and/or post-accident conditions, and under seismic loading.
k2 are those items installed in the containment which must perform their functions under environmental conditions corresponding to normal operating conditions, and under seismic loading.
k3 are those items installed outside the containment which must perform their functions under environmental conditions corresponding to normal operating conditions, and under seismic loading.

[6] Personal communications between S. Kasturi and EDF personnel indicates that the French are now considering the application of the harsh environment qualification requirements to electrical equipment located outside the containment, that could experience a harsh environment from HELB. Also, current French practice is to qualify certain harsh environment mechanical equipment similar to their electrical counterpart, i.e., Category k1.

Equipment List

- A list of equipment to be qualified must be developed and maintained.

Environmental Conditions

- The environmental conditions must address the most severe DBA during and/or following which the equipment must remain functional. The environmental conditions must include the applicable temperature, radiation, pressure, humidity, chemical sprays, and submergence conditions.

Qualification Methods

- Qualification procedures must be approved by the Safety Authorities (Different from USNRC's approach)

- Aging degradation affecting equipment performance must be addressed.

Documentation

- Documentation demonstrating qualification must be auditable and traceable to the plant-specific equipment. Such documentation must contain information on the equipment performance requirements, and environmental conditions during and following design basis accidents (DBAs). This document must be maintained in an auditable form for the entire period during which the covered item is installed in the plant or is stored for future use. (Implied requirement)

Replacement of Equipment

The BSRs contain no specific requirements in this area. Since the French approach apparently involves no retrofit, there is no need for this provision. However, from discussions with EDF and Framatome staff[7], it was learned that:

- They select equipment for a specific application for use in a vintage or group of plants. Then, they work with the vendor to qualify the equipment. At this point, the equipment design is frozen for this group of plants.

- They (mostly the licensee) in effect have complete control over the design. Any changes to the design or materials of construction can be made by the vendor only after licensee approval.

- In addition, the vendor is contractually bound to supply spare parts for a certain length of time, usually several years.

Grandfathering

The BSR was issued in 1985. It states that the BSR is applicable to "any facility granted a construction permit more than one year from its publication." It also states that no backfit is intended "unless explicitly

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[7] Personal communications between S. Kasturi and staff of Framatome and EDF.

required." Licensees may choose to update their facilities technically. Thus, there is no need for this concept.

A5.1.2 Industry Standards

The primary industry standard that addresses both design and qualification of safety-related electrical equipment is RCC-E (20). The BSR requires the licensees to commit to this standard, as well as an annual review and update of this standard. Qualification specifications are generated (usually for each equipment type) and agreed upon with the Safety Authorities for a group of plants. They are based on RCC-E, IEC 780 (19, 20), and the requirements of the BSR. These specifications then become the basis for the acceptable qualification scope and methodologies for that group of plants.

A5.1.2.1 Scope of Applicability

Information not available

A5.1.2.2 What the Standard Requires

Information not available

A5.2 EQ Practices

Implementation model for EQ program in France is similar to that in US and generally consists of the following five elements:

- EQ Listing
- Qualification Specification
- Demonstration of Qualification
- EQ Documentation
- EQ Preservation

The program elements are implemented much like in the US and hence the discussion presented in section A2.2 apply. The concept of a qualified life is used only for harsh environment electrical equipment.

A6.0 EQ REQUIREMENTS AND PRACTICES IN GERMANY

This section discusses the regulations and standards that form the basis for EQ requirements in Germany. The information presented in this section is based on a review of the KTA standards governing the design and qualification of reactor protection systems and incident monitoring systems, the European Community (EC) Qualification benchmark Group's Report (29), and the author's conceptualization of the regulatory and standards process from these. It appears that the German Atomic Energy Act titled "Act on the Peaceful Use of Nuclear Energy and the Protection Against its Hazards, originally issued in 1976 and then modified in 1980 is a broad based regulation. The intent of the regulation is implemented through the Safety Standards known as Kerntechnischer Ausschuss (KTA) standards which are developed and issued by the Nuclear Standards Commission, a consensus body with representation from various segments of the industry and regulators. Therefore, this section of the report does not contain a separate subsection to discuss the regulations.

A6.1 Regulations and Industry Standards

A6.1.1 Standards

The requirements for environmental qualification of electric equipment important to safety originate from the two Safety Standards of the Nuclear Safety Standards Commission, also known as KTA Safety Standards 3501 and 3502 (21, 22). The Safety Standards are issued to support the Atomic Energy Act, and are ratified by the fifty member Nuclear Standards Commission. These standards state, in part, that I&C and electrical systems and equipment important-to-safety[8] must be designed to withstand without loss of function, the environmental effects of normal, abnormal and postulated design basis accident environments.

These two standards are supplemented by a number of daughter standards such as KTA 3505 for transmitters (23-25), that provide guidance on implementing EQ to specific equipment categories.

A6.1.1.1 Scope of Applicability

The standards apply *only to electric and I&C equipment important to safety* regardless of where they are located in a nuclear plant.

A6.1.1.2 What the Standard Requires

The standard may be construed to require licensees to establish a program for qualifying equipment covered by the above scope. Such a program must include the following key elements:

Equipment List

- A list of equipment to be qualified must be developed, categorized into safety and nonsafety-related based on their functions. This list should be maintained current and accurate.

Environmental Conditions

- The environmental conditions must address the most severe Design Basis Accident (DBA) during and/or following which the equipment must remain functional. The environmental conditions must include the applicable temperature, radiation, pressure, humidity, chemical sprays, and submergence conditions.

Qualification Methods

- Qualification may be demonstrated using tests, analysis, operating experience, or a combination thereof. Operating experience by itself is acceptable even for equipment that must remain functional during and after an incident, if the equipment item is "service proven." The demonstration of "service proveness" should be carried out by statistical analysis of service records

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[8] This includes electrical and I&C equipment systems designated as performing "Definitely safety-oriented" protective actions as mentioned in KTA Standard 3501, and those required for incident monitoring as mentioned in KTA Standard 3502. The scope of equipment covered by these are similar to those designated as "important-to-safety" in the US.

on the basis of operational characteristics and conditions. If the service proveness does not extend to incident-related environments, it is sufficient to perform supplementary tests only. Distinction is made between the rigor of the methods used for qualifying harsh-environment and mild-environment equipment similar to those found in IEEE Std. 323-1983.

One significant item of interest is the role of "the authorized expert" as required by section 20 of the Atomic Energy Act. Qualification must be demonstrated to him, and the qualification tests must be performed in his presence. Theoretical parts of the qualification analysis and type test documents must be checked by him.

- Significant aging degradation affecting equipment performance should be addressed. Items of interest in this regard are listed below:

A greater emphasis is placed on reliability analysis based on past operating history and failure effects analysis than accelerated aging models.

The Arrhenius model is used only for cables to determine aging time and temperature. For other equipment, it appears that climatic pre-stressing (e.g., for transmitters, a 2000-hour test at an elevated temperature of 70°C for a certain duration, as specified in KTA 3505) is used in lieu of the Arrhenius model.

In-containment equipment, cables and cable connections should be shown to be capable of withstanding stresses from leak rate tests. Provisions exist in the standards to permit their removal, if necessary, during such tests.

A qualified life is not required to be established and tracked. In-service testing and reliability assessments are depended upon to demonstrate continued equipment operational capability.

- Synergistic effects should be considered if they are expected to affect the safety-functional performance capability of the equipment.
- Margins should be applied to the test environmental parameters to account for uncertainties, such as those caused by production variations and test instrument inaccuracies.

Documentation

- Documentation demonstrating qualification must be auditable and traceable to the plant-specific equipment. Such documentation must contain information on the equipment performance requirements, and the environmental conditions under which such performance is expected. This document must be approved by the "authorized expert," maintained in an auditable form for the entire period during which the covered item is installed in the plant, or is stored for future use.

Replacement of Equipment

- Not Applicable.

Grandfathering

- Not Applicable.

A6.2 German EQ Practices

Although the details may differ somewhat, the German practices of implementing Environmental Qualification programs appear to be similar to those in the US nuclear power plants, and generally consist of the following five elements:

- EQ Listing
- Qualification Specification
- Demonstration of Qualification
- EQ Documentation
- EQ Preservation

Therefore, the details of implementation as discussed in section A2.2 apply in broad terms.

A7.0 EQ REQUIREMENTS AND PRACTICES IN SPAIN, MEXICO, SWITZERLAND, BELGIUM AND FINLAND

Spain, Mexico, Switzerland, Belgium and Finland have adopted the practice of following the rules, regulations and standards from the Country Of Origin (COO) of the Nuclear Steam Supply Systems. Hence, their EQ requirements and practices are very much the same as either US or Germany.

It should be noted that even though the COO rules apply in principle, all changes that take place in the base country subsequent to the original contract are not automatically adopted. Item-specific negotiated agreements between the regulatory body and the licensee are used to adopt subsequent changes on a plant specific basis. This process results in deviations in substance, and time lag. EQ falls in that category, and thus the details of the implementation model at each plant may be different. Substantive differences are in the area of retrofitting older plants, and the strength of conviction with which the concept of qualified life is embraced in those plants which follow the US model.

A8.0 COMPARISON OF EQ REQUIREMENTS AND PRACTICES

This section provides a tabular presentation of the EQ requirements and practices in the various countries reviewed in this report. Table A8.1 presents the US requirements vs. those in Canada, France, Germany and UK. Table A8.2 presents the US requirements vs. those in Spain, Belgium, Finland and Switzerland. Note that Spain and Switzerland have both US and German designed plants. Even though the table shows only the US based requirements, for the German designed plants the KTA standards and requirements similar to those in Germany are used.

A9.0 CONCLUSIONS

Based on the comparative study of the EQ requirements and practices presented in sections A2 through A7, the following conclusions may be drawn:

Table A8.1 Comparison of EQ Requirements in the US vs. Those in Canada, France, Germany and UK

EQ Requirements	USA	CANADA	FRANCE	Germany	UK
Base regulation	10 CFR 50.49	Regulatory Documents R-7, R-8, R-9	Basic safety Rules IV.1.a, IV.2.b, V.2.d	None specific to EQ Identified	Safety Assessment Principles 139 & 140
Primary Industry Standard	IEEE Std.-323	Standard being developed. IEEE Std.-323 is the basis for current programs	RCC-E is the core document. IEEE Std. 323-1974 and IEC 780 are also used.	KTA 3501, KTA 3502	IEEE Std. 323-1974
EQ Listing	Required for Harsh environment electrical equipment	No specific requirement, but it is a practice. The list includes all equipment (mechanical, electrical, and I&C) important to safety in all plant areas.	No specific requirement, but it is a practice. The list includes all equipment (mechanical, electrical, and I&C) important to safety in all plant areas.	No specific requirement, but it is a practice. The list includes all equipment (electrical, and I&C) important to safety in all plant areas.	No specific requirement, but it is a practice. The list includes all equipment (mechanical, electrical, and I&C) important to safety in all plant areas.
Scope of equipment covered	Harsh-environment electrical equipment must be included for all plants. Some late vintage plants were required to include additional equipment	Harsh-environment electrical equipment must be included for all plants. Recent vintage plants are required to include additional equipment	Harsh-environment electrical equipment must be included for all plants. Recent vintage plants are required to include additional equipment.	Electrical and I&C systems and equipment used in safety-oriented and not definitely safety-oriented systems regardless of their location in the plant.	Includes all Safety Category 1 electrical, I&C and mechanical equipment.
How environments are derived	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.
Qualification methodology	Test, Analysis, operating experience or a suitable combination thereof. Type test is strongly preferred. Operating experience by itself is not acceptable.	Test, Analysis, operating experience or a suitable combination thereof. Type test is strongly preferred. Operating experience by itself is not acceptable.	Test, Analysis, operating experience or a suitable combination thereof. Type test is strongly preferred. Operating experience by itself is not acceptable.	Test, Analysis, operating experience or a suitable combination thereof. Greater reliance on operating experience and analysis than in the US.	Similar to the US

Table A8.1 (Cont'd)

EQ Requirements	USA	CANADA	FRANCE	Germany	UK
Is aging considered?	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.
Is a qualified life established?	Yes, it is required for all harsh environment electrical equipment	Yes, it is required for all harsh environment electrical equipment	Only selectively, and is used as a guide for maintenance	NO	Similar to US
Test sequence	For plants committed to 323-74, the test sequence including preaging is required.	Similar to the US	Similar to the US	Similar to the US	Similar to the US
Are test parameter margins required?	Yes, in accordance with IEEE Std.-323. Older plants were permitted to account for margin by conservatism employed in the calculation of environments.	Yes, in accordance with IEEE Std. 323-1974	YES	Yes, as specified in KTA standards	Yes. in accordance with IEEE Std. 323-1974
Treatment of mild environment equipment	With some exceptions, qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.

Table A8.2 Comparison of EQ Requirements in the US vs. Those in Spain, Belgium, Finland, and Switzerland

EQ Requirements	USA	Spain	Belgium	Finland	Switzerland
Base regulation	10 CFR 50.49	None specific to EQ Identified	None specific to EQ Identified	None specific to EQ Identified	None specific to EQ Identified
Primary Industry Standard	IEEE Std. 323-1974	IEEE Std. 323-1974	IEEE Std. 323-1974	KTA 3501, KTA 3502	IEEE Std. 323-1974
EQ Listing	Required for Harsh environment electrical equipment	No specific requirement, but it is a practice. The list includes all equipment (mechanical, electrical, and I&C) important to safety in all plant areas.	No specific requirement, but it is a practice. The list includes all equipment (mechanical, electrical, and I&C) important to safety in all plant areas.	No specific requirement, but it is a practice. The list includes all equipment (electrical, and I&C) important to safety in all plant areas.	No specific requirement, but it is a practice. The list includes all equipment (mechanical, electrical, and I&C) important to safety in all plant areas.
Scope of equipment Covered	Harsh-environment electrical equipment must be included for all plants. Some late vintage plants were required to include additional equipment	Harsh-environment electrical equipment must be included for all plants. Recent vintage plants were required to include additional equipment	Harsh-environment electrical equipment must be included for all plants.	All safety-oriented and not definitely safety-oriented electrical equipment regardless of their location.	Similar to the US for use design plants and similar to Germany for german designed plants.
How environments are derived?	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.	Analysis of LOCA, MSLB, and other high energy line breaks inside and outside containment.

Table A8.2 (Cont'd)

EQ Requirements	USA	Spain	Belgium	Finland	Switzerland
Qualification methodology	Test, Analysis, operating experience or a suitable combination thereof. Type test is strongly preferred. Operating experience by itself is not acceptable.	Test, Analysis, operating experience or a suitable combination thereof. Type test is strongly preferred. Operating experience by itself is not acceptable.	Test, Analysis, operating experience or a suitable combination thereof. Type test is strongly preferred. Operating experience by itself is not acceptable.	Similar to Germany	Similar to the US
Is aging considered?	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.	Yes, focus is on significant aging mechanisms.
Is a qualified life established?	Yes, it is required for all harsh environment electrical equipment	Similar to US	Similar to US	Similar to US	Similar to US
Test sequence	For plants committed to 323-74, the test sequence including preaging were required.	Similar to the US	Similar to the US	Similar to the US	Similar to the US
Are test parameter margins required?	Yes, in accordance with IEEE Std. 323-1974. Older plants were permitted to account for margin by conservatism employed in the calculation of environments.	Yes, in accordance with IEEE Std. 323-1974, and older plants treated the same as in the US.	Yes, in accordance with IEEE Std. 323-1974.	Yes, as specified in KTA standards.	Yes, in accordance with IEEE Std. 323-1974.
Treatment of mild environment equipment	With some exceptions, qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.	Qualification addressed through design control and maintenance.

1. In all the countries reviewed, environmental qualification is recognized and treated as a safety-significant issue.

2. The need for implementing a program for environmental qualification, particularly for electrical equipment important to safety, and located in potentially harsh environment areas in a nuclear plant is deemed to be a necessity. The same cannot be said about the harsh-environment mechanical equipment or equipment located in mild environment areas.

3. The scope of equipment covered is generally limited to harsh environment electrical and I&C equipment only in all countries. There are, however, exceptions in some countries wherein, depending upon plant vintage, the scope may also include certain mechanical equipment located in harsh environments and certain mild environment electrical equipment.

4. The model for implementing a program for environmental qualification at nuclear power plants is similar to that in the US. There are variations in details reflecting the differences in organization, procurement practices, and conduct of maintenance.

5. The EQ requirements and standards in the countries reviewed are similar to those in the US, but there are variations in details reflecting country-specific philosophy. It is also important to recognize that the US stands alone in establishing a set of very prescriptive requirements, i.e., 10 CFR 50.49 as well as in retrofitting older plants.

6. None of the countries reviewed appeared to have employed the application of Probabilistic Safety Analysis (PSA) driven prioritization of EQ either in establishing their EQ requirements or in establishing their EQ equipment population. Recently, some efforts have begun in this regard in the US. Of the other countries reviewed, it appears that UK and Canada are in discussion stages in this regard.

7. The concept of a qualified life for harsh environment electric equipment is used in all countries reviewed with the exception of Germany, and to some extent France.

A.10 REFERENCES AND BIBLIOGRAPHY

1 Code of Federal Regulations, Title 10, Part 50.49, "Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants."

2 Code of Federal Regulations, Title 10, Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," February 1971.

3 NRC IE Bulletin 79-01B, "Environmental Qualification of Class 1E Equipment," including attachments and supplements 1-3.

4 NUREG 0588, Rev. 1, "Interim Staff Position on Environmental Qualification of Safety-related Electrical Equipment."

5 Regulatory Guide 1.89, Rev. 1, "Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants."

6 Commission Memorandum and Order, CLI 80-20, "Environmental Qualification of Safety Systems," May 27, 1980.

7 IEEE Standard 323-1974, "Standard for Qualifying Class 1E Equipment for Nuclear power Generating Stations." 1974, also 1971, & 1983.

8 IEEE Standard 383-1980 "Standard for Type Test of Class 1E Electric cables, Field Splices, and Connection for Nuclear Power Generating Station."

9 IEEE Standard 627-1980, "Standard for Design Qualification of Safety Systems Equipment Used in Nuclear Power Generating Stations."

10 IEEE Standard 308-1991, "Standard Criteria for Class 1E Power Systems for Nuclear Generating Stations."

11 Deleted.

12 IEEE Standard 497-1981, "Standard Criteria for Post Accident Monitoring Instrumentation for Nuclear Generating Stations."

13 Deleted.

14 Regulatory Guide 1.97, Rev. 3, "Instrumentation for Light-Water cooled Nuclear Power Plants to Assess Plant Environmental Conditions during and Following an Accident."

15 Safety Assessment Principles for Nuclear plants, Health & Safety Executive, UK.

16 Basic Safety Rule IV.1.a, "Classification of Mechanical Components, Electrical Systems and Civil Works Structures."

17 Basic Safety Rule IV.2.b, "Requirements to be Taken into Account in the Design, Qualification, Startup and Operation of Electrical Equipment for Safety-related Electrical Systems."

18 Basic Safety Rule V.2.d, "General Rules Applicable to the Construction of Electrical Equipment."

19 IEC Guide 780, "Qualification of Electrical Items of the Safety System for Nuclear Generating Stations," 1990.

20 French Qualification Specification, RCC-E, "Electrical Equipment Design and Qualification Specifications."

21 German Safety Standard, KTA 3501, " Reactor Protection System and Monitoring Equipment of the Safety System."

22 German Safety Standard, KTA 3502, "Incident Instrumentation."

23 German Safety Standard, KTA 3503, "Type Testing of Electrical Modules for the Reactor Protection System."

24 German Safety Standard, KTA 3505, "Type Testing of Measuring Transmitters and Transducers of the Reactor Protection System."

25 German Safety Standard, KTA 3506, "Tests of Electrotechnical Control System of Nuclear Power Plants."

26 Canadian Regulatory Document R-7, "Requirements for Containment Systems for CANDU Nuclear Power Plants."

27 Canadian Regulatory Document R-8, "Requirements for Shutdown Systems for CANDU Nuclear Power Plants."

28 Canadian Regulatory Document R-9, "Requirements for Emergency Core Cooling Systems for CANDU Nuclear Power Plants."

29 Report of the Qualification Benchmark Group, ETNU-CT92-0049, "A Comparison of European Practices for the Qualification of Electrical and I&C equipment important to safety for LWR Nuclear Power Plant."

A.11 GLOSSARY OF TERMS AND ACRONYMS

A11.1 Glossary

Equipment Important-to-Safety: The following categories are subsets of equipment important to safety which are covered by the EQ Rule:

- Safety-related equipment required to remain functional during and following design basis events (DBEs) to assure performance of the required safety functions
- Non-safety-related equipment whose failure during postulated DBEs could hinder performance of safety functions
- Accident monitoring instrumentation that are classified as Category 1 or 2 in accordance with Regulatory Guide 1.97 (7).

Design Basis Events: Design Basis Events (DBEs) are defined as conditions of normal operation, including anticipated operational occurrences, design basis accidents, external events, and natural phenomena, for which the plant must be designed.

> *It should be noted that although the above definition is contained in the EQ Rule, environmental qualification of equipment addresses only the demonstration of the safety-functional capability of electric equipment under design basis accidents.*

Safety-related: Safety-related electric equipment is the same as those referred to as "Class 1E" equipment in IEEE Std. 323.

Also called Safety Category 1 in UK
Further subclassification of Class 1E systems exist in France and Belgium.

Class 1E: The safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, containment heat removal, and reactor heat removal, or otherwise essential to preventing significant release of radioactive material to the environment.

APPENDIX B

REVIEW OF NUS EQ DATABASE FOR ENVIRONMENTAL QUALIFICATION INFORMATION - CABLES

CONTENTS

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B1.0 INTRODUCTION

As part of the NRC's Environmental Qualification (EQ) Task Action Plan (TAP) (1) to identify, evaluate and resolve EQ concerns, a task was developed to review the existing technical literature and databases to determine the current state of knowledge in EQ findings, specifically electric cables. The focus of this Appendix is to provide an overview of the information in existing EQ databases, as well as a technical evaluation of this material **solely** with respect to the goals and objectives as stated in the Research Program Plan (2). A summary of the issues raised are reiterated here as:

- Adequacy of preaging requirements,
- Conservatism in the qualification process,
- Accident survivability of naturally aged cable,
- Effects of high stress areas (i.e., hot spots, bends, overhangs, etc.),
- Availability of condition monitoring techniques.

An important point to note, in light of this review, is the fact that the databases being discussed here may not have been originally intended for the use with which they are now being reviewed with respect to the research needs mentioned above. Therefore, one must temper the subsequent comments against the original intent of these databases, and understand that this review provides a means to identify their usability strictly from the perspective of this research project.

With this in mind, the remainder of this Appendix will focus on the NUS Equipment Qualification Databank (EQDB). Also included in the discussion, as a means of providing a baseline for this review is a review of selected manufacturer's cable EQ test reports developed as part of the utility EQ submittal process.

B2.0 NUS EQUIPMENT QUALIFICATION DATA BANK

The Equipment Qualification Data Bank (EQDB) was created based on a feasibility study performed by the Electric Power Research Institute (EPRI) in 1979 (3). This study concluded that the dissemination of summary qualification data in a "data bank" could foster a uniform, consistent, cost-beneficial approach to the selection, testing and documentation of qualified equipment. This was followed by a recommendation in 1980, by the NRC, that an industry-wide clearinghouse of qualification information be established. The EQDB was developed under EPRI's R&D program, and is maintained on a remotely-accessible computerized data system that has been implemented by the Haliburton NUS Environmental Corporation (4).

The EQDB program is currently a collection of five data banks (5): 1) the Environmental and Seismic Qualification Data Bank (ESQDB), 2) the Materials Qualification Data Bank (MQDB), 3) the Manufacturer's Catalog of Safety-Grade Equipment (MCSE), 4) the Contact Data Bank (CDB), and 5) the Document Information Data Bank (DIDB).

To accomplish the task of reviewing the existing EQ data, BNL requested and received permission to obtain user access to the EQDB. As part of an agreement between EPRI, NRC, NUS, and BNL, BNL was provided with a "limited" on-line user access. This "limited" access allows for the on-line searching of selected portions of the EQDB (MQDB, MCSE, DIDB-limited), in addition to BNL receiving a set of "filtered" records from portions of the EQDB (ESQDB, DIDB) in the form of database files. The sole basis for the "limited" user access, and "filtered" data is so that the identities of the associated utilities/plants would remain anonymous.

The review of the EQDB performed as part of this task in the research program is therefore limited to those areas identified above, bearing in mind the associated restrictions of the "limited" user access discussed.

B2.1 Environmental Seismic Qualification Data Bank (ESQDB)

The Environmental Seismic Qualification Data Bank (ESQDB) is broken up into four separate databases consisting of the following:

1) Electrical Environmental data base,
2) Mechanical Environmental data base,
3) Seismic data base,
4) Generic Seismic Test data base.

Based on the "limited access" agreement obtained by BNL, NUS delivered database files for both cable and penetration data from the electrical environmental data base, again, "filtered" to remove any plant or utility references. The remainder of the discussion in this section focusses on this cable data, as that is a primary area of interest of the EQ project at this time.

B2.1.1 Electrical Environmental Qualification Data Description: Cables

As mentioned, the NUS corporation provided BNL with the data from this portion of the EQDB in the form of database files with plant and utility references removed. There is a sum total of 1600 records associated with environmental qualification data relating to cables, submitted as 88 separate plants, encoded for BNL use (28 BWRs and 60 PWRs). The total number of plants represented is somewhat higher due to the fact that EQ submittals for "sister" plants are included as one plant entry. Discussions with NUS indicates that all but five plants are represented in the EQDB. The maximum number of submittals from any plant was 48 records, the minimum was 1 record, and the average over all the plants was 18 records. Table B2.1 summarizes the information contained within each field of the database.

The information in these records consists of submittals, which predominantly reference the respective qualification test reports, utility correspondence, and calculations associated with the qualification material submitted to the NRC. The following are more detailed descriptions of the associated fields along with technical comments associated with the usefulness and usability of the associated data.

B2.1.1.1 Manufacturer

As its name indicates, this field includes the name of the cable manufacturer, along with an NUS-specific alpha-numeric code, for identification purposes. Inconsistencies in the way entries were submitted was a finding when an attempt was made to develop a distribution of the population by cable manufacturer. In the process of developing this distribution, it was found that one manufacturer's name was input using two different spellings; this led to an incorrect distribution ("Samual Moore vs. Samuel Moore") of cables manufacturers. While this was easy to spot among the 61 manufacturers of cable, inconsistent/incorrect entries will lead to problems in using the data in certain automated database functions (searching, querying, etc.); these will be highlighted further in the following section related to cable type/models.

Table B2.1 Field Descriptions for the Electrical Environmental Database

FIELD NAME	DESCRIPTION
MNAME	Cable manufacturer's name, includes NUS specific code.
MODEL	Model number of cable. In most cases this is manufacturer specific. XLPE/Neoprene, coaxial, etc).
PCODE	Encoded identification of plant submitting qualification record (e.g. PWR1) based on BNL's limited user access agreement.
CODE1,2	Industry code(s) or standard(s) to which cable conforms (e.g. IEEE 323-1974).
ACCURQ	Accuracy of equipment used, in percent, to qualify cable. In the majority of instances this was identified as N/A or was left blank.
TIMEQ	Demonstrated post-accident operating time for equipment in hours. Usually a value based on analysis, and not the actual time that the cable was tested in the environmental extremes indicated.
HUMIQ	Qualified peak value of humidity, in percent, as determined by qualification test or analysis.
TEMPQ	Qualified peak temperature, in °F, as determined by qualification test or analysis.
PRESQ	Qualified peak pressure, in psia, as determined by qualification test or analysis.
RADQ	Actual total integrated radiation dose, in rads, for which equipment is qualified by test or analysis.
ATEMP	Actual peak temperature of aging tests, in °F, if known.
ATIME	Length of time, in hours, at aging temperature of the accelerated aging test, if known.
QUAL-IFE	Estimated qualified life, in years.
SPRAQ1-4	Composition of chemical spray(s) used in qualification test, if applicable. Provision for up to four entries.
SUBM	Indicator that the cable was evaluated for operation below the waterline during an accident.
QUA-LM1-3	Qualification method(s) used to qualify cable. Examples include: simultaneous tests, sequential tests, analysis, etc.
DOCR1-5	References to reports supporting the qualification evaluation.
COMMENT	Any significant comments germane to the qualification of the subject equipment.

As indicated, the large cross-section of manufacturers (61) included in the database will most likely satisfy the needs of the EQ project with respect to providing qualification data on almost all cable models of interest.

B2.1.1.2 MODEL

The next field in the database is intended to identify the cable model or type. A review of the information in this field indicates that many plants use the same models/types of cables. This is manifested in multiple records for the same cable models, submitted by different plants. This was not unexpected since the database was intended as a means for gathering data throughout the commercial nuclear plant community into one central repository. Using this field should allow the user to quickly identify which of the 1600 records belong to those of a given model or type of interest. Normally this would simply be a matter of searching through this field, and developing a subset of cables based on *type* or *model* criteria. However, there are some difficulties in doing this in an efficient manner, namely inconsistencies with respect to how the information was entered by the individual utilities and resides in the EQDB. These inconsistencies manifest themselves in various forms such as:

- model name input variations (SIS Firewall 3 vs. Firewall III)
- trade name vs chemical or generic name (Okozel vs Tefzel)
- variations of input for similar cable models (XLPE vs. XLPE/????)

Inconsistencies in the input for this field are due to the fact that the data consists of information taken from submittals by various EPRI member utilities, and not one central source.

B2.1.1.3 PCODE

This field contains encoded plant names, specifically created for use by the BNL EQ project, so that the identities of the plants that have submitted their data to the EQDB could remain anonymous. The identities of the individual plants have been preserved in coded form, i.e., PWR10, BWR21, etc. Given the need for a plant to be identified with respect to the cable EQ data, NUS will be requested to obtain permission to release the associated plant's identification.

B2.1.1.4 CODE1,2

These fields identify the qualification code(s) or standard(s) to which the cable has been qualified to. A list of the referenced codes and standards, along with the frequency with which they were cited, is provided in Table B2.2. There are two fields provided in the database to accommodate cables that are qualified to more than one code or standard. Each record had an entry in the **CODE1** field, whether it was a code or standard, or identified as "None Given." The **CODE2** field was provided for instances where the record in question was qualified to more then one code or standard. Based on the review of the data, there were 131 records with "multiple" qualification references, the remaining records had this field left blank.

The availability of this information provides users of the database with the capability of quickly identifying which cables are qualified to a particular code or standard. This is useful if there are questions, or concerns, regarding the acceptability of cables qualified using a particular code or standard.

Based on the review of the information in this field, one would assume that much of the cable data (73%), was submitted without "directly" referencing <u>any</u> code or standard (entries of "NONE GIVEN" or left blank). A thorough review of the document reference fields (DOCREF1-5), which will be discussed in a subsequent section of this report, indicates that the submittals of nearly all of the records

Table B2.2. Frequencies of Referenced Codes and Standards from Fields CODE1 and CODE2

Referenced Code or Standard	Times Cited as CODE1	Times Cited as CODE2
10CFR50.49	120	6
79-01B	58	0
IEEE 323-74	101	36
IEEE 344-75	0	12
IEEE 383-74	24	63
NONE GIVEN	1172	0
NUREG 0588 (Unspecified)	47	1
NUREG 0588 (Cat 1)	47	9
NUREG 0588 (Cat 2)	19	2
RG 1.89, Rev. 1	10	0
RG 1.97, Rev. 1	1	2
Subtotals	1599	131

for which there is no reference to any code or standard have excluded the information that is part of the qualification test reports referenced. A sampling of these test reports (6,7,8,9) indicates that codes and standards to which the testing was performed is identified, and simply has not been explicitly referenced in the database.

As with the discussion of the **MODEL** field, there appears to be a fair amount of inconsistency in the way the records have been input to the database. This problem lies at the source where the data originates, and not necessarily with NUS. However, based on the information presented at this time it would appear that, given the time and resources, this information could be gathered from the existing documentation (i.e., qualification test reports). Having nearly three-quarters of the information in this field left essentially blank makes an important data field almost useless, due to the fact that the user must extract this information through a review of the qualification test reports.

The codes and standards that are identified in CODE1 and CODE2 reference the principal documents related to environmental qualification. A breakdown of the number of plants which cite these codes and standards in the database, as either **CODE1 or CODE2**, is provided in Figure B2.1. The references to NUREG 0588 are subdivided into three groups based on the information provided in the database:

- NUREG 0588 (Unspecified)
- NUREG 0588 (Category I)
- NUREG 0588 (Category II)

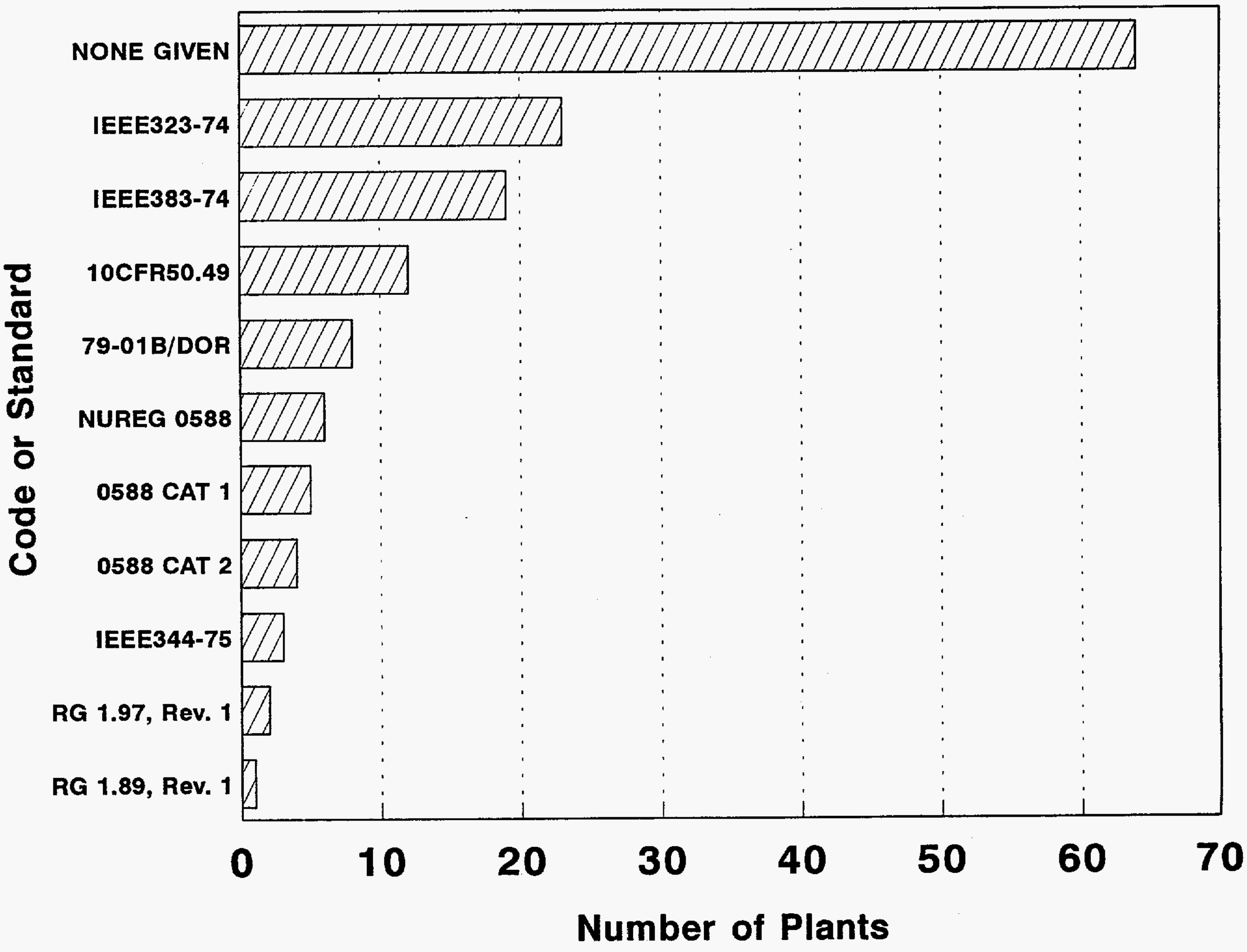

Figure B2.1. Referenced codes/standards versus number of plants

Those records identified as either Category I or Category II in the database reflect the qualification criteria based on the time the plant became operational (Cat I pre-1980, Cat II post-1980). Those records in the "unspecified" NUREG 0588 group have been input to the database as such, however, it is not apparent from the information available which group (cat I or II) these records belong to since plant identification is not readily available. This may be clarified with a more thorough review of the "raw" data contained in the original submittal information, or the associated qualification test reports, if applicable. The group identified in the table as **79-01B** represent the sum total of those records identified in the database as either 79-01B **or** DOR in the *CODE1* and *CODE2* fields since these are both often used interchangeably as qualification criteria. The remaining entries in this field have been presented in the table as they appear in the database. The information in this field, aside from those entered as "Not Given," provides useful information with respect to identifying the appropriate codes and standards for use by the current EQ project.

B2.1.1.5 ACCURQ

This field is supposed to identify the accuracy, in percent, of the equipment used in the qualification process for the cable in question. A review of the 1600 records indicates that this field is of little or no value as far as providing any information to the EQ project at this time. Of the 1600 records in the database, there were only 876 entries in this field, of which 853 were either NA, NGVN (not given), or N/A. The remaining 23 entries did include some information with regard to the accuracy of the equipment, although in most cases it was listed not in per cent but rather in Ohms, most likely a reference to qualification test equipment for measurements related to insulation resistance (IR). The other 725 records had this field left blank.

B2.1.1.6 TIMEQ

This field contains the **qualified post-accident operating time** (in hours) of the subject cable, in most instances determined by analysis, performed for plant licensing purposes. Entries in this field range from "Not Given" to "Continuous." The variability of the entries to this field reflects the changing regulatory requirements over the years as specified by the various codes and standards associated with EQ. The groups most often associated with the various licensing criteria for post-accident operating times, identified in the database were:

- 8760 hrs (1 year) - 324 records
- 720 hrs (1 month) - 244 records
- 4320 hrs (6 months) - 215 records
- 2880 hrs (4 months) - 124 records
- 2400 hrs (100 days) - 111 records

The reference to a rating of "continuous" (41 records) would indicate that there is no endpoint in the "qualified" post-accident life of the cable as determined by analysis. Further clarification to these entries is required if this information is to be useful to the EQ program.

B2.1.1.7 HUMIQ

The HUMIQ field contains the peak qualified test humidity value, in percent, as determined by either testing or analysis. The predominant qualification test humidity is 100%; 93% of all of the cable records indicate qualification to this value, with 5% (82 records) having a qualified humidity of 0%. A review of the database indicates that some of the cable records reference the same test reports, yet in some cases the qualified humidity is listed as 0% while in other instances a value of 100% is given. This is not consistent given their similar test report references, unless the submittal information selectively references only portions the test reports leaving out, in some instances, the LOCA portion of the qualification process. These discrepancies, however, should not be critical to the use of the data for the EQ project.

B2.1.1.8 TEMPQ

This field contains values for the peak qualified temperature in °F, as determined by test or analysis. The majority of the cable submittals (72%) were qualified between 340 and 400 °F. There is a qualification temperature input for nearly every record in the database, although 43 records (2.7%) were indicated as having a qualification temperature of 0°F, while 6 records were blank. It is not certain if entries of 0°F were intentional, or were simply put there in deference to being left blank; the current EQ requirements do not require 1E cable to be qualified below freezing.

B2.1.1.9 PRESSQ

This field contains values for the peak qualified pressure, in psia, as determined by test or analysis. The database includes a peak qualified pressure for all but five records. The peak pressure values ranged from 0 psia (104 entries) up to 5000 psia (1 entry). The most prevalent peak pressure was 127.7 psia (345 records) with submittals citing 0 psia as the second most frequent value. Of the 104 *none given* entries, *none given* was also entered as the **CODE1** reference, making this portion of the submittal information less then meaningful without further clarification. As for the records with data in this field there is a fair amount of records clustered in the 65-95 psia range, and a second group clustered in the 112-130 psia range. These pressures correspond to the criteria of the various EQ codes or standards (i.e., NUREG-0588, IEEE 323-1974, IEEE 323-1978) for accident conditions.

B2.1.1.10 RADQ

This field contains the values for the actual total integrated radiation dose, in rads, for which the equipment is qualified by test or analysis. The database contains a value for each cable record. Table B2.3 provides a breakdown of the distribution of qualified radiation doses, by bin. The bins indicate the number of records that fall between each value and the previous value indicated in the table. For example, there are 41 records that have radiation qualification values greater than 1E+6 and less than or equal to 1E+7. As indicated in the distribution, the predominant bin is 2.0E+8 (67% of all records). The associated qualification values correspond to the radiation levels specified in the referenced codes/standards for the given cable records (i.e., NUREG-0588, IEEE 323-1974, IEEE 323-1978). This field is amenable to querying should one require identification of those records qualified to a given integrated dose rate, and will be useful in future efforts by the EQ program should specific radiation levels become a parameter of interest to the researchers.

B2.1.1.11 ATEMP

This field provides values for the actual peak temperature of the aging tests for the cables specified. A review of the database indicates that 72% of the cable records submitted (1153 entries) do not have any

Table B2.3. Distribution of Qualified Radiation from NUS Database

Qualified Radiation (Rads)	Number of Records
up to 1.0E+5	16
1.0E+6	11
1.0E+7	41
1.0E+8	262
1.8E+8	87
2.0E+8	1071
1.0E+9	108
1.0E+10	1
1.0E+11	4

value input for this field. Of the identified temperature values, 132 records indicate testing up to 302 °F, followed by 83 records at 212 °F. These are the two predominant test values in the database. This field will provide an indication as to which submittals to the database have identified values; however, due to the small number of entries it does not appear likely that this field will provide much insight toward furthering the knowledge of EQ testing to date. A more in-depth review of the associated test reports would need to be performed to provide the information that is missing.

B2.1.1.12 ATIME

This field contains values for the length of time, in hours, that the cables tested spent at the aging temperature of the accelerated aging test, if known. The review of the data in this field indicates that again in 73% of the submittals a value of "Not Given" (1166 records) was input to the database. For those values that are provided the predominant "Aging Time" was 168 hours or 7 days (87 records), followed by 624 hours (26 days) which was attributed to 80 records. There are a number of submittals (37 records) which have identified an aging time of 40 years; clearly these entries are erroneous, based on the definition of this field, which to reiterate, is intended to provide values for the time that the equipment in question was artificially aged. It is highly unlikely that values of 40 years are indeed intended as entry to this field. What is more likely is that there was a misunderstanding between this field, and the next field identified as **QUALIFE**, which gives the estimated time that the cable is qualified to.

Once again the data in this field represents approximately 27% of all of the entries to the database, and, based on the lack of information, may or may not provide enough useful information to the EQ project.

B2.1.1.13 QUALIFE

This field contains values for the qualified life for each record. The majority of the submittals identify a qualified life of 40 years (1176 records). Entries to this field also included "Not Given" (91 records) and blanks (227 records), making roughly 20% of the entries in this field invalid with respect to determining at a glance the qualified life associated with a particular record. This is not to say that there will not be other records for the same cable model that do have a valid entry for qualified life associated with them. Some other entries to this field include >40 years (13 records), <40 years (7 records), 144 years (6 records), 25 and 47 years (4 records each). The remaining entries, each with two records or less, give "exact" values for qualified lifetimes that fit into the aforementioned groups. It is most likely that most of the submittals indicating 40 years qualified life have some value, determined by test and analysis, greater than 40 but indicate this value as a licensing requirement. Those cases where the values are less than 40 years may require more investigation to determine what problems were identified in the qualification process that led to these determinations, since this will require early removal of the cable in question.

B2.1.1.14 SPRAQ1-4

These four fields identify the composition of any chemical spray(s) used as part of qualification testing, if applicable. Provision is made for up to four entries since certain qualification tests include spray tests using various chemical solutions. A distribution of the various spray types is provided in Table B2.4. In most instances an entry was provided in this field, as indicated by the data, though the prevalent entry was "Spray Type Not Defined" (652 records), in addition to 68 cable records with this field left blank, rendering ~126 without entries for the LOCA portion of the EQ submittal. There are an additional 58 records where the LOCA spray portion of the qualification was either "not applicable" or "not required". Of those records having identified spray types, the user of the database can easily chose from either of the three qualification spray fields to find a type of interest . The most predominant of these are: boric acid/boron - 396 records and sodium hydroxide - 225 records. There are nine other spray types identified, with no one contributing to more than 3% (water) of the total records submitted. Based on the information that is available in this field it appears that there is sufficient data to consider this field useful to the EQ project. A more thorough review of the entries that do not specify spray types, with their associated qualification test reports, may help to identify any possible missing information.

B2.1.1.15 SUBM

Indication whether the equipment, in this case cable, was evaluated for operation below the waterline during an accident. A review of the data indicates that of the 1600 records in the database 1115 records indicate that submergence testing was not applicable to the qualification of the cable. There were 298 records which indicate that the associated cables were qualified for submerged operation during accident conditions. Of the remaining records, 58 entries indicate that the cables were not submerged as part of qualification testing, while 129 records had this field left blank.

Use of this field is expected to be limited, however the approximately 300 records should provide sufficient information for cable which has been submergence qualified.

B2.1.1.16 QUALM1-3

These three fields are included to identify the test method(s) used for qualifying the cable in question; in many instances the database indicates at least two methods. These qualification "methods" indicate how the testing was performed. Examples in this field include simultaneous tests, sequential tests, analysis, etc. While these "methods" have not been identified in the User's manual, conventional test

Table B2.4. Distribution of LOCA Spray Types Identified in NUS Database

SPRAY TYPE	SPRAQ1	SPRAQ2	SPRAQ3
SPRAY TYPE NOT DEFINED	652	12	1
BORIC ACID/BORON	396	184	76
SODIUM HYDROXIDE	225	78	15
SPRAY QUAL. NOT APPLICABLE	57	0	0
WATER	49	7	0
SODIUM THIOSULFATE	38	84	45
POTASSIUM HYDROXIDE	28	0	0
TRISODIUM PHOSPHATE	24	10	0
CHROMATE SOLUTION	23	0	0
LITHIUM HYDROXIDE	17	0	0
HYDRAZINE	16	10	6
STEAM	4	0	0
DISODIUM PHOSPHATE	2	0	0
SPRAY QUAL. NOT REQUIRED	1	0	0
OTHER SPRAY TYPE USED	0	1	0
Subtotals	1532	386	143

practices allow the user of the database to make certain assumptions with regard to the general meaning of each qualification method. In this regard, simultaneous testing is taken to mean the coincidental imposition of any of a number of test conditions (e.g. LOCA, steam, temperature and radiation) as aging mechanisms on the cable specimen. Sequential testing on the other hand is taken to mean that the subject cable has had all or some portion of the qualification testing done in discrete parts as a series of tests. While most of these are standard techniques used to qualify equipment, the exact methods of the tests are not defined in the database, nor would it be expected that they would be. Further clarification should come from reading the referenced documentation associated with a specific cable model to acquire a more thorough understanding of the precise nature of the tests.

A review of the database indicates that there are different records referencing the same qualification test reports. These records do not contain consistent information in these three fields even though they do reference the same test reports. It is understood that there are other referenced documentation such as utility calculations, correspondence, EQ bulletins etc..., which will have an impact as to what is entered in the *QUAL1*, *QUAL2*, and *QUAL3* fields, but it should not preclude having at the very least similar information among records that reference the same qualification test reports. This again raises the issue of consistency with regard to how the data was input to the database, as well as how information within the given test reports are interpreted.

These issues aside, the results of the database review with respect to the given "methods" are provided in Table B2.5. The data indicates that most cable is qualified using simultaneous testing as the primary qualification method, with the next most prevalent method being sequential testing. Given the aforementioned limitations of this data the distribution provided here is not completely meaningful. As far as their usefulness to the EQ project, these fields are not overly critical, however more accurate information may help if cable test methods or sequences are found to be an important issue. One additional point to note is that the User's manual for the EQDB specifically states that these fields are not used for searching the on-line database, and are provided strictly for informational purposes.

For these fields to be more meaningful the entry choices would need to be clearly defined, and reasons provided as to why there are inconsistencies in those submittals which reference the same test reports. In addition, a basis needs to be provided as to why these fields should not be used for searching the database.

B2.1.1.17 DOCR1-5

These fields identify those references, other than the aforementioned codes and standards, used as part of the qualification of the equipment in question. Typical entries in this field include qualification test reports, utility calculations, manufacturer's product bulletins, relevant correspondence to/from utilities or manufacturers, and any other documentation that is germane to the qualification process of the equipment. The majority of the references, however, are test reports, followed by utility calculations/correspondence, and manufacturer's reports.

Table B2.5. Distribution of Qualification Methods Identified as QUAL1-3, and the Associated Subtotals

	QUALM1	QUALM2	QUALM3	Total
QM1 SIMULTANEOUS TEST (see B2.1.1.16)	606	9	0	615
QM2 SEQUENTIAL TEST	292	173	2	467
QM8 QUALIFICATION METHOD NOT GIVEN	203	0	0	203
QM0 COMBINATION TEST & ANALYSIS	71	147	18	236
QM9 TEST TYPE NOT GIVEN	283	43	10	336
QM3 SEPARATE RADIATION EXPOSURE TEST	11	328	3	342
QM5 ANALYTICAL QUALIFICATION	90	103	162	355
QM4 SEPARATE EFFECTS TESTS ON A SEQ. OF COMP.	42	0	0	42
Subtotals	1598	803	195	2596

These fields are useful to the EQ project in identifying those cables that have been qualified using a specific test report. It was through the use of these fields that some of the inconsistencies of the database were identified. Searching on a particular test report number and identifying varying inputs was useful in assessing the information used in other fields of the database. There were, however, some inconsistencies noted in the entries to this field, which is not unexpected due to the multitude of sources submitting data to the system. Performing searching and querying on these fields required some amount of care due to the varied inputs. It is understood, however, that these fields were not originally intended to be used in this manner, they were beneficial for review purposes.

B2.1.1.18 COMMENT

The comment field is provided as a place for the submittors of the data to add information relevant to the qualification of the equipment that either was not subject matter for any of the aforementioned fields, or the information for a particular field was not able to fit within the existing space limitations of the EEDB. Entries in this field include information related to such areas as:

- identification of the materials of construction of selected entries, (e.g., EP insulation with Hypalon jacket [Durasheath])
- information related to the application of the subject equipment, such as:
    - thermocouple extension, outside containment
    - 600V and 1000V control cable
- information associated with how qualification tests were performed on the subject cable.
    - *RADQ,AGEQ* by sequential test and analysis, *TIMEQ* by analysis.
- Combined information from the test report which identified specific qualified life and material data not included in the database:
    - coaxial cable with XLPE insulation and Hypalon jacket qualified life 40 years @ 57°C
- Notes regarding qualification testing not included, or listed as "not given," in the associated database field:
    - coaxial cable, qualified for 2.75 hours at 139.8 psia and 375°F
    - *SPRAQ* pH=9-11
- Supplemental information from specific fields, mostly identifying additional code references:
    - ...*CODE4:* NUREG-0588 Cat 2, 10CFR50.49
    - ...*DOCR6:* Letter Rockbestos to Bechtel dated 09/19/80

There were a total of 942 records which had comments of one form or another described above, the remaining records listed "none" or left this field blank.

While the information in this field is useful in developing a more thorough understanding of the qualification data for the associated cables, it was not intended as a field to be used to perform automated database functions such as sorting, searching or querying, and should be judged in that light. For the most part the information contained in this field could be gotten by reviewing the associated qualification test reports, if available. Information such as correspondence between utilities, manufacturers, and testing labs while referenced occasionally would not be available without contacting the associated senders or receivers of the correspondence. It is not likely that this information will benefit the EQ project at this time.

B2.2 Materials Qualification Data Bank

The materials qualification data bank (MQDB) is subdivided into two separate sub-databases, one containing thermal qualification data, the other radiation qualification data. The parameters in the radiation and thermal databases are based upon guidelines and recommendations of the EPRI Qualification Materials Data Committee. This data bank is one of the three portions of the EQDB that BNL has on-line access to. The following sections provide a brief description of the information contained in these two sub-databases.

B2.2.1 Radiation Data Bank

The radiation data bank (RDB) contains radiation qualification data for organic materials used in nuclear power plant applications. The format of the data is equivalent to "electronic data sheets." A brief description of each field is provided in Table B2.6.

The current structure of the radiation sub-database, and in part, the thermal sub-database, allows for *selective* searching and querying. These processes require that the user "SELECT" or "ADD" a group of records, known as a **SET**, based on one of the following four menu choices:

- manufacturer
- NUS record number
- material usage
- material name (generic, chemical, or trade).

Narrowing down the **SET**, based on particular criteria, requires that the user then perform a "KEEP" or "REMOVE" action, based on any of the four aforementioned menu choices, in addition to the following field selections:

- property measured
- radiation change dose
- particle type.

Using this procedure, the radiation sub-database was queried to find records with the material usage field equal to "cable." This resulted in a total of 249 records with the word "cable" in the **usage** field; this SET was later narrowed down to 236 records by removing records with material usage limited to "cable ties." These 236 records were then analyzed for distributions on the **manufacturer**, **particle type, radiation change dose**, and **property measured** fields. The results of these queries can be found in Tables B2.7 through B2.9.

Table B2.6. Summary of Field Descriptions for the Radiation Data Bank

FIELD NAME	DESCRIPTION
Record Number	NUS specific record number, **one of the four searchable fields.**
Contributor	Identification of the contributor of the qualification data.
Manufacturer	Name of cable manufacturer, **one of four searchable fields.**
Material Tested: Generic, Chemical, and Trade Names	Listing of the names of the material tested based on these three categories, **one of four searchable fields**
Material Use	Application(s) that the material is used in (e.g. cable insulation, jacketing, etc.) **One of the four searchable fields.** This field was used to find those records with material use equal to cable. This non-specific search captures any record containing the word cable in this field followed or preceded by any other characters, i.e., cable insulation, cable jacketing, power and control cable insulation, etc.
Property Measured	Physical or electrical property used as assessment criteria in radiation test. Entries to this field for "cable" include: absolute elongation, cracking, elongation, dielectric strength, flexural strength, tensile strength, electric strength, weight loss, etc. Used in ***keep*** and ***remove*** actions, see text.
Property Type	Indication as to whether the property measured is physical, mechanical, or electrical.
Property Change Point	Point at which the test for property measured has met failure criteria, in per cent.
Material Temperature	Test chamber temperature, in °C.
Change Dose	Radiation dose at which the property measured, changes, in rads. Used in ***keep*** and ***remove*** actions.
Particle Type	Radiation particle type produced by the test source which caused the threshold or property change damage. Used in ***keep*** and ***remove*** actions.
Test Dose Rate	Radiation/time imposed on the test sample, in rads/hr.
Remarks	Comments relevant to the environment of the test chamber.
References	Published source(s) of data.
Common, Trade Names	Listings of common generic, and trade names of the organic material.

Table B2.7 provides the distribution of Radiation Change Dose, by range, with the largest single group being the range from 1.0E+7 to 9.99E+7. The distribution of manufacturers (Table B2.8) indicates that the single highest entry for records in the RDB identifies **NOT GIVEN** (44%), with the most records among the 22 manufacturers being 31 (Pirelli).

Table B2.7. Distribution of Radiation Dose

Radiation Change Dose	
Range	Records
1.0E+05 - 9.99E+05	8
1.0E+06 - 9.99E+06	48
1.0E+07 - 9.99E+07	102
1.0E+08 - 9.99E+08	77
1.0E+09 - 9.99E+09	1

The RDB data indicates gamma type radiation source as the only radiation particle type for cable EQ tests (80 records), the remaining 156 records have entries of **NOT GIVEN**. A review of the RDB with respect to the **Property Measured** field can be found in Table B2.9.

The only fields of technical interest that are not used in the "KEEP" or "REMOVE" menus are the **Dose Rate** and **Reference(s)** fields. Having these fields available to perform filtering would allow the user of the database more flexibility to add or eliminate records based on specific dose rates or references. The manual review of the 236 records with respect to dose rates and materials tested is summarized in Table B2.10. The review indicated that more than half of the records have this field left blank, while the majority of the remaining records have dose rates in the 1E+07 range. The Materials Tested column identifies those materials associated with dose rate in the database.

B2.2.2 Thermal Data Bank

Similar in format to the radiation data bank, this sub-database contains relevant thermal qualification data for organic materials used in nuclear power plant applications. A brief description of each field is provided in Table B2.11.

A review of this sub-database indicates that the majority of these records were submitted by Wyle Laboratory (45 records) and The Franklin Research Center (21 records). Table B2.12 provides a summary of the materials contained within the Thermal Data Bank, and their associated activation energies. As previously discussed, the search and query capability for this sub-database is limited to searching on manufacturer, material, and usage. The previously discussed actions to "REMOVE" or "KEEP" records adds the **property measured** field for these two actions. The 74 records whose *material use* field is equal to **cable** were input to a spreadsheet to perform the summary statistics provided in Table B2.11. In the future, NUS may consider expanding the capabilities of the database to allow for searching and querying of key thermal parameters, such as:

- property endpoint
- activation energy
- Y-intercept
- maximum operating temperature
- references

Table B2.8. Radiation Data Bank Manufacturer Distribution

Manufacturer	Records
Okonite	7
Not Given	105
General Electric	17
Boston Insulated Wire	1
Datwyler	22
Felton & Guillaume	17
Pirelli	31
Parker Seal	3
Champlain	2
Raychem	2
Brand Rex	1
Anaconda	5
DuPont	1
Eaton	2
Silec	2
Haveg	2
Rockbestos	2
Continental	2
Draka	2
BICC	2
CERCEM	4
Dow Corning	2
AIW	1
Total: 23	236

Currently, only by importing this data to an aforementioned third-party software package (i.e., spreadsheet), is more efficient and thorough search, query, and statistical operations possible.

Table B2.9. Distribution of Measured Properties for the Radiation Data Bank

Measured Property	Records
Elongation	105
Tensile Strength	64
Hardness	19
Not Given	16
Flexure Strength	14
Elastic Modulus	4
Electrical Strength	3
Shear Strength	3
Compression Set	2
Voltage Withstand	2
Increased Oxygen	1
Thermal Conductivity	1
Cracking	1
Damage	1

Table B2.10. Distribution of Dose Rates and Materials Tested

Material Tested	Dose Rate (rads/hr)	Records
CSPE/Hypalon	1.5E+03	8
XLPE	1.0E+04	8
XLPE	1.0E+05	13
EPR, XLPE, Polyolefin	1.2E+06	7
EPDM, XLPE, Neoprene	1.0E+07	67
SR, XLPE, Neoprene, EPR, PVC, PE	1.1E+07	13
NA	Not Given	120
	Sub-Total	236

Table B2.11. Summary of Field Descriptions for the Thermal Data Bank

FIELD NAME	DESCRIPTION
Record Number	NUS specific record number, **one of the four searchable fields.**
Contributor	Identification of the contributor of the qualification data.
Manufacturer	Name of cable manufacturer, **one of four searchable fields.**
Material Tested: Generic, Chemical, and Trade Names	Listing of the names of the material tested based on these three categories, **one of four searchable fields**
Material Use	Application(s) that the material is used in (e.g. cable insulation, jacketing, etc.) **One of the four searchable fields.** This field was used to find those records with material use equal to cable. This non-specific search captures any record containing the word cable in this field followed or preceded by any other characters, i.e., <u>cable</u> insulation, <u>cable</u> jacketing, power and control <u>cable</u> insulation, etc.
Property Measured	Physical or electrical property used as assessment criteria in radiation test. Entries to this field for "cable" include: absolute elongation, cracking, elongation, dielectric strength, flexural strength, tensile strength, electric strength, weight loss, etc. Searchable, using keep or remove action.
Property Type	Indication as to whether the property measured is physical, mechanical, or electrical.
Property End Point	Point at which the test for property measured has met failure criteria, in per cent.
Activation Energy	Arrhenius equation zero value, in eV.
Y-Intercept	Intercept of Arrhenius Line on temperature axis, in °C.
Max. Operating Temp.	Maximum temperature for continued long-term or short-term operation which can be tolerated without premature catastrophic failure, in °C.
Remarks	Comments on the aging environment, techniques to determine activation energy, minimum aging requirements, etc.
References	Published source(s) of data.
Common, Trade Names	Listings of common generic, and trade names of the organic material.

B2.3 Manufacturer's Catalog of Safety-Grade Equipment

Another portion of the EQDB that BNL has on-line access to is the ***Manufacturer's Catalog of Safety-Grade Equipment (MCSE).*** This sub-database contains information input to the system by equipment suppliers which contains information about various equipment that has been subjected to generic qualification tests by the supplier or the manufacturer. The MCSE contains data on 34 "categories" of equipment deemed safety-grade based on function within the plant (i.e., accident prevention, loss of function, accident initiation, etc.).

Table B2.12. Summary of Selected Material Properties from the Thermal Data Bank

Material	Activation Energy Range (eV)	Number of Records
BR	1.03 -1.39	2
BUTYL	1.07	2
CPE	1.14 - 1.74	2
CSPE	0.93 - 1.66	2
CTFE	2.11	1
EPDM	1.23 - 1.48	10
EPR	0.71 - 2.0	13
EPR/CSPE	1.63 - 1.69	2
NEO	0.65 - 1.26	4
POLYALKENE	1.11	1
POLYOLEFIN	0.86	1
PVC	0.97 - 1.29	2
SBR	0.78	1
SR	0.94 - 1.97	15
SR/GLASS	1.59	1
TEFZEL	1.32	1
XLPE	1.1 - 1.62	14
Mat'l Subtotal: 17		#Recs: 74

The category of interest to the EQ project at this time has been identified as ***"Electrical Conductors and Connectors,"*** which is said to contain cables among other components, such as wire, wire terminal blocks, cable connectors and plugs, and cable/wire termination devices. A search of the database identified 49 records under this category. Further review of these records indicates that there are no records associated directly with cables, therefore the discussion on this portion of the EQDB is rather brief.

A review of the MCSE indicates a four-tiered structure broken up into the following:

- manufacturer/supplier identification,
- equipment specifications,
- environmental qualification,
- seismic qualification.

A sampling of these four sections include information on the codes/standards used for qualification, QA codes and standards to which the component was manufactured, model number, relevant EQ data, and seismic data where applicable. Most of the information in the MCSE overlaps that which is already contained in the EEDB, discussed in previous sections of this report. While it may have provided some additional data, the lack of cable information in this section does not diminish the usefulness of the EQDB, nor does it enhance it.

B2.4 Document Information Data Bank

The ***Document Information Data Bank (DIDB)*** portion of the EQDB, which BNL has on-line access to, is currently comprised of the following four sub-databases: 1) Audit Information Data Base, 2) NRC/Industry EQ document bibliography, 3) 10CFR Part 21 Reports and 4) NRC Generic Communications in Preparation. The limited user's-agreement does not provides BNL with on-line access to the Test Report Bibliography Data Base, as indicated earlier, this information was submitted to BNL in the form of a database file.

The **Audit Information Data Base** contains information regarding **10CFR 50.49** related EQ audits. Users have the capability of searching the database by audit category, plant name, or a "keyword" field. This sub-database was searched using the category option , and selecting **cable/wiring**. There were a total of 49 audit summaries in the database under this category, which was reduced to 46 based on the "keyword" search. Each record provides a summary of audit findings, detailing the specific areas of cable environmental qualification deficiencies. While this portion of the EQDB contains valuable information with regard to NRC audits and the respective utility input to qualification documentation, it is not clear at this time that BNL can benefit from this information for its aging-related EQ research.

The **NRC/Industry EQ document bibliography** portion of the DIDB contains 1,300 records in the following 10 document type categories:

- NRC Bulletins, IE Circulars, Generic Letters, and Information Notices,
- NUREGS, NUREG/CRs,
- Regulatory Guides,
- IEEE/ANSI Standards,
- EPRI Reports,
- and miscellaneous documents.

A summary of this portion of the DIDB can be found in Table B2.13, in which each of the 10 document types were searched for keywords equal to "cable." While this is a good source of information regarding EQ related documents, it overlaps much of the information already gathered by the EQ project during the initial literature search. However, the on-line capability of the DIDB may prove beneficial in future literature searches for EQ documentation.

The review of the **10CFR Part 21** portion of the DIDB identified 63 records with the "equipment type" category equal to cable/wire/wiring; of which 25 satisfied a keyword search for the same equipment type. The review of these 25 Part 21 notices indicates that while of some these reports are attributed to cable, they are not all related to the issues regarding aging. Of the 25 "cable" notices, 5 were selected for further review. Specific deficiencies identified in these five reports involved a failure of a particular cable to meet the IEEE 383-1974 requirement for flammability, incomplete manufacturer's qualification files,

Table B2.13. Summary of NRC/Industry EQ-Related Documents

Document Type	Total Number of Records	"Cable"-related
NRC Bulletins	59	4
NRC IE Circulars	11	4
NRC Generic Letters	60	7
NRC Information Notices	340	38
NUREGs	28	0
NUREG/CRs	369	28
Regulatory Guides	30	3
ANSI/IEEE Standards	0	0
EPRI Reports	115	7
Miscellaneous	289	10

incorrect cable construction (2 reports), and use of incorrect activation energy for cable qualification. Having the information available on-line format is beneficial to the EQ research team as an additional source of data for present and future project use.

As previously mentioned, the data from the **Test Bibliography** portion of the DIDB was transferred to BNL, in the form of a "filtered" database file containing approximately 115 "records" on test reports related to cables. It was determined that many of these were duplicate references to the same reports, but are separate records due to the fact that the reports are applicable to more than one cable model. BNL has received a "hard copy" of 33 qualification test reports for use on the EQ cable research project from NUS. The reports cover 12 cable manufacturers, and in most cases, several models of cables from each. Contained in the reports are all of the relevant information that has been input to the various sections of the EQDB, mainly into the EEDB.

The reports that were not submitted to BNL at this time require additional approval from either manufacturers, utilities, or testing laboratories, prior to their release. The information in the DIDB will be used to identify applicable test reports of interest based on cable manufacturer, and/or model. For those reports which are currently unavailable, BNL will utilize that information that exists either in the EEDB or the MQDB.

B3.0 SUMMARY AND CONCLUSIONS

Based on the previous discussions on the NUS maintained Equipment Qualification Data Bank and its associated sub-databases, a number of points can be made regarding its usefulness to the current EQ research project on cables, as well as the data as a whole.

With regard to the EQ project, this database will provide useful information that is currently not available to the EQ project team in the electronic form. One must be aware however, that there are limitations to this data and in some cases the data itself is not complete. As mentioned earlier, due to the large number of sources which have submitted data to the EQDB and its sub-databases (e.g. utilities, manufacturers, testing labs) it is understandable that the inputs to the database in many areas do not have what could be considered a "standardized" format, therefore making it somewhat difficult to use efficiently.

The following is a summary of the specific comments with respect to the EEDB:

- While the database does not directly help resolve the issues to be addressed in the EQ research program, it does contain a significant amount of useful information for understanding how equipment was qualified.
- The EQDB database does have information useful in developing the research program, for example:

  - activation energies,
  - materials used,
  - radiation dose rates,

- Some inconsistencies in the database did limit its usability, for example:

<u>**EEDB Specific:**</u>

- inconsistent entry of **model** names/numbers to the database making the identification of similar information in this area difficult to find in an efficient manner

- the lack of data entry in the **CODE1 and -2** fields, whereby the majority of the records (73%) were left without input to this field, while this information was, for the most part, available as part of the qualification test reports cited in the database fields **DOCR1 through 5**.

- entries to the **QUALM1-3** field are not explicitly identified with respect to exactly which methods were used and in what sequence they were used, leaving the user to make assumptions in this regard. Another issue related to this field involves entries in the database referring the same qualification test reports, but having different entries for qualification methods in the **QUAL1 through 3** fields. There are no reasons given for these anomalies, other than speculation that certain EQ submittals only reference portions of qualification test reports. This is not clearly spelled out in any of the documentation.

- Information included in the **DOC1 through 5** fields is not input in a manner which allows for the most efficient searching and querying as a database field. Examples cited include instances where the same reference is cited in numerous entries to the database in various forms. The most prevalent examples include missing or extra characters in a report number.

Once again, it should be stressed that the EQDB may not have been originally intended to be used as a tool for EQ research, therefore these comments, while pertinent to its use for research, may in some opinions have no bearing on its intended function a repository of information for the commercial nuclear power industry. These comments reflect suggestions and improvements that are aimed at making this a more functional database, strictly from the research vantage point, which would benefit all who use it as an information source.

B4.0 REFERENCES

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APPENDIX C

INEL EQ DATABASE REVIEW

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C1.0 BACKGROUND

As part of the NRC IEB 79-01B qualification review process, all nuclear plants in operation and under construction were required to identify their safety related equipment and verify that it was qualified. The NRC had identified a specific format for reporting information in a summary fashion. This summary information was known as Safety Component Evaluation Worksheets (SCEW). The NRC and their contractors evaluated submittals from nuclear plants and prepared Technical Evaluation Reports (TER), which identified deficiencies in the qualification documentation as well as concurrence that equipment was qualified. The NRC in turn, after reviewing the TER with the plant, and obtaining additional information and commitments, generated Safety Evaluation Reports (SER). Plants made commitments to complete qualification activities, such as replacing equipment, completing testing and/or completing modifications. The SER documented the status that the plant was safe to operate. Originally, nuclear plants were to have completed the qualification review process and have all qualified equipment installed and operating in March 1982. However, due to the volume of submittals as well as unavailability of sufficient resources to complete all efforts, the NRC changed the completion date until the end of November, 1985.

The INEL EQ database is a database developed from the SCEW sheet information prepared during the period 1980 to 1982 and it represents the EQ status by plant as of the 1982 time frame. Since then some equipment represented in the database may have been changed in the plant, the qualification status may have changed and the list of equipment required to be qualified may have changed. It is a snapshot of the qualification status at nuclear plants at the time.

It appears that the primary uses of the data base were to allow comparisons of qualification information among the plants, summarize the status of qualification, and compare qualification levels, requirements and references to qualification documentation. The database was reviewed to determine if it provides information useful for resolving any of the EQ issues.

C2.0 CONTENTS

The INEL EQ Database includes nine database files. The file names, file contents and file characteristics are summarized in table 1.

Completeness and Limitations: The INEL EQ Database reflects the information at the time. Since qualification reviews and qualification documents were not all completed in the 1981-82 time frame, many of the fields are incomplete. Additionally, since actions were taken by most, if not all licensees between the period of 1981 to 1985 to complete documentation and change out and modifications are continually being performed, the database cannot reflect the current qualified condition of equipment. However, for the qualified equipment, it is assumed that much of the equipment is still in service and this represents a significant sampling of qualification records and parameters.

Some of the limitations are 1) not all nuclear plants are included, 2) not all qualified equipment is included, and 3) not all qualification requirements are identified.

The data is useful from many aspects, since it is a representation of a snap shot of the qualified equipment status at plants.

Table 1 Contents of INEL EQ Database

INEL EQ File Name	Contents	Characteristics
CO.DBF	Global Data - Identifies 87 Nuclear Plants	This contains nuclear utility and plant information, such as Docket, Nuclear plant, operating or construction status, BWR or PWR reactor type, NSSS, AE, and permit date. This information allows the identification of which plants are required to meet DOR Guidelines, NUREG 0588 Category I or II.
C100.DBF	Component Data	This file ties the records of equipment to be qualified by component type and model number to the nuclear plant from the CO.DBF.
C200.DBF	Vendor Data	This file identifies the manufacturer of the equipment to be qualified in C100.DBF.
C300.DBF	Qualification Data	This file identifies qualification summary information of the equipment to be qualified in C100.DBF. Summary information consists of plant location, Qualification Peak Temperature, Qualification Peak Pressure, Humidity, Spray, Radiation TID, Submergence, Qualified Life, Qualification methods used for operating time, temperature, pressure, humidity, spray, radiation, submergence and aging.
C400.DBF	Reference Data	This file identifies the qualification reference document for qualification parameters of operating time, temperature, pressure, humidity, radiation and aging. This data is indexed to C300.DBF.

Table 1 (Cont'd)

INEL EQ File Name	Contents	Characteristics
C500.DBF	Equipment Data	This file provides an identification number for each component to be qualified at each plant and identifies the status of the installation date, date of submittal of the records to NRC, System, Replacement, Maintenance, and Qualification status.
C600.DBF	Notes Data	This file documents the notes for each equipment and is keyed to C300.DBF. The notes add information such as continuous or intermittent operating requirements, and assumptions.
C700.DBF	Documentation References	This file identifies the utility reference document, which forms the basis of the qualification record. This data is keyed to the qualification parameters of C300.DBF.
C800.DBF	Environmental Data	This file identifies the qualification specifications or requirements for each location in each plant. Information is provided on operating time in a DBA, peak temperature, pressure, humidity, spray, radiation and submergence.

Nuclear Plants: The data represents 87 nuclear plants, of which 71 were operating reactors and 16 were Near Term Operating Licensees (NTOL). Only 2 of the 87 plants were noted to have construction permits after July 1974, which would have required them to meet NUREG-0588 Category 1. Thus 85 nuclear plants were required to meet DOR Guidelines or NUREG-0588 Category II.

DBA Temperature requirements: There were approximately 4,000 entries of safety related Class 1E Electrical equipment which identified the peak DBA Temperature requirements for items reported in the database. The data was analyzed and graphs were made of the distribution of Peak DBA temperatures (Figure 1) and a cumulative distribution of DBA Temperature requirements (Figure 2). This represents the distribution of peak DBA temperatures identified for equipment with harsh environment requirements. It is interesting to note that 49% of the equipment have DBA Temperature requirements that are below saturated steam conditions of 212°F. Additionally, the often quoted 340°F, from IEEE Std-323-1974 envelopes the peak DBA temperature for 94.6% of the qualified equipment. It is significant to note that 5.4% of safety related equipment have peak DBA requirements exceeding 340°F. Since cable is necessary to operate Class 1E electrical safety related equipment, some safety related cable has to meet all of the requirements including the highest requirements. The distribution of DBA temperature requirements exhibits two significant distributions. The first distribution is centered around 150°F and the second is centered around 340°F. A few requirements exist out to 500°F and these are plant specific requirements.

Cables: A total of 257 cable entries were present in the data base. The cable materials identified were:

Asbestos Braid Silicone	FR/HTR	PVC/PVC
Butyl/PVC	HT/FR	Rubber/Hypalon
EP/Neoprene	HT/NS	Rubber/PVC
EPDM/Hypalon	HTK/FR	Silicone Rubber
EPDM	Mineral Insulated	SBR
EPR/Hypalon	Okolite/Okolon	Tefzel/ETFE
Firewall III	Okonite/Okoprene	Vulkene
Flametrol	Okozel	XLPE/Hypalon
FR-EP/CPE	PE	XLPE/Neoprene
FR-EPR Neoprene	PE/PVC	XLPE/PVC
FR/FR	Poly Nylon	XLPO/Neoprene

Many cable manufacturers were identified:

American	BIW	Belden
Brand Rex	Cerro Wire & Cable	Eaton
Essex	General Electric	Haveg
ITT	Kerite	Okonite
Raychem	Rockbestos	Westinghouse

DBA Radiation requirements: There were approximately 7,500 entries of safety related Class 1E Electrical equipment which identified the Radiation Total Integrated Dose (TID) requirements for items reported in the database. The data was analyzed and graphs were made of the distribution of Radiation requirements (Figure 3) and a cumulative distribution of radiation requirements (Figure 4). This represents the distribution of harsh radiation environment requirements. It is interesting to note that 65% of the equipment have radiation TID normal plus accident requirements that are below 1E6 Rads. Also 98.5 % of the radiation requirements were 2E8 Rads or less. Those radiation requirements in the 1E9 Rads range were noted to be Beta Doses. The radiation requirements have three distinct distributions. The first distribution is for equipment with radiation requirements below 1,000 Rads. The second distribution is centered around 10,000 Rads and the third distribution is centered around 1E6 Rads. The first distribution probably represents equipment that is classified as requiring qualification because it is in a harsh environment for temperature and not radiation. The second distribution probably represents equipment that is located outside of containment and classified as requiring qualification because it is in a harsh environment for temperature and/or radiation. The third distribution probably represents equipment that is located in containment.

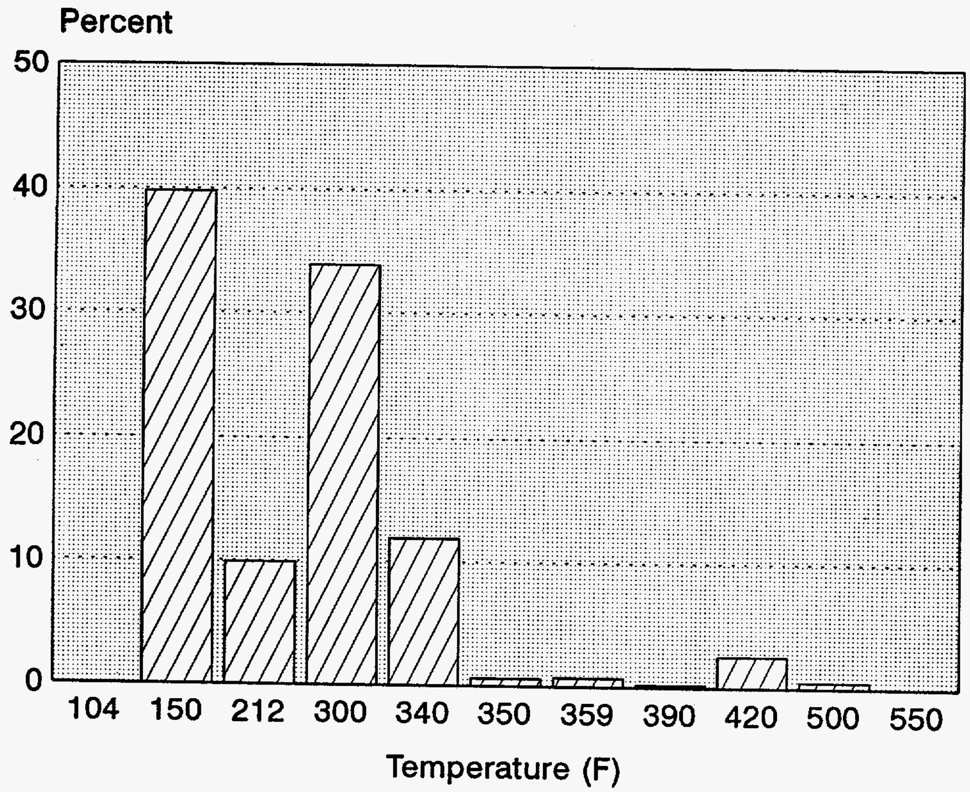

Figure C.1 DBA temperature distribution for equipment in INEL EQ database

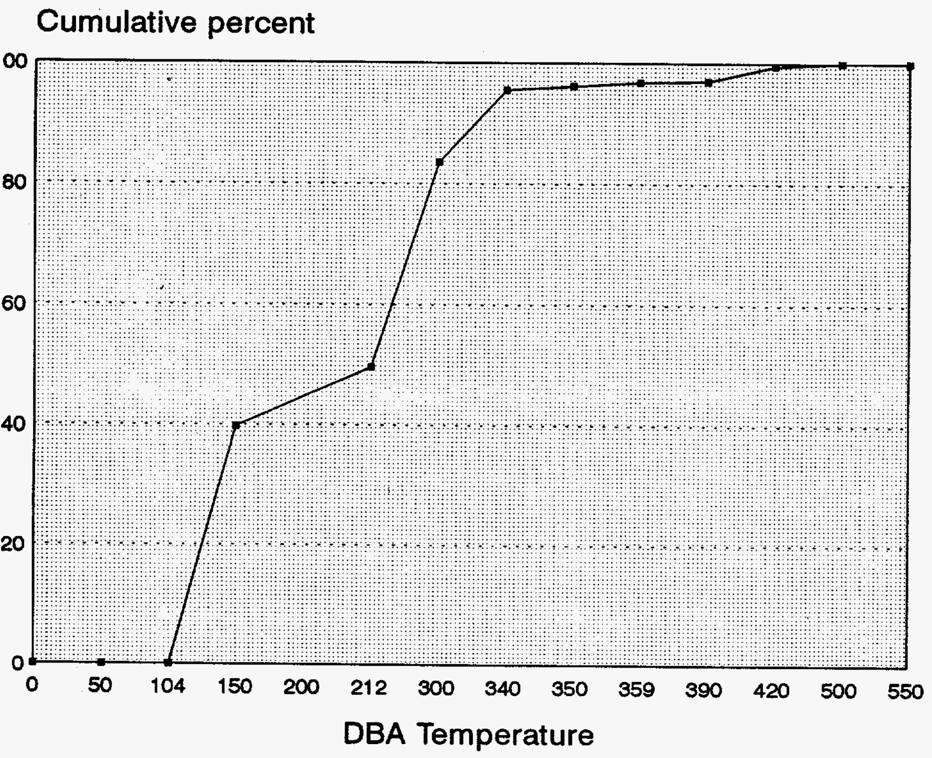

Figure C.2 Cumulative percent of equipment in INEL EQ database versus DBA temperature

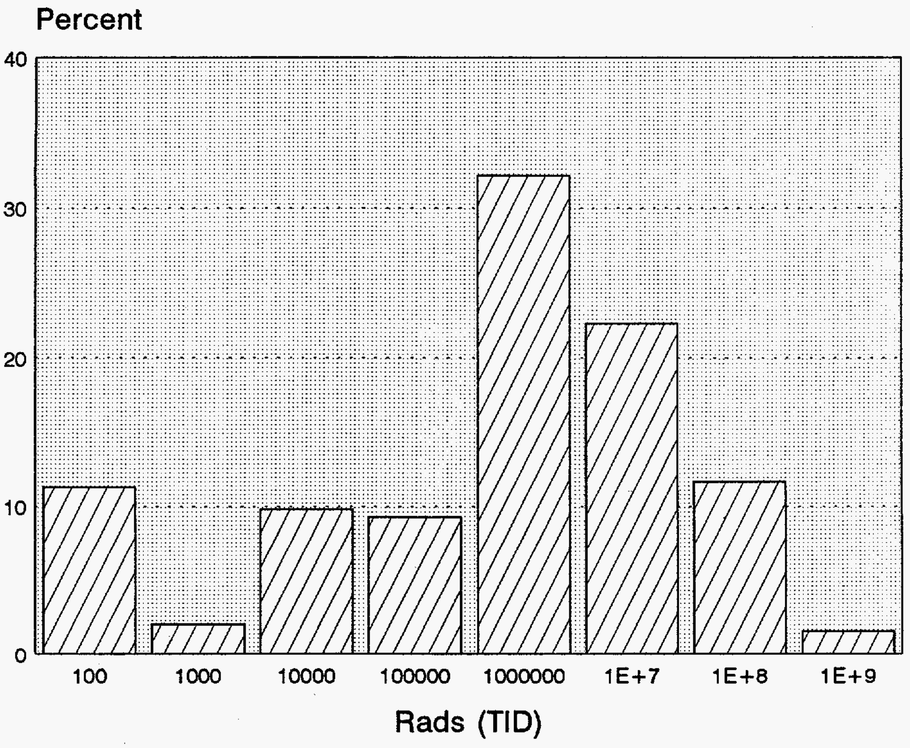

Figure C.3 Radiation TID distribution for equipment in INEL EQ database

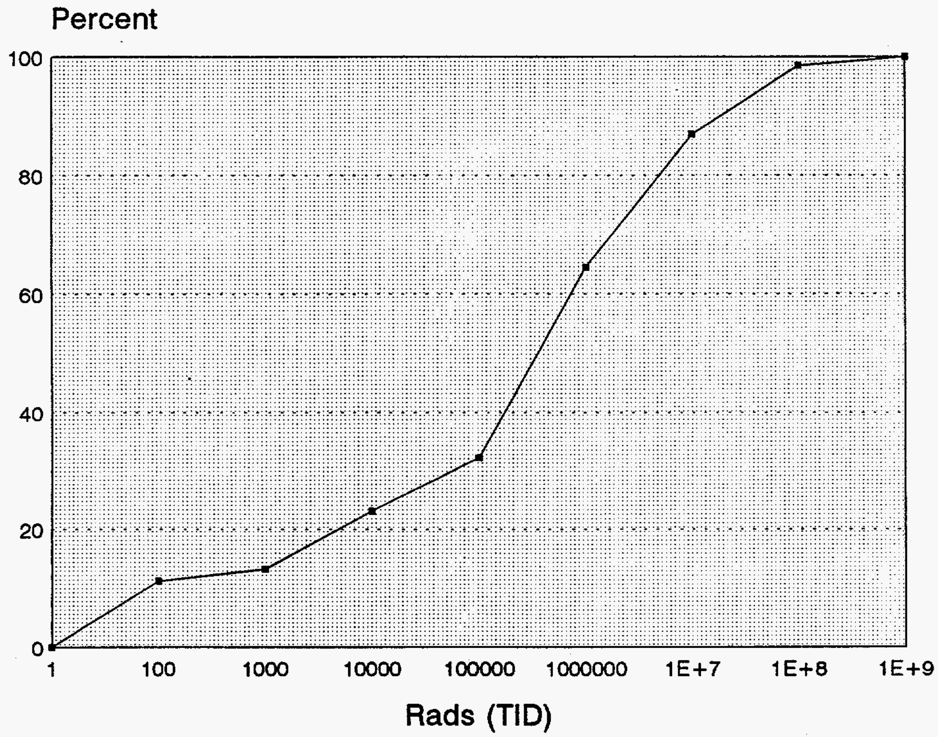

Figure C.4 Cumulative percent of equipment in INEL EQ database versus radiation TID

Qualification Method - Aging: For the entries that identified that qualification was complete, the qualification methods used for aging were analyzed. Methods which were identified as simultaneous,sequential, Arrhenius, accelerated aging, were grouped together and classified as aging by test. The aging by test classification represented 77.9% of qualification methods. The methods identified as Engineering, Surveillance, and Failure Analysis were classified as Analysis. The aging by analysis classification represented 22.1% of the aging methods utilized.

Qualification Method - DBA Temperature: For the entries that identified that qualification was complete, the qualification methods used for DBA Temperature were analyzed. Methods which were identified as simultaneous, sequential, combined test and analysis, were classified as test methods. The test method represented 85.2% of the qualification methods for DBA Temperature. Methods which were identified as Engineering and similarity, were classified as analysis methods. Analysis methods represented 14.8% of the DBA Temperature qualification methods utilized.

C3.0 CONCLUSIONS

The INEL EQ Database allows the following conclusions to be made.

1. Even though only 2 out of 87 nuclear plants, 2%, were required to perform aging by testing, the aging test method was utilized to qualify safety-related equipment in over 77% of the qualified equipment.

2. The test qualification method was utilized to qualify safety related equipment for the DBA Temperature conditions in over 85% of the qualified equipment.

3. The requirements for DBA radiation and temperature were based on actual plant analysis. The generic DBA temperature curves in the appendix of IEEE 323-74 envelope approximately 94.6% of plant specific requirements.

4. The distribution of radiation requirements shows that only 15% of safety related equipment, required to be qualified, have radiation qualification requirements of 1E7 Rads or greater.

5. The distribution of DBA Temperature requirements shows that less than 20% of safety related equipment, required to be qualified, have DBA temperature qualification requirements greater than 300°F.

Applicability to Current EQ Research: The INEL EQ Database provides summary evidence about the qualification of safety related equipment. It is applicable to the current EQ research as follows.

1. The INEL EQ Database does not resolve any of the EQ issues by itself, however, it is useful for providing evidence that supports the resolution of some of the issues.

2. Issues have been raised with regard to the overall level of conservatism or margin in the EQ process, including the pre-aging process and LOCA testing. Relevant information is provided in the INEL EQ Database regarding specific issues of conservatism. For instance the database shows that significant percentage of safety related equipment has been qualified using pre-aging, even though it was not the licensing basis. Additionally, a high percentage of safety related equipment has been qualified to DBA conditions by testing. Testing has been a preferred method. The database provides objective evidence that nuclear plants have performed the vast majority of qualification programs by the test method. The utilization of pre-aging and qualification by testing contribute to increased confidence in the EQ process.

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3. Issues have been raised with regard to the graded approach to EQ. Relevant information is provided in the INEL EQ Database regarding specific issues of test parameter margins and accident profile variations. The database shows that a significantly high percentage of safety related equipment is required to be qualified to conditions significantly less severe than the worst case DBA profiles. Since cables are qualified to the enveloping requirements of all applicable locations, significant additional margin exists for typical applications in which the service conditions are less severe than those for the enveloping application.

The effect of pre-aging variations in the graded approach to EQ is an issue. The BNL analysis of the INEL EQ Database shows that even though only 2% of plants were required to qualify equipment with pre-aging, over 77% of the equipment was qualified by pre-aging test methods.

The effect of test parameter margins in the graded approach to EQ is an issue. The BNL analysis of the INEL EQ Database shows that EQ qualification requirements have been established through plant specific accident and radiation determinations. Equipment requiring qualification has a wide distribution of radiation and DBA Temperature requirements. The distributions show that the significant percent of equipment are required to be qualified to conditions significantly less than the test parameters identified in the Appendix of IEEE Std 323-74.

4. The INEL EQ database provides evidence of qualification for a wide variety of equipment types, including cables. Thus the conclusions have applicability to all safety related electrical equipment required to be harsh environment qualified.

5. A ranking of types of safety related equipment in harsh environments was prepared from the review of the INEL database. Figure C-5 shows the ten equipment types, which were listed in the database. These ten comprise 83% of all of the safety related equipment in the database. These data do not represent the quantity of these types present in nuclear plants, since each equipment listed could represent multiple individual plant items. It does, however, provide insight into the most prevalent safety related equipment types.

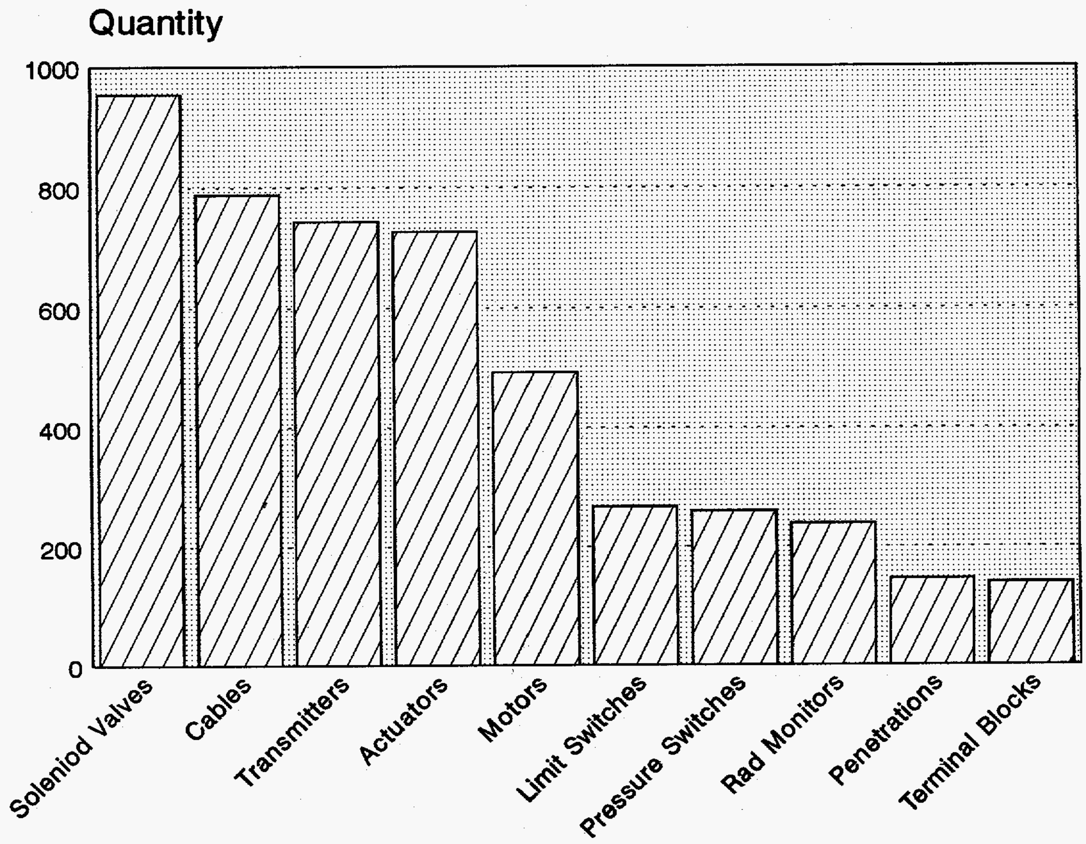

Figure C.5 Equipment types in INEL EQ database

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10. SUPPLEMENTARY NOTES
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11. ABSTRACT *(200 words or less)*

In support of the U.S. NRC Environmental Qualification (EQ) Research Program, a literature review was performed to identify past relevant work that could be used to help fully or partially resolve issues of interest related to the qualification of low-voltage electric cable. A summary of the literature reviewed is documented in Volume 1 of this report. In this, Volume 2 of the report, dossiers are presented which document the issues selected for investigation in this program, along with recommendations for future work to resolve the issues, when necessary. The dossiers are based on an analysis of the literature reviewed, as well as expert opinions. This analysis includes a critical review of the information available from past and ongoing work in thirteen specific areas related to EQ. The analysis for each area focuses on one or more questions which must be answered to consider a particular issue resolved. Results of the analysis are presented, along with recommendations for future work. The analysis is documented in the form of a dossier for each of the areas analyzed.

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