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Workshop on Environmental Qualification of Electric Equipment

Held at
Holiday Inn Crowne Plaza
Rockville, Maryland
November 15-16, 1993

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SUMMARY

Questions concerning the Environmental Qualification (EQ) of electrical equipment used in commercial nuclear power plants have recently become the subject of significant interest to the U.S. Nuclear Regulatory Commission (NRC). Initial questions centered on whether compliance with the EQ requirements for older plants were adequate to support plant operation beyond 40 years. After subsequent investigation, the NRC Staff concluded that questions related to the differences in EQ requirements between older and newer plants constitute a potential generic issue which should be evaluated for backfit, independent of license renewal activities.

EQ testing of electric cables was performed by Sandia National Laboratories (SNL) under contract to the NRC in support of license renewal activities. Results showed that some of the environmentally qualified cables either failed or exhibited marginal insulation resistance after a simulated plant life of 20 years during accident simulation. This indicated that the EQ process for some electric cables may be non-conservative. These results raised questions regarding the EQ process including the bases for conclusions about the qualified life of components based upon artificial aging prior to testing.

To address the issues related to the EQ process, the Office of Nuclear Reactor Regulation (NRR) developed an EQ Task Action Plan (TAP) in June 1993. The purpose of this TAP was to identify, evaluate and resolve EQ issues and related questions. To achieve these objectives, the support of the Office of Nuclear Regulatory Research (RES) was requested. Subsequently, RES held a public workshop to obtain technical input for the formulation of an EQ research program.

This report contains the minutes of the Environmental Qualification Workshop held November 15-16, 1993 at the Holiday Inn, Crowne Plaza in Rockville, Maryland. This workshop was sponsored by the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Division of Engineering. The purpose of the workshop was to solicit information to be used by NRC/RES in the development of a research program to examine issues related to environmental qualification of electrical equipment in commercial nuclear power plants.

Approximately 215 people attended this two day workshop, including representatives from 40 utilities, as well as manufacturers, consultants, contractors, and NRC Staff. A complete list of registrants is included in Appendix G. Nationally recognized experts in the field of EQ were invited to participate on four separate panels. Each panel addressed a different issue related to EQ. On the first day of the workshop, a plenary session was held. Presentations were made by the panelists, then questions and comments were taken from the audience. On the morning of the second day, four separate breakout sessions were held simultaneously; one for each panel. Discussions were held related to the individual panel issues to provide suggestions on how best to address that issue. In the afternoon of the second day, summaries of the breakout sessions were given by the panel chairmen in a plenary session.

The results of this successful workshop include a rare opportunity for an open exchange of ideas and information between industry personnel, researchers, equipment manufacturers, and regulators involving EQ issues, descriptions of state-of-the-art activities in condition monitoring and research techniques. The discussions included several recent equipment failures and their causes at operating facilities, and presentations describing current licensee actions related to

monitoring normal service conditions, such as on line temperature monitoring in specific plant locations. Additional discussions pointed out that there are no condition monitoring techniques currently available which are capable of determining the extent of cable degradation in the context of remaining qualified life. Several participants discussed a concern that any testing could lead to additional regulatory burden on licensees.

The workshop was very beneficial in providing useful input to the development of a research program. One of the main points made by participants is that there is a large amount of information currently available, and should be used by the NRC. This information will be collected for review, and will be considered by the Staff. Also, a great deal of background information was obtained related to the development of the EQ process. The utility representatives provided a number of insights into EQ from their plant experience which will be very useful in helping to understand the EQ issues of concern.

Experts in the field provided a number of insights into areas of concern related to EQ. For example, it was pointed out that there are apparently no requirements to monitor and evaluate degradation of EQ equipment located in normal plant operating conditions of high temperature and/or radiation. Additional highlights are presented in a subsequent section to this report.

The minutes presented in this report were developed from detailed notes taken by Brookhaven National Laboratory (BNL) engineers attending the workshop. BNL compiled and edited these notes for inclusion in these proceedings. Transcripts of the workshop plenary sessions were made by the NRC, and were consulted during the preparation of these minutes to ensure accuracy and completeness. These transcripts are available in the Public Documents Room. Full text of the papers and visuals presented at the workshop are included in the Appendices to this report.

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WORKSHOP AGENDA

SUNDAY NOVEMBER 14, 1993

5:00 pm to 7:00 pm		Registration

MONDAY NOVEMBER 15, 1993

PLENARY SESSION

8:00 am	Introduction	Eric Beckjord, Director RES
8:15 am	NRR EQ Overview	Ashok Thadani, Director NRR/DSSA
8:30 am	RES EQ Program Plan	John Craig, Deputy Director RES/DE
8:45 am	NUMARC EQ Perspective	Alex Marion, NUMARC
9:00 am	Remarks on EQ from Nuclear Utilities Group	Bruce Tuthill, Northeast Utilities
9:15 am	Overview of EQ Practices	Salvatore Carfagno, Consultant
9:30 am	Break	
9:45 am	Preaging and Preconditioning	Session A Panel Members
11:00 am	EQ Operating Experience	Session B Panel Members
12:30 pm	Lunch Break	
1:30 pm	Condition Monitoring Methods	Session C Panel Members
3:00 pm	Break	
3:15 pm	EQ Testing	Session C Panel Members
4:45 pm	Summary	John Craig, NRC/RES
5:00 pm	Adjourn	

TUESDAY NOVEMBER 16, 1993

BREAKOUT SESSIONS

8:30 am	Breakout Sessions	All Panel Members
12:00 pm	Lunch Break	

PLENARY SESSION

1:30 pm	Session Chairmen Summary Reports	Session A and B Chairmen
3:00 pm	Break	
3:15 pm	Session Chairmen Summary Reports	Session C and D Chairmen
4:15 pm	Audience Comments	
4:45 pm	Concluding Remarks	John Craig, NRC/RES
5:00 pm	Adjourn	

PANEL MEMBERS

SESSION A: PREAGING AND PRECONDITIONING

Salvatore P. Carfagno, Chairman	Consultant
Ken Gillen	Sandia National Laboratory
Larry Gradin	Eco Tech/RAM-Q
Phil Holzman	Strategic Technology & Resources
Jack Lasky	Okonite
Louis Test	Consultant
Harold Walker	NRC

SESSION B: OPERATING EXPERIENCE

Robert Smith, Chairman	Duke Power Company
Vincent Bacanskas	Gulf States Utilities
Kent Brown	Tennessee Valley Authority
Jerry Edson	Idaho National Engineering Laboratory
George Hubbard	NRC/NRR, Plant Systems Branch
Sonny Kasturi	MOS

SESSION C: CONDITION MONITORING

George Sliter, Chairman	Electric Power Research Institute
Sue Burnay	AEA Technology, United Kingdom
Wells Fargo	Pacific Gas & Electric Company
J. B. Gardner	Consultant
Greg Henry	Applied Power Associates, Inc.
Francois Martzloff	National Institute of Standards and Technology
Paul Shemanski	NRC/NRR, License Renewal & Environmental Review Project Directorate
Gary Toman	Ogden Environmental & Energy Services Company

SESSION D: TESTING

James Gleason, Chairman	GLS Enterprises
Satish Aggarwal	NRC/RES, Electrical & Mechanical Engineering Branch
Mark Jacobus	Sandia National Laboratory
Michael Kopp	Farwell & Hendricks
Richard Miller	Westinghouse
Michael Saniuk	National Technical Systems

WORKSHOP HIGHLIGHTS

Throughout the workshop a number of important issues related to environmental qualification (EQ) were discussed, and various opinions were expressed by the participants. The following highlights represent opinions expressed by more than one participant and, in most cases, by a majority. It is recognized that many of the issues discussed are controversial and no attempt was made to obtain a consensus on each issue. However, the highlights presented represent those opinions that the NRC staff, panelists, and many other participants felt should be considered in planning research efforts.

GENERAL

1. The workshop was attended by approximately 215 people, with 40 utilities represented (see Appendix G).

2. Industry representatives stated that, in order to make the NRC's EQ research efforts cost effective and to avoid redoing past efforts, it is essential that all previous work in the EQ area be reviewed and utilized as appropriate in the research.

3. If the utilities are to be expected to provide data and material for testing, then the issue of enforcement requirements must be addressed.

4. The focus of the NRC's attention should be on components that are long lived and very burdensome to replace, i.e., those that are not routinely replaced and are potentially expensive to replace. Industry representatives stated that this focus should be on two components: cables and electrical penetrations.

5. Industry representatives stated that techniques for prioritization of components to be researched should be used that are based on safety/risk significance.

6. EQ should be kept in perspective; it is just one of many safety assurance activities, such as maintenance, monitoring, etc.

OPERATING EXPERIENCE

Industry representatives stated the following:

7. Radiation and temperature hot spots have been found in nuclear power plants that have significantly affected aging degradation. For example, the qualified life of some cables that were originally evaluated to see an ambient temperature of 104°F were actually experiencing temperatures of 160 to 200°F. The identification and location of hot spots and appropriate potential equipment degradation analysis needs to be part of EQ analyses.

8. Some data for selected cables indicate that naturally aged cable and other equipment may degrade at a slower rate than indicated from accelerated aging techniques.

9. When evaluating cable qualification, you must consider the entire cable system, e.g., connectors, terminal blocks, grounds, etc.

10. Operating experience should be used to compare and evaluate different guidelines and standards, such as NRC Division of Operating Reactors (DOR) guidelines and NUREG-0588.

TESTING

11. Some participants stated that, when testing naturally aged cables, the mandrel bend test appears to be too conservative as an ultimate acceptance criterion in that many cables will fail that would have operated through a Loss of Coolant Accident (LOCA). However, it may be possible to correlate bend behavior with LOCA performance with additional research.

12. A sample size of one has been accepted for qualification testing because there is a lot of conservatism built into the test program; e.g., two LOCA peaks, generally conservative assumed environmental conditions, and margin.

13. In general, sequential application of radiation/thermal environments for qualification testing is acceptable in place of simultaneous application on the basis of margins applied in testing and supporting research.

PREAGING/PRECONDITIONING

14. The preaging/preconditioning process needs to be validated by comparison to naturally aged equipment. In particular, this holds true for the Arrhenius methodology, where questions on extrapolation or mis-application of the technique may exist.

15. Research should address the need for and adequacy of current methods (analysis or preconditioning) for addressing thermal aging degradation and its effects on accident performance. (Current requirements permit aging to be addressed using aging analysis or age preconditioning prior to accident qualification testing. Differing views exist concerning the adequacy of aging analysis and the need to perform preaging for all equipment applications under the scope of 50.49.)

16. In view of the uncertainty in establishing the qualified life of safety equipment by the process of preaging/preconditioning, there is a need to evaluate its contribution to safety assurance in relation to its cost. Options that may contribute equal or greater safety assurance, at lower cost, should be investigated.

17. The perception that the qualification of cables to DOR Guidelines did not include preaging needs to be corrected; instead, the adequacy of the preaging that was conducted should be evaluated.

CONDITION MONITORING (CM)

18. There are some condition monitoring methods for evaluating the integrity of cable insulating systems which are potentially useful but need further development. They were categorized by participants as follows: non-destructive techniques such as indenter, oxygen induction time (OIT), dielectric loss, and density measurements; destructive techniques such as elongation to break, bend test, and LOCA tests on cable segments removed from plants.

19. Acceptance criteria need to be developed for the various CM techniques that are in use.

20. CM should be able to predict the ability of electrical equipment to function under accident conditions, as well as normal conditions.

21. Several utilities have insitu cable samples, which are used to gauge aging degradation.

22. Some utilities are doing "Indenter" and electrical characteristic testing on cable insulating systems on a trial basis, but none are doing it on a routine basis yet. Some participants stated that prescriptive CM requirements should not be a part of EQ.

23. No matter which CM techniques are used, cross-correlation with other techniques is a wise practice.

1. MONDAY NOVEMBER 15, 1993 PLENARY SESSION MINUTES

The workshop began on Monday morning with a plenary session. Approximately 215 people attended. Opening remarks were made stating the purpose and goals of the workshop, then each panel made their presentations. The minutes for this plenary session follow:

1.1 Opening Remarks

1.1.1 *Introduction (Eric Beckjord, Director, Office of Nuclear Regulatory Research, NRC/RES)*

(Full text of prepared speech in Appendix A. No viewgraphs used.)

Dr. Beckjord made the following comments regarding the workshop:

- The purpose of this workshop is to solicit ideas on technical issues related to environmental qualification
- An EQ research program plan based on the input from this workshop will be developed which addresses the technical and regulatory issues
- Four subject areas will be reviewed; preaging, condition monitoring, operating experience, and testing practices
- Good operating experience records are supported
- Technical issues and solutions need to be integrated for electrical equipment

QUESTIONS AND COMMENTS

NONE.

1.1.2 *NRR EQ Overview (Ashok Thadani, Director, Division of Systems Safety and Analysis, NRC/NRR)*

(Viewgraphs in Appendix A)

Dr. Thadani made the following comments on NRR's view of EQ:

- Due to license renewal, differences between qualification requirements for older plants and newer plants should be reassessed
- The Sandia cable test results raised questions with respect to accident performance of aged equipment
- Inadequate EQ could be a contributor to increased core damage frequency
- The Fire Protection Reassessment report concluded that EQ should be reviewed

- He compared the EQ requirements of NRC Division of Operating Reactors (DOR) Guidelines and NUREG-0588 (see chart in viewgraphs)

- Sandia cable tests:

  - Tests on damaged cable to determine the minimum insulation thickness needed to survive a LOCA at the end of life were performed

  - NPAR cable tests to study the possibility of extending cable qualification to 60 years were performed

- Sandia findings:

  - bonded-jacket cables may be susceptible to failure during LOCA when installed service conditions exceed temperatures of 50 C for 40 years

  - EQ testing that doesn't use jacketed configuration may not be representative of actual cable performance

  - there is a potential problem with using accelerated aging to simulate actual plant aging

- 84 plants do not have to consider preaging effects; is this decision valid with today's knowledge?

- Risk Scoping Study Conclusions:

  - there are large uncertainties with EQ issues

  - reduced equipment reliabilities due to harsh environment could increase core damage frequency for BWRs and PWRs

  - the core damage frequency impact of EQ is plant specific

  - more detailed technical work is needed to resolve EQ issues

- Fire Protection Reassessment Report recommendations:

  - EQ should be reviewed

  - EQ action plan includes EQ programmatic review by NRR/DSSA/SPLB

  - NRR\PMAS is reviewing the applicability to other generic issues

- The Task Action Plan was described with emphasis on elements 4 and 6. Element 4 is data collection and analysis, and 6 is technical issues; how well do we understand accelerated aging? Can condition monitoring be used for in-service inspection? We are looking for the workshop to recommend ways to proceed.

QUESTIONS AND COMMENTS:

QUESTION: (George Sliter, EPRI) What weaknesses did you find from the fire protection work? You talked about programmatic weaknesses. I have no idea what that means.

ANSWER: (Ashok Thadani, NRC/NRR) We found a number of weaknesses in our review and inspection activities. Questions exist on the following subjects:

- acceptance criteria for adequacy of the barriers that are used to meet fire protection requirements, one-hour barrier versus three-hour barrier

- what is considered a failure

- was a review done that recognized safety significance of some barriers. Reviews should be done through interdisciplinary teams, with a fire protection engineer and a systems engineer

- were the Appendix R requirements focused on the broad safety aspects of fires. Requirements may be too prescriptive in some areas and perhaps unnecessary in that Appendix R was silent in some areas where probably it ought not to have been silent.

QUESTION: (John Osborne, Baltimore Gas and Electric) Given the NRC's apparent reluctance to credit the seismic experience data base, why should we take time now to look at the experience data base for EQ? Are we really going to rely on it and accredit it appropriately?

ANSWER: (Ashok Thadani, NRC/NRR) It is our intention to utilize the EQ experience data base to establish a solid technical base for deciding on a course of action.

QUESTION: (Rick Naylor) The NRC has collected data for the last 13 years from all of the plants in regards to the equipment qualifications. Why is the NRC looking again at collecting data that they already have, and why hasn't the NRC used that data up to this point in their research, since they have every test report all the utilities have done since the original?

ANSWER: (Ashok Thadani, NRC/NRR) The NRC will be looking at the information already obtained, however, there is still useful information at the sites. For example, we would like to get an understanding of maintenance practices and replacement strategies. It is important that our information not be limited just to test reports. We need to visit sites and see how people are addressing these issues.

QUESTION: (Gene Kopecky, Omaha Public Power) What assurance do we have that you've fully implemented the corrective actions suggested to you from the fire program? That was, essentially, an internal audit. It's basically the NRC's problem and it appears to me that you are trying to pass it on to the industry. You need to correct your own house before you come and ask people to start doing things in their programs.

ANSWER: (Ashok Thadani, NRC/NRR) As far as EQ is concerned, there are obvious questions. Before we go into license renewal we, clearly, need to understand the current licensing base. There are technical questions about whether, in fact, what we have today is as good as it should be, and we intend to try to answer those questions. We are also going to look at programmatic aspects, simply because there are some similarities between environmental qualification and fire protection programs. I think we ought to learn from our past mistakes.

COMMENT: (Millard Allen, Allen Engineering Services) The issue here is the application of operating experience and how you go about applying operating experience qualification. Testing was never an end product. The testing that we performed on the equipment was to establish a baseline, not a necessarily credible potential for that equipment to survive the real accident. So the issue is operating experience, not testing of the equipment.

COMMENT: (Paul Boucher, GPU Nuclear) It seems as though we have gone back 10 years, and we're starting from scratch again. NUMARC has put out an industry report on cable. They have tediously gone through all the records and set up a program. There is a matrix in there on where we should start. It is a very complicated issue. And they have tried to get the issue to a point where you could address it.

Unfortunately, the NRC is limited in funds and the Sandia testing has tried to accomplish too much out of too little funding. In other words, they have tried to test too many cables at one time, and we have had a lot of problems with the results of it.

Unfortunately, the industry report did not take into consideration the recent Sandia tests, but all the other testing that was done in the industry is in there. It would seem as though the NRC would start with that document. If you don't like it, change it, but at least it's a starting point. It's a goal, it's a place to start from -- and not start back 10 years ago and recreate the issue. Most of the questions are documented, all of these questions that are coming up today are in the record someplace. I feel that the industry report would be the starting place to begin with.

COMMENT: (Ashok Thadani, NRC/NRR) I agree that you don't want to immediately start with a big program without looking at the available information. We've worked very hard trying to get as much technical information as we could, because ultimately these issues have to be resolved on a technical basis.

However, it is disappointing that we have not been able to find a good basis for some of the past requirements and for grandfathering plants.

1.1.3 *RES EQ Program Plan (John Craig, Deputy Director, Division of Engineering, NRC/RES)* (No prepared speech or viewgraphs used)

Mr. Craig made the following comments regarding the workshop:

- With regard to the comments made about past work done by the industry, the NRC is not starting over. Information that exists and is available to the staff will be used.
- The purpose of this workshop is to obtain input from the industry regarding the development of the research program plan.
- NRC research needs to be focused, cables are the initial area of emphasis.
- NRC is not requiring licensees to embark on a new program.
- The results of this program will be applicable to a broad spectrum of plants.
- NRC is hoping to finalize the program plan by the end of the year and have a draft available for comment in the early part of next year.
- This may be the first in a series of interactive discussions between industry and NRC.

QUESTIONS AND COMMENTS:

QUESTION: (John Bonner, Yankee Atomic) The NRC has dollars for research, but they also have an enforcement requirement. For a utility with a 20-year existing license to go and pull a cable out of a plant and run the risk of that cable failing, due to unknown circumstances, is a great risk for the utility. For me to go back and tell my plant that we want to get involved in the research by taking a cable out of the plant, the licensing people are going to say, "Are you crazy? We've got 20 years. We'll let somebody else do it." How is the NRC going to address the enforcement and the research requirements? Is the plant going to be penalized for getting involved, for example, if something happens, and they have to get into the paperwork of trying to justify why this was a separate case?

ANSWER: (John Craig, NRC/RES) I understand the question, and I'm glad you asked it. Our focus right now for getting cable samples is on plants that are being decommissioned, and the same questions have come up. It is even broader than that; there are reporting requirements for 10CFR50.72, 50.73, and Part 21. If we find something, it may cost a lot of money to do the engineering analysis to evaluate the finding and make the reports. How do we go about that?

A plant that is in a decommissioning mode is under a great deal of scrutiny, and they are not going to spend a lot of money to do engineering evaluations that, if they didn't look, they wouldn't have to do. There is something called enforcement discretion that allows us to waive the enforcement option if the violations are not of a wilful nature. The specifics would be reported, but it wouldn't necessarily be a violation against that licensee.

The reporting requirements issue is one that is a little thornier. There are more aspects to it, but that question is one that we are dealing with today. There is a certain liability there, and we recognize that.

On the other hand, the utilities are looking for problems or anything that may be abnormal. To suggest that, because you are going to participate in a research program, you might find something that you would not have otherwise found, I think, does a disservice to the licensee activities that are in every station and ongoing. That is not to minimize the issue of the potential liability, and we are going to try to address that in an up front, forward manner before we engage in any program with a specific plant.

QUESTION: (Phil Holzman, STAR) You mentioned something about the plan. Is there in general some expected end date for the research and how does that integrate into the task action plan?

ANSWER: (John Craig, NRC/RES) I don't have a good answer for that question. We certainly want to implement specific research projects that will answer these types of questions. The questions are going to be prioritized and we will try to develop specific programs to get the information to address those.

It takes a few months for us to get contracts in place, however, I truly believe, if the engineers, utilities, and the NRC decide this is something that is worthwhile, it does not have to drag out two or three years. I think the overall EQ research program is going to go on for a number of years, but I think we are not looking at a 10-year program. It has to be much sooner than that.

QUESTION: (Francois Martzloff, NIST) You mentioned in situ test of cable. Do you see a clear distinction between doing tests at the decommissioned plant and tests at an operating plant?

ANSWER: (John Craig, NRC/RES) The answer is no, other than at a decommissioned plant it might be a lot easier, because you can take cable samples out that won't involve licensing them, tech spec changes, access as far as radiation exposure, and those kinds of things. But that also carries with it the potential that cables may be affected by decommissioning activities in that specific area.

Some of the plants that I have talked to have said, "You are better off going to a plant that is just decommissioned and do whatever you want to do in a plant quickly, because we are going to forge ahead and start removing equipment, and you don't want to have any of the test results questioned by activities that may have taken place."

Other than those kinds of considerations, I don't see a significant difference, other than the fact that the first plants they decommission are going to be the older ones, and I'm not sure how representative the cable types in those plants are, relative to the newer plants. I just don't have that information yet.

QUESTION: (Rick Naylor, CECo) How is this program going to be different from the NPAR Program, and what are the results that have been applied from that program thus far to what the NRC has learned? If inspection enforcement has just finished up in 1991-1992, the initial implementation of the EQ Program, why isn't your branch looking at that information that has been just gotten from those plants, those recent audits and then applied to this as well?

ANSWER: (John Craig, NRC/RES) The NPAR Program is within the Division of Engineering and that information -- as is the information from the EPRI testing, the SANDIA testing, and the other ones -- is going to be factored into the program. The test results from the NPAR Program concerning cables and EQ are a little bit mixed, depending on the statistics or your inclination. You can argue that 30 percent of the cables that were tested under that program failed. You can also look at the specific tests and other questions, and the number comes down somewhat.

I think the thing that is significant about the results of the NPAR Program is that some of the cables that had previously been qualified by preaging and testing for 40 years, when they were tested as part of the NPAR Program, some of them failed after 20 years. That in itself raises some questions, and we need to look at those.

In the context of the other equipment that we have looked at as part of the NPAR Program -- breakers, relays, and other electrical components -- I think that just by the fact that we are focusing initially on cables and things that are longer-lived in the plants indicates we have recognized that a lot of the programs in plants for equipment such as a breaker or celluloid that is easy to replace and easy to test, compared to a cable, reflect that we are considering the results. To the extent we can, we are going to continue to do it.

We haven't excluded any information that is available to us yet. We are still identifying potential sources of additional information. There is an IAEA meeting coming up in early December. The IAEA is about to embark on similar kinds of testing. To the extent that we can, we would like to build on those research activities in a coordinated sense so that we can benefit from their work and they can benefit from our's.

QUESTION: (Dave Medick, Arizona Public Service) What are the agency's plans for resolving the industry comments received about a month ago on the Sandia cable tests; there were some that were sent in by NUMARC and some by utility groups? Second, what plans does your office have for accessing the wealth of data from the Three-Mile Island accident?

ANSWER: (Ashok Thadani, NRC/NRR) As far as the NUMARC comments on Sandia testing, the comments are under review. I've read the two letters sent to me and there are some very good points made in them. I assure you they will be considered as we go forward.

COMMENT: (John Craig, NRC/RES) I haven't read the reports on the Three-Mile Island accident; although, I do remember in late March and early April of '79 when we were trying to de-energize circuits because things were failing. I'm told that there are some reports that indicated a substantial fraction of the electrical equipment was failing. I don't know the causes. We are in the process of trying to get that information, and we are going to include it in our considerations.

1.1.4 *NUMARC EQ Perspective (Alex Marion, NUMARC)*

(Full text of prepared speech in Appendix A. No viewgraphs used. Comments in Public Comments Section)

Mr. Marion made the following comments regarding NUMARC's position on EQ:

- His comments do not address licensing or policy issues.
- He stated that utilities should be responsive to questions since that is how the state of knowledge and technology advances.
- A great deal of effort has been expended in the past to demonstrate the adequacy of Class 1E service equipment to perform in the event of a design basis accident. The question now is what have we learned from this activity during the past 14 years? The conclusion that failure of Class 1E cables in a harsh environment is risk significant was already known.
- The advent of new tools and technology should not declare the past null and void. Deterministic approaches used in the past provided for levels of defense in depth. Hopefully, with insights gained from probabilistic safety we can conclude that reasonable levels of defense in depth exist, as opposed to the addition of more requirements.
- Class 1E cables are important, as evidenced by the money spent on the NRC's NPAR program and the EQ testing by manufacturers and utilities. His personal opinion is that properly designed cable is robust; the weak link being in the termination point.

- Given the finite types of materials used in cable insulation systems, it is surprising that we are still asking questions about what is acceptable.

- Understanding aging and its effects on performance of Class 1E equipment is important, however, understanding the materials used is nothing new.

- Margins are still a contentious issue.

- Questions alone should not necessarily lead to major research.

- He supports John Craig's comments about holding open meetings on these issues.

Questions and Comments

None.

1.1.5 *Remarks on EQ from Nuclear Utilities Group (Bruce Tuthill, Northeast Utilities)*
(No prepared speech or viewgraphs used)

Mr. Tuthill made the following comments regarding EQ:

- NUG includes 35 utilities and has been involved in EQ for many years.

- Share and support NUMARC's views on the EQ issue.

- He considers this workshop a valuable first step in assessing the need for further research. He hopes similar openness will be used by the staff in developing and implementing research topics.

- He urges that efforts focus on topics important to plant safety.

- He encourages the staff to examine relevant data and research that already exists, which is substantial.

- An important step is to identify specific questions that need further review. NRC resources will not be well spent on research simply for the sake of research.

- Unless other specific questions are identified, future effort should focus on aging of long-lived components, such as cable.

- Research should focus on areas with greatest potential safety significance. This will require research topics be selected and prioritized. Impact must be evaluated in context of overall EQ process, including program elements that provide significant margin.

- Relevant PRA insights should be factored into the assessment of potential safety significance. He recommends a separate PRA effort be conducted in the context of the EQ action plan and be integrated into research efforts.

- NRC should consider research on developing a more complete understanding of the importance of existing conservatisms, e.g., post accident operating times, beyond design basis radiation dose, and leak before break considerations.

QUESTIONS AND COMMENTS:

None.

1.1.6 *Overview of EQ Practices (Sal Carfagno, Consultant)*
(Full text of prepared speech in Appendix A.)

Dr. Carfagno made the following comments on EQ practices:

- The objective of EQ is to prevent common cause failures that could disable redundant safety systems. It is a deterministic process.

- Practically all equipment qualification is conducted with a single specimen; confidence comes from conservatisms built into process.

- Qualified life is the period of normal service prior to start of design basis event. In nuclear safety systems the situation is different from ordinary equipment applications since the major demand may come after a long period of operation under normal service conditions. At that point functional capability must be adequate to meet requirements in harsh environments.

- If service and operating conditions cause significant deterioration of the functional capability, aging should be accounted for in the EQ process.

- We have learned that we can't depend solely on the qualification process. EQ is only one part of a broader system for assuring safety. Must also rely on surveillance, maintenance, refurbishment, and condition monitoring.

- We are concerned mostly with, and must focus on, equipment not amenable to refurbishment or maintenance, such as cable and penetrations. This places a greater dependence on condition monitoring, such as surveillance and monitoring activities.

- We still have reservations about impact of PRAs. It is difficult to predict how they will influence EQ process.

- We now have a better idea of the role EQ plays in plant safety. We learned to place more dependence on surveillance and maintenance.

QUESTIONS AND COMMENTS:

None.

1.2 Session A: Preaging/Preconditioning

1.2.1 *Summary of remarks by Salvatore Carfagno (Consultant)*

(Full text of prepared speech in Appendix B)

- Aging is the deterioration of functional capabilities during normal service.

- Preconditioning refers to whatever is done to a piece of equipment to simulate the deterioration of its functional capability. It is used to establish the qualified life of equipment, i.e. the period of time to end of service life when the equipment must still perform its intended function during a DBA.

- Stressors that contribute to significant aging mechanisms include heat - defined by Arrhenius Formula (temperature, frequency of molecular interactions, activation energy), radiation - defined by equal dose/equal damage model, humidity, pressure, vibration, electric fields, dirty/corrosive atmospheres, installation damage, sharp bends, unsupported runs, and hot spots.

- There is a need to develop models to address the stresses which cause the aging of materials. Currently, Arrhenius is used for thermal stress and equal dose/equal damage is used for radiation effects. No other stresses are modeled.

- The Arrhenius Model can give good results when applied to material specimens in a laboratory; however, there is little good comprehensive comparative data between lab results and actual plant service.

- The equal dose/equal damage model is used for radiation aging. However, at high dose rates, damage is found to be less in the lab than an equivalent total dose accumulated in the field at a low rate.

- The use of these models is not very accurate. One problem is that in service, the stresses appear simultaneously, whereas in a preconditioning program, they are typically applied sequentially.

- There are many reactions involved with complex equipment. How much preconditioning contributes to safety is difficult to assess, but we tend to have more confidence in equipment which is preconditioned prior to accident simulation in contrast to equipment in which significant aging is addressed entirely by analysis.

- If a preconditioned sample and a non-preconditioned sample are EQ tested, and both pass then it is hard to assess their relative performance unless it is feasible to measure their residual functional capability at the conclusion of EQ testing. Otherwise, we are compelled to have more confidence in the preconditioned sample because it passed the EQ test in spite of having its functional capability partially degraded prior to the accident simulation.

- Safety related equipment located where the operating environment does not change, even after a DBA has occurred, may be capable of performing its safety function during an accident, even though it might not be able to survive worst case DBA conditions.

QUESTIONS AND COMMENTS:

None.

1.2.2 *Summary of Remarks by Louis Test (Consultant)*
(Full text of remarks in Appendix B. Comments in Public Comment Section.)

- IEEE 279 was the initial kickoff to EQ.

- IEEE 323 group was initially flying blind; it was not the identification of best practices which was the intent of most other standards.

- A lot of conservatism was built into the standard.

- Failures in EQ were determined to be design flaws, not aging related.

QUESTIONS AND COMMENTS:

None.

1.2.3 *Summary of Remarks by Larry Gradin (EcoTech/RAM-Q)*
(Viewgraphs in Appendix B)

- He stated that DOR Guidelines and NUREG-0588 do not make a real difference in how the EQ testing program may have actually been conducted. The key is a good engineering effort demonstrating equipment adequacy based on test and analysis regardless if the governing EQ document is the DOR guidelines, NUREG-0588, or 10CFR50.49.

- He cited the definitions and importance of the concept of significant aging mechanisms, derating of equipment, and experienced validation of accelerated aging for motors and transformers.

- He cited lots of non-nuclear related information. For example, the airlines found that only 11% of the components have a wear-out failure mechanism, whereas a greater percentage (reported to be 68% or more) have infant mortality. If that were the case in a power plant, then replacement of parts can prematurely decrease the level of safety.

QUESTIONS AND COMMENTS:

None.

1.2.4 *Summary of Remarks by Phil Holzman (STAR)*
(Viewgraph in Appendix B. Comments in Public Comment Section.)

- He addressed aging management methods and the importance of maintenance, testing, condition monitoring, failure investigations.

- He stated that radiation is very conservative for preaging, and that EQ requires less reliance on predictive techniques and more on maintenance and testing.

QUESTIONS AND COMMENTS:

None.

1.2.5 *Summary of Remarks by Jack Lasky (Okonite)*
(No prepared speech or viewgraphs used)

- He talked about the Arrhenius model-what it is and what are the limitations.

- Regarding the application to polymeric materials; there is a concern about extrapolating beyond the experimental data.

- At least 4 different reactions occurring in thermal aging that makes it difficult to apply simple equations to the complex kinetics. Part of research program should be to determine the temperatures to apply to preaging.

QUESTIONS AND COMMENTS:

None.

1.2.6 *Summary of Remarks by Ken Gillen (Sandia National Lab)*
(Viewgraphs in Appendix B)

- Two major preaging issues were discussed; one being the reduced oxidation caused by diffusion limitations that takes place in accelerated aging vs. what occurs in natural aging.

- While Arrhenius works in many applications, it may not work if jackets cover the insulation; because oxidation of the insulation during accelerated aging may be minimal or significantly reduced due to diffusion limitations.

QUESTIONS AND COMMENTS::

COMMENT: (George Sliter, EPRI: Viewgraphs in Appendix B) Referred to the EPRI EQ Reference Manual as a source of good information, especially for activation energy curves. Generally, elongation to break studies of electrical cables showed that natural aging was less severe than artificial aging.

1.3 Session B: EQ Operating Experience

1.3.1 *Summary of Remarks by Robert Smith (Duke Power)*
(No prepared speech or viewgraphs used.)

- He feels we are getting smarter in terms of EQ. They are using knowledge on non-EQ equipment at Duke.

- Operating experience shows EQ equipment is no different from other equipment.

- They haven't rethought their assumptions about testing based on operating experience.

- Actual installed conditions are less severe than postulated test conditions. EQ equipment is replaced and refurbished periodically and is not aging to the extent that is predicted by the test methodology.

- Operating experience suggests that further research into age-related degradation needs to focus on equipment with long-term qualified life.

QUESTIONS AND COMMENTS::

None.

1.3.2 *Summary of Remarks by Vincent Bacanskas (Gulf States Utilities)*
(Viewgraphs in Appendix C)

- At Riverbend, cable in the ceiling area of the drywell had hot spots. The cable indenter was used to test the cable, which showed a high modulus for cable exposed to high temperatures. The cable is made of polyethylene insulation with Hypalon jacket. The cables were replaced. He emphasized that the cable did not fail.

- Safety analysis shows that the loss of the cable function would increase the core damage frequency only by 0.4 % of the base line IPE and 0.06 % of the NRC Safety Goal.

- He expressed the opinion that research to eliminate regulations marginal to safety should be completed before additional research is performed.

QUESTIONS AND COMMENTS::

None.

1.3.3 *Summary of Remarks by Kent Brown (TVA)*
(Viewgraphs in Appendix C)

- Some premature failures of cable have occurred at TVA plants, including some in the main steam valve vault at Sequoyah.

- He felt that we are going too far with the installation specifications. It may be better to rely on the technician's experience.

- Three types of cable failure causes were identified, thermal and mechanical degradation, and manufacturing defects. Thermal degradation was noticed in cables close to hot pipes and valves.

- Thermal degradation has been experienced at Sequoyah due to steam leaks and missing insulation. Some thermal mapping of valve vaults has been done by analyzing polystyrene tags.

- Mechanical degradation was caused by ring cuts when terminating, gouges at seals, gouges and tears from pulling, impact, and pull-by. All these mechanical degradations were due to human factors.

- A third problem is manufacturing defects. There is no specification for void/particle size for low-voltage cables.

- Plasticizers are another concern. If they are unstable, they could leak from the cable jacket and drip onto other components and degrade them.

- More attention should be paid to jacket materials. There is an anticipated move away from the chlorosulfinated polyethylene due to the environmental concerns. When a new jacket system is used, the compatibility between the jacket materials and the insulation should be studied.

- The EQ process should be a part of the design process, not an after thought.

- They are purging the warehouse of problem cables.

- Need to identify what the limit of cable damage is before functionality is lost.

- A recurring problem is that material selection is done by electrical engineers, not by materials engineers. At least this should be done with the supervision of materials engineers or polymer engineers.

- EQ should not be required for cables outside containment since it adds little to plant safety.

QUESTIONS AND COMMENTS::

None.

1.3.4 *Summary of Remarks by Sonny Kasturi (MOS)*
(Viewgraphs in Appendix C)

- Equipment failures appear to be proportionately divided between EQ and non-EQ equipment relative to their respective population size.

- Very few cable failures were reported, and some of them were not cable failures but connectors, lead wires, and others. MOVs have the most reported failures.

- Causes of failures for both EQ and non-EQ equipment include misapplication, improper installation, inadequate maintenance, learning curve, i.e., personnel training in equipment operation, maintenance and EQ specifics, and aging effects.

- The first four items were responsible for about 75% of all the failures.

- Research efforts should be focused on the development of condition monitoring techniques, particularly for those pieces of equipment that are not included in periodic maintenance schedules and those with a long qualified life, such as cables and penetrations.

- On the question of whether the number of failures will increase in the future, his opinion is that plants are better prepared due to the emphasis on EQ programs.

- On the question of whether EQ equipment is any more vulnerable to aging than any other equipment, his opinion is that EQ and non-EQ equipment are the same in aging vulnerability.

- The available evidence appears to suggest that because of the higher level of maintenance and surveillance attention to the harsh environment equipment, they may be experiencing fewer failures, and that we can expect a significantly reduced potential for common cause failures.

QUESTIONS AND COMMENTS::

COMMENT: (Paul Boucher, GPU) A lot of statements are being made here, which I could have a lot of comments against. You are not giving the people a chance to speak up. These things are going to be published as a result of this workshop, and I don't think it's correct. There are some statements being said supposedly like factual statements which are not true. Not all of the information you people are presenting are facts.

COMMENT: (Robert Smith, Duke Power) That to me is why we have this next 15 or 20 minutes and we have discussions tomorrow. If you don't agree with what has been said up here, then you need to present some facts yourself as to what exactly you are contesting.

COMMENT: (Larry Gradin, Eco Tech/RAM-Q) One of the points dealt with: Is EQ equipment better than the non-EQ equipment? In fact, for much equipment it is. Almost everyone's motor if it is an environmental-qualified motor uses very high temperature insulation systems with very low temperature rise. Those motors will fail probably a 100 years in the future, where a standard Class B motor with a Class B temperature rise may fail in 10 years. That is also true of selection of high temperature wiring for lead wire. It is true of oversizing of contactors. It is true of a lot of equipment that you consider the need for extended life, therefore the design is far more conservative in selection of equipment. You will not find the same piece of equipment in a -- we'll call them EQ item or not. You have epoxy encapsulated windings versus dip and bake, things like that. In fact, much of the EQ equipment is, in fact, superior to the normal run-of-the-mill equipment.

QUESTION: (Jim Houghton, NRC/AEOD) When I looked at your slide, I was looking for the source of your failures. There are two basic data bases that we use for failures, one of them is the LER and the other one is the NPRDS. Are the failures that you based your information on from either of these two data bases or some combined one?

ANSWER: (Sonny Kasturi, MOS) They are based on NPRDS and LER data bases.

QUESTION: (Jim Houghton, NRC/AEOD) The NPRDS data base is limited. It doesn't identify EQ; it does identify safety-related. Did you therefore lump them under the safety-related and then follow that up to identify which were EQ, or did you just look at them as the broad safety-related group?

ANSWER: (Sonny Kasturi, MOS) I'm not sure I would agree with you with respect to the fact NPRD is limited with respect to identifying the EQ. The NPRDS does contain an environmental code which gives you information about the actual equipment internal and external operating environment. It's optional, but it does, for the most part, contain information in it. So if you look at it, you should be able to get that information. But I didn't stop there. When I looked at the equipment, because of my familiarity with the equipment itself and what happens to be in the typical EQ master list, when I reviewed the abstract I did look for: Is this potential EQ equipment? Could this be EQ equipment or not? I did not stop just at safety-related, but I went beyond that.

QUESTION: (Jim Houghton, NRC/AEOD) You made a judgment call, but you didn't necessarily match it to a plant's equipment qualification list; is that correct?

ANSWER: (Sonny Kasturi, MOS) Since the data was scattered over all different plants and all different plant types, I couldn't do that.

COMMENT: (George Sliter, EPRI) I would like to make a couple of comments, one about getting more facts and LER data, and the other one concerns the importance of the environment and monitoring.

First, Paul Boucher said this morning that a cable industry report had been prepared, and I want to bring up one part of the report that reinforced what Sonny said. A study was done by Sandia to support license renewal of plants. They looked for NRC Information Notices and found two which deal with cable degradation. IN-86-49 discusses degraded cable insulation discovered on a cable located near a local hotspot. The second is Information Notice 89-30. It describes instances of excessive temperature inside the containment drywell of PWR and BWR plants. Only two Information Notices, both not having to do with aging, per se.

EPRI recognizes the importance of monitoring environments, so a couple of years ago we had a workshop on environmental monitoring of nuclear plants, and have published the proceedings to help utilities define the most cost-effective ways of going in there and making sure they know their ambient environments and that they don't have hotspots, et cetera. Then the Sandia report looked very closely at LERs involving cables. They looked at hundreds and hundreds and hundreds of records and they put failures in various categories, very similar to Sonny Kasturi's: misapplication, mechanical damage, a big category called nonspecific, and then one category that came the closest to aging called degradation.

Sonny, you said that about 80 percent of the failures were due to non-aging. Well, the numbers from the Sandia report, Table 3.5, show that there were 72 total LERs that had to do with some kind of problem with cable. Many of them were due to mechanical damage: somebody made an error, misapplication, nonspecific. Out of the 72 only 8 were in the degraded category, that could even be looked upon as some kind of thermal degradation, so that's only about 10 percent that were due to aging. Then if you look carefully at the 8 you will find that, indeed, many of those were again error-induced and not aging under design conditions. Continuing, one more fact here on environmental monitoring, I said in my last remarks at the last session that the EPRI program at the University of Connecticut was monitoring the environments at these nine plants that we have. There are nine plants, but there are two locations at each plant. So there are, roughly, 17 or 18 actual plant locations and measurements, and this is their last interim report, so this is the report of the first five years.

What is done here is you measure the radiation environment, you measure the temperatures. For radiation you extrapolate the measured value to a 40-year life. I guess in this case you just multiply by eight and they have total dose measured at the 17 locations.

I will just quote the highest ones, the highest original utility estimate, i.e., the design radiation that's listed here is 22.1 megarads, which is in the ball park of the 50 megarads that is used to qualify these cables. The measured extrapolated-to-40-year dose at that location is 0.018 megarads. The next highest is 19 megarads from another location at another utility; measured 40-year dose, 0.38 megarads. The next lowest original design estimate was 10 megarads; measured, 1.57. That 1.57 extrapolated 40-year dose is the highest one of all of the locations that they looked at.

So this is the good side of it that, in general, environments are much lower than estimated, but you have to look out for hotspots and, therefore, the utilities should have an environmental monitoring program that assures there are no hotspots.

COMMENT: (Ashok Thadani, NRC/NRR) This morning Mr. Holzman made a very important comment. He hoped that we as an agency will focus attention on safety significance and pay attention to those elements, and that's clearly our intent. Just a few minutes ago a slide was shown that indicated for at least one plant that core damage frequency was on the order of 6×10^{-8}, whereas the overall core damage frequency for that plant was in the range of 10^{-5} per reactor year.

I guess the implication simply was you don't need to worry about this issue, and I think we need to be a little careful. It's very easy to use probabilistic estimates, and it's also very easy to abuse them. I think it's important before we draw conclusions about how significant an issue is that you go back to the base. What's the level of confidence? What's the data base behind those conclusions?

I'll show you something we did. Some of our staff took a look at how the reliability of certain components changes, depending on the environment that those specific components are exposed to. Some scoping type of analyses were done which involved varying failure rates, varying coupling factors in terms of common cause contributors and so on. It's not to say this is correct, however, before you start working on an issue you should get some sense of its importance.

They looked at three specific plants, with three specific probabilistic safety studies. For the BWR, large LOCAs are not significant, however, when you look at various types of transients, and intermediate and small LOCAs, there are other sequences that are important. With certain assumptions, the core damage could be in the range of 10^{-5} to 10^{-4}. Lack of knowledge is really the issue here, but that's what the contribution might be.

Similarly, they looked at two pressurized water reactors and found nothing radically different. I wouldn't pay too much attention to differences in factors of 3, 4, 5, in this kind of approximate assessment. Again, this points out that, if it's an issue, you should get more information, and a better understanding of it before you discard it.

There might be plant-specific issues and it is possible that a plant has core damage frequency as low as indicated. However, I would just like to caution you, the idea behind this whole activity was to develop an information base so we can actually have some confidence in what we are saying about the importance of specific components.

Our intention is to go forward and take into account safety aspects. The more important the components, the more attention we ought to be paying to them. I hope that that's where we end up. That's our goal. But I also hope that if we go forward with arguments that are probabilistic in nature, that there would be a sufficient supporting base for those plans.

QUESTION: (Unidentified) What is beta?

ANSWER: (Ashok Thadani, NRC/NRR) Let me use an example. Basically, for small LOCAs, if you have two trains, and 0.1 is the failure rate for one train, beta being 0.5 in that case would be applied as the failure rate of the second train. That is, there is some coupling because of the environment. That's the common cause coupling factor due to the environment that's folded in. There are three numbers shown in my viewgraph. If you take the first one and the second one and you multiply them, you get the third one.

COMMENT: (Satish Aggarwal, NRC/RES) This workshop is the beginning of a dialogue, not the end. If there is a problem or disagreement on any issue presented here, you have 30 days to provide written comments to us, and they will be included in the proceedings of the workshop.

QUESTION: (Paul Boucher, GPU Nuclear) Will I have all the written documents for all these people who are presenters so I can comment on them?

ANSWER: (Satish Aggarwal, NRC/RES) Yes. A copy will be ready in one week.

QUESTION: (Paul Boucher, GPU Nuclear) When will I get the transcript?

ANSWER: (Satish Aggarwal, NRC/RES) You will not get it. It will be placed in the PDR one week after this workshop.

1.4 Session C: Condition Monitoring

1.4.1 *Summary of Remarks by George Sliter (EPRI)*

(Viewgraphs, EPRI paper, and EPRI report summaries in Appendix D.)

Dr. George Sliter (EPRI and Session Chairman) introduced the Conditioning Monitoring panel and gave a brief biography of each member. He then gave a presentation in which he made the following points:

- Cables are qualified by means of aging and LOCA simulation.

- The role of surveillance (observation of current condition) in EQ is essential, but the conventional EQ approach does not require CM (trending of measured condition over time). IEEE 323 covers only the 'qualification' part of the Program. The 1974 version required maintenance and periodic testing. The requirement of surveillance was added in the 1983 edition of IEEE-323. This last version of the standard also provided the option that if qualified life cannot be determined, then condition monitoring can be used instead.

- Ability of condition monitoring techniques is extremely limited in the area of determining the ability of an SSC to withstand a DBE.

- The EPRI report on "Common Aging Terminology" was referenced and definitions were presented for the following terms: surveillance, conditioning monitoring, condition indicator, and functional indicator.

- It was pointed out how cables fail; that mechanical failures occur before electrical. Failure mechanisms were presented for shielded and unshielded cable. The observation was made that cables can be functioning at an acceptable level during normal operation and yet still fail during a LOCA.

- A list of EPRI reports on aging and condition monitoring activities was presented.

- A summary of conclusions from an EPRI condition monitoring workshop was presented:

    1. cables are reliable

    2. conventional test techniques for cables are for trouble shooting malfunctions, not for the condition monitoring of functioning cables.

    3. it is very difficult to identify condition monitoring techniques that can predict capability to withstand a LOCA.

- EPRI is planning a computerized cable database, a user's guide to in-plant cable monitoring techniques, and methods for extending qualified life.

QUESTIONS AND COMMENTS::

COMMENT: (Paul Boucher, GPU Nuclear) I just wanted to clarify what I was saying this morning. As far as DOR guidelines on testing are concerned, do you have to have steam testing if it was not going to be exposed to steam? There were certain materials that were limited and that you had to look at. There is more information on the DOR qualification than really came out this morning. The same thing with the radiation and thermal aging. There was a statement made this morning that combined testing is worse than sequential testing, and I don't agree with that.

1.4.2 *Summary of Remarks by J.B. Gardner*
(Full text of prepared speech in Appendix D. Comments in Public Comments section.)

J.B. Gardner discussed some EQ issues which are highlighted below:

- There are three publications that address EQ issues; NUREG-4731, EPRI Technical Report 102399, and the IEEE NPEC Ad Hoc Committee report.

- Relationship between EQ and CM- they both provide the assurance of operability.

- Cable installation procedures and techniques should be studied more closely- some cables are damaged during installation.

- The NRC research effort should focus on practical safety improvement.

- Key elements to focus on for cable systems are:

  1. common cause (moisture trigger is the key) CM to detect the susceptibility of cable to moisture does not exist,

  2. IEC is going to four levels of safety for I&C cables,

  3. cable seal interfaces are important,

  4. installation configurations are worthy of note, i.e. abuse outside of the EQ scope.

- Examine for susceptibility to common cause failure. Focus on cable systems, not just cable, and preventing moisture intrusion should be a priority.

- Equipment important to safety should be reexamined. Discriminating by two classes 1E and non-1E is not sufficient; the IEC is going to four levels of safety.

- There is no super solution to EQ issues. What is needed is to focus on many specific issues to improve the current situation.

QUESTIONS AND COMMENTS::

None.

1.4.3 *Summary of Remarks by Wells Fargo (PG&E)*
(No prepared speech or viewgraphs used. Comments in Public Comment Section.)

Wells Fargo stated that he was going to provide a utility perspective by discussing a short wish list:

- Condition monitoring should be non-intrusive, and should have good acceptance criteria.

- Utility personnel who maintained the electric distribution system, switchyard, and protective relays (typically not part of plant staff) had very useful practices for CM of electrical equipment.

- He cited some cable failures at Diablo Canyon, but did not go into detail.

QUESTIONS AND COMMENTS:

COMMENT: J.B. Gardner commented that the indenter technique can also be used as an environmental monitor, based on known environmental effects on cable jackets.

1.4.4 *Summary of Remarks by Gary Toman (Ogden)*
(Viewgraphs and two papers in Appendix D)

Gary Toman presented CM techniques with a focus on the indenter and oxygen induction time (OIT). The following points were made:

- The indenter tool and technique uses an NDE instrument and is effective over a wide range of material. Its principle of operation is that as cable insulation/jacket degrades, it becomes more brittle, and the degree of embrittlement is measured by an "indenter modulus," which is the ratio of the change in force to the change in indenter tool position. The indenter modulus is trended with time and typically increases with time.

- He is presently in the process of developing acceptance criteria. Pilot tests have been run at Dresden and compared to test results from Sandia. Preliminary results indicate that naturally aged cables do not age as fast as cables that are aged in an accelerated fashion.

- Cable indenter is primarily used for low voltage applications. It is not good for XLPE.

- Electrical properties are OK as long as mechanical properties are intact, and maybe even beyond if no moisture gets in.

- Reperforming accelerated aging to obtain acceptance criteria; comparison of actual to anticipated value based on accelerated aging.

- OIT is a technique that is suitable for cross-linked polyethylene cable. It is based on the principle that if anti-oxidants are present in a polymer material, then the anti-oxidants will react with oxygen, and act as a buffer to polymer oxidation, which will degrade mechanical properties.

- OIT evaluates the amount of anti-oxidants remaining in insulation material by measuring the period of time before a sample experiences rapid oxidation when subjected to elevated temperatures in an oxygen environment.

- For OIT, a 10 mg sample is required. The time it takes to decompose is indicative of the age; it takes only a few minutes to decompose if its aged, longer if it is not.

- The amount of anti-oxidants is being evaluated by Al Reynolds of U of V.

- OIT changes in an orderly manner in proportion to the degree of aging. Current developmental efforts will be published in 1994.

QUESTIONS AND COMMENTS:

COMMENT: (George Sliter, EPRI) I think we need more funding to create an industry-wide cable database. EPRI can put together the software and the format with an industry committee as to what we should be storing. The key here is cooperation by the industry in feeding the information. For example, Sandia National Laboratory has the biggest data base of good aging data, and we would like to have them put their data in. I encourage people, if we head in this direction, to please cooperate to make the data base as useful as possible.

With the indenter, Gary mentioned some work at Sandia and at Commonwealth Edison. EDF in France also owns one and has tried it on their cables. They liked the results, so they are going to be using it in their plants.

Tomorrow, I'm heading to Sweden because I heard that some researchers there have made their own indenter. It's not patented; it's just a hardness tester, really. I looked at the results, and it was interesting that they were using Arrhenius to plot the indenter results. They're getting pretty good results. Something we hadn't thought of even trying.

In Japan there is a similar technique they have developed where, instead of indenting the cable and using the compressive modulus, they are measuring in-situ the sheer modulus in torsion. They have a device that clamps onto a section of cable a few inches apart, and twists it.

QUESTION: (Maury Canter, Bechtel) Did you say it was limited to low-voltage cables, or are medium-voltage cables included also?

ANSWER: (Gary Toman, Ogden) The only problem I see with medium-voltage cables is that you could have electrical deterioration of medium voltage and above. If it's a dry environment, de-energized cable application, as you get in many nuclear applications, the indenter would be useful there, I would think. But again, those probably wouldn't age very fast at all. But if you have water or something like that, I could make inferences about thermal aging, but I can't make any inferences about what water might do to polymers, its predominantly for low-voltage cable.

COMMENT: (George Sliter, EPRI) If it had armor on it or any kind of metallic outer surface of course the indenter couldn't be used.

COMMENT: (J.B. Gardner, Consultant) Sometime back I tried to get people to think of the indenter as being an environmental monitor in that the jacket that rides along may or may not be vital to the cable's operation once it's in, but the jacket can act as a total thermal and radiation continuous dosimeter of a sort. You saw the profile of the cable that went through the heat, for instance, that tells you a lot about what the environment was at that point. It may tell you a lot about the cable, but it certainly can tell you a lot about the environment, even if it doesn't tell you much about the insulation in the given case.

QUESTION: (J.B. Gardner, Consultant) What is the sample size needed for the OIT test? I think maybe some people don't appreciate the flexibility to its use.

ANSWER: (Gary Toman, Ogden) It's in the range of 8-milligrams; a very, very small amount. The test specimen fits into a tray much smaller than an aspirin, so you do not need much at all.

QUESTION: (J.B. Gardner, Consultant) It can be a nondestructive sampling of the cable; right?

ANSWER: (Gary Toman, Ogden) Yes; especially if you're taking it off near a termination. You're not going to miss an 8-milligram piece of your termination. The termination is generally the worse place anyhow.

COMMENT: (Vince Bacanskas, River Bend) You spoke about cable previously and we had also wanted to use the OIT testing but it came out of a drywell above the shield wall and it was highly activated. So I think everybody needs to look at the methodology, since a lot of the trace elements in the insulation will become active. They need to look at the technology when they will be performing OIT on contaminated samples.

QUESTION: (Unidentified) Regarding the OIT sampling, how would the sample results or methodology established deal with variations in batches and lots from the cable manufacturers, in addition to the antioxidants present, jacket formulations, et cetera?

ANSWER: (Gary Toman, Ogden) We would be doing it on a manufacturer-by-manufacturer basis. All the acceptance criteria we are developing are based on specimens of the material from specific manufacturers. If we're seeing much batch variation, we may have some problems there. Although, the one thing I will say is, for a similar amount of aging, we see a very similar shape in the curve and a very similar endpoint,at least for Hypalons. It's encouraging. We may, over the long-run, be able to take some of the manufacturer and material-specific manufacturer's information away from it and still be able to succeed, but right now we are going specifically to the polymer that was manufactured and tested by one person or one company, rather, and making criteria on that basis.

QUESTION: (Unidentified) Wouldn't they have to implement controls limiting the formulation? For example, isn't the amount of antioxidants present in the formulations something you want to look at maintaining and keeping constant for the next 10 or 12 years?

ANSWER: (Gary Toman, Ogden) I don't have all the answers to that one. Right now, we are going along with a product line that has a stable name and a stable qualification, and the formulation isn't changing tremendously.

COMMENT: (George Sliter, EPRI) I think some of the answers to your question might be in a study that Al Reynolds at the University of Virginia did for EPRI a couple of years ago. He wrote a report called, "The Effects of Antioxidants on the Durability of Cables," looking into is there an optimum amount? Is there an optimum kind?

You talked about the scatter due to batches of different material from one manufacturer. There are many other sources of scatter, and so any acceptance criterion that you come up with really has to account for this fact.

QUESTION: (Unidentified) Are you going to address the manufacturers that are out of business?

ANSWER: (Gary Toman, Ogden) That is a problem as far as getting the specimens to test. We do know that certain plants have abandoned cables that are available for testing.

The other thing that I'm seeing is that many polymers have a very general characteristic. They start out with almost the same hardness or modulus reading all the time. If I go up to a Hypalon jacket, I know I'm going to get something in the 60 to 90 range almost every time, no matter how old it is. If I go to the qualification it says I could have 200 or 300 at that age, so it's indicating it's not seeing the stresses.

As we build more information, we will be able to generalize it more, but I expect that I will go back and get specimens either from the warehouse, which I know are disappearing very rapidly if they are not gone already, or have to go out to abandoned circuits to get specimens to do further aging on it to see how it does change.

1.4.5 *Summary of Remarks by Francois Martzloff (NIST)*
(No prepared speech or viewgraphs used.)

Francois Martzloff presented a wish list in the form of questions that he would like answered:

- There is confusion on appropriate and acceptable CM techniques; which are the correct ones to use?

- What kind of problems are we looking for?

- Using cable condition as a means of reference, what is the appropriate definition for "end of life"?

- It is unacceptable to have to disconnect cable to perform CM.

- For the partial discharge technique, we need to identify conditions under which tests can be done.

QUESTIONS AND COMMENTS::

COMMENT: (Larry Gradin, EcoTech/RAM-Q) The discussion here is all about cables and cables only so far. I would just like to mention sometimes we're negative in commenting on the NRC actions or research. The NRC did, in fact, fund the program at Oak Ridge National Laboratories for motor current signature analysis, with Dave Eissenberg and Howard Haynes and it was very effective and that system works. It is not intrusive and detects rotor damage, bearing degradation, and general motor health. It is done with the equipment in normal operation.

COMMENT: (Unidentified) A comment on partial discharge testing. In a plant that's operating, unless you have a shielded room and you have a Faraday cage, you're going to get more noise than you're going to get on your detectors.

QUESTION: (Robert Smith, Duke Power) What are we condition monitoring against? I don't have any benchmark on my cable to test against. I can hit it with your graduated fingernail all day long, but I didn't know what it was on day one when I put the cable in.

What is going to be good enough for similarity to what I had in there 20 years ago and what I'm going to test today, if you're going to test?

Also, has there been any technical review by the NRC for the indenter data, and is it pro or con? What's the opinion of the regulators who I'm going to have to answer to in the long-run on this type of monitoring and what's happening?

ANSWER: (Gary Toman, Ogden) We have demonstrated the machine to the NRC, and they have expressed interest in us trying it out on a decommissioned plant. Beyond that, they have made no opinion. They did include it in the three, six, and nine month tests at Sandia, and the data is in three volumes.

COMMENT: (John Craig, NRC/RES) We have not performed a review of the data for specific cables. We had some questions and Gary's response to some of them was, "Well, we need some more work on that." At this point it is one of many potential monitoring techniques that may be available with some caveats about access and cable types and other things, and that's as much as we can say.

COMMENT: (George Sliter, EPRI) In terms of EPRI development, we have shown the feasibility of the indenter approach and that report has been published and it is available. Now we are trying a plant application at CECo to come up with acceptance criteria. When those programs are finished, the reports will be submitted and reviewed by the utility industry, and then given to the NRC to look at.

I do want to caution that there is this mind-set that if a technique is available that the regulator will say, "Go out and use it." I would ask the NRC to be cautious about that and use it only when damage is suspected, when you suspect there has been some local high environment, i.e., for spot checking, not a blanket use in the industry. Because as you see from much of the data, it would be a monumental waste of effort to apply it widespread in plants today.

COMMENT: (Rick Naylor, CECo) One of the reasons we had Gary come out to CECo was that we went out and did our inspection program, and we used Mr. Gardner's finger tester. We also had in the test criteria to flex the cable and the conductor. When you flex a cable like that it breaks, but it doesn't break 3 feet from the reactor piping, it breaks within 6 or 8 inches. We were continuously cutting pieces off and after a while you can run out of cable to do that. The question is, is that the test that we now presently have? From the research that has been presented, all are destructive tests. I think where the research needs to be put into place using the indenter or other nondestructive tests is that you still have use of the equipment and it has not failed.

COMMENT: (S. Bailey, So. Carolina Electric & Gas) One of my goals is that I would like us to be able to eventually agree on a baseline qualification for something like cable, and have a reasonable way of going out in the plant and verifying the condition of the cable to see if we have cracks, et cetera, if we have a systematic approach, or maybe something like that, just actually looking at the conditions.

COMMENT: (George Sliter, EPRI) To Mr. Martzloff's question about the difference between destructive and nondestructive, and between a test for aging and a test for local degradation: An aging test looks at the bulk properties of a material, and what we call a troubleshooting test looks for local degradation or damage -- somebody or something damaged the cable. Then you can break both categories into the categories of destructive and nondestructive.

I was just reminded that CECO is doing a technique that I like because it's a simple type of condition monitoring; bending. It could be destructive, of course. If the cable is fragile it will break.

QUESTION: (P.K. Doss, Rockbestos) Regarding the measurement you talked about, could it be done by thermal gravimetric analysis (TGA)? I think it's the same application because you can also measure the cross-linking of the product whether it's uniform or not, even if there is porosity there. On a TGA type you can make it a function of temperature, and also it will give you the cross-link density.

ANSWER: (George Sliter, EPRI) I think we will put that method on our list of ones that will be talked about tomorrow, so bring that up tomorrow, please.

1.4.6 *Summary of Remarks by Sue Burnay (AEA, U.K.)*
(Viewgraphs in Appendix D)

Dr. Sue Burnay (AEA, U.K.) presented an overview of cable CM techniques, which was based, in part, on testing performed in the U.K., and in part, on world wide experience. Her sources are the EPRI workshop (2/93), IEC guide for inservice monitoring (SC15BWG2), IEC report on aging, IAEA program on aging and plant life extension, and specific testing in the U.K. Siemens in Germany has good records on naturally aged cable. She made the following points:

- There are two categories of CM techniques: local and global.

- Local techniques include those which do not require samples, such as the indenter, and those that require small samples, such as OIT and infrared spectroscopy.

- Global tests include those with spatial resolution, such as TDR and partial discharge, and those without spatial resolution, such as dielectric loss.

- The current status of cable CM techniques was summarized as follows:

promising:	indenter, OIT, dielectric loss, and density
some promise:	infrared spectroscopy, torque testing, plasticizer content, and TDS
limited promise:	near infrared reflectance, partial discharge, and sonic velocity
troubleshooting:	TDR

QUESTIONS AND COMMENTS::

COMMENT: (Francois Martzloff, NIST) I've heard twice now the partial discharge approach being put in doubt because of the background noise problems. Of course, if one tries to assess partial discharge by just the charge, there will be problems. But there are a number of sophisticated techniques now under development which are, I think, promising.

COMMENT: (Bob Campbell, Rockbestos) I would, respectfully, disagree with that because I think the partial discharge is much too sensitive to the environment.

COMMENT: (S. Lefkowitz, CM Technologies) We have been promoting this ECAD system for many years now. I'd like to let it not go unnoticed that we agree with Dr. Burnay's observation that dielectric measurements in conjunction with TDRs can be very useful. We have been very successful over the years in producing systems that do this, and I think there is value.

QUESTION: (Dick Meininger, Char Services) Has anybody considered when you're doing the oxidation diffusion consideration for your cables that after 10 or 15 years in situ you've got a layer of non-cable chemicals on the surface that may actually slow that process down and contribute to the data where it looks much lower than you expected?

ANSWER: (Sue Burnay, AEA) Yes, it's one of the things that has been recognized, that particularly when you've got aging you get oxidized layer on the outside surface. You can actually reduce the rate at which oxygen diffuses in and so you actually enhance this heterogenous oxidation that you get across cables, or particularly in accelerated aging that could be a major problem.

QUESTION: (Dick Meininger, Char Services) But that isn't considering the other contaminants that you have in the operating environment.

ANSWER: (Sue Burnay, AEA) Yes, this could be a problem for those techniques that require a surface sample. One of the things that will need to be done is to specify in the test procedure how the surface of the cable should be cleaned before taking a sample. Otherwise all that will be sampled is a 8 milligram sample of surface crud.

QUESTION: (J.B. Gardner, Consultant) You mentioned the EPR, XLPE, and the EVA cables, but what kind of coverings do these have?

ANSWER: (Sue Burnay, AEA) All three of these materials are of interest. We were specifically talking about insulation materials but not excluding EVA and EPR sheath materials. Many countries do not use Hypalon as a sheath material.

Because of funding restrictions, and with the number of participants in the program, the IAEA does not actually provide funding for doing the work. All it does is provide funding for holding the coordination meetings for us to exchange information and the individual participants have to find funding to do their part of the program, and so one cannot actually undertake a very extensive program.

We decided to actually limit it to at least three materials. We may have to restrict even further in view of the limited number of participants so that we could actually get some meaningful information from a small range of materials. It wouldn't cover everything, but at least we should be able to get some reasonably detailed data on some materials which are of interest worldwide.

1.5 Session D: EQ Testing

1.5.1 *Summary of Remarks by Mark Jacobus (Sandia National Laboratory)*
(Viewgraphs in Appendix E)

Mark Jacobus gave a presentation on Perspectives on EQ Issues from Research Testing. He made the following points:

- Addressed functional performance monitoring; what parameters should be monitored and what are the acceptance criteria?

- Suggested more fragility testing- raise temperatures very high to see if cables survive.

- Stated his opinion that the current sequential aging in general is sufficiently conservative that you don't really need to do simultaneous aging in most cases.

- Cited the conservatism of the mandrel bend test in IEEE 383-1974.

- Recommended that testing be done of complete, installed systems; that further testing be performed of bonded jacketed cables under realistic aging environments and simultaneous accident environments; and that detailed information of all available sources be combined.

QUESTIONS AND COMMENTS::

QUESTION: (Rick Naylor, CECo) One of the main questions that I've had over the years is: How come none of the Sandia reports are prepared under a quality assurance program that would allow us to be sure that the test protocols that you use and methodologies and the sequencing is performed in a controlled manner versus a standard research lab? You've done a lot of testing and probably have a better knowledge of test protocol than some of us. However, we can't use any of it because every time you present a case where you go to fragility or an end of life condition, we have to react to that because you failed your test but our's passed. So we go on the defensive because it's issued as a NUREG and we have to look at it. Can you address that?

ANSWER: (Mark Jacobus, Sandia) One of the things is we are a research lab and we do research testing. We do not do EQ testing. As such we are frequently doing just the kind of thing that you mentioned; i.e., changing direction based on test results. Admittedly, there is not necessarily a test plan that we follow detail by detail, but I don't think that's necessary because we don't have an end objective of qualifying a piece of equipment. We are trying to get information on the equipment. Now, all of the information similar to the kinds of quality assurance that is available for any EQ test is there. However, it doesn't have the things like the test controls that specify you must follow a test plan and document every time you deviate from it. We have a general test plan and we document what we actually do, which is the important thing.

COMMENT: (Bill Farmer, NRC Retired) Mark, you mentioned that the quality assurance efforts that are put into making sure the test programs all are valid are run under controlled conditions. The implication is you run your tests sort of without controls, and that's not really the case. You have specific test plans that are approved and you conduct the test in accordance with those plans and they are all monitored and have to meet quality assurance requirements, and calibration requirements.

COMMENT: (Gene Kopecky, Omaha Public Power) Your end product is not the qualification of a piece of equipment, but your end product is your test. What you are lacking is Part 21 reportability. You are not accepting responsibility for your own product, and I think that is what the gentleman from the Commonwealth was alluding to. We can't use your product because you won't say, "It's error-free and we will stand behind it."

RESPONSE: (Mark Jacobus, Sandia) Oh, we will certainly say that. However, we do not accept Part 21 reportability since we don't have any customer placing that responsibility on us.

COMMENT: (Phil Holzman, STAR) I think that to some extent some of these questions are driven from the observation that in the past when Sandia has done work that has appeared appropriate and maybe useful as a basis to determine qualification of a piece of equipment, such as a cable, there has been a sense from some in the industry that the NRC has been unwilling to accept that testing as a basis. I guess I would direct that question to someone in the staff and say: Is that understanding correct, or should this be something that should be looked at?

RESPONSE: (Mark Jacobus, Sandia) As I mentioned before, we do not do EQ testing or qualify pieces of equipment. I was at many EQ inspections and very frequently during those inspections people would cite data from our tests as supporting data, not as the actual qualification. Because very rarely, if ever, will you find in our report something that qualifies things exactly as somebody needs it anyway.

COMMENT: (Phil Holzman, STAR) In response to that, after having been on the procedural end of many of those inspections, that is true, we have used it as supporting data. In most of those cases the inspectors would not allow that to be used as supporting data because it was not done under controlled conditions and it was not performed under a quality assurance program, even though we reviewed and approved the portion ourselves that we used.

RESPONSE: (Mark Jacobus, Sandia) In that case we have to defer to NRC, because I accepted those as supporting arguments when I was working for the NRC.

COMMENT: (Rick Naylor, CECo) Information Notices are another case where research information is used against us. Every case in which a failure comes up we have to justify it. But there has been a lot of research that is very good test data that never sees the light of day because it cannot be used as establishing more reasonable assurance versus absolute assurance.

COMMENT: (John Craig, NRC/RES) On the subject of whether or not it is acceptable to use the research data as supporting information, and variations between inspector's opinions, I'm sure some NRC inspectors accepted it while others didn't. I think it is one of those issues where the bigger the uncertainty, the more you want to rely on that kind of data, and the less willing somebody was to give credit for it. It is an on-balance kind of argument.

Regarding the comment that there is "information not seeing the light of day," we have a clear responsibility when we conduct research and when we have inspection findings to get the information out to the industry. We have done that by publishing reports. Now, I'm not going to argue that every bulletin, generic letter, and information notice that ever went out should have gone out. However, that is part of the process to give you the information. It didn't require specific actions. You responded to it. You characterized that as "using it against you." I think that getting the information to the utilities so they can make the proper determination was the goal.

QUESTION: (Milt Vagins, NRC/RES) Mark, you pointed out you're interested in common mode failure as differentiated from random failure. How do you do that without a statistical base? What is random to me today could be common mode tomorrow if I have 15,000 random failures out of, let's say, a half a million failures and those 15,000 failures occur at one plant. How do you make that determination without a statistical base?

ANSWER: (Mark Jacobus, Sandia) If you, for example, look at a cable that has failed, generally if that cable fails perhaps at a single point due to a manufacturing defect, and you've got four other cables that all pass, you can probably make a fairly good argument that one was random, perhaps. Now, you can also say that might be common mode. It might be indicative of a common-mode failure if that failure occurred at a defect in the insulation that is a high probability occurrence in manufacturing.

COMMENT: (Milt Vagins, NRC/RES) All I'm really getting at is the fact that we are dealing with polymers, and two batches of polymers are never going to be exactly the same. We have variations in quantity. In other words, what you are dealing with is distributed space. If we are going to make any judgments about whether it's a common-mode failure or an individual failure, you better know something about distributed space, either that or understand the basic failure phenomena, which we don't. We understand it oxidizes but it isn't general. So I'm just saying the use of the word "common-mode failure" and the use of the word "individual failure" has a lot different meaning in different applications. I think we need a lot more testing and a lot more statistical base to make that kind of judgment.

COMMENT: (James Gleason, Consultant) The one thing that was kind of precedence in the labs and from reviewing a bunch of qualification assessment reports, the opinion was whenever you had a failure, you assumed it was common mode until you could prove that it was random. Normally, the proof that it was random was by reperforming the tests or doing additional testing on it to prove, in fact, that you had isolated the failure down to a root cause.

1.5.2 *Summary of Remarks by James Gleason (GLS Enterprises)*
(Viewgraphs in Appendix E)

James Gleason gave a presentation on EQ Testing Conservatisms. He made the following points:

- The presentation included examples from the NUS EQ Database to illustrate the wide range of accident conditions that could be encountered, and which equipment has been tested.

- The example included peak accident temperatures for limit switches from 11 different plants and solenoid valves from 16 different plants showing the wide range of this parameter in the different organizations.

- There were also data for radiation total integrated dose for solenoid valves and peak temperature and total dose for electrical cables.

- The vast majority of EQ testing included preaging regardless of the plant's requirements.

- Because the presence of oxygen has so much to do with aging, inverted containments may help deter aging.

- The radiation doses are typically done to beyond design bases events; severe accident.

- Considerable "worst case" testing has been performed with worst case conditions (enveloping many line breaks and many plants), orientations, mountings, and loading.

QUESTIONS AND COMMENTS::

COMMENT: (Millard Allen, Allen Engineering Services) I disagree with you on one point. You were saying that most cable has been pre-aged. That is probably true of testing done by utilities, but not necessarily true of testing done by the manufacturer. I have that from my own experience, and I won't mention any manufacturers.

1.5.3 *Summary of Remarks by Michael Saniuk (NTS)*
(Viewgraphs in Appendix E)

Mike Saniuk gave a presentation on "Test Simulations, How They Account for Installed Conditions." He made the following points:

- A lot of EQ testing is still going on.

- EQ testing is performed to installed conditions as often as possible.

- There are some shared cost approaches (Raychem splices).

- Areas for potential study are the basis for activation energies, and establishing a correlation between aging and the ability to withstand DBEs.

QUESTIONS AND COMMENTS:

QUESTION: (Paul Boucher, GPU Nuclear) Are you familiar with the industry cable report? Eight utilities were chartered by NUMARC along with some experts in the field. The industry cable report, covers all the testing that was done as of two years ago, and it covers all the activation energies. That report is available today.

ANSWER: (Mike Saniuk, NTS) I am familiar with that report. But I believe if I have a new cable insulation system, just because that report has identified certain activation energies for a material type, that does not mean that the new one is the same, or similar enough to use the report's number. Also, I'm not referring to just cable in my presentation. This is an all-encompassing instrument area also.

COMMENT: (Millard Allen, Allen Engineering Services) Being familiar with the progression of EQ over a number of years, I think everybody understands that the Arrhenius formula never meant anything. It was never intended to mean anything, other than being the best that there was to offer. To say that we are inaccurate with the Arrhenius equation, that has always been the case. Operating experience was supposed to bring this into reality, not the accuracy of the Arrhenius equation.

RESPONSE: (Mike Saniuk, NTS) I don't disagree with that. Operating experience can only get you so far. You don't know at that point unless you do additional testing after a certain number of years that it can withstand the DBE.

RESPONSE: (Millard Allen, Allen Engineering Services) Again, that is still having to be based on imperfect methodology, and we are never going to achieve perfect methodology because the real world is nonlinear, is differential, is all of the complexities of the real world.

RESPONSE: (Mike Saniuk, NTS) I agree, but I believe I also gave a potential answer to try to correlate those two things together.

COMMENT: (Paul Boucher, GPU Nuclear) Regarding the NUMARC industry cable report [Low-Voltage Environmentally-Qualified Cable License Renewal Industry Report, NUMARC Inc., Washington D.C., Revision 1, March 1983].; the report looked at all plants and determined where the cables were, what types of cables were used in all the plants, and the testing, including equipment qualification testing. The report summarizes the cables that are at most of the plants. It includes information from Sandia on cables which have problems above a certain temperature and radiation. That report should be looked at as a starting point.

1.5.4 *Summary of Remarks by Michael Kopp (Farwell & Hendricks)*
(Viewgraphs in Appendix E)

Michael Kopp gave a presentation on "How Synergisms Are Accounted For In Typical Testing Programs." He made the following points:

- A lot of conservatism is built into EQ testing.
- Components see less stress in actual service than encountered in EQ testing.
- Before beginning research, we should look at what actually happens in the plants.

QUESTIONS AND COMMENTS::

COMMENT: (Paul Boucher, GPU Nuclear) Other than the Sandia Lab tests, I don't know of any qualification report that I've reviewed in the last 12 years that ran LOCA radiation before it went to thermal aging. In the real world, accident radiation cannot occur before the 40-year life of the component.

1.5.5 *Summary of Remarks by Richard Miller (Westinghouse)*
(Viewgraphs in Appendix E)

Richard Miller gave a presentation on "Sensor Environmental Uncertainties." He made the following points:

- Sensor environmental uncertainties are included in plant setpoints.
- Leakage currents in the cables could be a concern for I&C.
- Environmental terms are usually treated as biases in setpoint studies.
- High confidence level is difficult to justify.

QUESTIONS AND COMMENTS::

COMMENT: (George Sliter, EPRI) A message to the NRC, please use the work you have already. In 1986 Sandia published NUREG/CR-4301 ["Status Report on Equipment Qualification Issues Research and Resolution," Sandia National Laboratories, Albuquerque, NM. September 1986], which was a status report on equipment qualification issues, research, and resolution. Ten years of research, millions of dollars of research. It summarized all the work and it had an industry panel to look at the conclusions and make sure they were in keeping with the reality from the utility side. I think you should look at this work and then update it with Ken Gillen's work that he has done since then.

The following is a list of lessons learned from Dr. Lloyd Bonzon of Sandia National Lab.: 1) know your equipment, 2) know your environments, 3) maintain your equipment, particularly against moisture intrusion, 4) share generic lessons from tests, and 5) synergistic effects are second order effects. We should concentrate primarily on the first order effects, such as moisture.

2. TUESDAY NOVEMBER 16, 1993 MORNING BREAKOUT SESSION MINUTES

2.1 Session A: Preaging/Preconditioning

Approximately 40 to 50 people attended this breakout session. Dr. Carfagno made some opening remarks about the goals and objectives, and read his prepared questions/list of issues (see Appendix B) that he hoped to address during the session.

QUESTION: (Unidentified) A question was asked about the NRC statement that there were major differences in the EQ programs between DOR plants and NUREG-0588 Category 1 plants. The question was whether NRC knew if plants did preaging or just that they were not required?

ANSWER: (Sal Carfagno) Valve operators, motor windings and cables were tested with aging regardless of requirements.

NOTE: The following question numbers refer to the list of questions prepared by panel members included in Appendix G. The questions are presented in the order discussed.

QUESTION 1: In response to the technical basis for preaging, it was commented that a database of materials that experience aging is necessary to eliminate preaging requirements wherever possible. This would permit us to evaluate the preaging requirements for only those components for which aging is **significant**.

QUESTION 2: This question asked how actual temperatures and radiation levels compare with test requirements? Phil Holzman commented that with the possible exception of "hot spot" areas, the temperature and radiation levels assumed during the establishment of equipment qualification are generally higher than those actually occurring during normal operation. The assumed radiation levels are often higher by an order of magnitude or more. He cited the UCONN study as evidence. Andy Hodgdon of Yankee Atomic provided a different perspective. He stated that UCONN placed cables in a relatively benign area of containment (for accessibility reasons). Andy told of hot spots at the Yankee plants that far exceeded the projected temperature and radiation levels, especially in cable vaults and reactor cavities; i.e., 235°F (113°C) and 300rad/hr. at one of the BWRs. Harold Walker of NRC supported this by saying that there were numerous occasions where utilities have come in with that observation. **The conclusion reached is that we cannot generalize that the initial assumptions used for preaging are conservative.** Recommendations were made to measure temperatures and radiation levels at plants, and to develop a true indicator of what the thresholds for damage are to various materials and components.

QUESTION 11: The panel skipped to question 11 for a discussion of the aging management techniques that are available to support EQ. Phil Holzman repeated his day one observation of 8 methods, including robust design, and engineering analysis. Larry Gradin supported this by saying that the volts/mil and temperature ratings of cables are very conservative. Several people commented that more information is needed before a complete and effective aging management program can be developed. Ghassan Attiyeh, Niagara Mohawk, stated that acceptance criteria for condition monitoring techniques need to be developed to know when the end of qualified life is reached. Concurrence on this point from others. However, Rick Naylor of CECo said that some criteria exist; i.e., if <35V/mil, then failures can occur. Harold Walker wondered how acceptance criteria of CM techniques could be related to assumptions made using the Arrhenius technique.

QUESTION 12: Other preconditioning techniques that could be used were addressed by Larry Gradin, who offered that 10CFR50.49 does not **require** preaging. Sal Carfagno discussed the intent of IEEE 627 regarding significant aging mechanisms; only those which are significant have to be addressed in preaging. If it is not significant, then do not include it in EQ Program. **S&L stated that at activation energies of 1.3 and above, thermal degradation is minimal. Ghassan Attiyeh, Niagara Mohawk stated, there is a lot of data to support this plus information from ASTM and UL that we are not taking advantage of.** Larry Gradin concurred with this statement and added that only good engineering is required to put a good EQ argument together; a super database is not necessary.

QUESTION 13: Differences in requirements from DOR to NUREG-0588 plants were discussed, with Harold Walker of NRC commenting that he feels that the original DOR requirements are inadequate because of his feeling that preaging is extremely important. Bill Clune of PECO stated that even though Limerick is a Category 2 plant, at least 80% of the EQ Program meets Category 1; Peach Bottom is a DOR plant, however, at least 50% of their EQ Program meets Category 1. Therefore, he felt confident that most equipment was pre-aged. S&L representative questioned whether or not NRC would give credit for applying CM techniques rather than retesting. Milt Vagins offered that no decisions had been made by the NRC.

QUESTION 10: Is Arrhenius adequate and what are the uncertainties? Ken Gillen of SNL emphasized that the misapplication of Arrhenius in short term experiments should be avoided; cited a Bell Lab experience with premature telephone cable failures due to errors in Arrhenius application. Recommended longer term tests (~1 year) to reduce the uncertainty in the extrapolations. Even with this type of testing, extrapolations to 40 or 60 years still raises questions. Jack Lasky of Okonite said that he had data to show differences between Arrhenius and natural aging. Agreed that the "danger of extrapolation is intense". The slope of the line changes with time, as do the activation energies. Suggests looking at elongation of new cables versus elongation of cables **prior to** LOCA testing. He doesn't think that this has been done, it's only been looked at after LOCA testing. Sal mentioned that when one considers assemblies such as SOVs, the complexity of the problem increases. A discussion followed as to why the activation energy changes. Gillen stated that it is a 'complex story', but methods are being developed by the IEC to make a standard in this area. P.K Das of Rockbestos and Solano of TU stated that there was much data on activation energies, but it was difficult to know which numbers to use. EPRI and NUS were identified as sources.

Jack Lasky stated that the formulations of cable materials have not changed for cable since they were developed. This assures continued adherence to the original EQ testing, but does not take advantage of improvements that have been made since a new EQ Program would be necessary.

The discussion then turned to whether preaging accurately simulated natural aging. Gillen thought that if large radiation doses are applied, then 'equal dose, equal damage' theory does not work. The materials are not exposed to the effects of oxygen in that situation. Pre-aging for some materials must also consider synergisms. A key element is to identify the failure mechanism; for cable it is elongation.

The international approaches to aging were discussed; the French are moving towards standardized tests and activation energies. They are also working on methods to determine residual life (although Sal is skeptical that such methods can be developed in time to be applied to existing plants).

Andy Hodgdon of Yankee suggested that research be conducted to quantify the margin in ambient and accident environments to determine what the overall level of conservatism is. It was added that reasonable assurance is OK; does not have to be scientifically precise.

Phil Holzman suggested several research ideas as follows:

1. Are the methodologies for deriving activation energies and applying them to service life accurate? Suggests an assessment of techniques based on today's knowledge.

2. Radiation aging causes the most significant portion of aging degradation (this is not universally agreed on). If it is over conservative, then what effect does this have on qualified life.

3. For some materials, preaging makes no difference in determining qualified life. Research needs to identify the materials/components which do not require preaging.

Dominion Engineering representative felt that the variety of plants, A/Es, and cable manufacturers makes it difficult to come up with common requirements for extending the life of cables. Rick Naylor of CECO feels strongly that research in this area is needed. Suggests more complete testing rather than 'a little here, a little there'. Also thought that research reports could be more user friendly.

Sal then asked each of the panel members to summarize their thoughts:

Larry Gradin: should correct the perception that DOR guideline plants are different than plants with the latest requirements. DOR did require addressing significant aging mechanisms; for equipment outside containment, analysis was used.

Phil Holzman: reiterated the three items identified above.

Jack Lasky: Suggests forgetting about activation energies; concentrate on techniques to compare naturally aged samples to those obtained from LOCA testing.

Ken Gillen: Learn the environments that we are dealing with so that they can be properly simulated. Arrhenius is not going to go away, so we better work to understand it better. Accelerated aging performed 10 to 20 years ago is wrong due to oxidation rates being incorrect.

Louis Test: Real time data needs to be evaluated to see how good the EQ efforts were at time zero. Need to use tools like PRAs to focus on the most risk significant equipment.

Harold Walker: Need to reexamine the applications of Arrhenius to see if it has been abused or misused. If there are other methods possible, then they should be developed. Activation energies applications are not consistent. We need to identify which should be used for different materials. We need to put EQ issues to bed such as: a) radiation dose rate effects, b) what are acceptable condition monitoring techniques, c) real time data needs to be made available to NRC.

2.2 Session B: EQ Operating Experience

Participants in this session were mostly EQ personnel with operating experience. Among the 40 to 50 people in the session, approximately 20 utilities were represented. A question and answer format was used in this session. The following points were made:

- (Robert Smith, Duke Power) Operating experience is tied very closely to condition monitoring. They are not separable. Operating experience is tied to everything.

- (Vince Bacanskas, River Bend) Don't know why we should be concerned about cables and penetrations. No good reasons presented.

- (Robert Smith, Duke Power) Question: Is there any type of equipment out there that we should be looking for things that are happening to it? Examples are cables and penetrations that have a qualified 40 year life established using the Arrhenius methodology, on which we don't have full-fledged maintenance programs. Motor operated valve is another example. At Duke Power, we refurbish MOVs at every third outage. Penetrations, we do inspections on, but we do not go in and test seals to see how hard they are. When a guy works on a piece of equipment, he looks at a cable, but there is no maintenance schedule. One recommendation that should come out of this session is exactly what kind of equipment we are talking about.

- (James Houghton, NRC) Relays and cables do not have good information, but motors, circuit breakers, etc. have enough information and if the EQ program is working, the failure rates should be low.

- (Vince Bacanskas, River Bend) Except for MOVs, the records on operating experience are good. The questions on how to use this experience should be,

  1) how to validate the old concept with the experience and/or

  2) how to modify the existing ones using the experience.

- (James Houghton, NRC) EQ components should be replaced more often due to the rules. If there is life left on EQ equipment, what should we do? Shall we replace it, or use it longer? What about the old plants that do not have EQ programs if they want to extend their life?

- (Vince Bacanskas, River Bend) NRC is hung up with the difference in test standards. When the EQ test documents were reviewed, the standards were different.

- (George Hubbard, NRC) One important point is the difference in standards as well as what they were tested for. The differences between DOR and Category 1 were identified, but that is no big deal.

- (George Hubbard, NRC) It is felt that in the area of solenoid valves or limit switches, industry probably got rid of them and upgraded them.

- (George Hubbard, NRC) It is important to get information on the difference between DOR and newer standards. Hopefully, some of this information will be obtained from the planned plant visits. Some plants might be DOR plants, but their equipment might be qualified to much higher standards. We want to find out these things.

- (Kent Brown, TVA) Question on where they keep EQ equipment.

- (Unidentified) Plants will try to meet only minimum requirements and maybe no information will be given out.

- (Robert Smith, Duke Power) No more activation energy study should be conducted in the new research. Operating experience shows that plants are actually conservative. Oconee of Duke Power installed sacrificial cables in 1970. Some samples were analyzed by University of Connecticut. The materials are Neoprene and EPR, and they are not getting the radiation damage predicted by Arrhenius plots. I indenter was also used on cables, and the level of damage is much less than predicted. Should focus on DOR guidelines that did not have preaging.

- (George Hubbard, NRC) The current rule says all safety equipment in a harsh environment should be EQ tested. Maybe, we can rule out some non-significant equipment outside the containment.

- (Robert Smith, Duke Power) Data on monitoring of environment and testing more useful at plant licensing than recalculation analysis.

- (George Hubbard, NRC) Program should look at whether cable has residual life after 40 years.

- (B. Metro, Westinghouse) Some EQ components should be removed from the EQ programs.

- (Unidentified) Ventilation change will get rid of harsh environment, and can take many pieces of equipment off the list.

- (Robert Smith, Duke Power) For utilities to do testing and other extra research efforts, they need guarantee that NRC will accept it. Guidelines and resources are needed.

- (George Hubbard, NRC) On the issue of DOR vs later requirements, the main issue is how they actually age vs prediction based on Arrhenius method.

- (Robert Smith, Duke Power) Utilities will be happy to answer those questions, but NRC should make it clear what programs it wants.

- (George Hubbard, NRC) Lots of data out there, but what data should we look at? No good answers now.

- (Vince Bacanskas, River Bend) Why don't we continue the existing data analysis programs? Why don't we stay on the course of the aging program? Why change course?

- (Robert Smith, Duke Power) We want to have something concrete.

Jit Vora came into the session meeting room to describe the NPAR program and its accomplishments, which can be summarized as the following:

- NPAR program studied 30 components and 20 systems resulting in 130 technical reports

- 25 years of EQ programs and 10 years of NPAR program represent large amount of information. Let's use these results.

- This workshop will show the way to go from here. We will find out what else should be done.

- Maintenance rule will be implemented in 1996.

- (Jerry Edson, INEL) Cable failures represent small portion (6%) of all the failures, and 3% of that 6% are related to the environment.

- (Robert Smith, Duke Power) Measured radiation is much lower than was calculated. Environmental data should be emphasized to show that the real environment is milder than predicted.

- (Vince Bacanskas, River Bend) Utilities are monitoring all the temperatures in the harsh environment area twice a day.

- Question: How many monitors are needed? What is appropriate?

- (Robert Smith, Duke Power) Don't ask for regulation for monitoring. Don't recommend that.

- (B. Metro, Westinghouse) Old plants do not monitor the temperatures as the new ones.

- (George Hubbard, NRC) NRC doesn't know how much data is enough for monitoring the environment. Is 5 years good? 10 years?

- (G. Kopecky, Omaha Public Power Dist.) Establish clear guidelines for the inspectors to follow to eliminate the individual differences.

- Representatives from some utilities briefly described their activities related to EQ:

  Oconee: Trending surveillance program is active.

  Florida Power: When EQ fails an LCO should be generated. At Florida Power, everything is open to air except the containment. Water and moisture problems exist. Unanticipated environmental factors cause unexpected failures, too.

  San Onofre: Daily walkdown is needed to find problems such as steam leaks from valve packings. As the plants age, environmental stresses can change.

  PSE&G (Salem): In the pressurized enclosure, environmental changes reduced qualified life. Hot spots reduced the cable's qualified life.

  Survey at this session shows that most of the utilities check whether it is an EQ equipment or not on work request.

- (Robert Smith, Duke Power) Questions that we are trying to answer:

  1) How many utilities have processes that provide for EQ input? Processes like root cause analysis. All the utility representatives raised their hands.

  2) Do you evaluate equipment at the end of its qualified life? After replacement?

     - Three plants took a look at the periodic replacement of components.

     - Gulf States: MSIV solenoids failed prematurely within the normal EQ environments due to design defects.

     - PSG&E : Fuses, microswitches failed before their qualified life.

  3) Does the Arrhenius method provide enough conservatism? Most attendees believe so.

2.3 Session C: Condition Monitoring

Dr. George Sliter of EPRI, the session chairman, provided a general introduction of the panelists and let the audience introduce themselves. He stated that today the real workshop begins. There were 50 to 60 people in attendance, with 22 utilities represented at the session. Dr. Sliter provided some guidelines and protocol for the session. He mentioned that many of the people who were originally involved in the development of IEEE STD-323 were present today at the various sessions of the workshop. The NRC was commended for doing a good job on the workshop. Dr. Sliter read the NRC questions on EQ (see Appendix H) to get the audience in the right frame of mind.

Some of the panelists made initial comments:

- Wells Fargo of Pacific Gas & Electric Company, stated that he has confidence in EQ but knows that he has not addressed everything, so CM is necessary. We need to develop more tools for normal surveillance.

- J.B. Gardner felt that if EQ's primary goal is to identify common cause failures, then this is the most important issue to resolve at this session.

- Dr. Sliter commented that nuclear power plants are designed with redundancy, and therefore there is a tolerance for random failures. That is why EQ aims at identifying common cause failures (CCFs). He stated that there are two classes of CCFs: generic and environmental. Generic CCFs cause point defects, and result from errors in design, fabrication, installation, etc. Environmental CCFs are the province of EQ and result in bulk damage.

At this point observations were made by the audience:

- Point defects will not generally lead to CCF.

- You cannot test or examine cables in containment.

- The plant personnel are a big help in finding problems because they are observant.

- Are we talking about CM on inaccessible cable? Yes if we can, and we will discuss this later.

- Wells Fargo pointed out that you have to look for hot spots. In his plant, it was found that some cables that had been originally evaluated for an environment of 104 degrees F were actually seeing temperatures ranging from 160 to 200 degrees F.

- We need to come up with ideas that are useful in the field.

- At our plant, if we find something degraded we simply replace it.

- George Sliter asked the audience if they consider common cause when they replace items. (no response)

The session then shifted to a discussion of CM techniques, which were categorized into groups: 1) those techniques that are good maintenance practices, 2) those that are more formal, but not full EQ requirements (voluntary), and 3) those that are EQ requirements. (Note: the following discussion is what was summarized in the PM session)

- Discussion on maintenance good practices

  - Include ambient temperature monitoring, training, visual/reporting of anomalies, feedback of actual degradation, ALARA concerns.

  - The purpose of surveillance is to determine if "it is OK now".

  - The amount of CM required may increase as a result of the Maintenance Rule.

- Discussion on more formal, but not full EQ requirements

  - Root cause analysis, aging monitoring, circuit meggering as part of periodic checks.

  - A show of hands was taken in regards to which utilities have in-situ cable specimens. Six affirmatives: Toledo Edison, Oconee, Nine Mile 2, Vogtle, Northeast Utilities, Maine Yankee. For these in-situ samples, mechanical tests and OIT are performed.

  - Another show of hands for which utilities have EQ personnel involved in maintenance activities. Response was some, but no count taken.

  - Some utilities are actually using ECAD and Indenter testing to monitor cable condition.

- Discussion on CM as part of EQ program

  - Inspection, access at end devices, photographs, environmental monitoring.

  - Generally CM is not specified as part of EQ.

  - EQ equipment is flagged on work orders by some utilities.

  - If effective CM were available, most utilities would use it.

The discussion then turned to categorizing CM techniques into groups such as promising, some promise, limited promise, etc. Dr. Sue Burnay's (AEA Technology) viewgraph was used as a starting point. (The results of this discussion are summarized in the CM summary session. Comments from this discussion are noted below.)

- Discussion on categorization of CM techniques

  - Dielectric tests pick out the worst spot on the cable.

  - One way to get an unaged cable sample if there are no new ones available, is to use a sample from control room cable in that it has been in a benign environment.

  - Jacket degrades faster than the insulation, so there is justification for monitoring the jacket to trend aging degradation.

  - TDS not yet out of the lab, and it cannot be used for unshielded cable.

  - The premise for most CM techniques is that condition of equipment must stay equal to or better than artificially aged equipment that was LOCA tested.

  - With all CM techniques you need cross correlation.

  - Sometimes pulling out a cable is not a bad idea to get a sample, when no other options are available.

  - UK, Ontario Hydro, and EPRI were mentioned as having ongoing research programs that could be useful in providing effective CM techniques.

  - The utility members of the audience were asked if they would want condition monitoring to be a regulatory requirement for EQ. Although they had previously indicated that CM was important, they responded that they would not want CM added as a regulatory requirement.

  - Under what circumstances would it be prudent to use CM in EQ?

  1) When you suspect a problem,

  2) For a systematic program for selected cables,

3) To support extended qualified life,

4) For cables identified as important by risk prioritization.

- Then courses of action were identified. (see session summary)

2.4 Session D: EQ Testing

This session was attended by 30 to 40 people. Discussions by the panelists were guided by the list of prepared questions on the subject of EQ testing given in Appendix H. The session opened with questions from the floor.

- (Dave Jackson, NAMCo Controls) They want to focus on IEEE requirements during qualification testing of products. Why are new requirements continually being brought in, and of what benefit are they? He is referring, for example, to changes in requirements for thermal cycling, mechanical cycling during aging, multiple LOCA profile requirements, and plant specific seismic requirements.

- (R. Miller, Westinghouse) The standards are presently being revised to remove what are considered excessive requirements. The IEEE 382 standard will soon begin the revision process.

- (James Gleason, GLS Enterprises) This session is intended to focus on EQ of electrical equipment rather than seismic requirements.

- (Unidentified) What are the NRC requirements with respect to IEEE standards?

- (Satish Aggarwal, NRC) If you meet the requirements of IEEE Std. 323-1974 you satisfy the requirements of the NRC; we have not endorsed IEEE Std. 323-1983. However, NRC has endorsed IEEE Std. 344-1987 for seismic qualification of electrical and mechanical equipment.

- (Satish Aggarwal, NRC) The input from the workshop is more important to NRC to help to determine where to proceed from here. Should we concentrate on electrical equipment, electrical cable, etc. only? Should we do additional testing, and if so, to what standards?

- (Paul Boucher, GPU) What is the role of the NRC? If the industry did contribute all of their test results would this information then be used to determine which qualified equipment is safe and which needs more work?

- (Paul Boucher, GPU) The NUMARC report [Low-Voltage Environmentally-Qualified Cable License Renewal Industry Report, NUMARC Inc., Washington D.C., Revision 1, March 1983] shows the status of EQ electrical cable in all nuclear plants at the present time.

- (James Gleason, GLS Enterprises) We want to get opinions in this session from the industry about EQ testing issues. Is more research needed on each topic? If so, what direction should this work take? For example on the subject of electrical cables, what else should we be looking at? Should tests be structured so that research test results are valid for the purpose of industry using all or part of the results to qualify some equipment?

- (Charles Butz, DuPont) What does the nuclear industry need in the future as far as insulation on electrical cables? Many new polymers have been developed and are available that would help the nuclear industry, but testing is very expensive, and the manufacturers are not sure how to proceed with testing, what are or will be the requirements? The 200 Mrad radiation requirements, for example, are overly conservative and may unnecessarily eliminate many new polymers that would legitimately add to the safety performance of nuclear plants.

- (Paul Boucher, GPU) One big question is what are we going to do about the older plants (DOR guidelines)? After all these years, no consolidation of test results and information has been reached.

- (Charles Butz, DuPont) Maybe we should be looking at two separate areas for tests: 1) old equipment and 2) new products and equipment.

- (James Gleason, GLS Enterprises) The new generation of plants should concentrate on the design aspects of reducing EQ requirements. They should look to relocate safety related equipment out of the harsh environment areas, thereby cutting down on the quantity of EQ required equipment.

- (Charles Butz, DuPont) Our [cable insulation manufacturers] dilemma is: I have a new product, now how do I test it? The way you test will determine whether the product passes or not. Radiation first, thermal aging second, or whatever order might be chosen.

- (James Gleason, GLS Enterprises) IEEE Std. 323-1974 says that the test must be performed in the worst case sequence. IEEE Std. 383-1974 says that the test must be performed in the worst case sequence. In general if the product or equipment is not affected by a certain condition, such as cyclic aging, then there is no need to include it in the qualification testing for that product or equipment.

- (Michael Saniuk, National Technical Systems) Industry wants to keep the cables and equipment that they already have. In the future they may look to new and better products, and to relocating equipment into less harsh environments. For now, industry wants to know if the old equipment is okay, or if additional testing will be required.

- (Satish Aggarwal, NRC) The NRC will look at all information and test reports that are available before deciding on its course of action. If more testing is needed, we want the input from this workshop to help decide on what course of action to follow.

At this point, the session chairman directed the discussion to the consideration of the questions listed in Appendix H for Session D.

1. **Does experience continue to support the validity of the hypothesis that the proper application of sequential testing can simulate natural in-plant aging? If not, would simultaneous testing be more appropriate?**

- (Mark Jacobus, SNL) If you do a sufficiently conservative sequential test, then it is acceptable. We must know what the environments are in order to determine what is sufficiently conservative.

- (James Gleason, GLS) Do you know of any cables that needed simultaneous tests?

- (Mark Jacobus, SNL) Everything tested so far has been tested to such conservative conditions that they sufficiently envelope the actual plant conditions.

- (Michael Saniuk, National Technical Systems) Are there commercial simultaneous testing facilities available?

- (Charles Butz, DuPont) Yes there are several.

- (Charles Butz, DuPont) Simultaneous tests should include moisture.

- (James Gleason, GLS) Several tests are done considering moisture, for example, on electric motors. Right now we are covering cable thermal and radiation as simultaneous vs. sequential.

- (Charles Butz, DuPont) Why don't we do it both ways: sequential thermal, sequential radiation, and simultaneous?

- (James Gleason, GLS) That is probably a good idea for brand new products to uncover the synergisms.

- (M. Kopp, Farwell & Hendricks) Sequential testing seems to be okay provided you have the conservatisms built in. You would go to simultaneous to investigate further if you had failures occurring during sequential testing. We should be looking at what are the plant environmental conditions.

- (Satish Aggarwal, NRC) Are there instrumentations in the plants that can provide this information?

- (M. Kopp, Farwell & Hendricks) There is not extensive information, and there hasn't been in the past.

- (R. Miller, Westinghouse) Synergistic testing may tell you a lot about the equipment.

- (Bill Denny, Ogden) He has reviewed nearly all the testing information, research reports and other documentation on this subject, and it appears to him that we have all the information that we need. You just have to locate it, review it, and put it together in order to apply it to the present questions. Everything about cables is already known, you just have to consolidate it and present it to NRC.

- (Mark Jacobus, SNL) The problem with the testing that has already been done is that you don't know all the aging effects. We don't know everything we want to know about the aging of electrical cables.

- (Charles Butz, DuPont) Agrees with Jacobus, we don't know all the factors related to testing particularly in the early days.

- (Bob Gehm, Rockbestos) It seems that the conservatisms have serendipitously been included for electrical cables: 90 degrees C., 40 years life, 200 Mrad.

- (James Gleason, GLS) To summarize the discussions on this question, sequential testing is okay so long as the conservatisms are left in. Given the level of knowledge we have today, manufacturers must test new cables to whatever are the worst case conditions for the electrical cable.

- (Bob Gehm, Rockbestos) Note that thermal aging is critical for jacketed cable: there will be different activation energies for the insulation and the jacket materials.

- (James Gleason, GLS) If you have several different materials in a piece of equipment, you must select the lowest activation energy material to determine the aging, even though this results in overaging of the other materials in the equipment.

2a. How have the following been accounted for in EQ testing? Cable-to-connector interfaces?

- (Mark Jacobus, SNL) He does not see any significant issues on this subject.

- (James Gleason, GLS) He agrees with Jacobus, there are no significant issues on this subject; they use qualified connectors and splices whenever they do cable testing.

- (Mark Jacobus, SNL) It is not a research issue, but it is an area that testers and plants must be aware of, and that variations must be adequately justified.

- (James Gleason, GLS) If a plant installs equipment in the same configuration to which it was qualified, then there is no problem.

- (M. Kopp, Farwell & Hendricks) System tests are more realistic because then you are able to check cables, connectors, loops, lengths and all their interactions together.

- (Dave Jackson, NAMCo) Complained that they have been losing many vendors that had been supplying qualified cables for use in their products.

2b. How have the following been accounted for in EQ testing? Thermal/radiation hot spots?

- (Mark Jacobus, SNL) You are supposed to test to the worst case conditions in order to cover hot spots. For example, in yesterday's session it was mentioned that Gulf States had a problem with exceeding 300 degrees which was beyond the boundary envelop to which the equipment had been qualified. This equipment was no longer within the EQ limits.

- (James Gleason, GLS) In most cases if you exceed qualified environments, the equipment has to be replaced and the condition that caused the problem must be corrected.

- (Mark Jacobus, SNL) This is more a question of environmental monitoring. You must know your environments.

- (Paul Boucher, GPU Nuclear) This is not really an EQ testing issue, but rather a plant specific environmental monitoring issue.

2c. How have the following been accounted for in EQ testing? Long cable overhangs?

- (James Gleason, GLS) Sandia tested cables over sharp edges with weights hanging on them, and no breaks were found.

- (Mark Jacobus, SNL) They didn't subsequently LOCA test them.

- (James Gleason, GLS) He didn't recall ever having a cable seismic failure. The Mandrel bend requirement covers the issue.

- (Mark Jacobus, SNL) There shouldn't be any long unsupported runs in a plant without the proper supports. This is an installation issue.

- (James Gleason, GLS) Agrees with Mark Jacobus, SNL that this not really a research testing issue, but rather an installation issue.

- (M. Kopp, Farwell & Hendricks) The connector configuration question is a valid testing issue, but it is considered during EQ testing.

2d. Are additional EQ testing requirements or margins needed?

- (M. Kopp, Farwell & Hendricks) Margins are adequate.

- All the other panelists were in agreement.

3. Are techniques used to imposo combined thermal and radiation aging in current EQ testing still valid? How are synergistic and dose rates effects accounted for?

- (Mark Jacobus, SNL) Dose rate effect is a synergism; again, if conservatism is built in to the test, then the dose rate synergism is covered.

- (Charles Butz, DuPont). Don't some Sandia reports show dose rate effects for some materials?

- (Mark Jacobus, SNL) Yes, but if 1 Mrad is the actual level, and we test at 50 Mrads, then we adequately cover the dose rate synergism. With new materials, you may want to investigate the details more thoroughly. You would then run a series of tests.

- (Bob Gehm, Rockbestos) Dose rate effects are more noticeable at the lower levels. For most polymers at approximately 200 Mrads (based on elongation) the effects are found to converge.

- (M. Kopp, Farwell & Hendricks) Is that published information?

- (Charles Butz, DuPont) Caution should be used when generalizing that the effects on polymers will converge at about 200 Mrads. For today's cables, yes, however for new polymers this cannot be generalized as true in all cases.

4. What tests could be performed on naturally-aged cables (in-situ) to substantiate EQ tests?

No discussion of this question took place.

5. In view of the increasing use of PRA techniques, is it still justifiable to use the deterministic, single sample approach used in traditional EQ practice? What are the possible alternatives?

- (Mark Jacobus, SNL) He is comfortable with it the way it stands today. What we have done to this point is okay.

- (R. Miller, Westinghouse) A single sample is not realistic for sensors, such as pressure transmitters, temperature transmitters, etc.

- (Michael Saniuk, National Technical Systems) When economics are removed from the picture, it is better to test multiple samples. You try testing to different qualified lives. In Appendix B testing, you have assurance that all samples are built the same way, with the same specs, materials, procedures, tools, etc. If you have commercial equipment that is then being EQ tested, you don't have that same assurance.

- (Dave Jackson, NAMCo.) What is considered a sample for cable?

- (Mark Jacobus, SNL) 10 feet is what the standard (IEEE 383) says.

- (James Gleason, GLS) You need to do more than one sample if possible to gain confidence in your results. Michael Saniuk, National Technical Systems's point on commercial vs. Appendix B program equipment is important. You have to have more confidence in your results.

- (Paul Boucher, GPU Nuclear) Rosemount and NAMCo have been doing multiple sample testing through the years, and build up confidence based on similarity as more and more models are tested. Economics often limit the number of samples.

- (R. Miller, Westinghouse) These were the same basic models but in different ranges.

- (Satish Aggarwal, NRC) Experience has shown that in EQ testing, if one sample fails, a second was tested. If several attempts were made before a sample passes, then what level of confidence do we have? Should we seek testing by several different laboratories to justify the qualification?

- (Dave Jackson, NAMCo.) Testing labs get different results, especially in the case of LOCA testing.

- (R. Miller, Westinghouse) Westinghouse doesn't recall any cases where equipment failed qualification testing and no changes were made to the design before a new test was run.

- (James Gleason, GLS) When a failure occurs during EQ qualification, it is first determined if the test specimen has failed or if the laboratory's test equipment has failed. When the failure is in the test specimen, the failure is considered common mode and a failure analysis performed. Unless the analysis shows that the failure was definitely caused by some random phenomenon, the failure is considered common mode and the item is not qualified. Prior to repeating tests, one or more of the following is performed, a test specimen redesign, lessening of test conditions, changes in acceptance criteria, or lessening of qualified life (assuming a test specimen with reduced qualified life has passed). Tests are restarted at the last point successful performance was recorded. When redesign, changes in conditions or acceptance criteria have been made, this most likely causes the testing to be restarted at the beginning.

  In all cases, an item is qualified only when a test specimen has a clear path of successful performance through all phases of the testing. A mistake that uninformed people have made is by having test data which shows that the equipment did not perform, attributing a probable cause or even a design change and not retesting. The bottom line is that the recorded data still shows inadequate performance, unless retesting was done.

  Even for truly random failures and for laboratory test equipment failure, the test is restarted at the last point that successful performance was recorded.

  As an example, they had two items under test, a 20 year qualified life unit and a 15 year qualified life unit. The 20 year test unit failed, and the 15 year specimen had passed. The vendor elected to drop the 20 year qualification testing program (thus assuming a 20 year common mode failure), and simply offer the unit as having a 15 year qualified life.

- (Satish Aggarwal, NRC) If we were testing a 10-20 ft. length of cable, and found that 3 out of 4 samples passed, but one failed. What would we assume in such a case?

- (R. Miller, Westinghouse) We favor the use of a least 3 samples if possible. We can then use engineering judgement to determine whether the failure was common mode or random failure. Testing by multiple laboratories is not necessary. However, a set test plan is essential.

- (Michael Saniuk, National Technical Systems) Multiple samples is important. Using different labs is not necessary, just make sure that they follow good practices and techniques.

- Mark Jacobus, SNL and M. Kopp, Farwell & Hendricks agreed with R. Miller, Westinghouse and Michael Saniuk, National Technical Systems.

- (Bob Gehm, Rockbestos) What are the feelings about lab accreditation?

- (James Gleason, GLS) The major labs have no problem with the idea of accreditation. However the utilities use a number of smaller specialty labs that were not financially capable of attaining and maintaining accreditation, so this would be a problem for these smaller labs. Therefore, instead of accreditation, QA programs were then used to cover the question of lab credentials. For example, during one 1 year period, at least one laboratory was subjected to 56 one-week audits.

- (James Gleason, GLS) He agrees with testing of multiple samples. He also feels that it is a good idea for the research labs to test under an Appendix B/Part 21-type QA program so that the industry can make use of the results.

- (Satish Aggarwal, NRC) What do you mean by multiple?

- (James Gleason, GLS) For items like cable, you can cut it up into many smaller samples. For things like electric motors, you would typically use 2 or 3 samples. For statistical analysis, you would need 5, 6, or more samples.

- (Charles Butz, DuPont) In their testing, they would normally use from 3 to 5 samples of exactly the same item. The main thing is to try to determine the reason for any failure that may occur.

- (Bob Gehm, Rockbestos) They take 3 samples of exactly the same item, for example, jacketed cable, unjacketed cable, multiconductor, etc. But note that there may be different levels of voltage for each application of a particular type of cable. One cable model, for example, can be used for power cable at one voltage and for instrumentation and control service operating at a lower signal voltage level.

6. How do current EQ methods account for unanticipated modes of failure (i.e., moisture intrusion failure paths, interface relaxation/ creep effects)?

This subject was covered in November 15, 1993 presentations by Mark Jacobus, SNL, "Perspectives on Equipment Qualification Issues from Research Testing," and Michael Saniuk, National Technical Systems, "Test Simulations - How They Account for Installed Conditions," and in the above discussions following EQ Testing Session question 2.

8. Due to a numbering error there was no question number 8.

9. The LOCA simulation test includes exposure to two cycles of the predicted LOCA environment. The additional peak transient is intended to assure performance margin. How realistic is this test profile in terms of demonstrating that adequate margin exists?

- (Michael Saniuk, National Technical Systems) Two transient LOCA tests are a valid means of testing: the first peak is attained with superheated steam, then when the second peak occurs, everything is already saturated. This is very conservative and covers the margin.

- (R. Miller, Westinghouse) Westinghouse believes that the single transient with margin built in is adequate. This is as given in the IEEE Standard 323-1983.

- (M. Kopp, Farwell & Hendricks) Two peaks is simply stressing the equipment twice. A single peak transient with margin is adequate.

- (James Gleason, GLS) We did away with double peaks since there is no quantifiable margin attained in double peaks. The single peak transient with margin is adequate. The entire test chamber is brought up to the normal containment temperature prior to initiating the accident test simulation, (e.g. 150°F) this is typically done using steam. The typical worst case LOCA and MSLB requirements are superheated steam conditions, for instance 350°F and 50 psig is superheated, saturated conditions would require pressures in excess of 100 psig. Thus for the typical superheated LOCA requirements, the ramp would match the requirement as close as practicable, using superheated steam. The temperature and pressure would be controlled to meet and slightly exceed the ramp rate, temperature and pressure requirements. The temperature and pressure requirements typically contain 15°F and 10 psig margin. At the time that the LOCA requirements achieve saturated conditions, then saturated steam conditions would be utilized in the test chamber. Chemical sprays would be added at the time of maximum pressure and saturated steam conditions. This allows the chemical spray maximum penetrating capability and since the conditions are saturated, the pressure profile is not over tested. Since much equipment is susceptible to pressure, over pressurization is avoided when ever possible. For items like splices and cables, which are not as sensitive to pressure, saturated steam conditions could be performed, but these would result in high pressures exceeding the design bases and typically greater than 100 psig. Thermocouples are placed within 2 inches of the test specimens and normally three thermocouples are utilized.

- (Mark Jacobus, SNL) He has no strong opinion on the issue. IEEE Std. 323-1983 requires only 1; Sandia uses 2 peaks. the most important issue is that the profile should match the specific plant conditions.

- (Bob Gehm, Rockbestos) The early testing was done using one peak only. Most of the testing showed that if equipment passed a one peak LOCA, then they also passed a second peak LOCA successfully.

- (James Gleason, GLS) In his experience, the peak was not the most critical portion of the test. It was when the chemical spray came on that things began to fail. The moisture intrusion was what caused the most problems.

10. LOCA chambers have exhibited difficulty in controlling steam pressure and internal temperature such that temperature overshoots in excess of the test profile plus 15 degree margin often occurs. What is the impact on the qualification test results when equipment is exposed to these conditions? How adequately is the LOCA accounted for?

- (Michael Saniuk, National Technical Systems) Overshooting temperature is not as critical as overshooting the pressure. Higher pressure can cause additional failures by the process of moisture intrusion.

- (R. Miller, Westinghouse) It is important to get the ramp correctly, so that the integrity of the sample's seals can be verified.

- (M. Kopp, Farwell and Hendricks) Considers overshoot to be a conservatism, so it is not considered a problem in research testing activities.

- (James Gleason, GLS) He found that it was generally okay if overshoot occurred during a testing run as long as the equipment passed. However if the equipment was damaged during a run in which overshoot occurred, then the testing lab was responsible for doing the test over again.

- (Paul Boucher, GPU) The importance of adherence to a specified test ramp depends on the type and nature of the sample that is being tested. They have found that the test ramp can be a very hard thing to match up.

- (R. Miller, Westinghouse) For example, if the sample has seals, the ramp is very important.

- (Mark Jacobus, SNL) This is not really a research issue, it is more of a testing lab quality issue.

- (M. Kopp, Farwell & Hendricks) In the present context however, the research testing is being used to verify the validity of old test results. In that respect, adherence to a specified test ramp becomes important.

- (Satish Aggarwal, NRC) The NRC needs assurance that the equipment qualification methods are valid. Test profiles that were used to qualify equipment must match the profiles specified for the plants.

7. **The post-LOCA simulation test of thé IEEE standards (IEEE Stds. 383-1974 and 323-1974) demonstrates margin by requiring mechanical durability (mandrel bend) for cables and immersing them in water while being energized. Is the needed margin adequately accounted for in this test or is the test considered to be too conservative (and on what basis?).**

- (Michael Saniuk, National Technical Systems) The mandrel bend test following the LOCA test is ultra-conservative.

- (Satish Aggarwal, NRC) If we have naturally aged cable, do we then bend it around a mandrel?

- (Michael Saniuk, National Technical Systems) I still believe it is ultra-conservative.

- (James Gleason, GLS) He agrees with Michael Saniuk, National Technical Systems, that the mandrel bend requirement following the LOCA test is ultra-conservative. For naturally aged cables, if you want to do this test, you should do it in-situ. This is because when you move the cables to remove it from the plant, then you will wind up doing more damage, or at least as much, as the mandrel bend test would inflict on the cable samples. You could not definitively identify which damage was the result of cable removal process, and which could be attributed to the mandrel bend test.

- (Mark Jacobus, SNL) During his research testing work that is reported in NUREG/CR-5772 [NUREG/CR-5772, "Aging, Condition Monitoring, and Loss-of-Coolant Accident (LOCA) Tests of Class 1E Electrical Cables," Volumes 1, 2, and 3, Sandia National Laboratories, Albuquerque, NM. August 1992], they included a mandrel bend test for cables after they had undergone a LOCA test. They found that cables failed the post-LOCA mandrel bend test even after they had successfully passed the LOCA exposure test. They noted that the ones that did fail in this way were marginal anyway. Therefore, this represents a conservatism. He feels that they should perform the mandrel bend test on the naturally aged cables.

- (Michael Saniuk, National Technical Systems) He feels that any failure casts a doubt on the capability of the equipment. This is fine if research testing results in failure, but it doesn't then mean that the DOR-qualified cables are no good.

- (Paul Boucher, GPU Nuclear) He feels that removing the naturally aged cables from the plant will ruin them. He also feels that the mandrel bend test is not realistic.

11. **What gives you confidence that cables have been qualified to accident conditions? What conservatisms are typical in qualification testing?**

- (James Gleason, GLS) Many of the DOR qualified cables were qualification tested with preaging. Any that weren't pre-aged may be good research specimen choices. Are any of the experts aware of DOR cable that was not pre-aged?

- (Mark Jacobus, SNL) He was not aware of any that had not had some sort of aging.

- (Michael Saniuk, National Technical Systems) He feels that it would be valid research to retest or revaluate whether the qualification was adequate.

- (R. Miller, Westinghouse) He agrees.

- (Mark Jacobus, SNL) He feels this is valid. Also if there is equipment that was insufficiently pre-aged, then it should be reevaluated.

- (Satish Aggarwal, NRC) Should the NRC ask all utilities whether all safety cables were tested, what requirements were used, and what pre-aging methods were used? Is this too much information to request?

- (Bill Denny, Ogden) If the NRC wants to do research testing on old cables, and requests information on the cables in their plants, then NRC must let the plants know up front exactly how the information is to be used, and how they plan to treat a failure if it occurs.

- (Paul Boucher, GPU Nuclear) EPRI/NUMARC/NRC or some similar centralized industry organization should consolidate all the information that exists on qualified cables and equipment. This would be the most cost effective approach.

- (Satish Aggarwal, NRC) Should the NRC seek the information on electrical cables being used in harsh environments only?

- (Michael Saniuk, National Technical Systems) The information that Mr. Satish Aggarwal, NRC is looking for is already available in the NUMARC cable report ("Low-Voltage Environmentally-Qualified Cable License Renewal Industry Report," Nuclear Management and Resource Council, Inc., Washington, D.C. Revision 1, March 1993. (Includes In-Containment Cable Database as Appendix A and Cable-Related LER Database as Appendix B)).

- (Paul Boucher, GPU Nuclear) We qualify equipment to the worst case conditions that they might encounter. However the equipment may not always be applied in those worst case environments.

12. How have synergisms been addressed in cable qualification? What about other devices?

Synergisms were covered in the November 15, 1993 presentation by Michael M. Kopp, Farwell & Hendricks entitled "How Synergisms are Accounted for in the Typical Test Program," and in the above discussions following EQ Testing Session question 3.

3. TUESDAY NOVEMBER 16, 1993 AFTERNOON PLENARY SESSION MINUTES

On Tuesday November 16, the Session Chairmen summarized the results of the individual breakout panel sessions. All workshop participants were in attendance for this plenary session. The minutes of these summaries are presented here.

3.1 Opening Remarks

John Craig (NRC/RES) made the following opening remarks:

- The workshop has identified a number of questions that need to be answered related to environmental qualification. The sources of these questions are plant operating experience and testing experience.

- The NRC is not starting over in looking at the issue of EQ. Rather, they will build on past work.

- The fact that questions exist related to EQ does not mean that the staff has concluded an immediate safety issue exists which requires corrective action. It just means that more information is needed or a consolidation of information is required on this subject to answer the questions, and determine what, if any, action is necessary.

- This workshop is the beginning of a series of interactions between NRC and the industry on the subject of EQ. The lines of communication will remain open.

- If anyone has additional comments on the workshop, they can be sent to the NRC or BNL for inclusion in the proceedings.

QUESTIONS AND COMMENTS

None.

3.2 Chairman's Summary of Session A: Preaging/Preconditioning

Salvatore Carfagno made the following general comments:

The goal of this summary is to give a fair representation of the input obtained during the panel sessions, some of which are suggestions and some questions. No effort was made to resolve differences or disagreements. These should not be considered recommendations. It is up to the NRC to evaluate and decide on the approach to resolve issues.

The following items were then presented as a summary of the panel session results:

- It is suggested that the importance-to-safety approach adopted by the international community be investigated. Can PRAs be used to identify important equipment; e.g., can LOCA test specifications be modified if a PRA shows the plant can be maintained in a safe condition even if the equipment fails within a few days after the start of the LOCA?

- It is suggested that cables be tested in-situ. Also, small samples should be obtained from operating or decommissioned plants for testing. The properties of cables aged in service should be compared to properties of cables subjected to accelerated aging to determine if there is conservatism in the existing practices. After determining the condition of naturally aged cables, develop methods of accelerated aging to simulate the naturally aged condition. To the extent other equipment is of interest, do the same for it.

- In the area of operating experience, it is suggested that data be identified that the utilities should obtain to evaluate the adequacy of existing qualification programs, as well as to evaluate recommendations for modifying industry standards and government regulations. Industry fulfillment of the need to monitor service conditions varies, therefore, guidance may help.

- Now that we have about 25 years of operating experience, we should evaluate the aging occurring in service and answer the following questions:

  - Do the data identify equipment which does not age significantly?

  - Can preconditioning be modified or omitted for such equipment?

  - How do service conditions compare to the conditions assumed in qualification; are some less severe or more severe?

  - How can such information be used in modifying qualified life?

- On the issue of DOR Guidelines versus 10 CFR 50.49, it is suggested that the adequacy of equipment qualified by the DOR Guidelines be evaluated; e.g., if cables are the key issue, the perception that cables were not aged should be corrected. Instead, the adequacy of the accelerated aging that was done should be evaluated.

- On the issue of margins, the original margins included in the standards were arbitrary. We should try to determine the degree of conservatism associated with the margins. Also, we should try to quantify the overall level of conservatism in the EQ process.

- On the issue of the Arrhenius Method, the following questions should be answered:

  - Is this method adequate to establish a qualified life?

  - To what extent is extrapolation acceptable?

  - What are the acceptable methods of determining activation energy, e.g., is TGA acceptable?

  - How do we define relevant indicators of degradation?

  - How is the selection of end points determined?

- The data (ASTM, Underwriters Lab) that supports the view that, if activation energy is greater than 1.3 eV/molecule, then thermal degradation is minimal, should be reviewed to determine if thresholds can be set for thermal aging, just as we have done for radiation aging.

- On the issue of radiation aging combined with thermal aging, it should be determined how important dose rate and synergistic effects are in the context of the overall qualification process and the entire program of assuring plant safety. If they are judged to be important, state-of-the-art models should be verified by additional testing under combined thermal and radiation environments.

- On the issue of alternatives to the present EQ approach, i.e., preconditioning to simulate significant aging mechanisms, the following options should be evaluated:

  - Omit preconditioning altogether?

  - Standardize testing as foreign countries are doing, without requiring a qualified life, and depend on surveillance, maintenance, and refurbishment to assure equipment adequacy.

  - Specify standard values of activation energy.

  - Use different approaches for different types of equipment, based on results at PRA/PSA analyses.

In addition to answering the above questions, degradation monitoring procedures should be evaluated. NPAR has established the state-of-the-art, therefore, NPAR results should be reviewed to identify methods that have prospect of predicting residual life and which merit further research.

One often stated opinion is to make sure that all existing information is digested relative to the issues to be decided.

- In reviewing the workshop input, the following factors should be taken into account:

  - What is the key information needed to resolve the issues faced?

  - What is the relative value of the candidate investigations in resolving the issues?

  - When are results needed?

  - What are the prospects of success of the candidates?

  - Is the realistic time needed for investigation consistent with satisfying the need?

QUESTIONS AND COMMENTS

QUESTION: (Alex Marion, NUMARC) On the issue of operating experience the panel suggested that utilities should evaluate data on inservice aging. Was the cost and value added of such an activity discussed by the panel?

ANSWER: (Salvatore Carfagno) I don't recall if those specific points were discussed, however, several utilities approved of looking at the operating experience to identify problems they are not aware of. Also, it was felt that some guidance would be useful.

COMMENT: (Bill Farmer, NRC Retired) 1) Regarding the implication that accelerated aging is conservative, this is not true in some instances. High radiation dose rates used for accelerated aging can mask real aging and, therefore, not accurately simulate the effects. For example, the oxygen diffusion phenomenon, low dose rate effects, etc. There are some materials that don't age in accelerated dosage as fast as in actual plant operation. Consideration must be given to this issue.

2) Regarding end points, from the SNL work, when measuring elastic properties 90% can be lost and the component can still pass. Therefore, it won't be easy to find end points.

QUESTION: (P. DiBenedetto, DiBenedetto Assoc.) Regarding programmatic and planning aspects, 1) how will EQ research data be integrated into the action plan, and 2) will scheduling impact the EQ task action plan?

ANSWER: (John Craig, NRC) 1) There are a number of activities identified to look at data. The NRC is working with the National Labs to integrate this data into the plan. 2) The plan has an aggressive schedule. In order to accomplish all activities the NRC will structure and prioritize its approach.

COMMENT: (Phil Holzman, STAR) In S. Carfagno's comments on margins, it should also have been mentioned that there needs to be an investigation into the margin assumptions regarding accident and normal radiation doses.

3.3 Chairman's Summary of Session B: EQ Operating Experience

Robert Smith made the following general comments:

The panel session focused on three main areas; 1) DOR guidelines versus later standards, 2) Where to focus research resources, and 3) what EQ issues need to be addressed. In the context of operating experience, the following questions were raised:

- What operating experience databases exist?

- What are they telling us?

- Are there EQ failure experiences which require more attention?

The following items were then presented as a summary of the panel session results:

- On the subject of DOR guidelines versus later standards, emphasis should be placed on how the testing was done and not what standard was used. The equipment does not know what standard was used.

- Research focus should be toward safety significant/critical components/systems/etc. The tools to be used include PSAs, operating experience, and emergency procedures. Equipment outside containment may not need to be included in the research effort.

- Existing research should be utilized, such as NPAR and EPRI work.

- Plants should be categorized based on potential sensitive areas for equipment requiring EQ, such as hot spots, to identify locations for monitoring, frequency, and durations needed to validate designs. It may be possible to do this on a generic basis, however, it must be realized that this will take time and money to do. To accomplish this, an acceptable agreement with the NRC Staff is needed.

- EQ is integrated into all aspects of the plant, e.g., maintenance and operation. Existing programs seem to be working. Criteria should be developed to address the issue of "value added" by additional work.

- Operating experience seems to indicate that we are getting smarter concerning what and where to look. Root cause, equipment history, and maintenance programs all have an EQ emphasis, and the programs are working.

- The conservatism built into the current aging methodology for EQ is not being challenged. This is verified by the UCONN cable program and the PACE cable program.

- There are efforts being made to examine the effectiveness of current EQ practices. For example, at Duke a program exists where sacrificial cables are examined to determine their condition. Commonwealth Edison also has a similar program. Most plants do some preaging; even those subject to DOR guidelines.

- Research should look at reproducing cable characteristics that exist prior to a LOCA. This could be used as a benchmark to measure against. It could also be used to provide a basis for acceptance criteria.

QUESTIONS AND COMMENTS

QUESTION: (P. DiBenedetto, DiBenedetto Assoc.) 1) Over the past 15 years research and testing has been performed in the area of EQ and the results have been given to the Staff. How will all this information be documented? 2) Will there be an opportunity for industry to comment on the initiation of a new EQ research program?

ANSWER: (John Craig, NRC) 1) The Staff will have to look at the information available, however, at the current time we don't know how this review will be documented. The Staff will address this issue. If anyone knows of information that should be reviewed, please bring it to the attention of the NRC. 2) A proposed plan will be published as a public record. This will not be for public comment, however, the Staff will consider suggestions on whether this plan should be issued for review.

QUESTION: (Phil Holzman, STAR) As a follow up on the last question, many of the questions provided have been well investigated and input on further research should be based on that information. How will industry know that the NRC will use that information?

ANSWER: (John Craig, NRC) As stated previously, it is not known how the NRC review of existing information will be documented. There were a number of questions published in the Federal Register to stimulate discussion in this workshop and they were successful.

COMMENT: (Alex Marion, NUMARC) Related to the NRC review of existing information, System Component Equipment Worksheet (SCEW) summary sheets exist which provide a standard format for assessing information by the NRC. These should be used for the NRC review.

QUESTION: (Rick Naylor, Commonwealth Edison) Can the NRC assure the industry access to work from any new program in the form of peer reviews, such as was done for the NPAR program?

ANSWER: (John Craig, NRC) There will be a peer review process.

QUESTION: (G. Kopecky, Omaha Public Power) What assurance can NRC give that research data will be made available to the Commission so that everything won't have to be redone?

ANSWER: (John Craig, NRC) Some of the databases that have been discussed at this workshop are undefined and it is not clear as yet how they will be defined. We will look at defining databases based on access to the Staff.

COMMENT: (Bill Farmer, NRC Retired) Regarding the research program plan, one aspect of the program depends on the availability of actual aged cables from plants. Currently there are road blocks to obtaining these cables. Utilities are reluctant to participate because they are afraid that adverse findings may be used against them, to it is very difficult to obtain samples. The Big Rock Point Cables are available, but little was known about their inservice operating environment; no funding has been available to perform testing research on them yet. If the industry pulls samples for testing, it is hoped that the results of those tests will be made available to the NRC Staff.

COMMENT: (Rick Naylor, Commonwealth Edison) In reference to the last comment, the issue of separation of regulation and research must be addressed. Currently, there is too much risk to the utility to provide test samples to the NRC. There should be a separation of regulation and research.

COMMENT: (Robert Smith, Duke Power) In reference to the last two comments, samples sent to the manufacturer for testing don't get any attention, therefore, the utilities are hesitant to do sample testing. This is because there is no separation of regulation and research. We don't know enough yet about how to remove cable from the older plants. You cannot control whether damage was done during the removal process.

QUESTION: (J. B. Gardner, Consultant) Did the operating experience panel discuss common cause failures?

ANSWER: (Sonny Kasturi, MOS) The panel did not specifically discuss common causes failures, however, they did discuss root cause analysis of failures, which addresses common cause failures.

ANSWER: (George Sliter, EPRI) Common cause failures are looked for during root cause analysis and are important in conditioning monitoring, however, it is not important to look at random failures. If the root cause is determined to be random, then the failure is not important to the qualified status.

3.4 Chairman's Summary of Session C: Condition Monitoring

George Sliter made the following general comments:

- There are a number of benefits of condition monitoring including the assessment of actual (not artificial) aging and all significant aging mechanisms.

- important factors to consider are:

    - identification of reliable CM indicators

    - assessment of cost effectiveness

    - CM should be able to gauge performance in accident conditions as well as normal conditions

The agenda for the panel session on condition monitoring included the following four topics:

- Role of surveillance/CM in EQ (today's practices)
- Promising CM techniques
- Useful troubleshooting techniques
- Views on courses of action

The following items were then presented as a summary of the panel session results:

- There are three groups of surveillance/CM practices currently in use:
  - maintenance good practices
  - more formal practices
  - EQ required practices

- Maintenance practices have the following characteristics:
  - they are voluntary and qualitative
  - they include the reporting of anomalies found visually/sensorially during maintenance or walkdowns (limited to what can be sensed by humans).
  - they require training to be effective
  - they are limited by access/ALARA

- The more formal practices have the following characteristics:
  - they are voluntary and quantitative
  - they involve the measurement of ambient/operational environment of cable (some plants)
  - they involve root cause analysis
  - they include age monitoring of cable samples placed in plants (several utilities), including some elongation/indenter tests
  - they include electrical tests to check operability
  - they include cable inspections during maintenance of end devices

- EQ required practices have the following characteristics:
  - they include the inspection of cable ends at terminations/end devices (flagged in work orders)
  - they include the measurement of environmental conditions (some plants)

- Utilities will consider the application of cost-effective CM techniques as they become available.

- Promising CM methods for monitoring aging degradation can be categorized as follows:

  - Group A: Currently available/ potentially useful (trial use providing data/accident criteria in approximately 2 years) which include:
    - non-destructive techniques such as indenter, OIT, dielectric loss, and density measurements
    - destructive techniques such as elongation to break, bend test, and testing of specimens removed from plant

- Group B: Under development (available/useful in approximately 5 years) which include:

  - infrared, torque tests, and time domain spectroscopy/spectrometry

- Group C: Under development (available/useful in approximately 10 years) which include:

  - on-line ground current and near infrared reflectance

- The following table categorizes each of these CM techniques

GROUP	TECHNIQUE	CONDITION INDICATOR	MECHANICAL (M) PHYSICAL (P) CHEMICAL (C) ELECTRICAL (E)	MEASURES LOCALLY (L) GLOBALLY (G)[d]
A	Indenter[a]	Compressive modulus	M	L
	OIT	OIT (remaining antioxidant)	P/C	L
	Dielectric Loss[b]	Dielectric loss (tan δ)	E	G
	Density	Density	P/C	L
B	Infrared	Oxidation	P/C	L
	Torque Tester	Shear modulus	M	L
	TDS	Dielectric loss	E	G/L
C	Ground Current[c]	Leakage	E	G

a) Cannot be used directly on XLPE insulation (use jacket material as indicator)
b) Works on all cable materials except rubbers (old)
c) Must be shielded cable
d) Whole cable length

- Promising CM methods for troubleshooting (monitoring local defects) are the following:

  - TDR
  - Insulation resistance
  - Capacitance
  - Polarization index
  - Partial discharge
  - Hi Pot (AC/DC) in air, water, pre-ionized gas (He)

- In response to the question should CM (as opposed to surveillance) be part of EQ programs, the panel's answer is no.

- The circumstances under which it would be useful/prudent for an owner operator to apply CM to cables are as follows:

  - adverse operational trends
  - suspicion of operational conditions greater than design/EQ
  - support of cable qualified life extension
  - PSA prioritization

- The recommended course of action is as follows:

  - Examine state-of-the-art/data and identify cost-effective CM and troubleshooting techniques (include international data)

  - Support and encourage development of most promising techniques, (including trial uses/research)

  - Support and encourage international cable materials/monitoring database

  - Develop PSA methods for prioritizing application of CM to cables (and other electrical equipment)

QUESTIONS AND COMMENTS

QUESTION: (M. Allen, Allen Engr. Services) Time domain spectroscopy was not mentioned as a troubleshooting technique. Was it considered?

ANSWER: (George Sliter, EPRI) Yes, it is a troubleshooting technique and was mistakenly left off.

COMMENT: (Mark Jacobus, SNL) I hesitate to agree that dielectric loss is a promising technique since SNL test data has indicated that it is not promising.

COMMENT: (George Sliter, EPRI) In reference to the last comment, the NRC should open a dialogue between M. Jacobus and S. Burnay.

COMMENT: (John Craig, NRC) In reference to the last two comments, the NRC is aware of the differences in opinion on this issue.

COMMENT: (J. Steiner, Abo Biddle Instr.) Data is available from NIST, Ontario Hydro, etc. which shows that dielectric loss is significant.

QUESTION: (Unidentified, Duke Power) Over the past five years the utilities have instituted life extension programs which include cable tests. These tests include all the techniques discussed. Has this been considered?

ANSWER: (Unidentified) This will be considered.

3.5 Chairman's Summary of Session D: EQ Testing

James Gleason made the following general comments:

There is a large volume of data that has been collected and passed to the Staff. Also, a lot of data is still available at the utilities. Discussions have been held about making this available to the Staff. The NRC has assured us that they will utilize existing data in their research considerations.

The following items were then presented as a summary of the panel session results:

- For typical conservative environmental requirements, such as 90°C/200 megarads, synergistic effects are second order effects and sequential testing is adequate. For new cable materials, multiple sequences may be prudent to assure consideration of synergistic effects, and new testing techniques may be required.

- If installed in accordance with manufacturers recommendations and qualification report requirements, then interfaces have been properly accounted for in EQ testing.

- Equipment operated within the qualification envelope is considered qualified for all temperature/radiation hot spots up to the envelope. If the qualification envelope is exceeded, an investigation is needed to determine continued reliance on the qualification report.

- Samples should be representative of the equipment being qualified. Multiple samples are encouraged by the majority, however, it depends on what the objective of the test program is.

- Mandrel bend tests are conservative in all respects. Some think they should be performed for research; some don't.

- IEEE standard 323-1974 includes a temperature profile with two peaks for EQ testing. The panel discussed this and feels that two peaks are not needed for qualification tests. Margins on temperature and pressure are adequate to account for margins in accident conditions. IEEE Standard 323-1983 does not require two peaks, however, this standard is not endorsed by the NRC.

- In the EQ test program, one should try to control temperature and pressure to simulate accident conditions, however, there is a trade off on whether to meet the ramp rate or to minimize overshoot. The panel feels that overshooting on temperature and pressure adds more conservatism to the qualification, therefore, this is not a problem.

QUESTIONS AND COMMENTS

QUESTION: (Kent Brown, TVA) An in-house program for EQ testing of new cable with new materials is being considered and I question the need for worst case sequential testing involving thermal-radiation-LOCA conditions. Is there a way of using short term tests?

ANSWER: (James Gleason, GLS) The tests specified in IEEE Standards 383 and 323-74 may not be enough due to synergistic effects. Multiple tests may be required. In general, based on SNL data, radiation-thermal-LOCA is the preferred sequence. There are screening tests that can be done first.

COMMENT: (Salvatore Carfagno, Consultant) In reference to the last question, early in the development of the standards we were told to use existing technology. NUREG-0588 also says that known effects should be considered.

COMMENT: (Bill Farmer, NRC Retired) In reference to the last comment, the issue of sequence was studied by SNL with the French using six inch cable specimens. Sequential irradiation and simultaneous testing was done and elasticity/tensile strength measurements were made for both.

COMMENT: (Salvatore Carfagno, Consultant) In reference to the last comment, when irradiation is done prior to thermal aging, the sequence is usually (aging & accident) radiation, thermal aging, and LOCA test. The question that should be asked is whether including accident radiation prior to (instead of after) thermal aging produces conditions different from inservice aging.

QUESTION: (P. DiBenedetto, DiBenedetto Assoc.) What is the Staff's position on endorsement of IEEE Standard 383-1974 and will a regulatory guide be issued?

ANSWER: (Satish Aggarwal, NRC) IEEE Standard 383-1974 is not acceptable to the Staff and NRC does not plan to endorse it. Therefore, no regulatory guide will be issued. The information in this IEEE standard is obsolete and the fire test as described is not acceptable. The Staff's position on this standard is contained in a brief report, which will be put in the PDR.

QUESTION: (Bob Gehm, Rockbestos) What is the relevant standard for EQ testing today?

ANSWER: (Satish Aggarwal, NRC) The requirements for qualification for all safety-related electrical equipment are contained in IEEE Std 323-1974. For qualification of cables, the Staff will decide the acceptability of IEEE Std. 383-74 on a case-by-case basis.

COMMENT: (James Gleason, GLS) IEEE Standard 323 doesn't specify a particular testing sequence; it requires that the worst case be used.

QUESTION: (Phil Holzman, STAR) Was there any discussion on saturated versus superheated steam conditions during LOCA testing and are there any data to show which is more accurate?

ANSWER: (James Gleason, GLS) If there is a superheat requirement the test should go to superheated conditions and limit pressure at the maximum plus margin. When the conditions go back to saturated, then the chemical spray is applied and the conditions will stay saturated. This sequence has more of an impact.

COMMENT: (J.B. Gardner, Consultant) There is an NPEC report available which discusses the IEEE Standard 383 concerns.

QUESTION: (R. Weinacht, Balt. Gas & Elect.) Was there any discussion on the acceptability of extrapolation for post accident time duration?

ANSWER: (Mark Jacobus, SNL) Based on PSA results, safety equipment is most important during the first few days of an accident, therefore, extrapolation should not be a problem. If the PSAs are wrong, this may need to be reconsidered.

3.6 Open Discussion

The floor was then opened for general questions and comments from the audience:

QUESTION: (Rick Naylor, Commonwealth Edison) Does the Staff still think there is something wrong with cables?

ANSWER: (John Craig, NRC) The Staff never thought there was a safety issue on EQ of safety equipment, but there are some questions that need to be answered. Through this workshop the Staff has learned a lot.

APPENDIX A

PRESENTATION FOR MONDAY NOVEMBER 15, 1993
PLENARY SESSION OPENING REMARKS

CONTENTS

NRC WORKSHOP ON
ENVIRONMENTAL QUALIFICATION OF ELECTRIC EQUIPMENT

INTRODUCTION

ERIC S. BECKJORD, DIRECTOR
OFFICE OF NUCLEAR REGULATORY RESEARCH
U.S. NUCLEAR REGULATORY COMMISSION

Thank you, John. Good morning, Ladies and Gentlemen. It is my pleasure to welcome the distinguished guests and participants to the NRC workshop on Environmental Qualification of Electric Equipment.

A dictionary definition of workshop is "a group of people emphasizing free discussion, exchanging ideas, demonstration of methods, practical applications of skills and principles, and participation i problem solving." Our goal for this workshop is to address the technical issues related to EQ in free discussion and benefit from the expertise and skills of the participants.

The purpose of the workshop is to solicit your inputs on technical issues related to EQ. The staff hopes to gain your frank opinions and open exchange of ideas. Then based upon the results of the workshop we intend to develop and finalize an NRC research program plan with well defined specific projects, milestones, and schedules. The workshop and your participation in it will enhance the research program in terms of both its technical value and ultimate utilization of results.

Upon reviewing the workshop agenda, I find that over the next 2 days, you will be exchanging ideas, and discussing methods and practical applications on four (4) important technical issues related to the Environmental Qualification of Electric Equipment that is within the scope of 10 CFR Part 50.49.

The issues are:
One, Preaging/Preconditioning of insulating materials associated with the electric equipment of interest. Preaging or Preconditioning of insulating materials is essential to properly simulate the influence and effects of operating environment over the life of the equipment.

Second, what can we learn from the Operating Experience of over 25 years, including designs, applications, qualification, replacement, refurbishment, and maintenance? Operating experience undoubtedly provides an invaluable library of information. If the information and data have been recorded, we can learn a great deal.

Third, the issue for the participants to consider is Condition Monitoring Methods useful to detect defects and anomalies in insulating materials preferably prior to failures and provide for decision making process for timely mitigation of the degradation effects. Perhaps one result may be a process of continuing qualification for some electrical equipment.

The fourth issue to be discussed is EQ Testing. This discussion provides insights into the testing process and questions related to the level of confidence which is demonstrated by current testing practices.

These issues are complex. On the other hand, when I look around this room and read the names of the participants and their involvement in EQ related issues, I realize that at this workshop, we have the country's top experts as well as international experts in the EQ field. I am confident that meaningful results will obtain during the next 2 days, addressing the four technical issues I just mentioned.

The workshop participants include scientists and engineers from the utilities; architect engineers; electric equipment manufacturers; universities; research institutes; national laboratories and consultants, as well as NRC staff. Also present in the audience today are the members of the Advisory Committee on Reactor Safeguards-and delegates form overseas.

I look forward to the technical presentations and discussions and hope to receive significant feedback on the technical issues and how the insights gained from this workshop can be reflected into the development of NRC's near-term and long-term research program. I request that you keep in mind as you deliberate in your breakout sessions and panel discussions, that the technical issues and their resolutions eventually must be integrated to address the very bottom line issue of how to ensure that the electrical components and systems, within the scope of 10 CFR 50.49, will continue to perform their intended functions. For example, will a cable system, from one end to other, withstand, at a given position its lifetime, the necessary voltages and supply and/or carry the power that may be needed during and after Design Basis Events?

I am determined to ensure that the results of the NRC research program on EQ are applied effectively and on a timely basis. These results will be utilized to help answer the technical safety and regulatory questions related to EQ. As I stated earlier, our goal is to develop a comprehensive research program plan that reflects expert knowledge and plant operating experience. This workshop provides the NRC, industry, and interested members of the public with an opportunity to exchange ideas and experience that will be utilized as we develop an EQ research program plan. With your help and participation, I believe that this workshop will provide an outstanding first meeting in a series of meetings which will focus on the environmental qualification of electric equipment.

I am truly delighted to have you all at this workshop and again welcome.

Now, I would like to introduce to you Mr. Ashok Thadani, who is the Director of the Division of Systems Safety and Analysis of the Office of Nuclear Reactor Regulation. He will provide the NRR's regulatory perspective on EQ issues. Ashok.

ENVIRONMENTAL QUALIFICATION OF ELECTRIC EQUIPMENT

Ashok C. Thadani
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
November 15, 1993

WHY EQ IS A CONCERN

- As a result of license renewal activities, the staff determined that the differences between the qualification requirements for older plants and newer plants should be reassessed for current operating plants.

- Sandia National Laboratory tests results raised questions with respect to accident performance capability of certain artificially aged equipment.

- A preliminary risk scoping assessment indicated that inadequate EQ could be a significant contributor to core damage frequency.

- The Fire Protection Reassessment Report concluded that EQ should be reviewed to identify and correct any programmatic weaknesses that may exist.

COMPARISON OF EQ REQUIREMENTS

	Preaging*	Test Margins	Synergistic Effects	Operating Reactors
1979 DOR Guidelines	N	N	N	60
NUREG-0588 Cat. II (IEEE STD 323-1971)	N**	Y	N	24
NUREG-0588 Cat. I (IEEE STD 323-1974)	Y	Y	Y	24

* Accelerated thermal and radiation aging

** Preaging required but only for valve operators & motors

SANDIA CABLE TESTS

Damaged Cable Test - to determine the minimum insulation thickness needed to survive a loss-of-coolant accident (LOCA) test at the end of qualified life.

Nuclear Plant Aging Research (NPAR) Cable Test - to study the possibility of extending cable qualification to 60 years for license renewal.

SANDIA TEST CONCLUSIONS

- Bonded-jacket electrical cables may be susceptible to failure during LOCA when installed service conditions exceed temperatures of 50°C (122°F) for 40 years.

- Qualification testing that does not use the jacketed configuration may not be representative of actual cable performance.

- Testing indicates a potential problem with using accelerated aging of cables to simulate actual plant aging.

RISK SCOPING STUDY CONCLUSIONS

- There are currently large uncertainties associated with electrical equipment EQ issues.
- Reduced equipment reliabilities due a harsh environment could significantly increase core damage frequency estimates for both PWR and BWR plants and change current PRA perceptions regarding important risk contributors.
- Core damage frequency impact of EQ is plant specific.
- More detailed technical work is needed to compare the risk impact of the different EQ requirements, to reduce risk uncertainties associated with EQ, and to evaluate the impact of risk reduction measures.

RECOMMENDATIONS OF THE FIRE PROTECTION REASSESSMENT REPORT

- Report issued February 27, 1993

- Specifically identified EQ for review

- EQ action plan includes EQ programmatic review by DSSA/SPLB

- PMAS reviewing applicability to other generic issues

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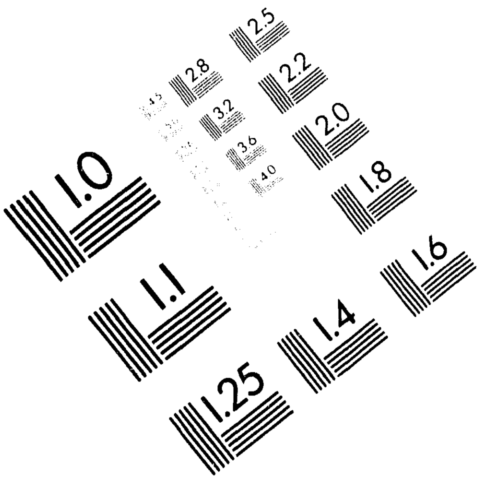

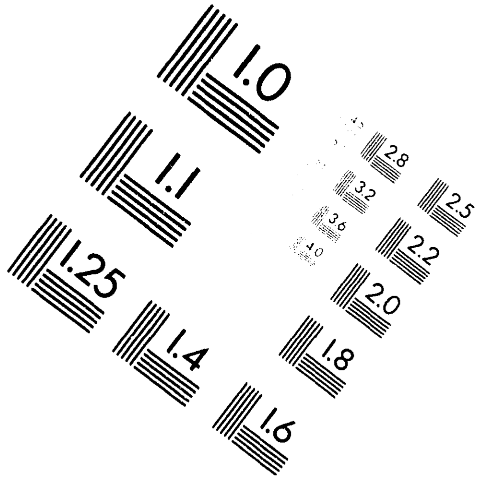

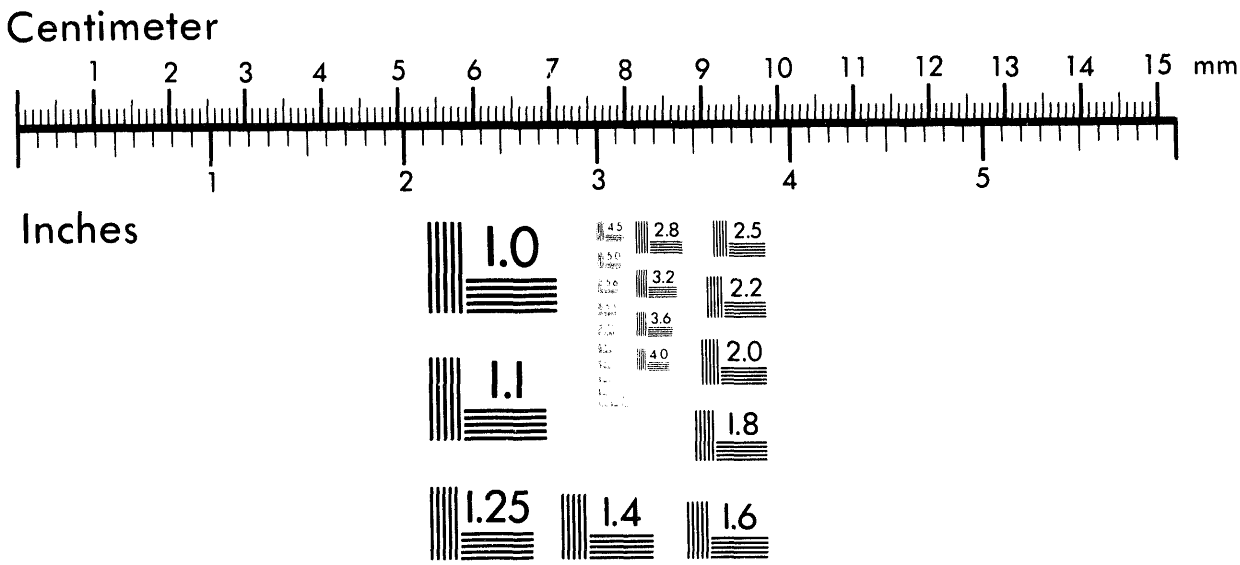

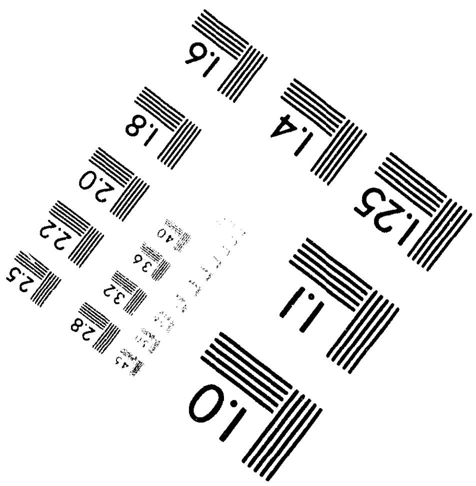

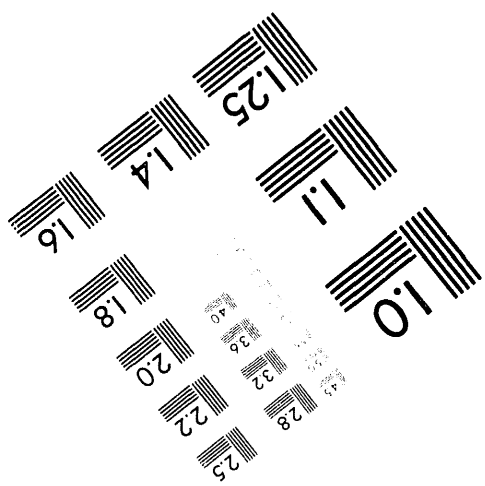

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MAJOR ELEMENTS OF EQ TASK ACTION PLAN

1. INFORM COMMISSION
2. MEET WITH INDUSTRY
3. PROGRAMMATIC REVIEW
4. DATA COLLECTION/ANALYSIS
5. RISK ASSESSMENT
6. TECHNICAL ISSUES
7. OPTIONS FOR RESOLUTION
8. IMPLEMENTATION

EQUIPMENT QUALIFICATION - A BRIEF OVERVIEW*

Salvatore P. Carfagno
Consultant

DEFINITION

Equipment qualification (EQ) is a process for demonstrating reasonable assurance that safety-related equipment can perform its specified safety function(s) at any time during its service in the operation of a nuclear power generating station. It is part of a comprehensive system of defense in depth, that includes redundance and diversity of safety systems. A principal objective of EQ is to protect against common cause failures that could affect more than one safety system within an interval too short to permit corrective action on the first failure before other failures occur.

This overview is limited to a discussion of the environmental qualification of electrical equipment; it omits any discussion of mechanical equipment and seismic qualification, which is the other main element of EQ.

REGULATORY REQUIREMENT

Equipment qualification is performed in accordance with a variety of industry standards, Regulatory Guides, and federal regulations or rules. One of the federal regulations provides a convenient definition of the equipment that requires qualification and the functional capability expected of it. This document is Part 50.49 of the Code of Federal Regulations, Title 10, which in early 1983 codified the requirements for environmental qualification of electric equipment important to safety for nuclear power plants. Equipment important to safety was defined as including safety-related equipment required "to remain functional during and following design basis events...," nonsafety-related equipment "whose failure ...could prevent satisfactory accomplishment of safety functions...," and "Certain post-accident monitoring equipment." Design basis events were defined "as conditions of normal operation, including anticipated operational occurrences, design basis accidents, external phenomena, and natural phenomena for which the plant must be designed to ensure..." that the following capabilities are maintained: "(i) the integrity of the reactor coolant pressure boundary, (ii) the capability

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*The intent of this overview is to provide a general review of the highlights of equipment qualification. For comprehensive information on this topic and the documents mentioned (e.g., industry standards and regulatory documents), the reader should consult a reference such as the Electric Power Research Institute report by P. Holzman and G. Sliter: Nuclear Power Plant Equipment Qualification Reference Manual.

to shut down the reactor and maintain it in a safe shutdown condition, and (iii) the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures..."

DEVELOPMENT of INDUSTRY and REGULATORY DOCUMENTS

In this brief overview, the following account is not comprehensive; but it highlights the changes in EQ practices. When the first EQ programs were initiated in the late 1960s, very little guidance was available; and qualification was conducted in accordance with generally accepted industry practice. (The first applicable IEEE documents did not appear until 1971.) Accordingly, the early qualification programs concentrated

on simulation of design basis events (DBEs), particularly the loss-of-coolant accident (LOCA).

A major change in EQ occurred in 1974 with the publication of IEEE Std 323-74 and its endorsement by Regulatory Guide 1.89. This standard specifically called for demonstration of a qualified life, the main option available for doing so being the accelerated aging of equipment to simulate the degradation of its ability to perform the specified safety function(s) during the qualified life. Many industry representatives had objected to this requirement, but others held that the requirement was already encompassed in an earlier standard (IEEE Std 279-71). To some of those who contributed to development of the standard, it seemed quite reasonable to require that simulation of hazardous environments (e.g., LOCAs) be conducted with specimens that had been preaged to simulate their functional capability at the end of the expected period of service. However, when manufacturers attempted to comply with the preaging requirement, the limitations of applicable technology were immediately apparent. Consequently, IEEE found it necessary to publish a supplement to IEEE Std 323-74, in effect acknowledging that the state-of-the-art of aging is limited and stating "it is expected that known technology be utilized in any aging program. Optionally...aging...may be addressed by operating experience, analysis, combined, or ongoing qualification..." The options did not provide significant relief, and industry was left to cope with the preaging requirement within the limits of existing technology. [The reader should consult the sections of this report on the Preaging Session of the Workshop for further discussion of this topic.]

IEEE Std 323-74 also introduced the use of margins to increase the severity of testing to simulate accident conditions. These margins were intended "to account for normal variations in commercial production of equipment and reasonable errors in defining satisfactory performance." When combined with the conservatisms employed in defining service conditions and functional requirements, the introduction of margins significantly increased confidence in the qualification process.

A later revision (IEEE Std 323-83) explicitly acknowledged that the equipment located in mild plant environments, defined as those that do not change significantly when a DBE occurs, does not require the demonstration of a qualified life. (It is recognized that equipment in a mild environment may experience sigificant deterioration as a consequence of its operation, independently of the environment.) For such equipment, surveillance and maintenance suffice to provide reasonable assurance of operability.

Two NRC documents that have played a key role in EQ are the so-called DOR Guidelines (published in 1979 as an enclosure to an NRC Bulletin) and NUREG-0588 (published for public comment in late 1979 and revised as an 'interim staff position' in 1981). NUREG-0588 established two categories of qualification: Category I for equipment qualified in accordance with IEEE Std 323-74 and Category II for equipment qualified in accordance with IEEE Std 323-71. The DOR Guidelines and NUREG-0588/Category II both allowed equipment aging to be addressed by analysis, with the exception that NUREG/Cat II required that valve actuators and motors qualified in conformance with IEEE Stds 382-72 and 334-71, respectively, should comply with the NUREG/Cat I requirements (i.e., requiring preaging). Both Cat I and Cat II of NUREG-0588 required margins; however, Cat I stated that the margins suggested in IEEE Std 323-74 were to be used as a guide, and Cat II stated that the design margins would be evaluated on a case-by-case basis.

The main consequence of this history of developments in standards and regulatory requirements is that approximately 80 (older) operating nuclear power plants are licensed in accordance with requirements that allow more flexibility in addressing the aging issue than is permitted to the remainder of the plants.

EQ AS a DETERMINISTIC PROCESS

An important feature of EQ is that qualification is achieved (in practically all cases) by the testing of one specimen. It is called a deterministic process in that a procedure is specified, acceptance criteria are defined, and the equipment passes or fails based on whether it meets the acceptance criteria. EQ does not result in a measure of reliability, which would require the testing of many specimens. The several conservatisms built into the EQ process are thought to justify reliance on the testing of a single specimen.

EQ RESEARCH

Considerable research on EQ has been sponsored by the NRC, DOE, and the Electric Power Research Institute (EPRI). To some extent the findings of the research have been reflected in modifications of the EQ process. The 1984 revision of Regulatory Guide 1.89, for example, states that synergistic effects identified prior to initiation of qualification should be accounted for. The synergistic effects that had been identified by research at that time were radiation dose rate effects during the simulation of radiation aging and the difference in degradation resulting when the sequence of thermal aging and radiation aging are reversed.

The results of probabilistic risk assessments (PRAs) show that accidents can be controlled much more easily than had been assumed in the early history of nuclear power. It is possible that PRAs will influence the further development of EQ. However, many are concerned with the adequacy with which PRAs account for equipment aging in normal service and failure rates under DBE condittions.

EQ REVIEWS

In the early 1980s, a detailed review of the utilities' documentation of their EQ programs was conducted by the NRC to verify compliance with applicable regulatory requirements. Although numerous deficiencies were identified, many of them attributed to inadequate documentation, the deficiencies were all resolved by additional analyses, some additional testing, equipment replacement in some cases, and improved documentation.

The NRC has also conducted plant inspections, including review of the utilities' EQ files (for relatively more critical equipment items) and plant walkdowns to verify whether equipment was installed in accordance with the documentation and to uncover any deficiencies. These inspections likewise uncovered some problems that required corrective action by the utilities.

In short, EQ has received considerable attention during the last 25 years. Very substantial investments have been by the utilities in implementing EQ programs, by the Government in exercising its regulatory function, and by both parties in sponsoring research to advance the state-of-the-art.

LESSONS LEARNED

Our 25 years of experience have taught us ways in which to improve the qualification process and to maintain equipment in a qualified state. Although these lessons are covered by the four major topics of this workshop, it may be reasonable to mention some key points here. With respect to preaging, we have learned that there are considerable uncertainties in the process of conditioning equipment to simulate the degradation of functional capability that takes place during a given period of service and that the qualified life established by preaging is not a precise number. Operating experience has identified equipment that needed to be replaced, identified hot spots and key equipment items on which to focus attention, and taught us how to maintain and refurbish equipment so that age-related degradation for many equipment items never proceeds very far and the functional capability is restored to the level of new, or nearly new, equipment. Condition monitoring has revealed deviations between service conditions assumed when EQ programs were initiated and actual service conditions; in some cases so-called hot spots have been identified that were not considered during qualification; but often it has been found that the assumed conditions were much more severe than the actual service conditions. In addition, the development of equipment condition monitoring has helped us identify the need for corrective action before equipment fails; and we are trying to develop methods for predicting the remaining useful life of equipment. In the area of testing, most of the development took place during the first decade of experience, when we learned of better ways to design and build test facilities to simulate specified test conditions more accurately, to install test speciments to better simulate plant installations, how to avoid damaging equipment and compromising its performance, and how to calibrate measuring instruments and record data to provide accurate accounts of equipment performance.

As must be obvious from the foregoing account, EQ is not a process amenable to precise definition. As with much of engineering, it requires the exercise of engineering judgment. The 'truth,' for want of a better word, lies not at a specific point, but in a range within which one must make choices. Depending on the objective, the choice may lie closer to one side of the range or the other; we must be careful not to go outside the range of technically justified choices.

NUMARC EQ Perspective

by Alex Marion

GOOD MORNING. IT IS A PLEASURE TO BE HERE TODAY TO PROVIDE YOU A BRIEF OVERVIEW OF THE NUMARC PERSPECTIVE ON EQ.

NOW I PROMISED NOT TO DWELL ON LICENSING AND POLICY ISSUES. AS YOU CAN IMAGINE, AS A REPRESENTATIVE OF NUMARC, THIS SEVERELY LIMITS MY CHOICE OF EXCITING TOPICS ESPECIALLY WITH REGARD TO A PERSPECTIVE ON EQ. BUT I WILL TRY TO KEEP MY WORD.

QUESTIONS HAVE BEEN RAISED RELATIVE TO THE ADEQUACY OF SOME ELECTRICAL CABLES AND GENERALITIES HAVE BEEN MADE INDICATING THAT FAILURES OF 1E EQUIPMENT IN HARSH ENVIRONMENTS COULD HAVE A POTENTIAL RISK IMPACT. QUESTIONS WILL ALWAYS BE ASKED - AND THERE IS NOTHING WRONG WITH THAT. THE STATE OF KNOWLEDGE AND TECHNOLOGY IS ADVANCING AND WE MUST PROGRESS WITH IT. YOU CANNOT SUCCESSFULLY ACHIEVE A LEVEL OF PROGRESS WITHOUT ASKING QUESTIONS. THE TROUBLING REALITY TO MANY INDIVIDUALS IS THAT SOME OF THESE QUESTIONS MAY ULTIMATELY FOCUS ON DECISIONS AND ACTIONS TAKEN IN THE PAST.

IN THE CASE OF EQ, THE PAST WAS QUITE SOME TIME AGO: AN INITIAL BULLETIN IN 1979, FOLLOWED BY SUPPLEMENTS TO THE BULLETIN, GENERIC LETTERS, A REGULATION, REGULATORY GUIDE, INSPECTIONS, VIOLATIONS, ETC. A TREMENDOUS EFFORT WAS PUT FORTH BY THE NRC AND THE INDUSTRY. HUNDREDS OF MILLIONS OF DOLLARS WERE EXPENDED ACROSS THE INDUSTRY TO DEMONSTRATE PROPER PLANT AND SYSTEM PERFORMANCE IN RESPONSE TO DESIGN BASIS ACCIDENTS. THE QUESTION

I OFFER YOU IS WHAT HAVE WE LEARNED FORM ALL OF THIS ACTIVITY DURING THE PAST 14 PLUS YEARS??

I DO NOT CONSIDER AS AN OVERWHELMING LEARNING EXPERIENCE THE CONCLUSION THAT FAILURE OF CLASS 1E ELECTRICAL CABLES IN A HARSH ENVIRONMENT COULD BE RISK SIGNIFICANT. RATHER, I ONLY CONSIDER THIS CONCLUSION AS CONFIRMING WHAT MANY HAD ALREADY KNOWN - THAT 1E EQUIPMENT IS INDEED IMPORTANT. QUITE POSSIBLY THE SOLE SIGNIFICANCE MAY BE THE FACT THAT WE CAN NOW DEMONSTRATE THE LEVEL OF IMPORTANCE WITH RISK-BASED METHODS. BUT WE MUST BE CAREFUL NOT TO BE LULLED INTO THINKING THAT IT MAY BE MORE IMPORTANT AN ISSUE TODAY THAN 14 YEARS AGO.

AGAIN WHAT HAVE WE LEARNED?? WHAT IS IMPORTANT TODAY THAT MAY NOT HAVE BEEN ADEQUATELY ADDRESSED 10 - 15 YEARS AGO?? THE ADVENT OF NEW TOOLS AND TECHNOLOGIES SHOULD NOT NECESSARILY DECLARE THE PAST NULL AND VOID. DETERMINISTIC APPROACHES USED IN THE PAST PROVIDED FOR LEVELS OF DEFENSE IN DEPTH. HOPEFULLY, WITH INSIGHTS GAINED FROM PROBABLISTIC SAFETY ASSESSMENTS WE CAN QUANTIFY THE REASONABLE LEVELS OF DEFENSE IN DEPTH AS OPPOSED TO THE ADDITION OF ANOTHER LAYER.

ARE CLASS 1E CABLES IMPORTANT - OF COURSE THEY ARE!! AFTER ALL CONSIDER THE MONIES SPENT ON CABLE RESEARCH UNDER THE AUSPICES OF THE NRC'S NUCLEAR PLANT AGING RESEARCH PROGRAM. ADD TO THIS THE QUALIFICATION TESTING CONDUCTED BY CABLE MANUFACTURERS AND UTILITIES. WHAT HAVE WE LEARNED?? AS AN ELECTRICAL ENGINEER I

ALWAYS BELIEVED PROPERLY DESIGNED ELECTRICAL CABLE TO BE RATHER ROBUST. THE WEAK LINK MORE OFTEN THAN NOT WAS THE TERMINATION POINT. GIVEN THE FINITE TYPES OF MATERIALS EMPLOYED IN CABLE INSULATION SYSTEMS, I HAVE DIFFICULTY ACCEPTING THE IDEA THAT THERE ARE QUESTIONS STILL REMAINING.

DO WE NEED TO UNDERSTAND AGING AND ITS EFFECTS IN DEGRADING THE PERFORMANCE CAPABILITY OF CLASS 1E EQUIPMENT?? OF COURSE WE DO!! UNDERSTANDING MATERIALS USED IN THE DESIGN AND MANUFACTURE OF A CLASSS 1E COMPONENT IS NOTHING NEW. IT NEVER WAS! HOWEVER, A NEW ENGINEERING DISCIPLINE EVOLVED - EQ ENGINEERS. THIS IS NOT INTENDED TO BE DEROGATORY, BUT ONLY TO EMPHASIZE THE SPECIALIZATION OFTEN RESULTING FROM NEW PROGRAMS (IN THIS CASE EQ) THAT IN EFFECT DIVERTED FROM CORE DESIGN PRINCIPLES AND PRACTICES.

WHAT HAVE WE LEARNED?? IN ADDRESSING THIS QUESTION, I PROPOSE THAT THE TRUE UNDERLYING ISSUE IS TO WHAT DEGREE. FOR EXAMPLE, CONSIDER LEVELS OF MARGIN. WHAT ABOUT UNCERTAINTY?? TO WHAT LEVEL OF INDEPENDENT VERIFICATION?? TO WHAT LEVEL OF ASSURANCE - REASONABLE OR OTHERWISE?? WHAT ABOUT ....?? HOW ABOUT...?? THESE QUESTIONS CAN CONTINUE AD INFINITUM. HOPEFULLY, DURING THE COURSE OF THIS WORKSHOP YOU WILL ADDRESS MANY SIMILAR ISSUES AND I TRUST DEVELOP THOUGHTFUL INSIGHTS.

MORE THAN 250 INDIVIDUALS FROM THE NUCLEAR POWER INDUSTRY REPRESENTING UTILITIES, NRC, MEDIA, CONSULTANTS, NATIONAL LABORATORIES, MANUFACTURES, ETC. ARE HERE TODAY TO DISCUSS WHAT IS REFFERED TO AS THE "MOST SIGNIFICANT TECHNICAL ISSUES RELATED TO THE ENVIRONMENTAL QUALIFICATION OF ELECTRICAL EQUIPMENT IN NUCLEAR POWER PLANTS." [THAT'S A DIRECT QUOTE FROM THE BROCHURE ANNOUNCING THIS WORKSHOP.]

IT GOES ON TO HIGHLIGHT THE FOLLOWING TOPICAL AREAS:

PREAGING

OPERATING EXPERIENCE

CONDITION MONITORING

TESTING

IN REVIEWING THE LIST OF RENOWN AND KNOWLEDGEABLE INDIVIDUALS PARTICIPATING IN THE PANEL SESSION DISCUSSIONS ON EACH OF THESE TOPICAL AREAS, I WAS STRUCK BY THE FACT THAT MANY OF THEM PARTICIPATED IN THE LAST EQ WORKSHOP HELD ABOUT 11 YEARS AGO IN BETHESDA. UNFORTUNATELY, I PARTICIPATED IN THAT WORKSHOP AS WELL. MANY OF THE SAME ISSUES WERE DISCUSSED THEN. THE SESSION ON OPERATING EXPERIENCE SHOULD BE ENLIGHTENING SINCE THE INDUSTRY HAS 14 YEARS EXPERIENCE WITH QUALIFIED EQUIPMENT.

I HOPE YOU DON'T LEAVE TOMORROW WITH THE UNDERSTANDING THAT THE TOPICAL AREAS ARE THE "...SIGNIFICANT TECHNICAL ISSUES..." IF YOU DO THEN I TRULY BELIEVE YOU HAVE MISSED AN OPPORTUNITY TO CONTRIBUTE. I SUBMIT THAT QUESTIONS ALONE SHOULD NOT LEAD TO RESEARCH IN A REGULATED INDUSTRY. RATHER, INVESTIGATING PROBLEMS THAT HAVE AN IMPACT ON PLANT SAFETY SHOULD BE THE GOAL OF RESEARCH WITH A FUNDAMENTAL FOCUS ON SEEKING SOLUTIONS. THESE SOLUTIONS MUST DEMONSTRATE A SAFETY IMPROVEMENT THAT CAN BE REASONABLY APPLIED. IF THIS IS NOT ACCOMPLISHED BY YOUR ACTIVE PARTICIPATION AT THIS WORKSHOP, THEN I WILL LIKELY SEE YOU IN ANOTHER 10-15 YEARS AND ASK AGAIN - WHAT HAVE WE LEARNED??

THANK YOU.

APPENDIX B

PRESENTATIONS FOR MONDAY NOVEMBER 15, 1993
PLENARY SESSION ON PREAGING AND PRECONDITIONING

CONTENTS

PREAGING/PRECONDITIONING

Salvatore P. Carfagno
Consultant

INTRODUCTION

As outlined in the overview of equipment qualification presented earlier in this Workshop, preaging is the component of qualification that is intended to simulate, in a short time (weeks, or at most, months), the functional degradation of equipment that takes place during normal service over a period extending as long as feasible, ideally as long as the anticipated life of the plant. This presentation focuses on the conditioning of a representative specimen of equipment through accelerated aging. Consequently, it is limited to equipment - whether it is located in a harsh or mild environment - that is expected to undergo significant degradation of its functional capability during normal service.

The EQ overview should be consulted for the introduction of the preconditioning requirement, the distinction between the aging commitments of older and newer plants, and the results of research and operating experience; the latter topic is covered thoroughly elsewhere in this report.

DEFINITIONS

To begin, it is useful to define the terms used in the preceding paragraph: preaging, preconditioning, and accelerated aging. The term aging relates primarily to the passage of time and all the changes in equipment characteristics that take place with time. Degradation focuses on the reduction of the functional capability of the equipment, particularly the required safety function(s), as distinguished from irrelevant changes. Conditioning refers to whatever is done to equipment (e.g., heating, irradiation, vibration, cycling) to simulate the deterioration of its functional capability. In this account, preaging, or more simply aging, will be used in reference to the deterioration of functional capability during normal service; and preconditioning, or accelerated aging, will refer to the simulation of functional deterioration. The prefix "pre" emphasizes the fact that the aging or conditioning takes place prior to the occurrence, or the simulation of, a design basis event (DBE). Accelerated aging emphasizes the fact that the preconditioning is done in a time short relative to the real time simulated.

QUALIFIED LIFE

The objective of accelerated aging is to simulate the functional degradation of equipment that is anticipated to occur from the time the equipment is manufactured until it may be required to perform its safety function(s) during a

DBE. One outcome of this process is the determination of a qualified life, which is defined in IEEE Std 323-83 as "The period of time, prior to the start of a design basis event, for which equipment was demonstrated to meet the design requirements for the specified service conditions." A note adds that "At the end of the qualified life, the equipment shall be capable of performing the safety function(s) required for the postulated design basis and post-design basis events."

In practice, the goal of most conditioning programs has been to simulate the aging that takes place during 40 years of service, the period for which operating plants have been licensed. Any deterioration that occurs prior to plant startup has not been addressed consistently; and, in fact, plant startup is generally taken as the beginning of qualified life. In reviewing the development of the aging requirement and its implementation, there appears to have been an implied assumption that safety-related equipment would be put into service and simply left in place for the operating life of the plant. That this is far from what happens in practice is amply evident; and this point is discussed further, later in this document.

For safety-related equipment, the greatest demand for functional capability is anticipated if, and when, a DBE occurs; and this could happen at the very end of qualified life, i.e., on the last day that a plant is scheduled to operate. Therefore, unlike most equipment we use in ordinary life, the functional capability of safety-related equipment used in nuclear power plants must have a very substantial functional capability at the end of its qualified life. This point emphasizes the importance of not using the term 'end of life' in place of 'end of qualified life.'

AGING ANALYSIS

To establish a preconditioning program, it is necessary to collect considerable data. The following list outlines the data needed.*

Definition of the safety function for normal service, including any abnormal occurrences, and applicable design basis events.

Identification of materials of construction, particularly all degradable materials and parts.

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* Numerous references are available that explain each category of data and the analysis, not only in general terms, but also for many specific equipment items. Principal among these are the reports produced by the NRC's Nuclear Plant Aging Research program.

Identification of all equipment failure modes.

Definition of all service conditions.

Definition of the equipment operating conditions.

Definition of all activities, such as maintenance, surveillance, calibration, parts replacement, and in-service testing, that can affect the functional capability.

The aging analysis proceeds with the identification of the significant aging mechanisms, which are defined basically as those that adversely affect the ability of the equipment to perform its safety function and that cause degradation during the qualified life that is appreciable compared to the degradation caused by the DBEs.

From the definition of service and operating conditions, one identifies the stressors that contribute to significant aging mechanisms. These stressors include heat, radiation, humidity, pressure, vibration, electric fields, and dirty and corrosive atmospheres. To acclerate the aging effects of these stressors, it is necessary to have aging models; in practice, however, models have been applied only for thermal and radiation aging. With few exceptions, the Arrhenius model has been used for thermal aging and the equal dose/equal damage model for radiation aging. Wherever the other stressors have been considered, the preconditioning has often been based on military specification testing, without any mathematical correlation between the effects of the test and deterioration during service. For cyclic devices, such as relays and valves, the deterioration caused by operation has been simulated by putting test specimens through a number of cycles, usually substantially exceeding the number anticipated in service. If the equipment has parts that deteriorate much more rapidly than the entire assembly and it is feasible to replace the parts, e.g., electrolytic capacitors, O-rings, and bearings, then suitable replacement intervals have been established.

In the early days of equipment qualification, there was a tendency to qualify for the severist plant environment (i.e., inside containment), so that the equipment would be qualified for application anywhere within the plant. Later, it was recognized that this approach did not make sense economically; and better guidance to account for aging was produced. In part, this was reflected in the explicit recognition that only significant aging mechanisms needed to be simulated. More important was the recognition that in plant locations where the applicable DBEs are not expected to change the service environment, the ability of safety-related equipment to function does not change when a DBE occurs. Accordingly, for such equipment it is not necessary to establish a qualified life by preconditioning. Aging can be accounted for by analysis, and equipment operability can be adequately assured by monitoring and maintenance.

APPLICATION of the ARRHENIUS MODEL for THERMAL AGING

The Arrhenius model relates the rate of a chemical reaction to the frequency with which the reacting molecules collide, the energy needed for the molecules to react (the activation energy), and temperature. It is strictly applicable to situations in which a single reaction takes place; however, it has been applied successfully to situations involving complex reactions, particularly if a single reaction is dominant in any given temperature range. For any material, the frequency factors and activation enegies must be determined experimentally, and they should be determined for the same reaction that is responsible for the deterioration to be simulated. It is also necessary to establish an end point, or the maximum extent to which the reaction may proceed if the material's deterioration is not to compromise the equipment's ability to perform its safety function. If all these data are available, it is possible to calculate two things: the time (life of the material) to reach the end point under normal service conditions and the accelerated aging conditions, i.e., the elevated temperature at which the same end point can be reached in a shorter time.

An example may help to make the use of the Arrhenius model clearer. For cable insulating materials, it has been found that the property that correlates well with retention of insulating capability is retention of the initial elongation. The end point frequently selected is 50% retention of initial elongation. By measuring changes in the elongation of insulation specimens after different exposure times, one can plot a curve of 'percent of initial elongation retained' vs 'time of exposure' at a given temperature. The process is repeated at several temperature levels. In accordance with the Arrhenius model, the plot of the 'natural logarithm of the time to end point' vs the 'reciprocal of absolute temperature' should be a straight line and the slope of this line yields the activation energy. A regression analysis of the experimental data should be performed to obtain the best value of the slope (the activation energy) and a measure of its uncertainty. Such analyses have shown that, for data typical of those used in qualification programs, a qualified life of 40 years may have an expected value at 95% confidence between approximately 10 and 400 years for thermal aging alone.

Experiments of the type described, performed in research laboratories, have shown good correlation with theory. In fact, research at Sandia National Laboratories has extended the model to include aging due to heat and radiation combined, and excellent correlation with experiment has interactions may not be well understood and, further, may be difficult to simulate.

DOES PRECONDITIONING CONTRIBUTE SIGNIFICANTLY to ASSURING SAFETY?

It must be clear from this discussion that accelerated aging produces at best a rough approximation of the degradation that occurs in real service; and the determination of qualified life produces a number that has considerable uncertainty. In view of this, one may ask whether preconditioning specimens prior to simulation of design basis events adds significantly to the assurance that safety-related equipment can perform as specified. To answer this question, we need to recall that accelerated aging, especially when coupled with the possibility of additional deterioration caused by handling of the preconditioned specimens in preparation for DBE simulation, is probably more likely to result in overaging than in underaging of the equipment specimens. We must also note that our ability to determine whether equipment has met the acceptance criteria for a DBE simulation is better than our ability to measure the residual functional capability that may remain in a specimen after the DBE simulation. Accordingly, if two designs for the same function (e.g., control cables made by two manufacturers) both pass a DBE test, except that one was preconditioned and the other was not, we would be compelled to have greater confidence in the preconditioned specimen. If this argument were accepted as justification for preconditioning, we would have to accept the possibility that some equipment items that might be truly capable of meeting the design requirements might nonetheless fail to qualify because of overaging during preconditioning.

The value of preconditioning and alternatives that may be proposed to account for aging merits further study.

WHERE ARE WE?

Because of the increasing recognition of the uncertainties associated with preconditioning, there has been a trend to place greater emphasis on other methods of assuring the safety of nuclear power plants. Utilities are investing more effort in surveillance, maintenance, and condition monitoring than was true during the early history of the nuclear industry.

At this stage of our experience with the operation of nuclear power plants, we have learned where the weak links are. Equipment has been upgraded, refurbished, or replaced as indicated by performance in service. Most plants are making effective use of surveillance and maintenance. Condition monitoring techniques are under development, and increasing use of them is anticipated.

been obtained for a number of polymeric insulating materials used in electrical cables. However, there is less evidence of a correlation between these research results and what happens to cables in service.

Thermal aging analysis is very sensitive to the value of activation energy, and the activation energy is very sensitive to material formulation; therefore the activation energy is frequently not known for the specific material of interest, or it may not be known for the property of interest. If one resorts to quick methods of determining activation energy (such as thermal gravimetric analysis) the value obtained is not as dependable as a measurement of activation energy based on the particular property that correlates with deterioration (e.g., the correlation of retained elongation of cable insulating materials with retention of insulating properties).

OTHER FACTORS that CONTRIBUTE to UNCERTAINTIES in QUALIFIED LIFE

In addition to the uncertainty associated with the application of the Arrhenius model to thermal aging, several other factors contribute to the difficulty of determining a qualified life. For one thing, the stressors that contribute to deterioration exist simultaneously in service, but it is usually necessary to simulate them sequentially in accelerated aging; although in a few instances, thermal and radiation aging has been conducted simultaneously. Research has identified certain materials and conditions under which synergistic effects cause the combination of heat and radiation to produce more deterioration than that produced by separate thermal and radiation aging. With regard to radiation, research has shown that the equal dose/equal damage model is deficient; for some materials the deterioration at the high dose rates used in some accelerated aging programs produces significantly less deterioration than is expected to occur in service. Since practical models for the aging effect of other stressors do not exist, it is not feasible for these other stressors to correlate preconditioning with equivalent time in service. Furthermore, accelerated aging does not directly account for many factors that affect equipment operability. In the case of cables, these factors may include damage during installation and deterioration of the insulation at points of high stress, such as places where there exists a long overhang of cable around a relatively sharp edge. Turning to equipment that consists of assemblies of different parts and materials, other problems of accelerated aging are introduced: since the materials may have different local environments and will likely have different aging rates, it is not feasible to precondition the assembly to the same equivalent age throughout (some parts may be overaged and others underaged). To the extent that interactions among different materials contribute significantly to aging, these

At present, concern is focussed on those items of electrical equipment that are not readily amenable to refurbishment or replacement if that should be shown to be necessary. Two items that have been identified as falling within this category are electrical cables and penetrations. As the life of operating plants increases, it becomes increasingly important to evaluate reliably the ability of these items to function as required and to estimate their remaining useful life.

TRANSCRIPT OF REMARKS BY LOUIS TEST

Sal Carfagno picked me to do the history because I guess I'm the only one old enough to have been there, and then he proceeded in his opening remarks to cover all the history very adequately and thoroughly.

Before I start I have to say something to Alex. I never expected to agree with you so much, but I do.

We've had something of a history together, also. We lose sight of the fact that there is no substitute for good design, and that was in our mind when we started this business. The trigger was in the late sixties with the issue of IEEE 279.

They in a paragraph started everything that brings us here today. They said, "You ought to test stuff to make sure it will do what you say it does, particularly with regard to safety equipment," which 279 was the guide for the design of safety systems. They were concerned primarily with single failure common cause that the accident might take out the equipment, all of the redundant equipment.

My boss received a call from a friend of his saying, "We need a volunteer from your organization to form this new subcommittee on qualification." He put it to us that one of us would have to do it, and I think I was talking instead of listening so I was chosen. As no good deed will go unpunished, here I am.

We came up with IEEE 323, and it was, basically, a design engineering test certification standard. It flew in the face of IEEE practices in that normally standards reflect existing practice and that practice which is the most beneficial is the one that's documented.

We were flying completely blind in a new area. There was no preaging. As I said we were very naive, mostly a bunch of design engineers. We didn't get much attention until we issued the standard. It had no seismic. We didn't know what to do about that. Again, talking instead of listening I said, "Well, that's simple, we've all had freshman physics and a little mechanics. What could be more?"

I was then chairman of the Seismic Task Force to write 344, surrounded immediately by a bunch of dynamicists whom I couldn't understand, but I could get the coffee and arrange for the rooms.

We got feedback from 323.71. It got a lot of attention primarily from the NRC through my good old friend Charlie Miller, who fed back the comments, "Well, suppose the equipment is real old when the design basis event occurs, is it still qualified or is it going to be near death?"

We didn't know. We sent out the call for more experts, and the next thing I knew, again, I was inundated with chemists and physicists and physical chemists and the word "arrhenius" came up. I thought it was the guy that owned the Greek restaurant down at the corner.

We had a big educational job to go through including ourselves, first. We made many momentous decisions, thousands of hours -- all in addition to our regular jobs, of course. First of all, as Sal mentioned, we attacked how many should you qualify? How many should you test? The electrical industry was big on classes, classes of insulation, classes of motors, classes of this, classes of that.

The first suggestion I remember was, "Well, if it's less than $100, let's call that Class A and we will test 100 of them. If it's more than $100 but less than $500," and so forth, obviously not because even in those days when we didn't have PRAs we knew that some little piece of equipment might be far more important than some big thousand horsepower motor that cost half a million.
As a practical matter, we decided that we would test the design as embodied in one instrument or one device. We understood the ramifications and we understood the lack of the so-called "reliability" aspect of such an approach, so we set about to poll the experts, primarily design people, some application engineers, and we had a fairly wide base of input as to: What do you think your equipment is good for? Ten percent in this particular area, 20 percent,
50 percent?

We collected all of this and sat around in a room in a motel in Chinatown in San Francisco and thrashed it out and came up with margin. With which we were all very comfortable. We all thought it was exceedingly conservative. In the years that have gone by, and my own experience with a large qualification program, I am still comfortable that we have a lot of margin -- I mean, a lot of conservatism built in.

Furthermore, we tracked back later on the conservatisms in the environments that were calculated. I won't go into that, but there is a lot. We included sequential testing. Again, questions from NRC through Charlie Miller. Is there a way? Is there a most severe way?

This developed the synergistic technology that we decided that again polling a lot of experts that, yes, there was one sequence that we felt was more severe than all the rest. It might not be completely realistic, but then we were working as a group sort of isolated from the world and we decided that that was a reasonably good, if perhaps a slightly conservative approach, again.
Following that, of course, you are all by now familiar with the outcome of all that: the regulations; the programs; as Alex pointed out, the millions of dollars that went into doing this. I look back on it and feel some responsibility for it, but I feel good about it. Because in running program for my former employer -- I didn't run it but I was the program manager, did things like that. I was sort of the technical advisor. The results were excellent. The good designs passed, the bad designs failed. When you did your failure analyses, you found out, yeah, there was a design flaw. I can't remember, of course I don't have the data any more. I'm not in that business. I can't remember a single failure that we were able to trace back to aging. When we looked at failures, we found design flaws. That has made me sleep better nights and made me feel a little better about the whole process.

Subsequently, as you are all aware, we are into modern times now. The daughter documents were developed. Again, a very solid group of very hardworking guys put out some excellent pieces of work, and here we are today.

NRC Workshop on Environmental Qualification of Electrical Equipment

Preaging Panelist Brief Presentation

Assigned Topic:
Lessons Learned From Operating Experience
Relating To Preaging For Environmental Qualification of Electrical Equipment

by
Larry Gradin
EcoTech/RAM-Q Industries
Director of Engineering

November 15-16, 1993
Rockville, Maryland

At Holiday Inn Crowne Plaza

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What Are The Fundamental Lessons Learned From Operating Experience Vs. Preaging or Preconditioning?

- ***Why is the Nuclear Industry Still Struggling With Concern Over Preaging or Preconditioning 10-12 Years After We Met Together In Various Aging Conferences Nationally and Internationally?***

Are their Problems or Perceptions Of Problems?

Hopefully We Will Find Some Answers Together. The Best Answer May Be Based On Experience Based Validation and Practical Engineering Assessments.

Can it be a perception that unique "age-related degradation" exists today based on:

(1) a focus on license renewal and maintenance almost remote from actual performance based assessment of electrical equipment in service,

(2) lack of use of more than 100 years of electrical equipment standards development, reliability, failure data, and equipment understanding,

(3) perceiving failures due to misapplication or equipment operation beyond its design intent as "aging degradation" rather than understanding the root cause,

(4) taking the very few suspicious operability problems and extrapolating these suspicions to all electrical equipment, or

(5) attempting to over-generalize from valuable aging research without use of the *key and vital element of Engineering Analysis*.

PREAGING RESULTS EVEN WHEN VALIDATED BY POSITIVE EXPERIENCE, CAN NOT BE THE COMPLETE STORY --

(1) It is recognized that performance during service, even if it greatly exceeds laboratory based predictions, does not necessarily assure adequacy during design basis accidents. Performance during accidents is addressed in other panel sessions.

(2) Vigilance must continue to prevent the attention to the trivial or insignificant many overshadowing the few significant concerns discovered in our industry which "appear as aging". Failures are usually the results of misapplication, contamination, or other factors.

Necessary Definitions As A Foundation of Common Understanding:

Failure **(IEEE 100) is the termination of the ability of an item or equipment to perform its required function.**

Significant aging degradation **(IEB 79-01B) is defined as that amount of degradation that would place in substantial doubt the ability of typical equipment using these materials to function in a hostile environment.**

Significant Aging Mechanism **is a mechanism which in its normal and abnormal service environment causes degradation during the installed life of the equipment that progressively and appreciably renders the equipment vulnerable to failure to perform its safety function(s) under Design Basis Event conditions.**

Typical Results of Experience Vs. Pre-Aging Available In Brief Presentation - 1

Motors - **The still current Class 1E motor qualification standard, IEEE 334- 1974 "Standard For Type Tests of Continuous Duty Class IE Motors for Nuclear Power Generating Stations," is the basis for motor qualification, referencing IEEE 117 and IEEE 275 methodology. The use of the methodology contained in IEEE 275 has in fact been utilized for decades for the design of motor insulation systems throughout industry. Westinghouse testing from the early 1950's through 1970's "represents an accumulation of almost 10,000,000 hours (over 1000 years) of thermal aging time on coils". Whereas the conservative IEEE 275 Arrhenius thermal life curve implies a 2-5 year life actual Westinghouse life data exceeds 20-50 years".**

Typical Results of Experience Vs. Pre-Aging Available In Brief Presentation - 2

Transformers **- Actual field experience from GE has demonstrated that the standard IEEE methodology of accelerated thermal aging of insulation systems is conservative. Data correlating IEEE Std 259, "Standard Test Procedure For Evaluation of Systems of Insulation for Specialty Transformers" and field data demonstrated the use of IEEE standard methodology is conservative (5-10 times or more) of laboratory life.**

Cable **- Worldwide commercial industry, LERs, NPAR research, EPRI research, interviews with dozens of experts, indicates a remarkable low number of failures of cables. Investigation of failures which have occurred especially for low voltage cables indicates failure attributed to physical damage, poor terminations, cable abuse, operation well beyond its ratings. Actual service life based on comparison to Arrhenius methodology may be 3-10 times predicted life.**

Is Successful Experience Based On Conservative Endpoints?

Endpoint Selection. The use of the typical accelerated aging techniques (i.e., the application of short time stresses which are more severe than normal stresses) such as the Arrhenius methodology appears conservative.

The application requires the determination of a readily determined "endpoint" prior to DBA stress. For the materials of major concern (i. e., electrical insulators) the endpoint is determined based on a change in a physical property such as elongation which is determined by lab test methods which are often conservative in relation to the equipment installation.

Mathematically significant change in other properties such as compressive strength, dielectric strength, compressive set , etc often do not relate to specific operability needs.

Is Successful General Experience Based On Conservatism & Margin In Derating And Applications?

Derating - Standard practice utilizes electrical equipment on a derated basis (temperature, loading. cycling, etc) as it is a well known phenomena that the "life" of most equipment increases in a continuous manner as the stress level is decreased below rated value. Praging typically assumes full operation at full rating.

Operating Regime - Typical application of much nuclear-safety-related equipment is not continuous, the design basis is either continuous or conservative.

PUTTING CHANGE IN PERSPECTIVE

"Aging" should not be construed as always being a negative contribution to equipment capability or operability.

Aging can produce either a degradation or improvement in a physical condition based on your application criteria. In addition, the change, whether a positive or negative change may not be significant to operability. For example, an accelerated aging process (e.g. radiation) or a chemical means is used to convert the thermoplastic polyethylene material, which is generally recognized as not suitable for Class 1E service in a containment environment subject to a LOCA event, to a thermoset cross-linked polyethylene material which is recognized to have overall superior qualities for nuclear plant safety related cable service. Typical values of original elongation are decreased by 50% in cross-linking yet most other properties improve (operating temperature rating, overload temperature rating, and short circuit temperature capability, radiation withstand capability, etc).

Reality Of Equipment Degradation With Time Deviates From Popular Perception

THE BATHTUB CURVE IS THE EXCEPTION -- NOT THE RULE

Of all the non-structural components studied by the airline industry when the initial concepts of Reliability Centered Maintenance were being developed 20-30 years ago only 11 percent were reported to have wear-out failures. In addition to the general positive results from experience vs. preaging, the data from RCM indicates 68% of equipment has infant mortality. Consequently, great care must be taken before one replaces equipment prematurely.

Aging Diversity Tendency **- Tendency towards diversity in redundant equipment due to slight differences in operating temperatures reported in EPRI NP 1558 results in deviation times in failure at twenty years may be as much as four years. Consequently, common mode failures due to aging is less likely as plants age.**

Figures 1-6 characterize failure patterns of typical components. Of all components, only eleven percent have wear-out failures as illustrated in Figures 1, 5, and 6. Note Figure 2 regarding infant mortality. Therefore, replacement which is unnecessary may be counter to safety by the introduction of equipment in their equipment mortality failure region.

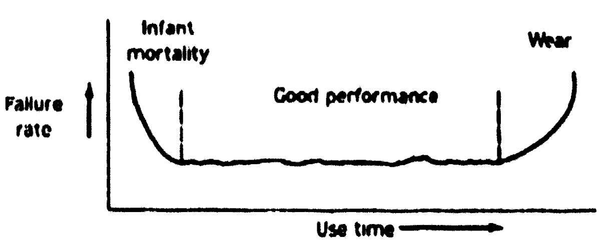


Figure 1
Infant mortality—stable—wear pattern: 4 percent.

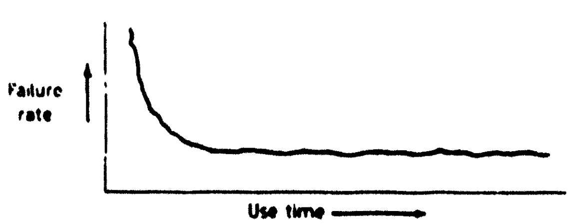


Figure 2
Early failures, then stable life: 68 percent.

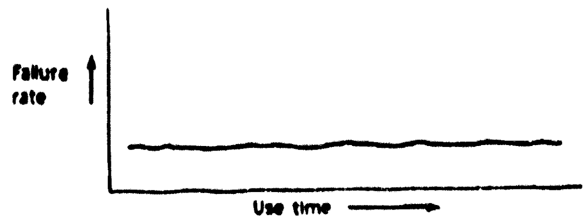


Figure 3
Consistent failure rate: 14 percent.

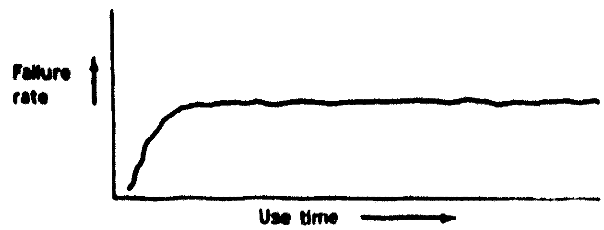


Figure 4
User-caused failures: 7 percent.

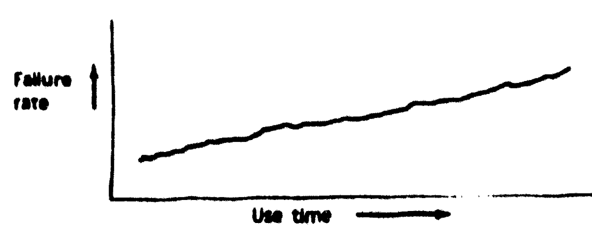


Figure 5
Increasing failures over life: 5 percent.

Figure 6
Wear after a good run life: 2 percent.

AGING MANAGEMENT METHODS

Engineering Based

1. Conservatism in Accident Conditions

2. Robust Equipment Design and Manufacturing Quality

3. Preaging as part of EQ Testing

4. Analytical Evaluations of Aging Effects

Operationally Based

5. Maintenance, Inspections, and Operational Testing

6. Conditioning Monitoring

7. Replacement

8. Equipment Degradation/Failure Investigations and Corrective Actions

I want to take this opportunity to thank the NRC for inviting me to participate in the panels during this workshop. Sal suggested that I discuss Aging Management in the five minutes allocated for me this morning. In this interests of brevity and clarity and with your indulgence I have decided to read some prepared text. Those of you who know me undoubtedly realize this is the only way I can possible limit this talk to 5 minutes.

Philip M. Holzman - Preaging Session
Aging Management

Age related degradation must be addressed independent of our view of environmental qualification as a method of providing reasonable assurance that equipment would function when required during hypothesized accidents or a means of minimizing environmentally-induced common-cause failures during these accidents. I choose here to describe all available methods of minimizing unacceptable effects of age related degradation as aging management. These methods can be broadly described in the following categories:

1. Conservatism in Accident Conditions
2. Robust Equipment Design and Manufacturing Quality
3. Preaging as part of EQ Testing
4. Analytical Evaluations of Aging Effects
5. Maintenance, Inspections, and Operational Testing
6. Conditioning Monitoring
7. Replacement
8. Equipment Degradation/Failure Investigations and Corrective Actions

Please note the first 4 methods can be viewed as engineering-based actions taken prior to equipment installation and use. The last 4 are operationally-based and directly involve the installed plant equipment.

Rarely can one of these methods alone adequately assurance that age-related failures will not occur during accidents. Similarly, no single prescribed mixture of methods is best for all equipment designs, applications, and accident conditions. In part the "art" of EQ requires the prudent exercise of engineering judgment to select an adequately conservative mixture. Importantly, even for one specific situation, several mixes may be adequate while others are clearly suspect. As we discuss and deliberate during these two days. I urge you remember that it is the collective application of these methods and not reliance on a single one that should determine adequacy.

Preaging

Since this session is intended to focus on Preaging, let me comment on it first. In the United States there has been an institutional fascination with preaging as part of environmental qualification. From a regulatory perspective its apparently quantitative nature is alluring since it appears less prone to disagreements over adequacy. From the industry's view the need to demonstrate aging tolerance prior to installation and a historical focus on engineering vs. operational solutions has conceptually fostered preaging as a preferred method. However, as I'm sure you will hear, in the U.S. it appears some have pushed the analytical precision of preaging-based age predictions beyond the state-of-the art.

Other countries with advance commercial nuclear programs, such as France and Japan, use preaging to demonstrate the inherent aging tolerance of equipment designs. They do not attempt to develop precise "life calculations" based on preaging test conditions. Rather, they rely on operational-based methods to minimize aging effects. I caution against viewing these types of programs as inferior to U.S. methods.

Conservatism in Accident Conditions

Regarding conservatism in accident conditions, let me make two observations. First, I believe that the radiation dose assumptions associated with Design Basis LOCAs (and even normal operation) are extremely conservative. My review of research work on aging and accident effects for common elastomeric materials suggests that radiation, and not thermal aging or accident steam conditions, is producing the most degradation during qualification testing. Any assessment of aging adequacy must consider the possibly excessive conservatism in these radiation assumptions. Secondly, I note that most qualification programs demonstrate equipment operability for weeks or months post-LOCA. Yet, PRA insights suggest that only failures during the first few hours or days may have safety-significance. If this is true then our aging management methods should focus on those aging mechanisms that have the most adverse impact on operability during this initial accident period.

Aging Analysis

Regarding the adequacy of using aging analysis in lieu of preaging, there has been recent regulatory concern. It is my opinion that the most cost-effective method of addressing aging for most outside containment equipment potentially exposed to short-term, pipe-break, steam conditions or to radiation-only LOCA conditions is through robust design, limited aging analysis, and prudent application of the four operationally based aging management methods.

Operationally Based Aging Management

The last four aging management methods can be collectively described as operationally based. Condition monitoring, when narrowly viewed as predicting future equipment condition based on current and past measurements, has generated the greatest engineering interest. I believe this "high tech" mentality misses the significant benefits derived from prudent and cost-effective application of the other operationally based aging management options. In a broader context than EQ, both the NRC and the industry have increased their attention on operation and maintenance as methods of improving plant safety and availability. I believe that we can all benefit from less reliance on predictive technology and greater focus on maintaining equipment condition.

Equipment Qualification Scope

If Sal will permit, let me make one final observation that is not limited to aging per se. I believe that if the industry resources currently applied to maintaining compliance with 10 CFR 50.49 were refocused on a smaller more safety-significant set of equipment, then an overall safety improvement would occur. Unfortunately, the current compliance framework requires the uniform application of qualification methods to all 50.49 equipment without considering the severity of its environment or its relative safety significance.

Presentation by

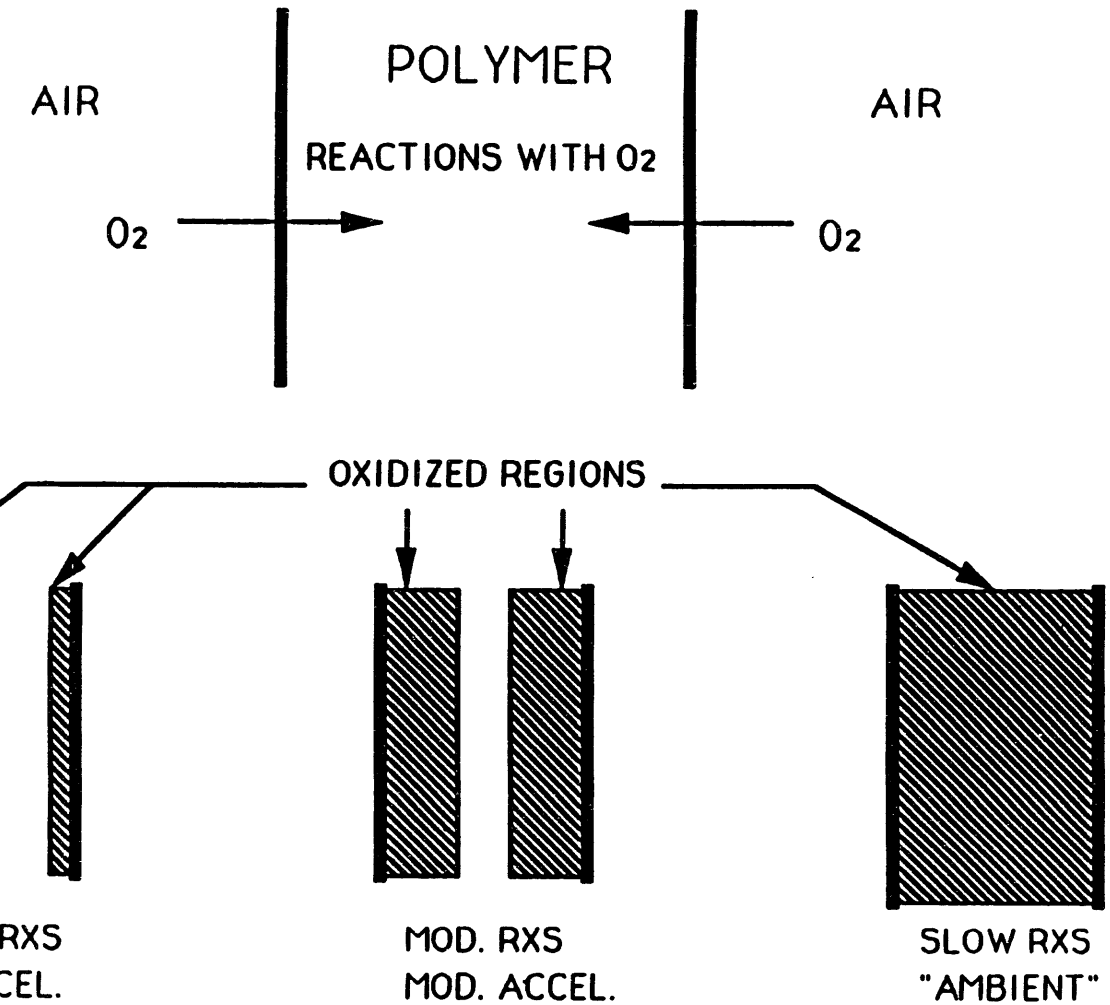
Ken Gillen

TWO MAJOR PREAGING ISSUES

1. **DIFFUSION-LIMITED OXIDATION- important for both radiation and thermal preaging**

2. **VALIDITY OF ARRHENIUS METHOD**

DIFFUSION-LIMITED OXIDATION EFFECTS

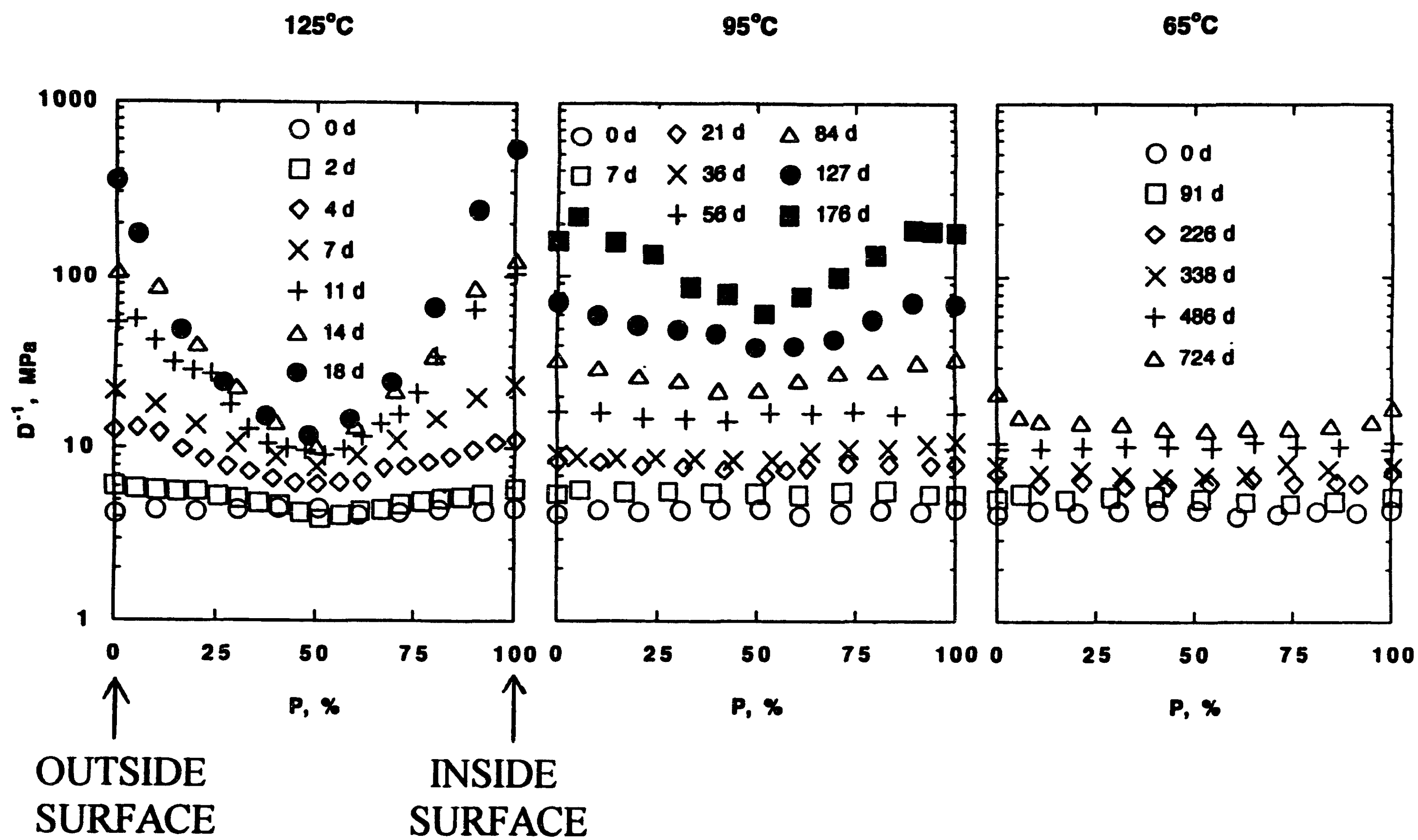


TIME FOR THERMAL DEGRADATION	DAYS TO WEEKS	MONTHS	YEARS

MODULUS PROFILES

Unique instrument allows quantitative mapping of modulus (D^{-1}) across material cross-section with 50 μm resolution.

RESULTS FOR NITRILE RUBBER

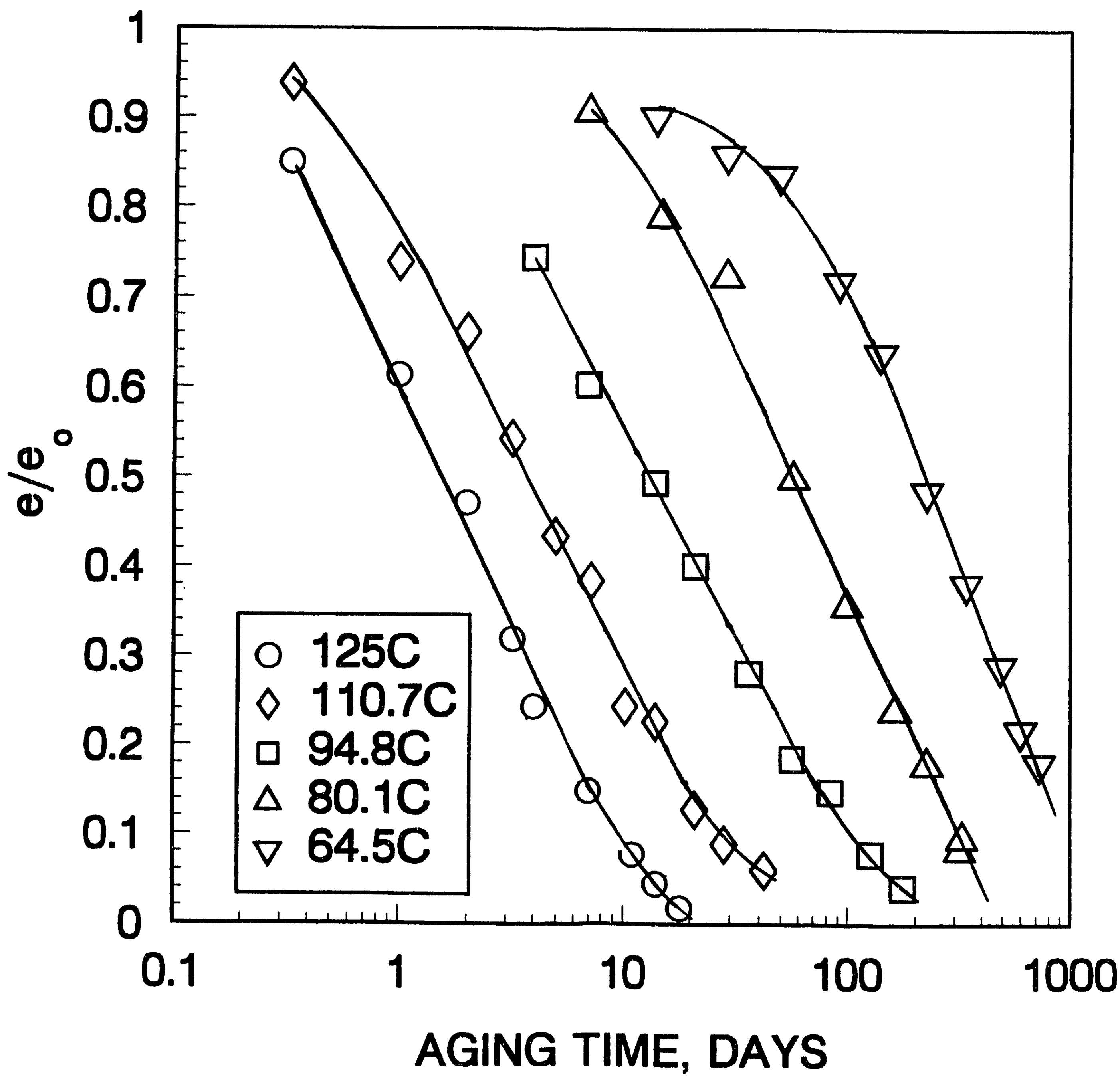


CRITICAL ASSESSMENT OF ARRHENIUS THERMAL AGING METHODOLOGY

GOAL- Demonstrate that Arrhenius is valid and often conservative.

Ultimate tensile elongation (e) often used when applying Arrhenius method.

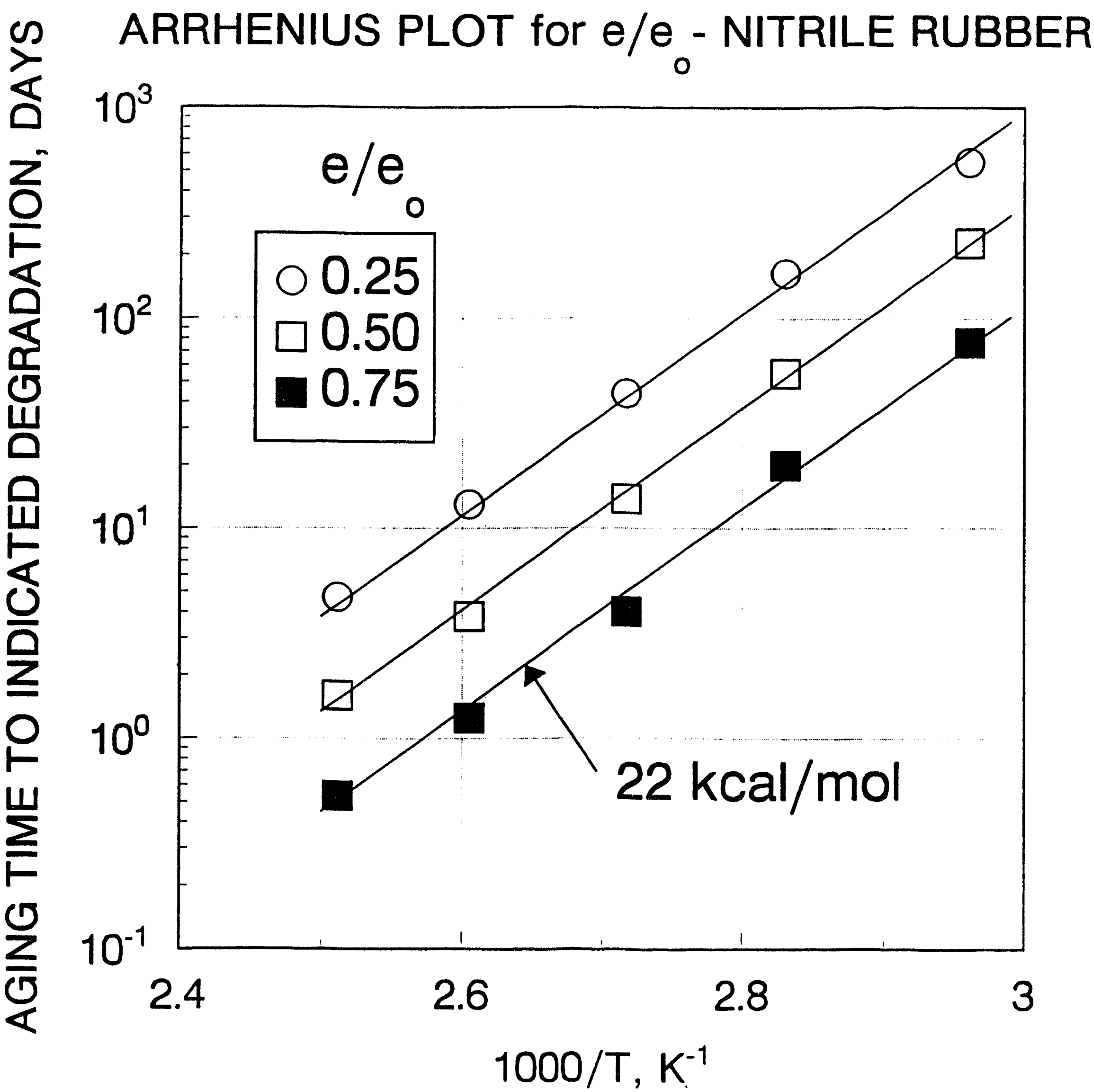
Example of raw data- normalized elongation (e/e_O) vs. time at 5 temperatures for a nitrile rubber.



ARRHENIUS ASSUMPTION- Degradation depends on underlying chemical reactions

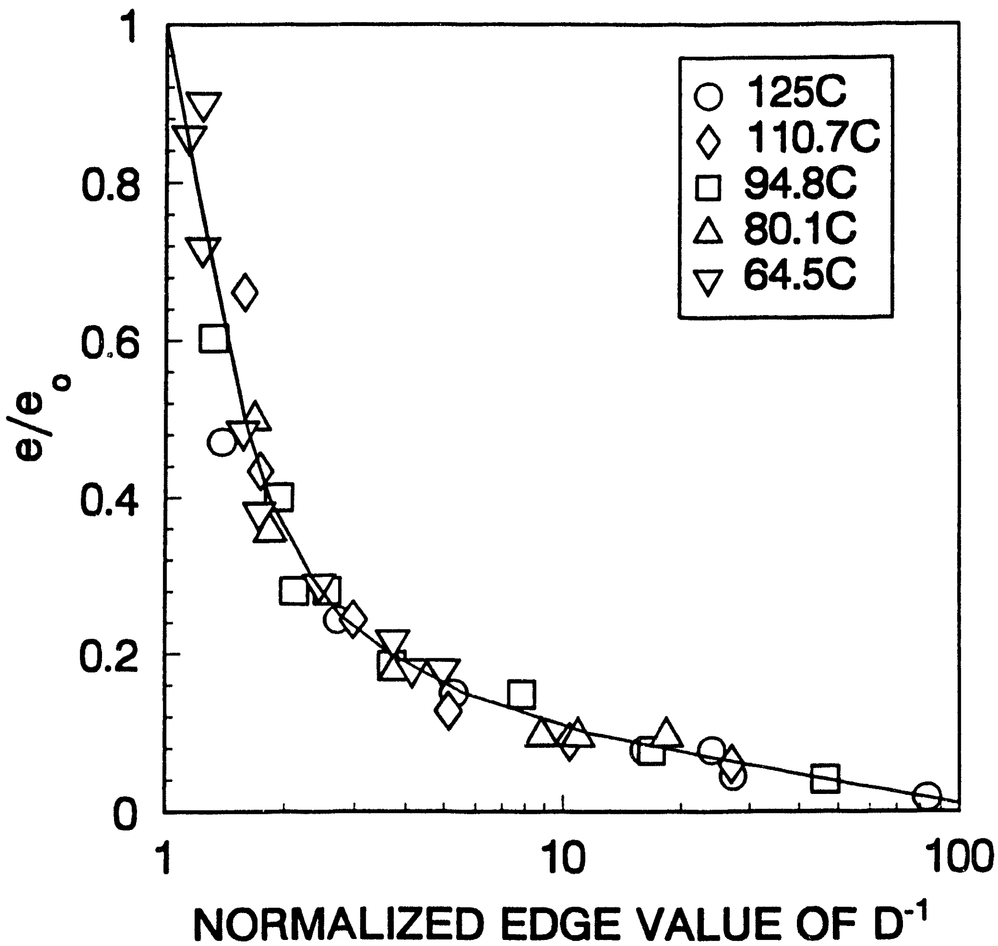
$$t \propto \exp(E_a/RT) \qquad \text{(from reaction rate theory)}$$

t = time E_a = activation energy R = gas constant
T = absolute temperature



CORRELATION BETWEEN SURFACE MODULUS & e/e_0

SHOWS THAT SURFACE PROPERTIES DETERMINE MECHANICAL FAILURE, IMPLYING THAT CRACKS INITIATE AT HARDENED SURFACE, THEN IMMMEDIATELY PROPAGATE



GOOD NEWS

1. **IF CRACKS PROPAGATE, ARRHENIUS (e/e_0) OK***
2. **IF THEY DON'T, ARRHENIUS PROBABLY CONSERVATIVE***

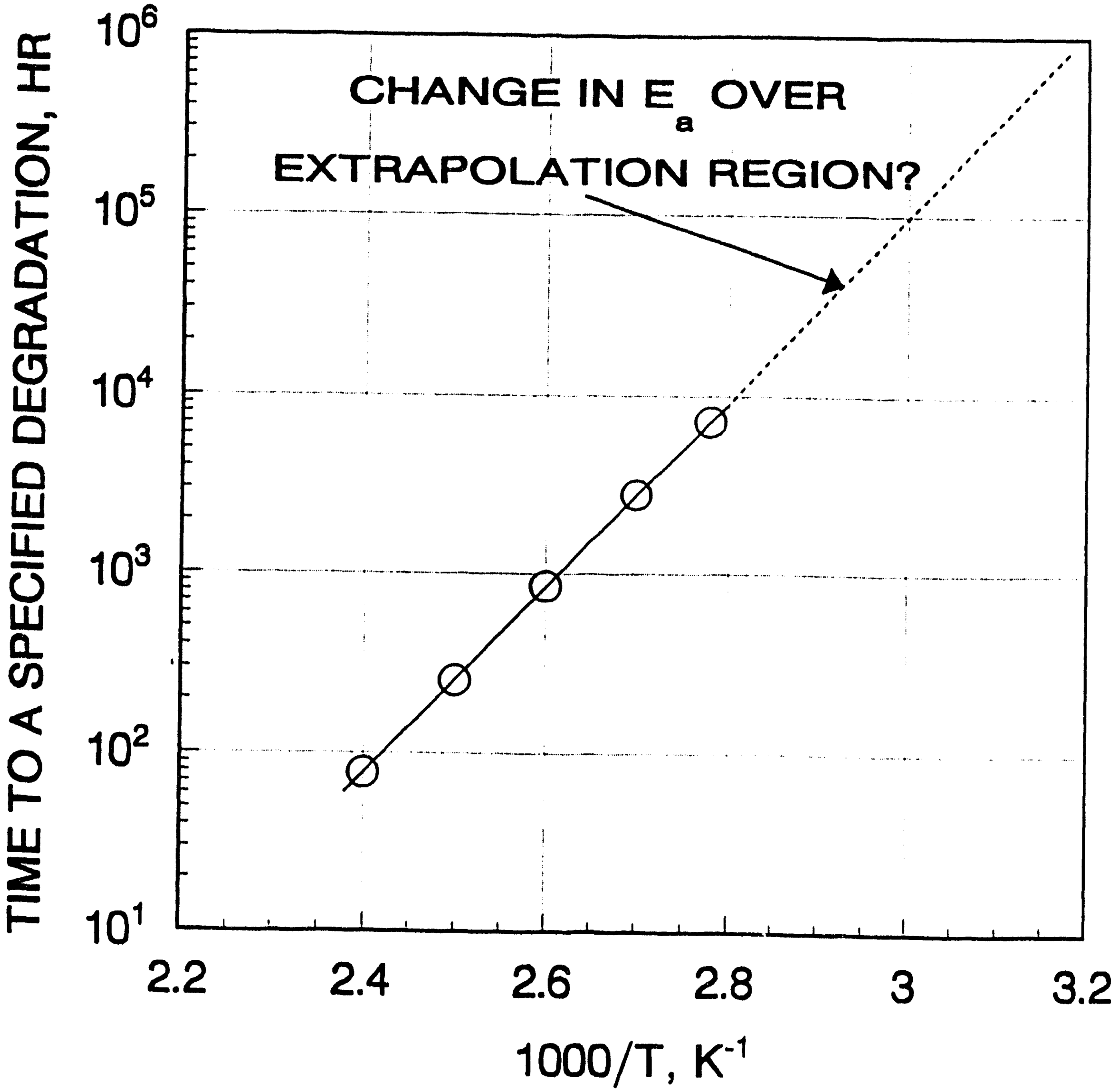
***IF E_a DOESN'T CHANGE IN EXTRAPOLATION REGION**

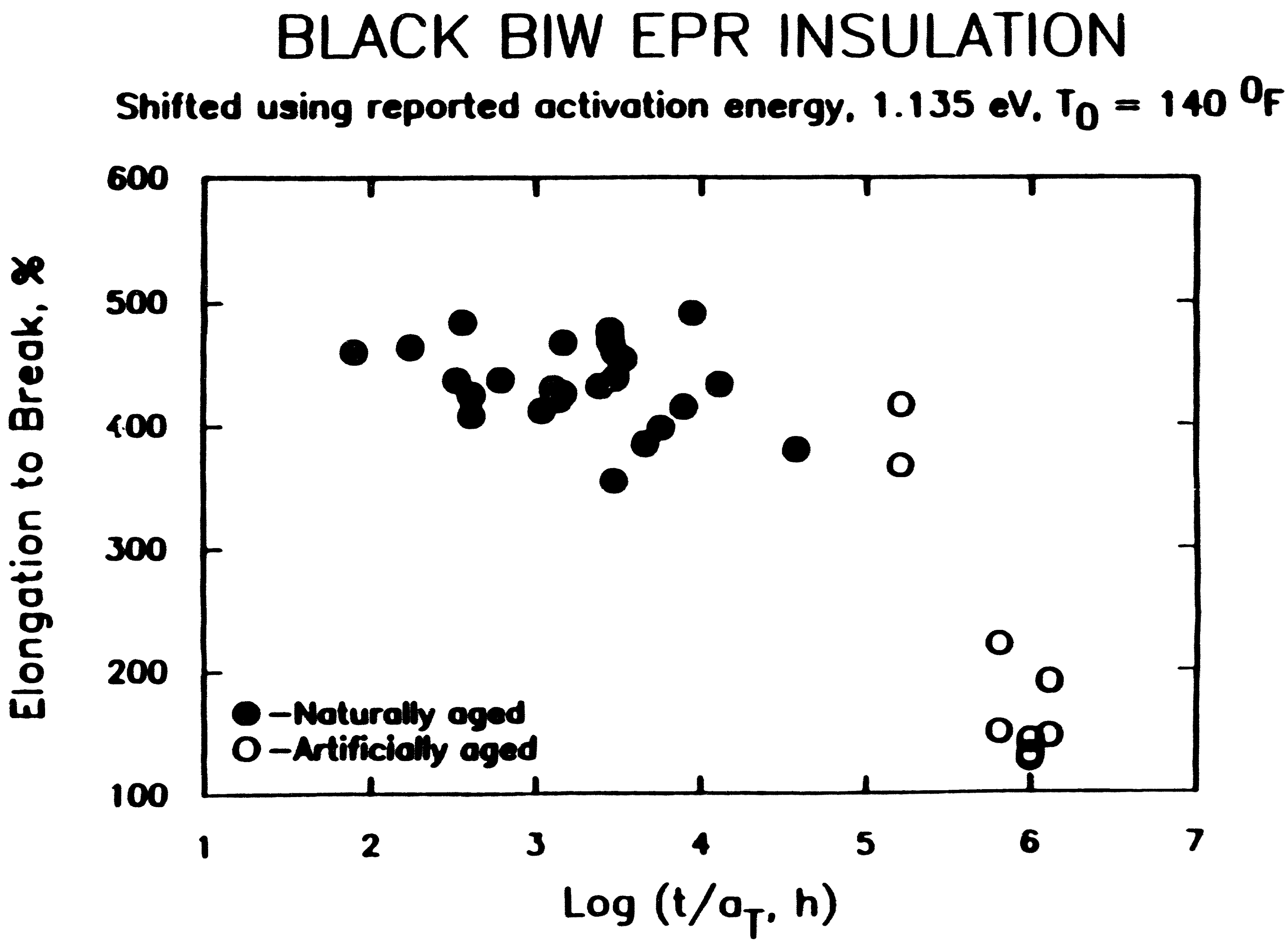
BAD NEWS

1. **IF JACKET(S) COVER INSULATION DURING EQ SIMULATION, INSULATION OXIDATION MAY BE MINIMAL**

CURRENT OBJECTIVE- DETERMINE WHETHER E_a REMAINS CONSTANT IN EXTRAPOLATION REGION

APPROACH- SENSITIVE TECHNIQUES (e.g., O_2 CONSUMPTION, μCALORIMETRY)




BLACK BIW EPR INSULATION
Shifted using reported activation energy, 1.135 eV, T_0 = 140 °F
Elongation to Break, %
600
500
400
300
200
100
1
2
3
4
5
6
7
Log (t/a_T, h)
● –Naturally aged
O –Artificially aged

Presentation by

George Sliter

EPRI Research to Support Cable Life Extension

- Natural vs. artificial aging study (4 cable types in 9 plants since 1985; measured environments lower than design; little degradation to date)
- Cable indenter aging monitor (uses compressive modulus of installed cable to compare with qualification 40-year value; trial uses at CECO, Sandia and EdF)
- Oxidation Induction Time (measure of remaining antioxidants; supplement to indenter)

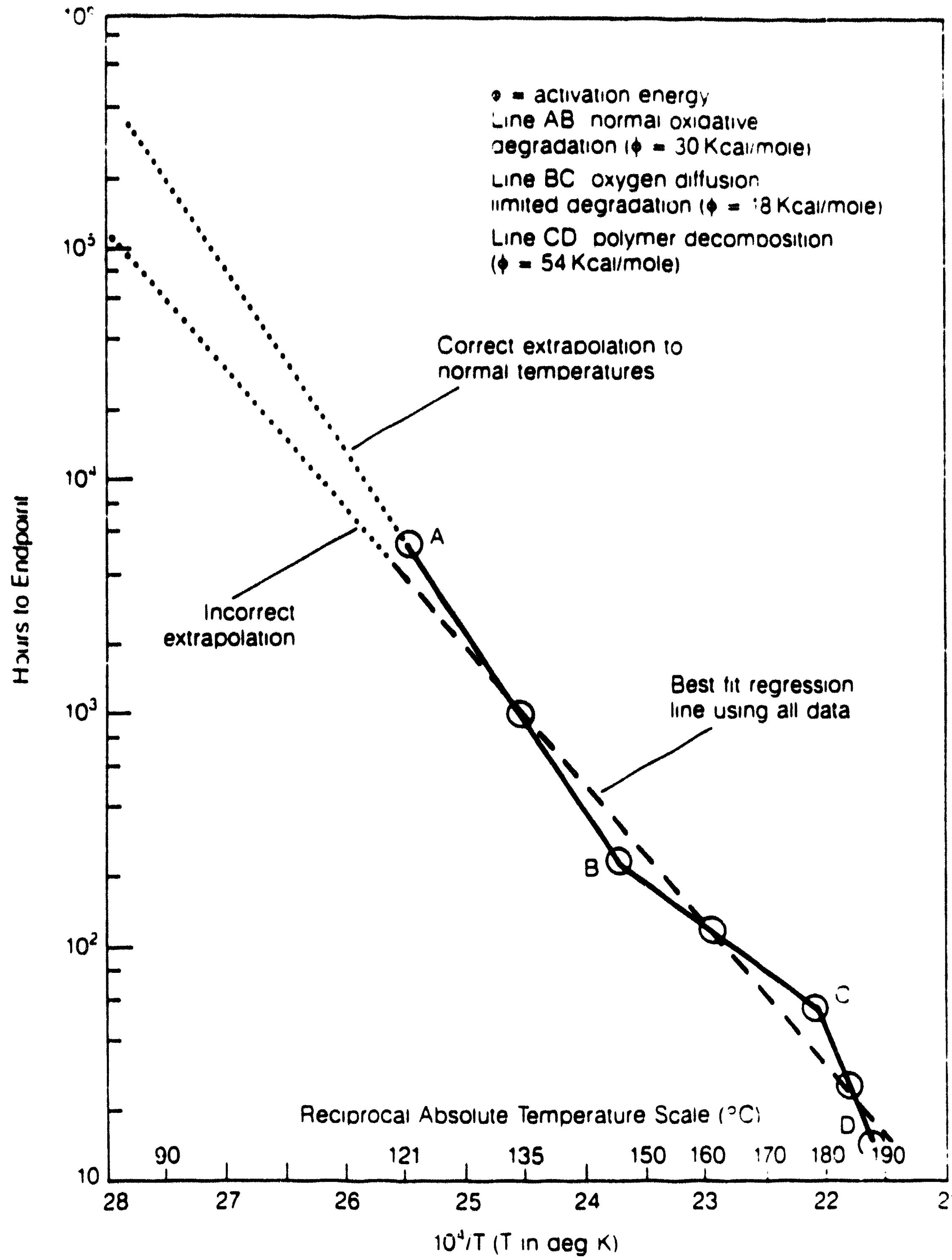


FIGURE 4.3 Single (heatshrink) material's differing activation energies in three temperature ranges

EPRI Equipment Qualification Reference Manual (TR-100516, November 1992)

Authors: P. Holzman, G.Sliter

Contributors: S. Carfagno, S. Kasturi
– R. Bolt, J. Gleason, M.Skreiner

B-42

- Compilation of EQ technology, requirements, and experience
- 500+ pages; 600+ references

APPENDIX C

PRESENTATIONS FOR MONDAY NOVEMBER 15, 1993
PLENARY SESSION ON OPERATING EXPERIENCE

CONTENTS

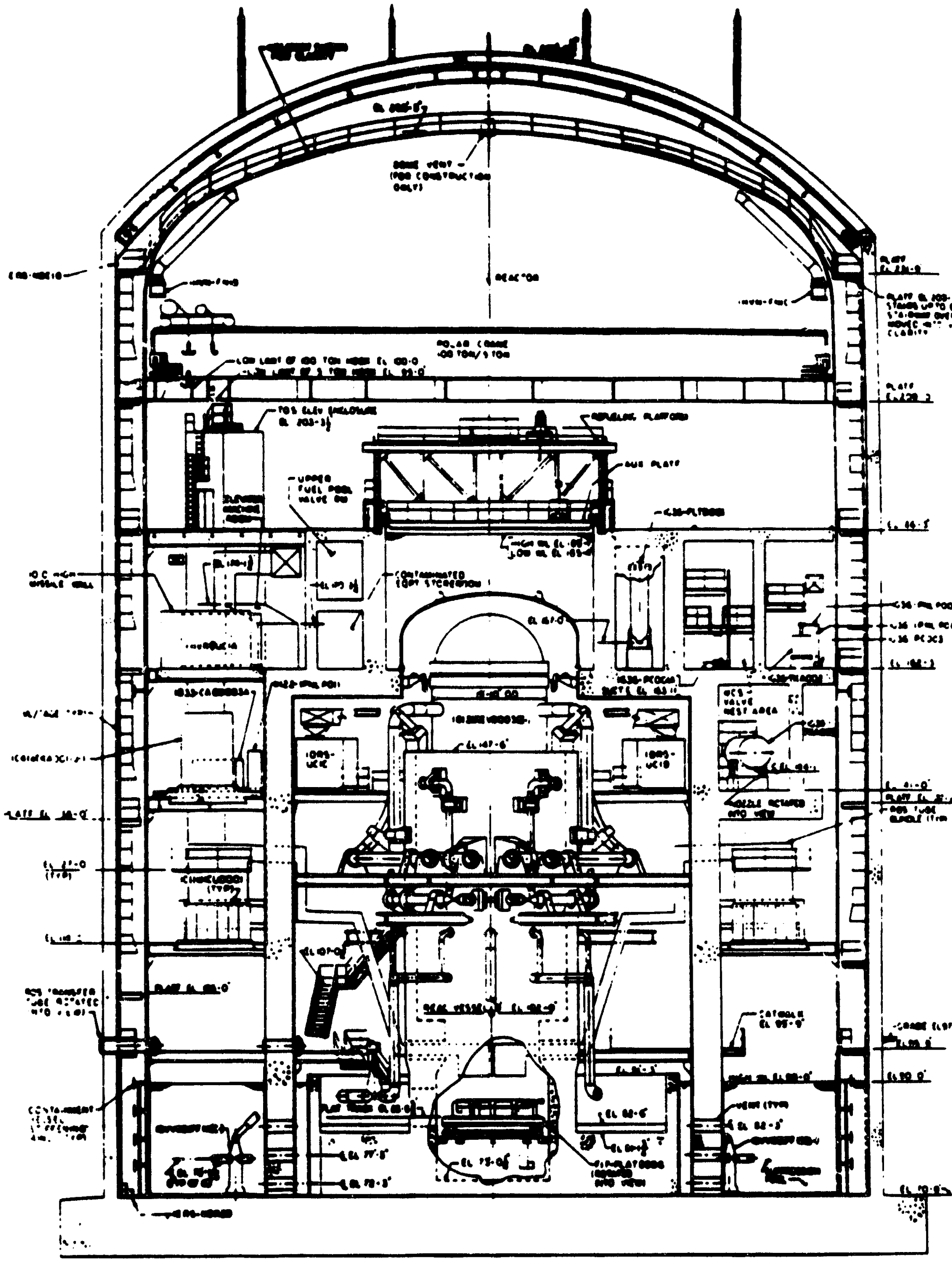
EQUIPMENT QUALIFICATION

OPERATING EXPERIENCE

CONTAINMENT HIGH TEMPERATURES

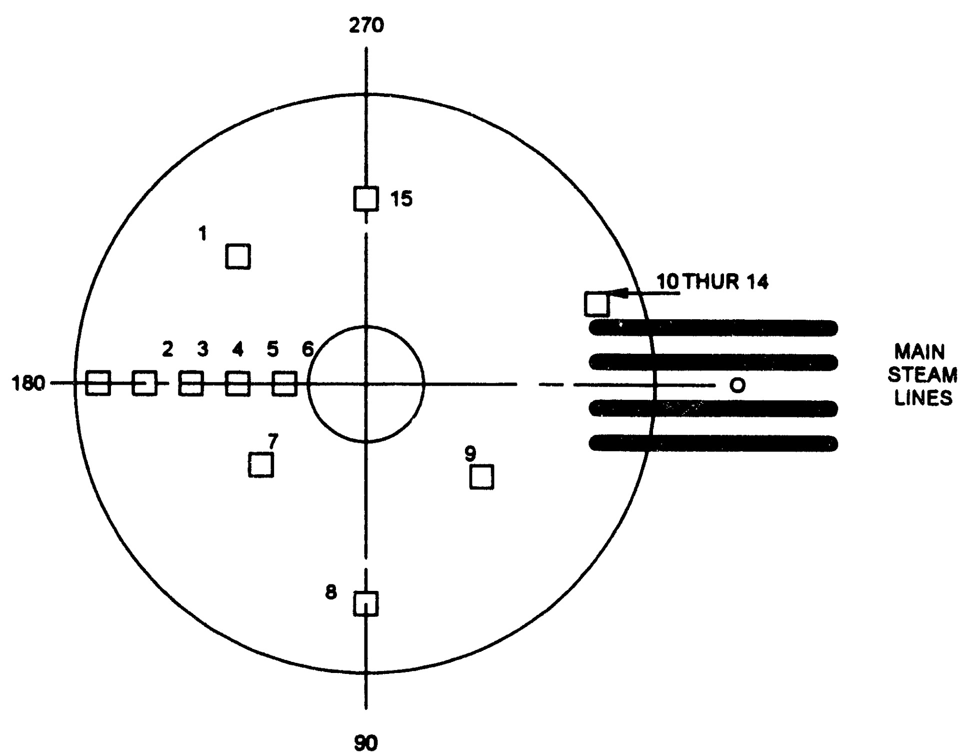
VINCENT P. BACANSKAS
Sr. Technical Specialist
Equipment Qualification

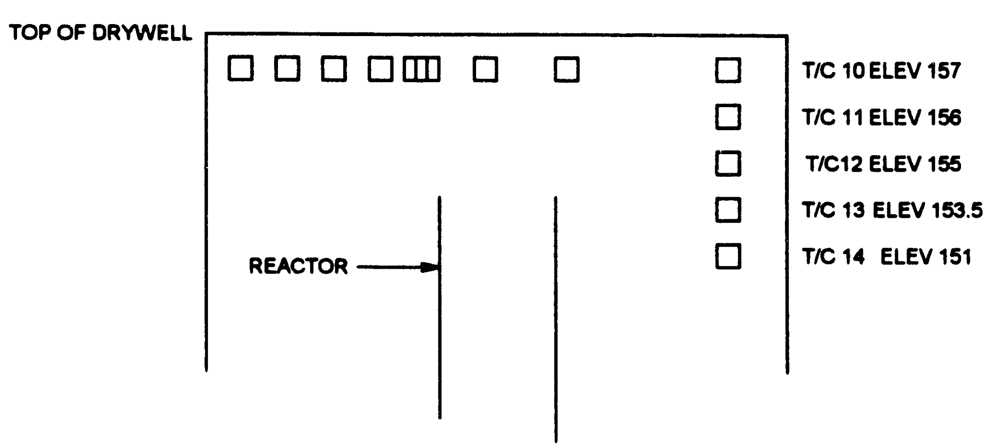
River Bend Station



River Bend Station

TEMPORARY THERMOCOUPLE LOCATIONS





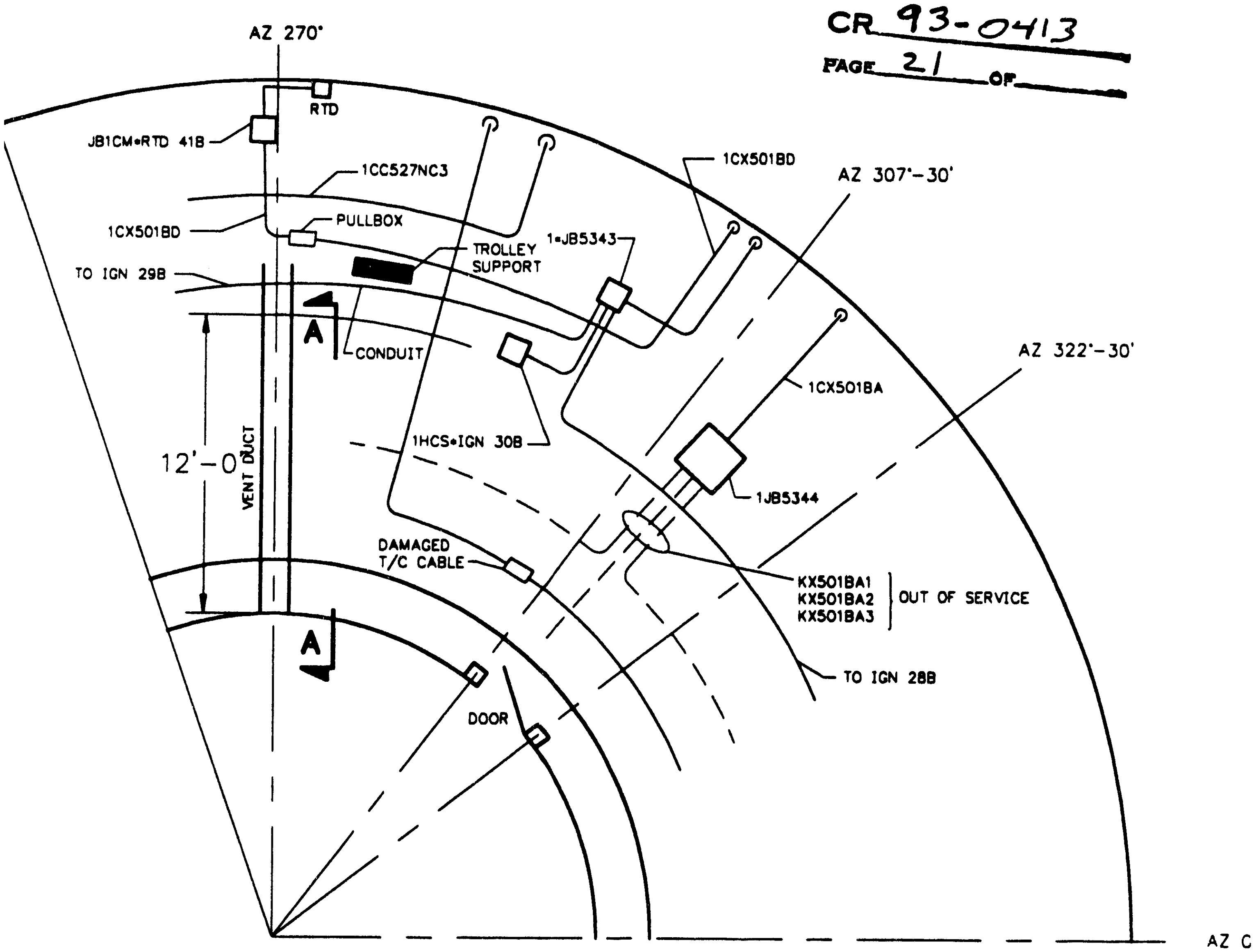
JULY 1993 Event

- Recirc Pump Seal Degrading
- Drywell Temperatures Trending Up
- Plant Shut Down to Replace Seal
- Drywell Walkdown to Investigate Temperatures
- Discovered Open Insulation Hatch

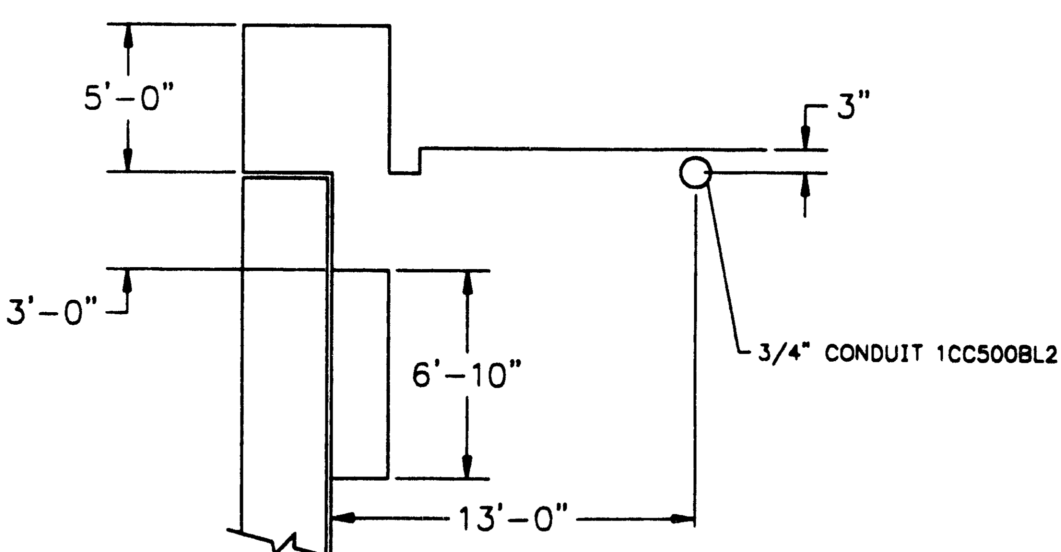
River Bend Station

CR 93-0413

PAGE 21 OF

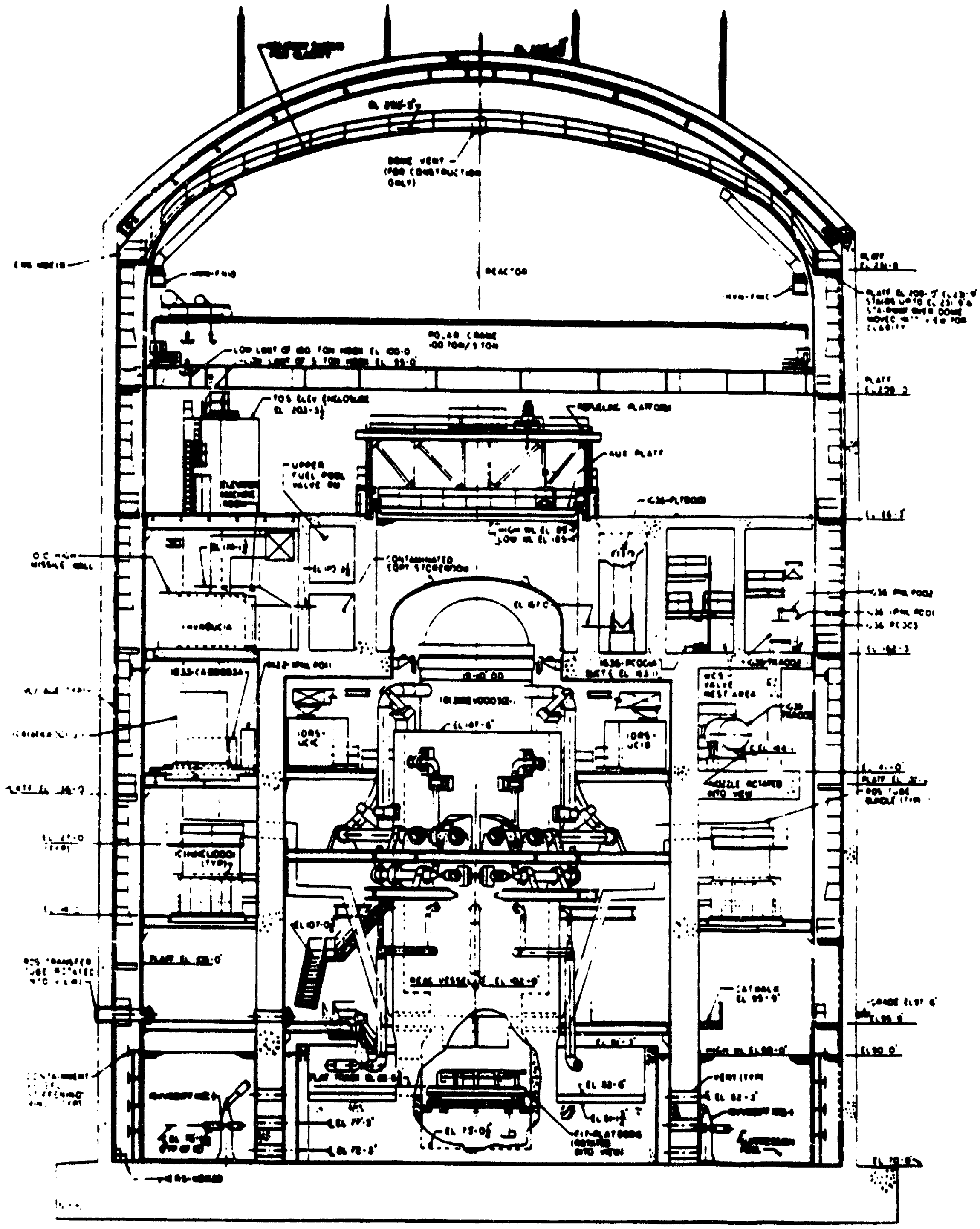


PLAN

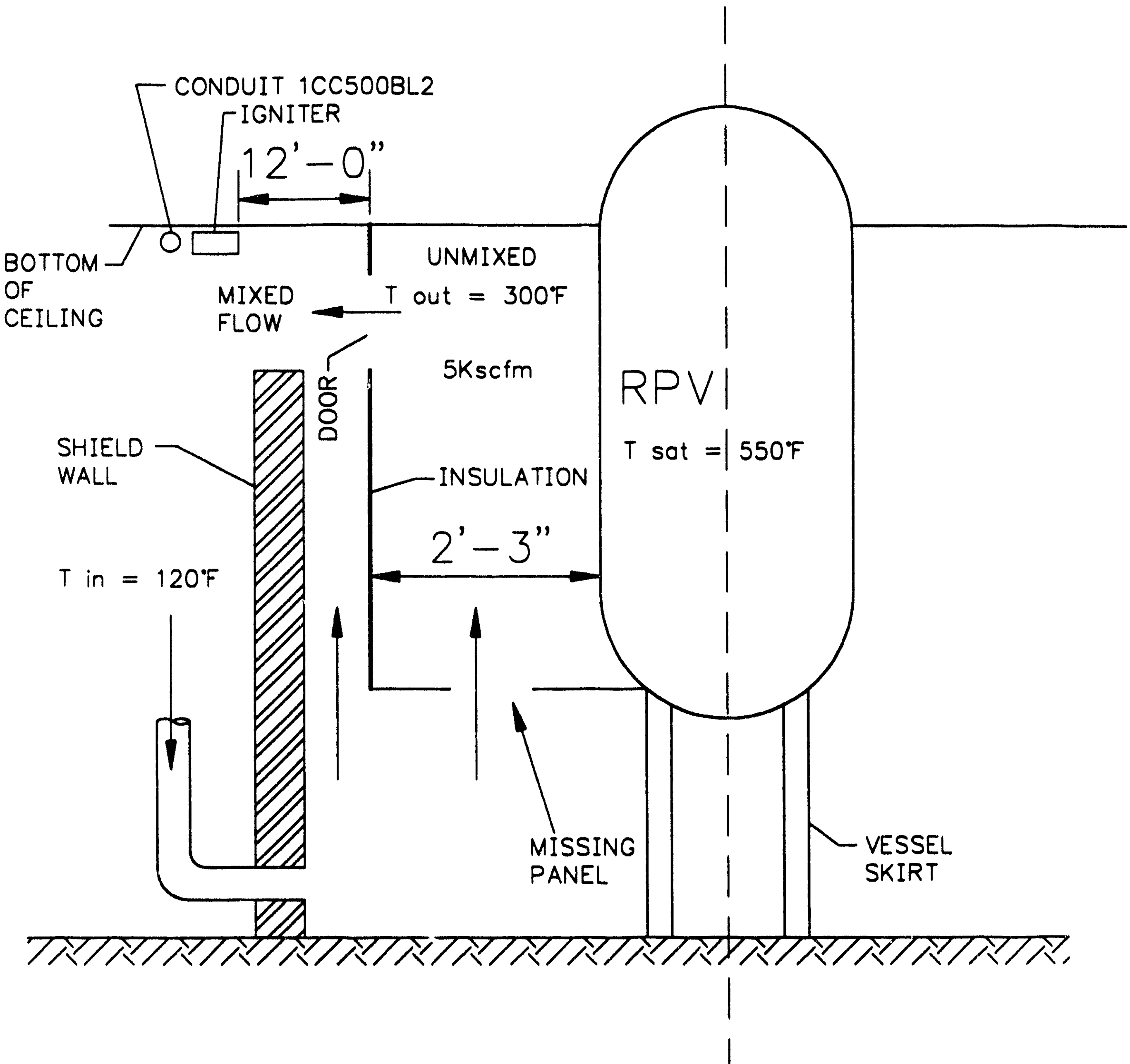


"A-A"

FIG. 7


DOME VENT –
(FOR CONSTRUCTION
ONLY)
REACTOR
POLAR CRANE
REFUELING PLATFORM

CR 93-0413
PAGE 18 OF



DRAWING NOT TO SCALE
DOOR POSITION NOT ACTUAL

FIG. 5

CABLE IGN29B

INDENTER MODULUS VS. LENGTH

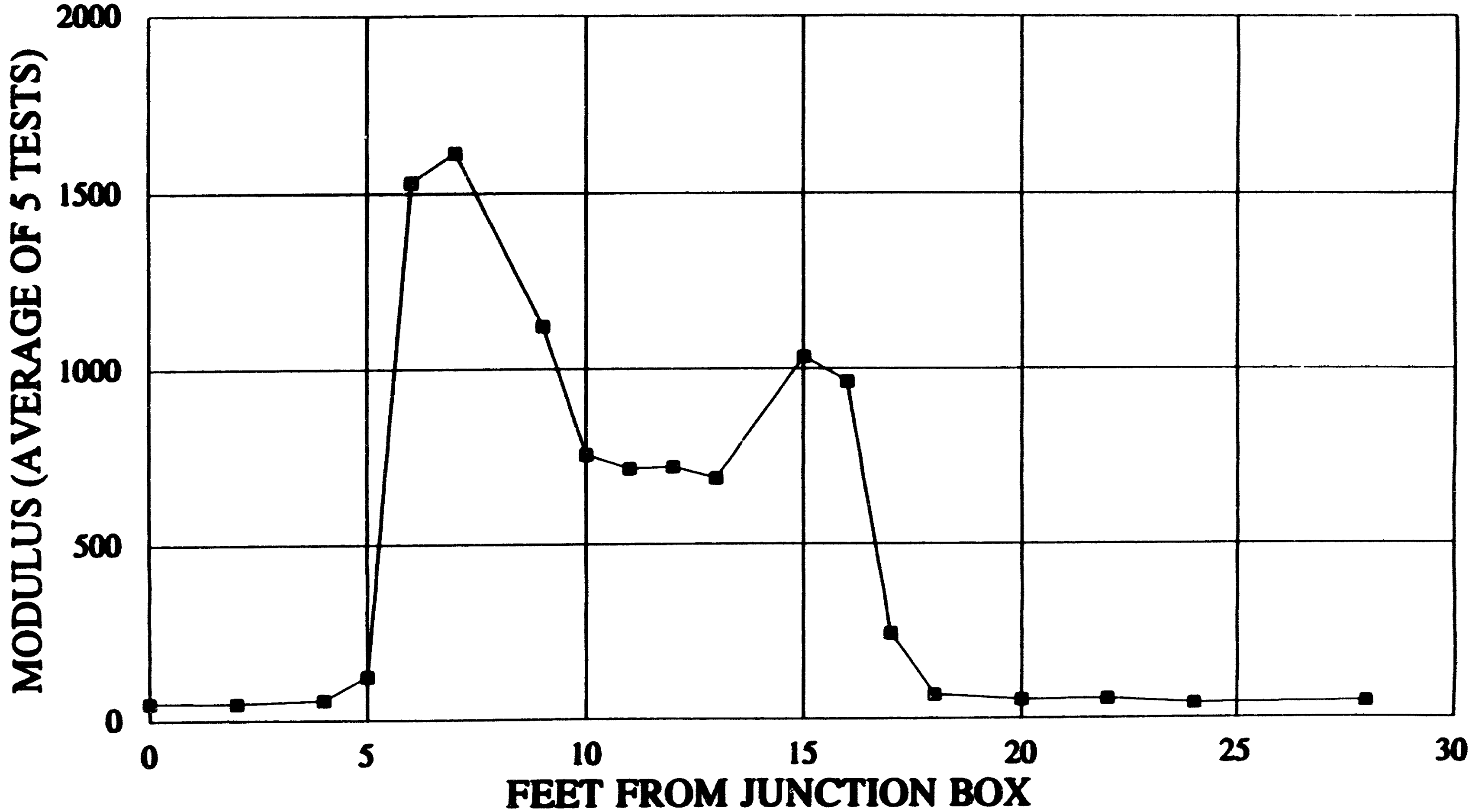


Figure 1

HARSH DRYWELL ENVIRONMENTAL QUALIFICATIONS SAFETY ANALYSIS

- Worst Environmental Conditions - Small High-Energy Break LOCA
  - Reasons - Highest Temperatures (~330°F) for the Longest Time (3 hours) from the Environmental Design Criteria
- Safe Shutdown Equipment Failures Assumed
  - All ADS and SRV valves ∴ Reactor Depressurization Failed
  - RCIC Steam Valve 1E51*MOVF063 ∴ RCIC Failed
  - SDC Suction Valve 1E12*MOVF009 ∴ SDC Failed
  - Drywell Hydrogen Igniters
- Systems Available for Reactor Injection
  - Feedwater
  - High Pressure Core Spray

HARSH DRYWELL ENVIRONMENTAL QUALIFICATIONS SAFETY ANALYSIS

	Drywell Environment	Base Line IPE	NRC Safety Goal
Core Damage Frequency	5.9E-08/yr	1.5E-5/yr	1.0E-4/yr
Percent CDF Increase	----------	0.4%	0.06%

Note: Negligible Effect on Large Release Frequency

TVA Operating Experience

Cable Degradation

- Operations problems, inspections and tests
  - Thermal
  - Mechanical
  - Manufacturing

Thermal Degradation

Sequoyah Main Steam Valve Vault

- Degradation first noted April 1986
- MSVV is 55' long by 25' wide by 50' high
- Numerous hot pipes
  - MSIVs, MFIVs and MSRVs
- 130 F design temperatures
- Steam leaks and missing insulation
  - Local temps 100 - 175 F
- Corrective action program implemented

NRC Workshop on Environmental Qualification

Mechanical Degradation

Operating and Inspection Experience

- Ring cuts when terminating
- Gouges at seals
- Gouges and tears from pulling
- Impact
- Pullby

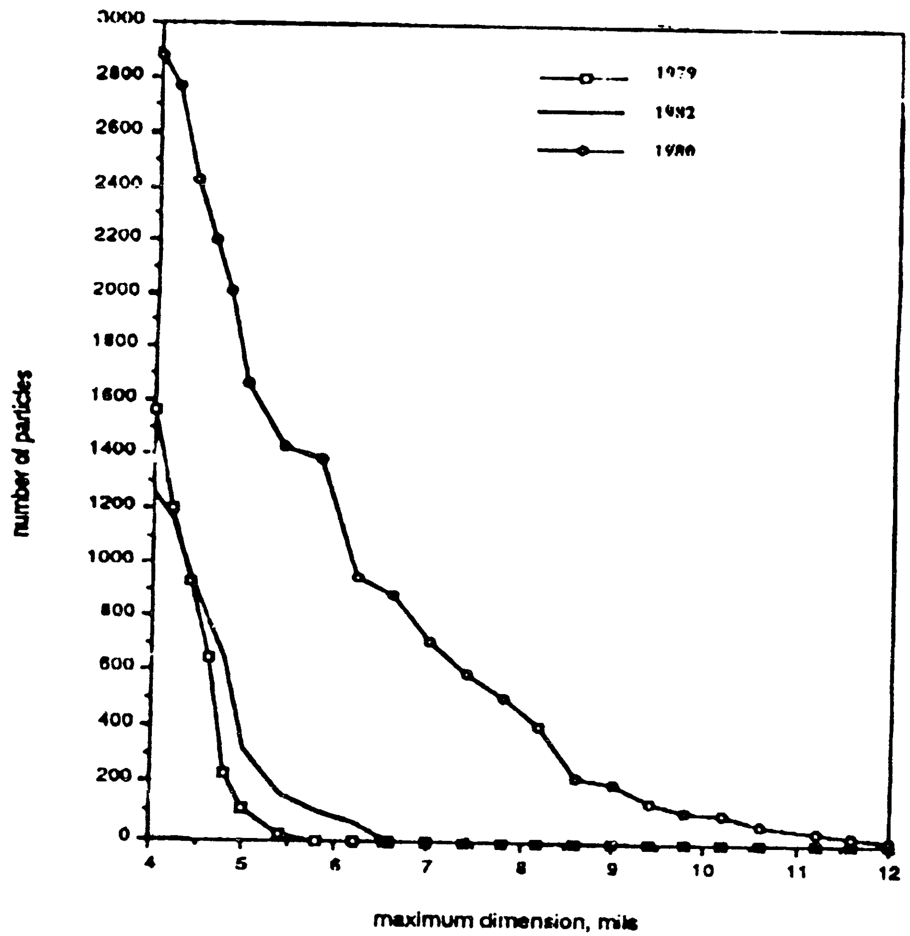
Manufacturing "Defects"

Test and Inspection Experience

- No spec for void/particle size for LV cables
- LV cables have minimal dielectric service
- Tests should reflect service requirements
- Insulation/jacket thermal compatibility must be improved

TVA Operating Experience

Particle Size Distribution



NRC Workshop on Environmental Qualification

EQ WORKSHOP SPONSORED BY USNRC

OPERATING EXPERIENCE PANEL

REVIEW OF INDUSTRY OPERATING EXPERIENCE RELEVANT TO EQ

SONNY KASTURI, MOS, inc.
11/15-16/93

MOS

- EXPERIENCE BASE
- SURVEYS AND REVIEWS
- WHAT WAS FOUND ?
- INDUSTRY RESPONSE
- PRELIMINARY OBSERVATIONS

MOS

EXPERIENCE BASE

INDUSTRY HAS ACCUMULATED:

- OPERATING EXPERIENCE WITH EQUIPMENT AGE FROM A MINIMUM OF 7 TO A MAXIMUM OF 23 YEARS. OVER ONE AND ONE HALF DECADES OF HEIGHTENED EQ AWARENESS
- EQ TESTING EXPERIENCE SINCE THE EARLY SEVENTIES

MOS

SURVEYS AND REVIEWS

- 4800 FAILURE RECORDS OF EQ EQUIPMENT AND NON EQ EQUIPMENT FROM THE NPRDS, LER AND NRC GENERIC COMMUNICATIONS DATABASES
- TELEPHONE SURVEY OF COGNIZANT EQ PERSONNEL FROM SELECTED UTILITIES DURING THE LAST WEEK
- EXPERIENCE WORKING WITH UTILITIES IN EQ PROGRAMS AND TRAINING OVER THE PAST DECADE AND A HALF

MOS

WHAT WAS FOUND ?

- NUMBER OF EQUIPMENT FAILURES APPEAR TO BE PROPORTIONATELY DIVIDED BETWEEN EQ AND NON-EQ EQUIPMENT RELATIVE TO THEIR RESPECTIVE POPULATION SIZE

- VERY FEW (26 BOTH EQ AND NON-EQ) CABLE FAILURES

- MOV LEADS THE PACK

- CAUSE OF FAILURES TO DATE FOR BOTH EQ AND NON-EQ EQUIPMENT, MAY BE CATEGORIZED UNDER ONE OF THE FOLLOWING THREE:

  — MISAPPLICATION
  — IMPROPER INSTALLATION
  — IMPROPER, INADEQUATE MAINTENANCE
  — LEARNING CURVE, i.e., PERSONNEL TRAINING IN EQUIPMENT OPERATION, MAINTENANCE AND EQ SPECIFICS
  — AGING EFFECTS

- THE FIRST FOUR ITEMS WERE LARGELY RESPONSIBLE FOR THE EARLY HIGH FAILURE RATES FOR MANY EQUIPMENT CATEGORIES.

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INDUSTRY RESPONSE

- STRENGTHEN THE ROOT CAUSE CULTURE AT ALL LEVELS INCLUDING MAINTENANCE CRAFT
- SELECTED EQUIPMENT WALKDOWNS DURING OUTAGES
- STRENGTHEN THE PHYSICAL EQUIPMENT CONFIGURATION CONTROLS
- STRENGTHEN THE INDUSTRY EXPERIENCE REVIEW PROGRAM
- EQ EMPHASIS IN MAINTENANCE PERSONNEL TRAINING
- PROMOTE AND PRESERVE A QUESTIONING ATTITUDE WITH RESPECT TO EQ THROUGHOUT THE ORGANIZATION
- IMPROVE PREVENTIVE MAINTENANCE PROGRAMS AND IMPLEMENT FOCUSSED ADDITIONAL SURVEILLANCE AND INSPECTION FOR CERTAIN EQ EQUIPMENT
- IMPLEMENT PLANT/EQUIPMENT SERVICE AMBIENT CONDITION MONITORING PROGRAM
- STRENGTHEN REPLACEMENT ITEMS (TECHNICAL EVALUATION) PROGRAM

MOS

PRELIMINARY OBSERVATIONS

- PLANTS APPEAR TO BE BETTER PREPARED TO IDENTIFY AND ARREST POTENTIAL FOR EQUIPMENT VULNERABILITIES FROM COMMON CAUSE
- TECHNICALLY SOUND AND COST EFFECTIVE EQUIPMENT CONDITION MONITORING PROGRAMS SPECIFICALLY FOR LONG LIFE ITEMS ON WHICH MINIMAL MAINTENANCE IS BEING PERFORMED e.g., CABLES, PENETRATIONS. ITEMS SUCH AS MOTORS MAY ALSO BE WORTH A CONSIDERATION BUT ON A LOWER PRIORITY.
- IN MANY CASES THE ACTUAL SERVICE AMBIENT TEMPERATURE CONDITIONS ARE LESS SEVERE THAN ASSUMED AND USED TO ESTABLISH QUALIFIED LIFE. IN SOME CASES, THEY HAVE BEEN FOUND TO BE MORE SEVERE.
- QUALIFIED EQUIPMENT ARE JUST AS VULNERABLE TO AGING EFFECTS AS OTHERS.
- AVAILABLE EVIDENCE APPEARS TO SUGGEST THAT BECAUSE OF THE HIGHER LEVEL OF MAINTENANCE AND SURVEILLANCE ATTENTION TO THE HARSH ENVIRONMENT EQUIPMENT, THEY MAY BE EXPERIENCING FEWER FAILURES, AND THAT WE CAN EXPECT A SIGNIFICANTLY REDUCED POTENTIAL FOR COMMON CAUSE FAILURES.

MOS

APPENDIX D

PRESENTATION FOR MONDAY NOVEMBER 15, 1993
PLENARY SESSION ON CONDITION MONITORING

CONTENTS

Presentation by

George Sliter

EPRI/NPD

Condition Monitoring of Cables and Other Nuclear Power Plant Electrical Components

George Sliter
Electric Power Research Institute

NRC Workshop on Environmental Qualification of Electric Equipment
Rockville, Maryland
November 15-16, 1993

Engineering & Operations

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How Cables Are Qualified
(IEEE 383 and 10 CFR 50.49)

- Type Testing (sequential aging/LOCA)
  - Thermal aging (high temperature/Arrhenius)
  - Radiation aging (equal dose-equal damage) 50 Mrad (high dose rate)
  - LOCA simulation (150 Mrad and 15% margin on temperature and pressure)
- Electrical Tests
  - During LOCA -- rated voltage and current
  - After LOCA -- 240 v/mil DC in water (5 to 15 times operating voltage), bent to 40 diams

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Qualification to Older Criteria

- LOCA test on unaged cable (or radiation aging only)
- Use separate effects tests to evaluate whether the cable is susceptible to thermal (or radiation) aging

  i.e., "no aging prior to LOCA"

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Role of Condition Monitoring in Equipment Qualification

- IEEE 323 -- Introduction: "This standard deals with the qualification portion of the program." This "program" includes
  - "maintenance and periodic testing" (1974 version)
  - "maintenance, periodic testing, and surveillance" (1983 version)
- IEEE definition of "surveillance" (Std 387 on DGs):
  - The determination of the state or condition of a system or subsystem
- 1974 version of 323 has no significant additional mention of maintenance/test

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Role of Condition Monitoring in Equipment Qualification (continued)

- 1983 version of 323 gives surveillance/maintenance more of a role:
  (1) if "the effects of the significant aging mechanism can be accounted for by periodic inservice surveillance/ maintenance," then "instead of qualified life, the periodic surveillance/maintenance interval becomes its operational limitation;"
  (2) documentation must include "periodic surveillance/ maintenance interval determination;"
  (3) surveillance/maintenance is a "method of extending qualified life"

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Difference between Surveillance and Condition Monitoring

NPP Common Aging Terminology (EPRI TR-100844)

- **surveillance**-- observation or measurement of condition or functional indicators to verify that an SSC currently can function within acceptance criteria
- **condition monitoring**-- observation, measurement, or trending of condition or functional with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of an SSC to function within acceptance criteria
- **condition indicator**-- Characteristic that can be observed, measured, or trended to infer or directly indicate the current and future ability of an SSC to function within acceptance criteria
- **functional indicator** (or performance parameter)-- condition indicator that is a direct indication of the current ability of an SSC to function within acceptance criteria

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Value of Condition Monitoring

- EPRI Preface in 1980 "Review of Equipment Aging Theory and Technology" (NP-1558) says: "A productive avenue for future research may be to establish in-service surveillance procedures geared to monitor equipment degradation in terms of specific degradation mechanisms where they can be identified."
- EPRI recognizes the value of being able to make an in-situ measurement of component condition for troubleshooting (effects of inadvertently great ambient temperature or degraded equipment performance) and as the basis for extending qualified life.
- EPRI also recognizes the potential value of condition monitoring as a complement to traditional "up-front" EQ methods -- an in-situ check in view of the uncertainties in traditional artificial aging methods based on Arrhenius and equal does/equal damage.
- However, based on a decade of research in this area, EPRI concludes that with 1993 state-of-the-art the ability of in-situ condition monitoring techniques for predicting with reasonable certainty whether a component can perform its safety related function under accident conditions is extremely limited.

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How Cables Fail

- Mechanical properties of insulation degrade before electrical properties
- Failure mechanisms:
  - Unshielded cables -- insulation cracking due to aging (with or without handling) leads to electrical failure during accident
  - Shielded cables -- low insulation resistance, but decrease from aging is small compared with decrease due to accident
- Failures caused only during accidents with damaged insulation (high reliability in operation is no surprise -- even cable with cracked insulation can function in dry operating environment)

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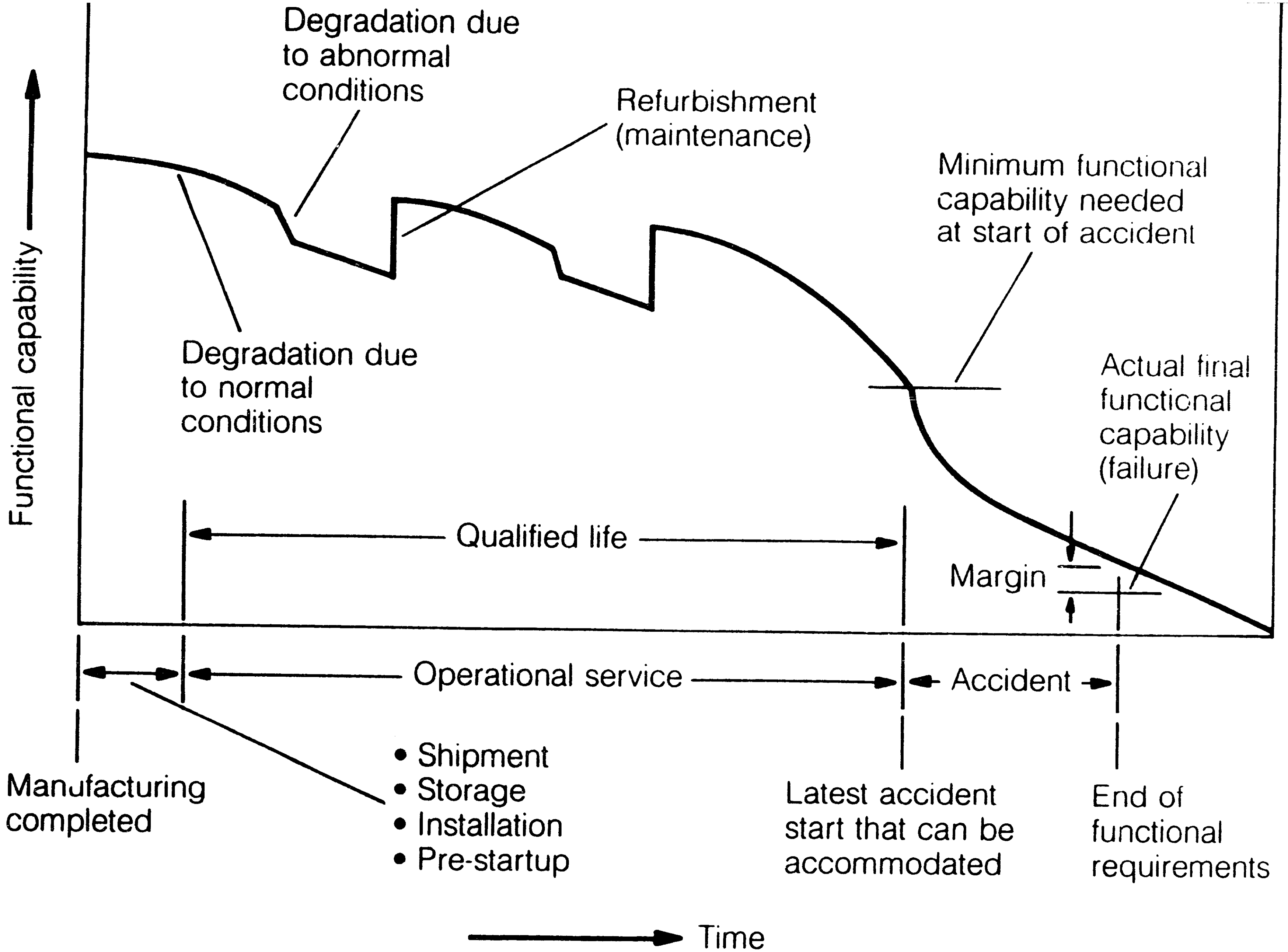

FIGURE 4.13 Relationship of functional capability to qualified life

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Some Cable Condition Monitoring/Surveillance Candidate Techniques

- Aging - destructive (bending, tensile elongation, breakdown voltage)
- Aging - nondestructive (indenter, oxidation induction time, density, dielectric response [IR, TDS])
- Damage (local degradation) - nondestructive troubleshooting (inspection, pneumatic, hi-pot [air/helium], partial discharge)

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EPRI Aging Monitoring Activities

- Condition Monitoring of NP Electrical Equipment (NP-33-57, 1984)
- Seismic Ruggedness of Aged Electrical Components (NP-5024, 1987)
- Cable Indenter Aging Monitor (NP-7348, 1991)
- Natural versus Artificial Aging of NPP Components (TR-100245, 1991)
- Time-Domain Reflectometry for Cable Changes (GS-6642, 1990)
- Power Plant Practices to Ensure Cable Operability (NP-7485, 1992)
- Oxidation Induction Time as a Cable CM Technique (in progress)
- Improved Conventional Cable Test Techniques (in progress)
- Two Cable Condition Monitoring Research Coordination Meetings (NRC, W. Farmer/Sandia, Gillen, Bustard, Jacobus/EPRI contractors)
- Two Cable Condition Monitoring Workshops (1988 and 1993)

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EPRI Cable CM Workshop Conclusions

- Cables very reliable (even in fossil plant up to 60 years old)
- Conventional troubleshooting techniques not good for monitoring aging
- Techniques for fossil/NP BOP need only give condition for functioning under operating conditions
- Techniques for nuclear plant cables must predict ability to function in harsh accident environment -- much more difficult
- Collecting, maintaining, and using cable information on installation, environments, performance, and testing would generate useful database.

EPRI IS PLANNING (1) EXTENSIVE COMPUTERIZED CABLE DATABASE

(2) USER GUIDE TO IN-PLANT CABLE MONITORING TECHNIQUES

(3) METHODS FOR EXTENDING QUALIFIED LIFE

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Cable Technical Issues

- Uncertainties in qualification methods
- Uncertainties in environments (hot spots)
- Accelerated vs. in-plant aging
  - Arrhenius/equal dose-equal damage
  - Dose-rate/synergistic effects
- LOCA cracking of insulation with bonded jacket

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Sandia/NRC Research to Support Cable Life Extension

- LOCA tests on common cables types aged to 60-year condition (almost all functioned)
- Extensive research on dose-rate/ synergistic effects

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EPRI Research to Support Cable Life Extension

- Natural vs. artificial aging study (4 cable types in 9 plants since 1985; measured environments lower than design; little degradation to date)
- Cable indenter aging monitor (uses compressive modulus of installed cable to compare with qualification 40-year value; trial uses at CECO, Sandia and EdF)
- Oxidation Induction Time (measure of remaining antioxidants; supplement to indenter)

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Table 4-1

MECHANICAL TESTING TECHNIQUES

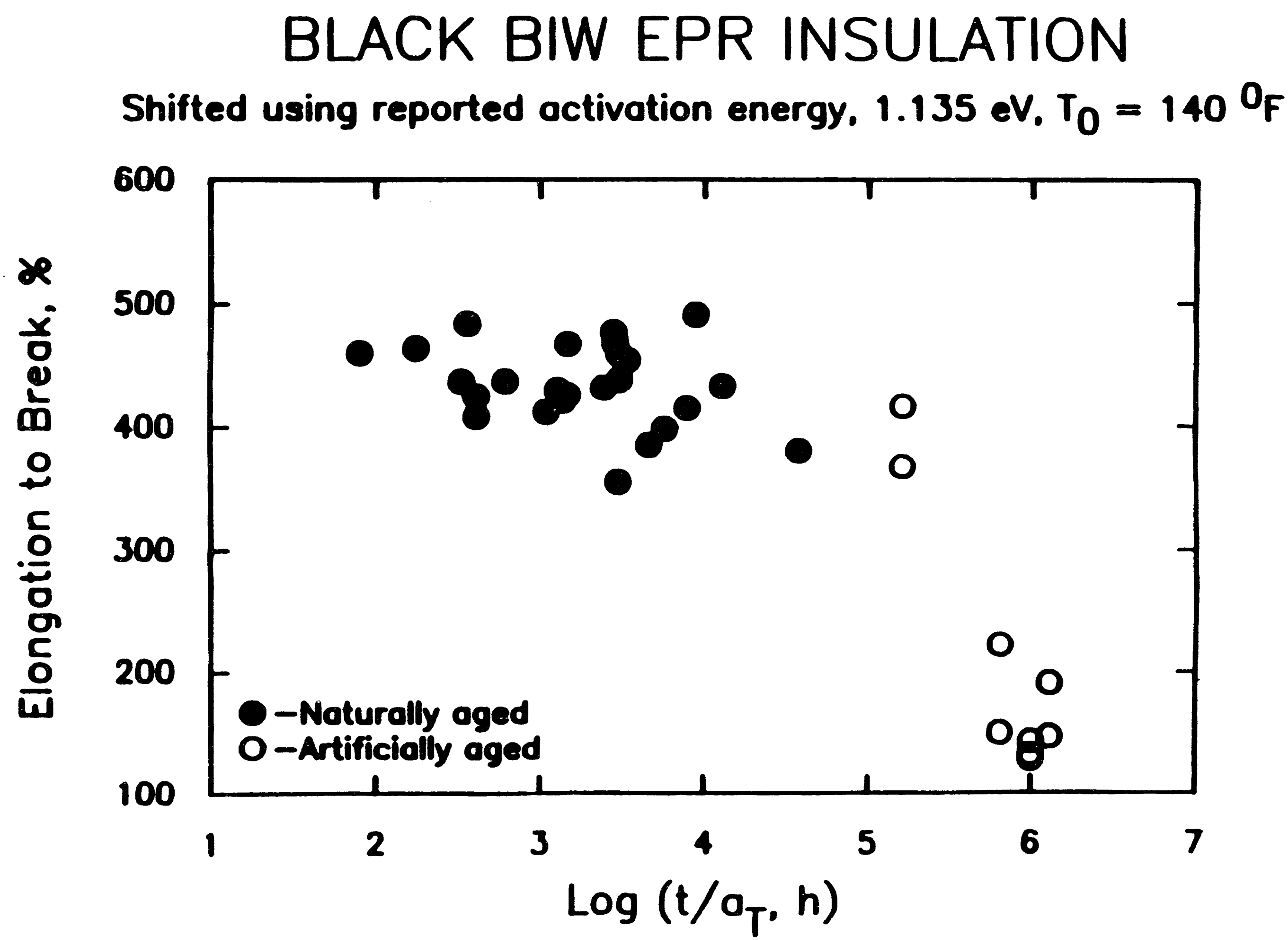
Sample	Method
Cable Jackets	
Rockbestos	Tensile
BIW	Fiber strips 0.040 in. x 20 mils x 2 in.
Kerite	Fiber grips
Okonite	Distance between grips 1 in.
	Gage length 0.5 in.
Cable Insulations	
Rockbestos - 3 wires	Tensile
BIW - 2 wires	Small wires-fiber strips 0.040 in. x 20 mils x 2 in.
Kerite	
Okonite - 3 wires	Large wires-fiber strips 0.040 in. x 20 mils x 2 in.
	Fiber grips
	Distance between grip 1.0 in.
	Gage length 0.5 in.
Shrink Tubing	
	Tensile
	Lathe used to create peels
	Micro tensile Dog Bones
	Cut in circumferential direction
Solenoid Diaphragms	
EPR	Vibrating Reed
Viton	Fiber strips prepared same as cables
Pressure Switch	
Cover Gaskets	Tensile
	4 fiber strips 0.050 in. x 20 mils x 2 in. taken from outer-most edges
	Microtensile Dog Bones taken from middle of gasket
Grey Disk	Tensile
	Fiber strips 0.040 in. x 17 mils x 0.75 in. prepared same as cables
	Distance between grips .25 in.
	Gage length = 0.125 in.
O-Rings	Tensile
	Entire O-Ring (special tensile testing fixture)
	Distance between grips = 0.88 in. [distance between centers of pulley + 1/2 (diameter of pulley)]

Table 3-6

COMPARISON OF ENVIRONMENTAL CONDITIONS: ORIGINAL VS. CURRENT ESTIMATES[b]

	Total Dose (Megarads/40 Years)		Temperature (°F)	
Utility and Location	Original Utility Estimate	Extrapolated Measurements From LF Detectors	Original Utility Estimates	Degredation Weighted Average
A1	0.070	0.22	82	86
A4	0.00070	0.22	120	119
B1	19	0.38	140	123
B2	6.0	0.20	94	108
C1	0.049	0.32	106	104
C3	1.2	0.41	115	106
D1	6.0	0.87	130	130
E1	0.70	0.10	135	144
E4	0.90	0.15	150	114
F1	0.010	<0.0070	95	100
F2	0.049	0.067	87	86
G1	22.1	0.018	130	133
G3	10	1.57	100	125
H1	6.0	1.50	130	115
H2	0.010	0.67	100	117
J1	240	NA[a]	175	NA
J2	0.16	NA	180	NA

[a] Not available
[b] As of December 7, 1990.



BLACK BIW EPR INSULATION
Shifted using reported activation energy, 1.135 eV, T0 = 140 0F
Elongation to Break, %
600
500
400
300
200
100
1
2
3
4
5
6
7
Log (t/aT, h)
●—Naturally aged
O—Artificially aged

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Information from EPRI Equipment Qualification Reference Manual Related to NRC EQ Workshop Goals

George Sliter
Electric Power Research Institute

NRC Workshop on Environmental Qualification of Electric Equipment
Rockville, Maryland
November 15-16, 1993

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EPRI Equipment Qualification Reference Manual (TR-100516, November 1992)

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Contributors: S. Carfagno, S. Kasturi

– R. Bolt, J. Gleason, M.Skreiner

- Compilation of EQ technology, requirements, and experience
- 500+ pages; 600+ references

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EPRI EQ Reference Manual

- Written to benefit utility personnel, reactor designers, standards writers, architect-engineers, equipment manufacturers , test labs, and regulators
- Identifies technical issues that could benefit from additional research such as:
  - Uncertainties in accelerated vs in-plant aging
  - Condition monitoring
  - Relationship of qualification to reliability and PRA

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Top Two Sentences on Page 1-1 of EQ Reference Manual

"Fundamental to the safe operation of commercial nuclear plants and to the protection of public health and <u>safety</u> through regulation is the need to ensure that <u>safety</u> systems and equipment can perform their intended functions during normal operation, earthquakes, and postulated accidents".	"The responsibility for <u>qualifying equipment and preserving its qualified status</u> throughout its installed life, while controlling operations and maintenance <u>costs</u>, lies with the plant owner/ operator."

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Top Two Sentences of Page 1-1 of EQ Reference Manual

Big Messages:

1. **Safety** first; **cost** control right behind it

2. Utility needs to **qualify** and **preserve** qualification during operation

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EQ Manual Overview of Qualification (Section 1)

- Plants are designed with defense-in-depth (redundancy); tolerance for single, random failures
- Qualification aims at eliminating "common cause' failures (systematic, multiple, non-random, concurrent failures that can defeat redundancy)
- Two broad classes
  - Generic errors (design errors, fabrication defects, faulty installation, errors in operations or maintenance) " Equipment Qualification"
  - Environments (ambient and operational) "Environmental Qualification"

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EQ Manual Overview of Qualification

(continued)

- Environment common causes
  - Aging degradation during operation
  - Accidental and suddenly intensified ("harsh") environment that triggers failure of redundant components

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Basic Approach to Qualification (Section 2)

- Key measure for preventing environmentally induced common-cause failures is EQ which is deterministic rather than probabilistic; that is, a proof of test is performed rather than a statistical analysis of results from a large number of tests. This is meant to provide "**reasonable assurance** that common-cause failures will not occur".

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Basic Approach to Qualification
(continued)

- Deterministic approach:
  - Defense-in-depth (redundancy)
  - Conservative design and design verfication (EQ) based on conservative bounding of operating and accident environments (margin)
  - Quality Assurance (App. B)
  - Periodic performance testing
  - Proper manufacturing, design, application, installation, operation, and maintenance

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Basic Approach to Qualification
(continued)

- Even rigid implementation of above measures does not provide a quantifiable measure of system or equipment performance reliability under progressiveiy more severe environments
- Test one prototype to design level plus margin (no "fragility" data at greater levels)
- No reliability data
  - Too expensive
  - Not encouraged by regulator (see next slide)

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Basic Approach to Qualification
(continued)

DOR Guidelines - "If a component fails at any time during the test, even in a so-called "fail-safe" mode, the test should be considered inconclusive for the entire period prior to failure"

EPRI EQ Reference Manual EQ Preservation Stage (Section 9)

- Qualification process not completed when qualified equipment is installed and operational:
  - Preventive maintenance (servicing, surveillance, condition monitoring, and refurbishment)
  - Corrective maintenance (repair and replacement)
  - Replacement at end of qualified life
  - Extension of qualified life (using e.g., on-going qualification, reevaluation, or condition monitoring)

EPRI/NPD

What During Operation Needs To Be Addressed for Potential Impact on Equipment Qualification?

- Plant modifications
- Installation of new equipment
- Changes in regulations
- **State-of-the-art information modifying original assumptions and methodologies (e.g., research results showing synergistic effects)**
- Experience with **equipment performance** in your own or another plant
- Generic, industry-wide problems and issues

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Fundamental Premise of Qualification

- Test sample condition prior to the accident simulation represents or envelopes the condition of the installed equipment
- Maintenance (as well as environmental monitoring) is relied upon to ensure enveloping

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AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

EPRI/NPD

Surveillance/Condition Monitoring

- Because of the uncertainties in the EQ process, plant experience is invaluable for reducing the potential impact of those uncertainties
- Only in the plant does equipment experience the combined effect of all actual environments and operational conditons
- Difference between surveillance and condition monitoring
  - Surveillance/periodic testing --go/no go-- functionability at a point in time
  - Condition monitoring --quantitative and predictive-- estimates condition at future point in time

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EQ-Required and Discretionary Maintenance

- **Required** EQ maintenance is minimum set of maintenance actions identified by EQ program as being essential
- Other specified maintenance actions are called "discretionary"
- Generally, condition monitoring is **not specified as required** EQ maintenance (i.e., it is descretionary; used for expensive equipment or if premature aging is suspected)
- Surveillance **is specified**

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Table 9.1
Questions to Determine the Need for EQ-Required Maintenance

1. Does the maintenance involve component replacements necessary to maintain the tested configuration (e.g., replace gaskets whenever the equipment is opened)?
2. Is the maintenance based on limits or values established by the aging portion of the test program (e.g., replace coil based on time and operating temperature)?
3. Does the maintenance address significant aging mechanisms not fully simulated by the aging portion of the test program (e.g., examine relay contacts for pitting or corrosion)?
4. Does the maintenance address aging mechanisms that render the equipment more susceptible to failure during the accident when compared to normal operation (e.g., periodic cleaning of a terminal block's insulating surface).
5. Does the maintenance reduce the potential for common-mode failures resulting from specific aging mechanisms?
6. Does operational and industry feedback (Sec. 9.5) indicate the need for specific maintenance actions to address specific aging mechanisms?

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Condition Monitoring can Support Qualification Process

- Assess in-service aging
- Verify that assigned qualified life reasonable
- Assure that all significant aging mechanisms are considered
- Must identify reliable condition indicators (performance parameters)
- Should have ability to gauge performance not only under normal conditions, but also accident conditions

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Condition Monitoring can Support Qualification Process
(continued)

- Unfortunately, qualification testing does not include measurements of condition indicators prior to LOCA; reasons--
  - generally beyond state-of-art
  - expensive
  - fear that NRC would reject qualification based on measured condition indicator rather than LOCA test
- Such measurements might be considered in future qualification testing, especially for long-lived components

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Condition Monitoring As A Predictive Tool is Limited

- EPRI Condition Monitoring of Nuclear Plant Equipment (NP-3357, 1984)
  - Some techniques show promise, but not enough experience either in laboratory or plant to justify widespread application
- EPRI Seismic Ruggedness of Aged Electrical Components (NP-5024, 1987)
  - Some candidate indicators not meaningful, others "show promise"

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Table 3-1

CONDITION MONITORING TECHNIQUES

Device	Condition Monitoring Technique Evaluated
Motors	Insulation Resistance
Motors	Polarization Index
Solenoid Valves	Insulation Resistance
Solenoid Valves	Polarization Index
Solenoid Valves	Dissipation Factor
Pressure Switches	Switch Point - Increasing Pressure
Pressure Switches	Switch Point - Decreasing Pressure
Pressure Switches	Deadband
Relays	Pull-in Voltage
Relays	Drop-out Voltage
Relays	Contact Resistance
Relays	Insulation Resistance
Contactors	Pull-in Voltage
Contactors	Drop-out Voltage
Contactors	Contact Resistance
Time Delay Relays	Pull-in Voltage
Time Delay Relays	Drop-out Voltage
Time Delay Relays	Contact Resistance
Circuit Breakers	Contact Resistance

Table 3-2

RESULTS OF CONDITION MONITORING TESTS

Device	Seismic Performance Degraded	Monitoring Technique	Nature of Trend	Potential Effectiveness of Technique
Circuit breakers	No	CR	10% increase	Ineffective
Contactors	No	PIV	3% decrease (improving)	Ineffective
Contactors	No	DOV	No change	Ineffective
Contactors	No	CR	No change	Ineffective
Motors	No	IR	No change	Ineffective
Motors	No	PI		
Motors	No	PI	No change	Ineffective
Pressure switches	Yes	Setpoint INC/DEC	*#1	Effective
Pressure switches	Yes	DB	*#1	Effective
Relays	No	PIV	3% decrease (improving)	Effective
Relays	No	DOV	*#2	Effective
Relays	No	CR	No change	Ineffective
Relays	No	IR	*#3	Ineffective
Solenoid valves	No	IR	No change	Ineffective
Solenoid valves	No	PI	No change	Ineffective

*Notes

1. Trends were device dependent -- some increased, some decreased, some constant, some erratic.
2. Trends were device dependent -- some increased, some decreased, some constant.
3. Most decreased up to 4 percent. One increased by 77 percent.

Table 3-2 (continued)

Device	Seismic Performance Degraded	Monitoring Technique	Nature of Trend	Potential Effectiveness of Technique
Solenoid valves	No	DF	No change	Ineffective
Time delay relays	No	PIV	14% decrease (improving)	Effective
Time delay relays	No	DOV	5% decrease	Effective
Time delay relays	No	CR	2% decreasing (improving)	Ineffective

EPRI/NPD

EPRI Has Focused on Cable Conditioning Monitoring

(Simplest component, expensive to replace)

- Two Cable CM Workshops (1988-1993)
- Cable Indenter
- Thermal Fingerprinting (differential scanning calorimetry, DSC)
- Oxidation Induction Time
- Improved Conventional Cable Test Techniques (IR, Partial Discharge, TDR)
- Cable Operability Report (recommends inspecting condition of cable ends while maintaining connected equipment)

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Conclusions From EPRI Cable CM Workshops

- Cables very reliable even in fossil plants up to 60 years old
- Conventional troubleshooting techniques (hi-pot, IR, power factor, etc.) not good for monitoring aging
- CM particularly difficult for nuclear plant cables in harsh environment
- Collecting, maintaining, and using cable information on installation, environments, performance, and testing would generate useful database; what techniques are useful today?
- Need standardized methods for
  - polymer tensile testing
  - activation energy measurements
  - indenter

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Desirable Attributes of CM Techniques

CM techniques should:

- Be related to acceptance criteria (for nuclear safety-related conditions, the acceptance criteria must be linked to accident functionality)
- Minimize intrusiveness or be non-disruptive
- Be possible during normal operation
- Not require disconnection or long equipment outages
- Be possible from readily accessible and convenient locations (e.g., cable ends)
- Have repeatable results
- Be applicable to a wide variety of cable types
- Be applicable to a variety of constructions
- Be applicable to varying installation configurations (e.g., conduits and trays)
- Not require special training
- Not demand high levels of expertise and special tools
- Require minimal safety precautions
- Not be detrimental to adjacent cables
- Be less expensive to implement than the cost of periodic replacement

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KAPTON (Polyimide)

- Wire used for equipment connector "pigtails" (especially on penetrations)
- Spiral wrapped polyimide tape bonded to conductor with teflon
- NRC Information Notice No. 88-89 and EPRI Report NP-7189 identify cautions
- Not forgiving of handling damage (4-8 mils thick)
- Avoid overbent, radiated wire in hot, moist condition

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Other Potential Failure Mechanisms for Cables

- No credit taken for jacket in EQ (it is there mainly to protect insulation during installation); but
  - jacket cracking can adversely affect performance of electrical connectors in harsh environments
  - jacket may be bonded (or unbonded and stuck to) insulation so that if jacket cracks from aging, crack can propagate into insulation
- Certain instrumentation cable when heated experiences buckling/kinking of coaxial center conductor which penetrates through insulation (bad weave angle of braid)

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Qualification Experience (Section 12)

Lessons learned about equipment vulnerabilities from testing and plant service for the following types (with 137 references):

Cables
Cable Splices
Terminal blocks
Electric motor actuators
Motors
Solenoid-operated valves
Electronic transmitters
Instrument switches
Temperature detectors
Radiation and neutron monitors
Containment electrical penetrations
Batteries
Relays

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EPRI/NPD

EQ Research and Development (Section 13)

- Summary and overview of EQ research efforts by EPRI, Sandia and NRC (NPAR)
- 155 references
- Appendix on material thermal and radiation data (charts and tables of activation energies and dose/degradation)
- EPRI R&D includes EQ Data Bank, material properties, training materials, shelf life, and environmental monitoring

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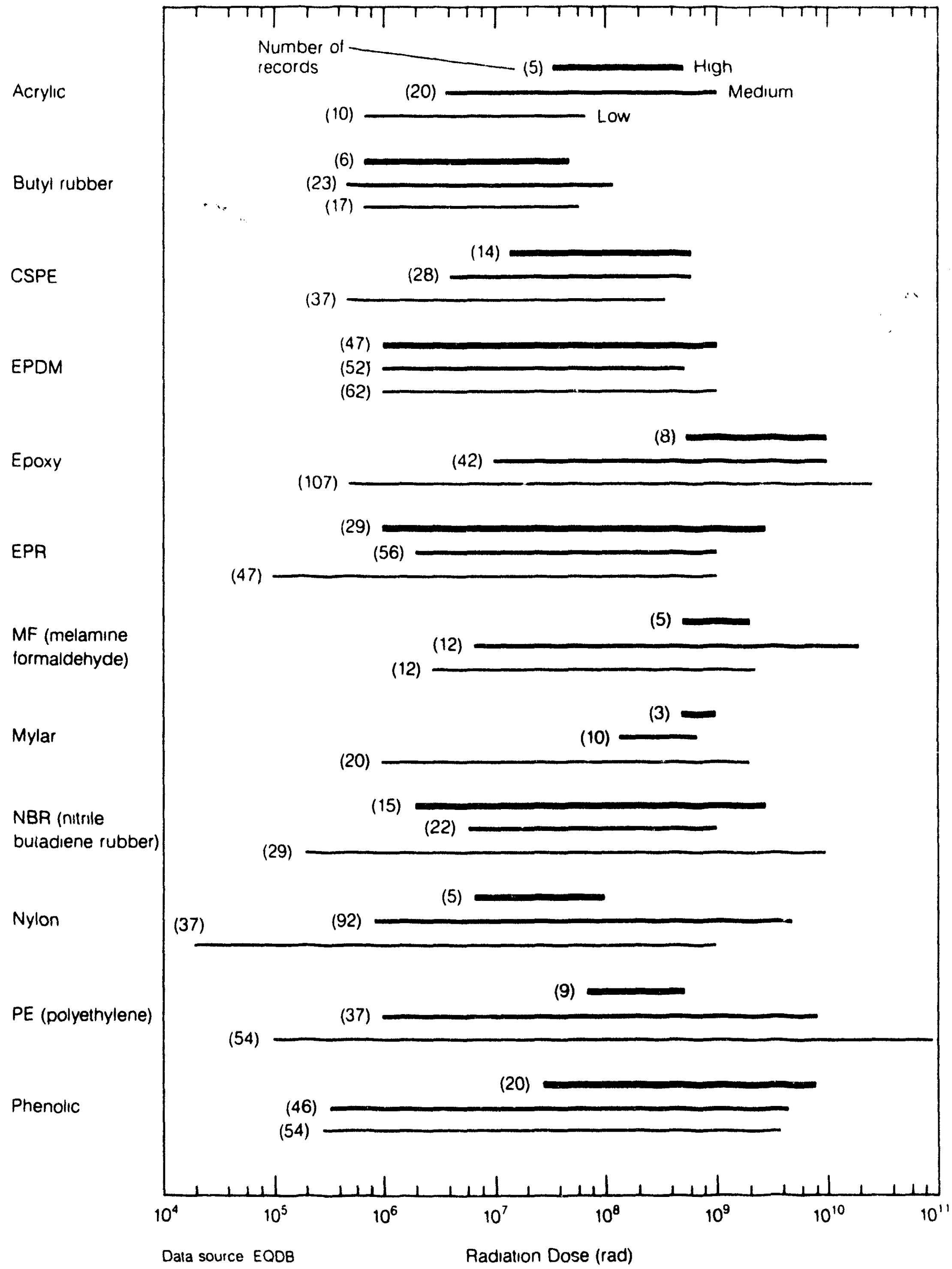


FIGURE A7.4 Summary of property changes due to radiation (from Equipment Qualification Data Bank [EQDB]) **(A7-4)**

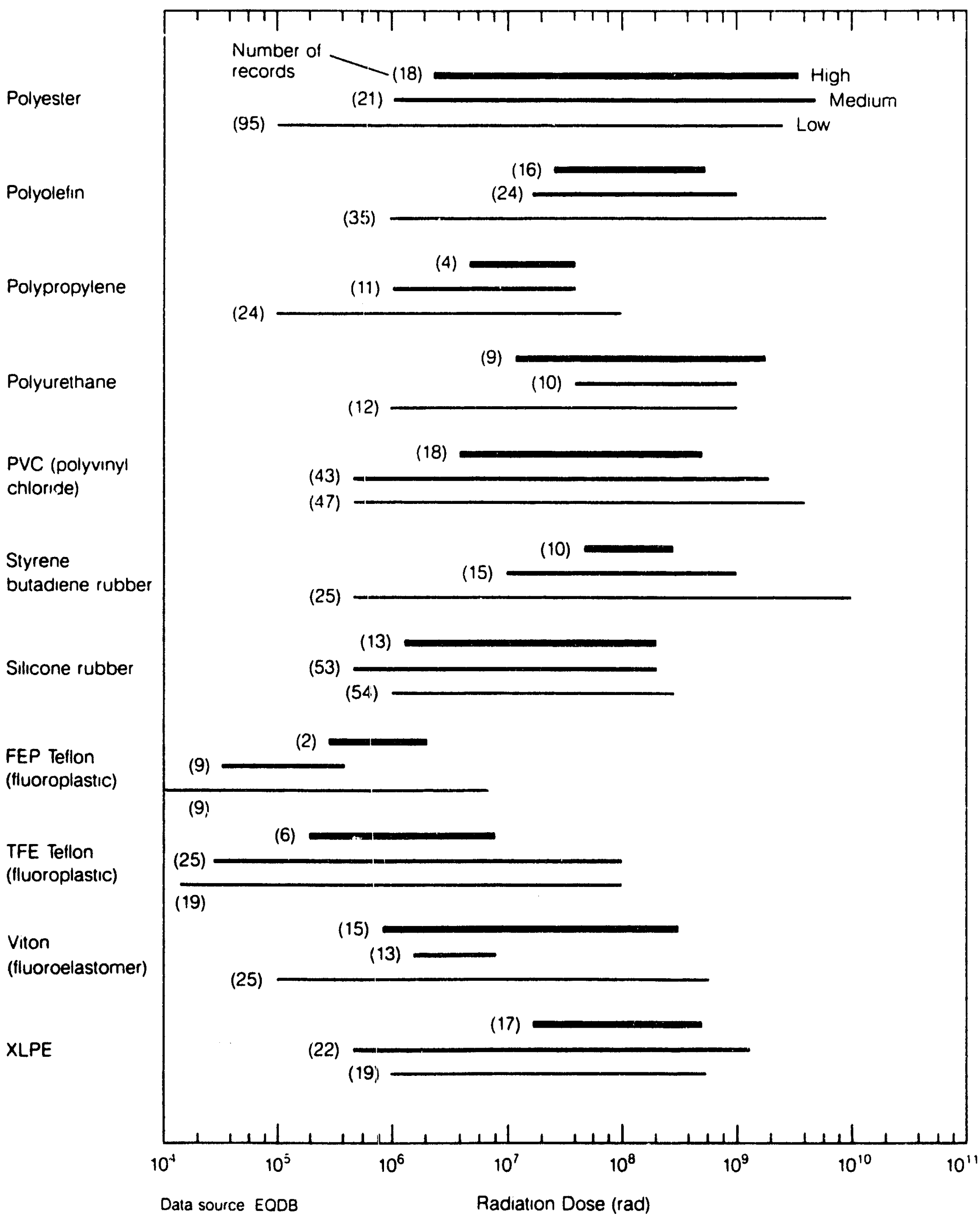


FIGURE A7.4 Summary of property changes due to radiation (from Equipment Qualification Data Bank [EQDB]) **(A7-4)** (continued)

INITIAL 11/15/93 PRESENTATION

BY PANELIST J.B. GARDNER, CONSULTANT

All the comments of this panelist are made from the perspective of one who, after leaving MIT, spent 35 years in cable design, manufacture and testing in the employ of a cable manufacturer and ten years in consulting for several nuclear projects.

For many years I have been involved with EQ testing, and EQ standards writing. In the last decade or more I have spoken and written about EQ concerns. Some of this has been published; Chapter 13 of NUREG/CR 4731 Vol. 2, Nov. 1989. "Residual Life Assessment of Major LWR Components - Overview," the introductory paper "Cable Condition Monitoring - The Challenge Before Us" for the Feb. 1993 EPRI Workshop on Power Plant Cable Condition Monitoring (EPRI TR-102399), and as a contributor to the Feb. 27, 1991 NPEC Ad Hoc Committee report on IEEE 383-74 Revision Issues. It is, of course, impossible to delve into details of these concerns and issues in this brief presentation although some have been and will be discussed in other parts of this Workshop.

May I share a few general thoughts from my experience that could be helpful or provocative to some of you.

The relationship of condition monitoring (CM) to equipment qualification (EQ): For a number of EQ programs' issues, questions, or omissions, or for issues of improper or questioned installation or random damage to cable system components, CM may be able to give assurance of adequate operability both at the time done and also in the future. However, if there is no rational question of a cable system's operability, then the cost and the possibility of incurring new damage by imposing CM tests are strong deterrents to their use.

With the array of EQ questions which have surfaced and the large number of safety-related cable circuits in our nuclear plants the potential engineering challenges seem almost boundless. To utility managers they may appear staggering, indeed prohibitive. Thus, I hope this workshop will find its way to recognize the importance of and discuss how to now focus the industry's energies and dollars only on the highest safety priority areas of risk. If we can do that, it would seem a very useful and practical outcome from this Workshop.

May I now note what seem to me are the four key elements to be considered in focusing on (prioritizing) the most important cable system safety issues. They may then be related to how and where we should apply CM methodologies:

1. Potential Susceptibility to common cause failure (CCFs).

Experience and rationality strongly indicate that moisture from steam or flooding is the most likely trigger for CCFs in cable systems. Seismic stress or motion is generally a distant second and with out plant designs, fire and missiles even less likely. Only those CCFs which occur within the time of required use and are not repairable within that time may be high risks to safety. In cable systems, the important moisture triggered service modes of failure are excessive leakage caused by cable insulation rupture or resistance drop or splice/terminal seal compromise, insulation rupture or burn-through due to local fault currents, and generation to spurious voltages due to moisture in connections. Moisture-intrusion should be a high priority safety concern. However, finding effective condition monitoring methods to detect susceptibility to moisture intrusion is still a major challenge. Fortunately, only cable system components in potentially harsh or floodable areas are susceptible to moisture-triggered CCFs

2. Importance to safety Having only one (very broad) safety classification for electrical systems, namely 1E, in our plants detracts from our practical incentives to prioritize the many safety-related circuits. PRA and times-required studies related to connected equipment seem so far to have had little impact in usefully narrowing out CM focus on those cable systems of highest safety impact. The writer assumes they would be those dealing with the monitoring of and mitigating the effects of a major accident if it was to occur.

3. Cable and seal/interface types Susceptibility to potential moisture intrusion leading to CCFs is greatly affected by cable system component materials and constructions. Sensitivity to handling and installation damage and to aging are very material specific. (Properties such as embrittlement, cold flow, and plasticizer migration). Nonshielded type cable, especially single conductor, present particularly difficult challenges for condition monitoring. Consideration of these factors should be made in focusing on circuits most at risk as well as in determining the best methods of condition monitoring.

4. Installation configuration Experience has shown us that certain installation practices may cause more failures or are further removed from EQ test conditions than others. The degree of risk may therefore be installation dependent. Unfortunately the installation conditions also can have a major effect on our ability to apply many CM methodologies.

The speaker sees little hope for any one or two super systems for either prioritizing circuits on which to focus our CM or for the best methods of monitoring. Not only does more work need to be done in developing CM methods but sound engineering should be used to narrow the size of our target cable systems so that it is practically addressable.

Presentation by

Wells Fargo

PRESENTATION OVERVIEW

Nuclear plants develop surveillance and maintenance programs to assure continuing adequacy of important plant equipment, especially nuclear safety-related equipment ("Safety-Related structures, systems, or components...") consistent with 10CFR50.65.

Electrical nuclear safety related equipment which may be subject to a harsh environment must be maintained in a state of readiness to perform during the harsh environmental conditions of the nuclear accident.

Cost- effective surveillance and maintenance program should assure that equipment adequacy to perform or remain operable is retained.

Criteria used for selection of a Non-Intrusive Condition Evaluation (NICE) system to assess selected conditions of relatively inaccessible in-containment motors during normal operation is presented. Included is the successful non-confidential results from such a system.

RELIABILITY CENTERED MAINTENANCE

Use of Reliability Based or Centered Maintenance techniques in the nuclear industry appears to promise both a reduction in cost and improvement in plant safety.

The Maintenance Rule is not prescriptive allowing use of the prudent Reliability Centered Maintenance concepts which is effectively endorsed by industry.

PERFORMANCE OR CONDITION BASED MAINTENANCE

NRC performance-based definition of Predictive Maintenance:

Predictive Maintenance includes the methods used to analyze and predict equipment performance so that planned maintenance can be performed before equipment failure occurs. Predictive maintenance is a performance-based activity. It includes the study of the ongoing operation of the equipment and uses performance-based criteria to determine when maintenance is required. Predictive maintenance criteria are determined by the type of analysis required to describe equipment performance.

NON-INTRUSIVE CONDITION EVALUATION (NICE) SYSTEM BASED ON MOTOR CURRENT SIGNATURE ANALYSIS (MCSA)

Nuclear utility requested assistance regarding determination of bearing adequacy for the relatively inaccessible Containment Cooling Fan Motors.

Fan vendor or the motor subvendor indicates an expected B-10 life in the magnitude of 100,000 hours. The actual statistical "life" of the bearing for a B-10 or today's L_{10} life being the point at which 10% of a group of bearings of a specific design, size, load, are expected to fail.

Bearing "life" determination requires knowledge of radial bearing load, axial bearing load, load factors appropriate to specific bearing, etc. Due to conservatism in installation, the L_{10} life should be well in excess of 100,000 hours. Lack of specific data and complex evaluations makes the calculated life difficult to project or provide sufficient confidence.

Motors are "enshrouded" by the mechanical fan assembly with the further complication of in-containment location, resulting in vibration analysis being not practical.

Modern non-intrusive signature analysis technique used to determine if bearing vibration is significant.

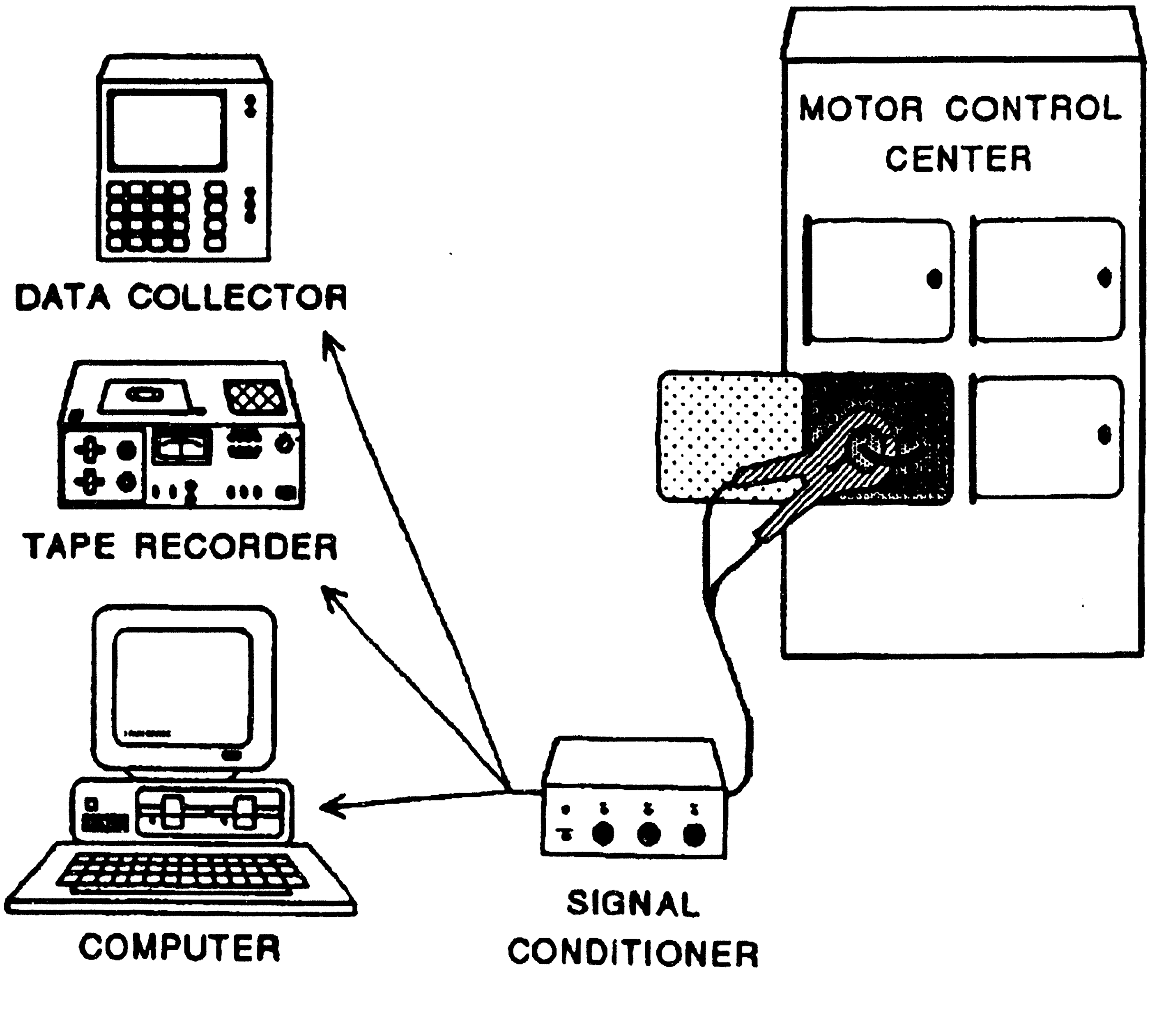
NON-INTRUSIVE CONDITION EVALUATION (NICE) SYSTEM BASED ON MOTOR CURRENT SIGNATURE ANALYSIS (MCSA) (CONTINUED)

Non- Intrusive Condition Evaluation (NICE) System selected was Motor Current Signature Analysis (MCSA) technique that was first developed by Oak Ridge National Laboratory (ORNL) under USNRC contract.

Motor Current Signature Analysis (MCSA) is a remote monitoring technique available from the motor switchgear or MCC location or any convenient location along the motor power lead by use of a simple clamp-on ammeter.

Motor current variations carried by the electric cables of the motor includes information from the motor which acts as a transducer by sensing load variations, mechanical vibrations, and various motor problems. The current signatures are processed by electronics into time and frequency information which provide equipment condition indication, trended over time which would allow early detection of degradation.

Technique has found problems with bearings, motor rotor bars, determines slip frequency, determines starting time, determines running load, can detect many circuit relay problems (e.g. bounce), determines fan or pump rotational speed, determines motor running speed, consequence of operation under degraded voltage, etc.


MOTOR CONTROL
CENTER
DATA COLLECTOR
TAPE RECORDER
COMPUTER
SIGNAL
CONDITIONER

SUMMARY OF RESULTS

- o Data from six motors for twenty four starting or running conditions obtained in a non-intrusive manner in well under three hours. Utility was only able to confirm the longer than expected starting time on a single motor using a somewhat intrusive data logger by measuring voltage drops through an available current shunt after more than a manday of preparation and set-up time. Furthermore, this traditional method did require connections and disconnections at Class 1E circuitry, while the MCSA technique did not.

- o Bearing degradation was detected in one motor which led to recommendation for investigation at the next convenient period. Utility physical inspection confirmed bearing defect with resulting bearing replacement.

- o Vibration was detected in signal which was not characteristic of motor or bearing conditions. Recommendation was made to inspect mechanical interface and ventilation ductwork. Inspection confirmed problem in mechanical ventilation ductwork which was utility corrected.

SUMMARY OF RESULTS (CONTINUED)

- o Long starting times and higher than expected running currents and loading determined on certain motors confirmed by plant personnel.

- o Use of technique and subsequent validation by utility confirmed usefulness and cost-effectiveness of Non-Intrusive Condition Evaluation by Motor Current Signature Analysis.

RESULTS OF INDENTER TESTING OF IN-PLANT AND ARTIFICIALLY AGED CABLE SPECIMENS

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ABSTRACT

The Indenter Polymer Aging Monitor (under license from the Electric Power Research Institute) is a non-destructive method of evaluating the aging of cable insulation and jacket material through measurement of compressive modulus. For many cable materials, modulus changes in an orderly manner related to the degree of aging. This paper summarizes the results from both the in-plant and artificial aging programs. These results indicate that the in-plant cables tested have aged little by comparison with the artificially aged specimens, and that practical acceptance criteria can be developed to support use of the Indenter system in field applications.

INDENTER OPERATION

The Indenter is a non-destructive test device that measures a compressive modulus of jacket and insulation materials of electrical cable. The modulus is determined by pressing a probe of known shape against the wall of the cable at a fixed velocity (0.5 in/min or 12.7 mm/min) while measuring the force. The test is terminated and the probe is retracted when a preset force limit (generally 2 lbf or 8.9 N) is reached. The modulus is calculated by dividing the change in force by the change in position during the inward motion of the probe.

The Indenter modulus measurements may be used for tracking aging of materials that change hardness in proportion to the cumulative effects of thermal and radiation stress. Materials for which the Indenter may be used to track aging include ethylene propylene rubber (EPR), chlorosulfonated polyethylene (CSPE), polyvinyl chloride (PVC), neoprene, butyl rubber, and silicone rubber. Some materials have properties that cause the Indenter modulus to be nearly constant over their life, making Indenter-based age evaluation impractical. Cross-linked polyethylene (XLPE) is such a material. It should be noted that elongation-at-break is not a useful evaluation technique for XLPE because the elongation properties are reasonably constant over the useful life of the material. However, if a jacket such as neoprene or CSPE is used on an XLPE insulated cable, the Indenter may be used on the jacket to monitor the relative age of the cable.

ACCELERATED AGING AND ACCEPTANCE CRITERIA DEVELOPMENT

Cable acceptance criteria have been developed by replicating the accelerated thermal and radiation aging from the environmental qualification programs for the cables. Cable specimens for a number of the cable types were taken from stock and subjected to incremental aging proportional to the aging from the qualification. Although it was desired to develop acceptance criteria for all of the in-plant cables tested, specimens for all cable types were not available at the start of the program.

Specimens included in the artificial aging program were thermally exposed and irradiated in 10-year equivalent intervals, with four 10-year intervals equaling the aging of the environmental qualification program. Additional aging beyond that of the qualification program was performed to identify behavior of the cable system beyond the qualified life limit. After being aged to the appropriate level, the Indenter modulus was measured. The multi-conductor specimens were tested with one end having the jacket removed and the conductors fanned out to allow jacket and conductor testing on the same specimen. Figure 1 shows Indenter modulus as a function of artificial aging (thermal plus radiation) for the individual conductor jackets of Okonite Okolon cables.

The instantaneous effect of temperature at the time of Indenter testing on Indenter modulus measurements was also evaluated. As temperature increases at the time of measurement, the hardness and modulus decrease proportionately but to a limited extent for most of the insulations under consideration. Figure 2 shows the correlation between modulus and specimen temperature (for a range of 70° to 120°F, or 21.1° to 48.9°C) for the outer jacket of an Okonite Okolon cable. For unaged cable, the effect of measuring cable modulus at 80°F versus 70°F would be small; a correction of approximately 2.4 lb/in would be required. Similarly, an Indenter modulus of 120 lb/in at 80°F would be adjusted to approximately 128 lb/in at 70°F. Although Figure 2 shows a large swing between 70° and 120°F for the more aged cables, most tests will be performed between 70° and 90°F, making the correction factor much smaller and, in many cases, making temperature correction unnecessary.

During evaluation of the data from the artificial aging program, a correlation between the thickness of the material being measured and its modulus after artificial aging was noted. As the thickness of the material decreased, the average modulus value, for the same level of aging, increased. This discovery is significant in that variation in rates of aging related to insulation and jacket thickness has not heretofore been recognized.

Figure 3 provides the conceptual basis for the formulation of acceptance criteria development for the Indenter. In this figure, Indenter modulus is plotted against % of the age conditioning limit. This plot is based on the results for the specimen with the same insulation and jacket thicknesses as were used in the manufacturer's qualification program. The age conditioning limit equals the state of the cables at the end of the environmental qualification aging simulation. If the Indenter modulus value at the 100% age conditioning limit is taken as the end of qualified life, it may be assigned any desired qualified life value and the in-plant readings may be compared to the accelerated aging results. For instance if a 60-year life were desired, and in-plant measurements were made at 30 years and found to fall in the region on or below the plot, a 60-year life would be indicated as possible. If the point fell above the plot line, a shorter qualified life would be indicated. Depending on the distance above the line, additional actions could be required such as monitoring more frequently, performing alternate evaluation techniques, or ultimately replacing the cable. Efforts are continuing to develop clear, practical acceptance criteria.

OBJECTIVES OF THE IN-PLANT PROGRAM

The objectives of the Indenter program were to:

- Evaluate the utility of the Indenter under field conditions
- Establish the Indenter methodology for evaluating cable condition
- Establish acceptance criteria for evaluating the as-found condition of cables
- Evaluate those in-plant cables tested as part of the program, and begin development of a utility's cable condition monitoring program.

IN-PLANT INDENTER TESTS

The Indenter was applied to cables at three Commonwealth Edison Company (CECo) plants:

- Dresden 3, a 773-MW General Electric BWR with commercial operation beginning in November 1971
- Zion 2, a 1040-MW Westinghouse PWR with commercial operation beginning in September 1974
- LaSalle 2, a 1036-MW General Electric BWR with commercial operation beginning in October 1984.

The in-plant tests were performed in late 1991. The tested cables were located outside containment. It was not possible to schedule containment entry for Dresden and Zion. The tests at LaSalle were performed with the unit at power. However, during the Indenter testing, efforts were made to test cables from a wide range of normal environments so that information could be obtained for cables exposed to relatively cool as well as elevated temperatures.

Several different cable types were tested during the in-plant trials, including Okonite Okolon, Kerite HTK, BIW Bostrad, and Samuel Moore (Eaton) Dekoron. During the in-plant trials, 26 tests were performed on 19 different cables at Dresden, 27 tests were performed on 22 cables at Zion, and 30 tests were performed on 22 cables at LaSalle. In each test, the temperature of the cable surface was recorded and 5 Indenter measurements were taken. These 5 measurements were averaged. The tests were performed twice to determine the most appropriate probe speed to use: once with a probe velocity of 0.2 in/min and once with a probe velocity of 0.5 in/min. Evaluation of the results from the in-plant trial verified that the 0.5 in/min velocity provides satisfactory data, thereby allowing the tests to be performed more quickly.

Testing was performed at Dresden on both the outer and individual conductor jackets of Okonite cables. All but one of the outer jackets had Indenter moduli between 56.5 and 74.2 lb/in for the 0.5 in/min tests. The exception had an Indenter modulus of 118.2 lb/in. The conductor jackets that were measured had Indenter moduli between 61.8 and 68.5 lb/in. The surface temperatures at the time of measurement ranged from 73°F (22.8°C) to 88°F (31.3°C). All of these cables were from original construction, making them at least 20 years old at the time of testing. The normal maximum design temperatures for the locations of the cables are either 104° or 120°F (40° or 49°C) depending on cable location.

Testing of Okonite cables was also conducted at LaSalle. The Indenter moduli for the outer jackets ranged between 55.1 and 73.4 lb/in for the 0.5 in/min tests. The conductor jacket moduli ranged from 64.4 to 79.5 lb/in. The surface temperatures of the cables at the time of the measurement ranged from 83.4° to 89°F (28.5° to 31.7°C). These cables were at least 7 years old at the time of testing. The normal maximum design temperatures for the locations of the cables range between 134° and 145°F (56.7° and 62.7°C).

A significant number of Kerite cables were tested at Zion. The Indenter moduli for the outer jackets ranged from 50.2 to 69.1 lb/in for the 0.5-in/min tests. The conductor jacket moduli ranged from 48.5 to 58.4 lb/in. The surface temperatures of the cables at the time of measurement ranged from 69° to 84°F (20.8° to 28.9°C). The cables were at least 17 years old at the time of the tests. The normal maximum design temperatures for the locations of the cables are 105° or 120°F (40.5° or 49°C) depending on the location of the cable.

Although the normal maximum temperatures for the plants are listed as being between 104° and 145°F (40° and 62.7°C), it is highly likely that the actual temperatures are well below these values most of the time. The Indenter measurements (by comparison with the acceptance criteria described below) also indicate that the cables have not been exposed to the normal maximum design temperature on a continuous basis.

COMPARISON OF IN-PLANT RESULTS WITH THERMAL AGING RESULTS

Table 1 shows a comparison of Dresden Unit 3 Okonite in-plant Indenter moduli results with those of the accelerated aging program. The in-plant data have been corrected to 70°F (21°C) to compensate for the temperature of the cables at the time of testing. Accelerated aging values for unaged, 10-year, and 20-year aging are provided. However, the results of the tests indicate that the jacket materials have temperature-corrected Indenter moduli that are below the 10-year aging data even though the cables had been installed for more than 20 years. Only one jacket had an Indenter modulus that was approaching the 10-year value. The individual conductors of this cable had moduli that were not significantly different from those of a new cable.

With respect to the Kerite cables, only a 5-kV specimen was available for accelerated aging. Only one 5-kV Kerite cable was tested at a plant, Zion 2. The average reading for the in-plant measurement was 71.6 lb/in. The accelerated aging Indenter modulus values for this cable type were 75.1 lb/in unaged, 76.4 at 10 years aging, and 91.1 at 20 years aging, indicating that this cable had not aged significantly to date even though in service for 17 years or more.

CONCLUSIONS FROM THE PROGRAM

The following conclusions have been drawn from the in-plant Indenter program:

- The current generation Indenter is practical for use in plant applications. It is transportable and can readily be used to test cables in trays, panels, and junction boxes. The Indenter can be used to test cables or individual conductors where approximately 3 inches of exposed surface along the length of the cable is available. Temperature compensation may be necessary under certain conditions to provide Indenter modulus information at a common temperature base.
- The Indenter is a useful tool for evaluating both the level and rate of aging of cable materials that harden (or soften) in an orderly manner. These materials include EPR, CSPE, neoprene, and PVC. The Indenter will not be useful for XLPE cables unless a jacket with trendable properties is present.
- The accelerated aging tests permit the development of useful acceptance criteria.
- Results from Indenter in-plant testing indicate that the installed cables have not aged significantly and appear to be aging at a slow rate.
- For one manufacturer's materials, a correlation between conductor jacket thickness and the rate of aging was observed.

Use of the Indenter on the three CECo plants provided an opportunity to inspect a substantial portion of the cable systems at the plants even though Indenter readings were taken on a limited number of cables. The overall conclusion from these observations was that the cables were in good condition and had not suffered significant hardening from aging. The Indenter will provide objective data to support such observations for many of the more common types of cable used in the nuclear industry.

An EPRI report detailing all of the pertinent findings of the program is currently being prepared.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of Stephen Hunsader, James Krass, and David Peters (Commonwealth Edison Company), as well as Dr. George Sliter (EPRI) during this project.

REFERENCES

1. Shook, T. A. and J. B. Gardner, "Cable Indenter Aging Monitor," EPRI Interim Report NP-5920, July 1988.

2. Toman, G. J. and J. B. Gardner, "Development of a Nondestructive Cable-Insulation Test," Proceedings International ANS/ENS Topical Meeting, Operability of Nuclear Power Systems in Normal and Adverse Environments, Albuquerque, NM, Sept. 29 to Oct. 3, 1986, pp. 289-296.

Figure 1. Okonite Okolon Individual Conductor Jacket Moduli
Thermal Aging and Irradiation

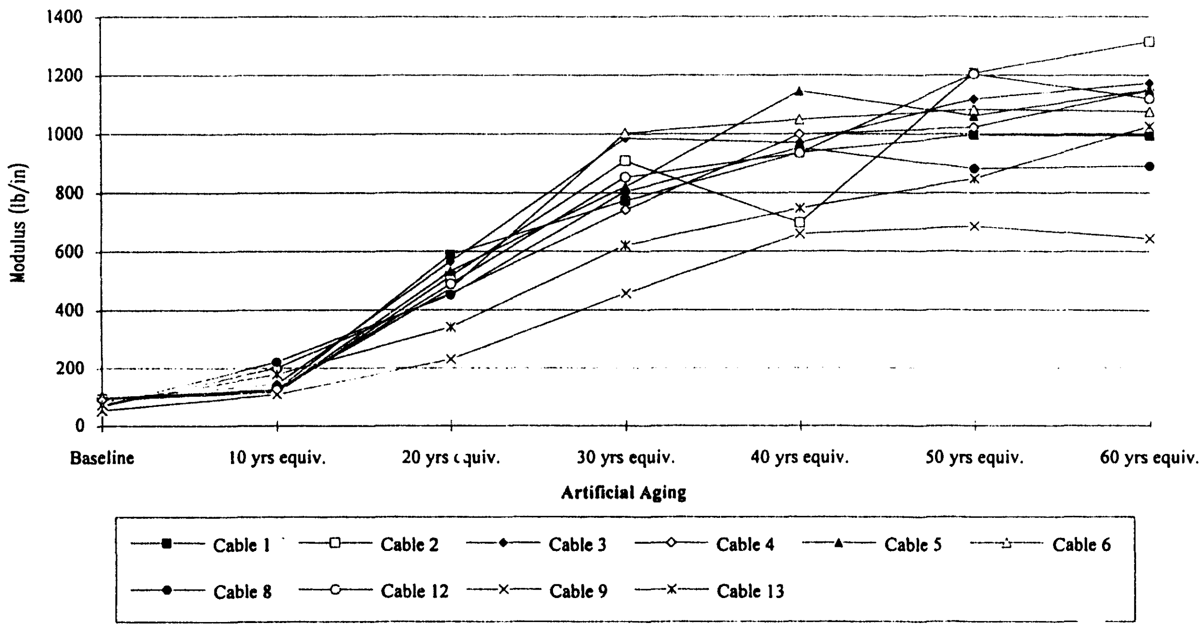
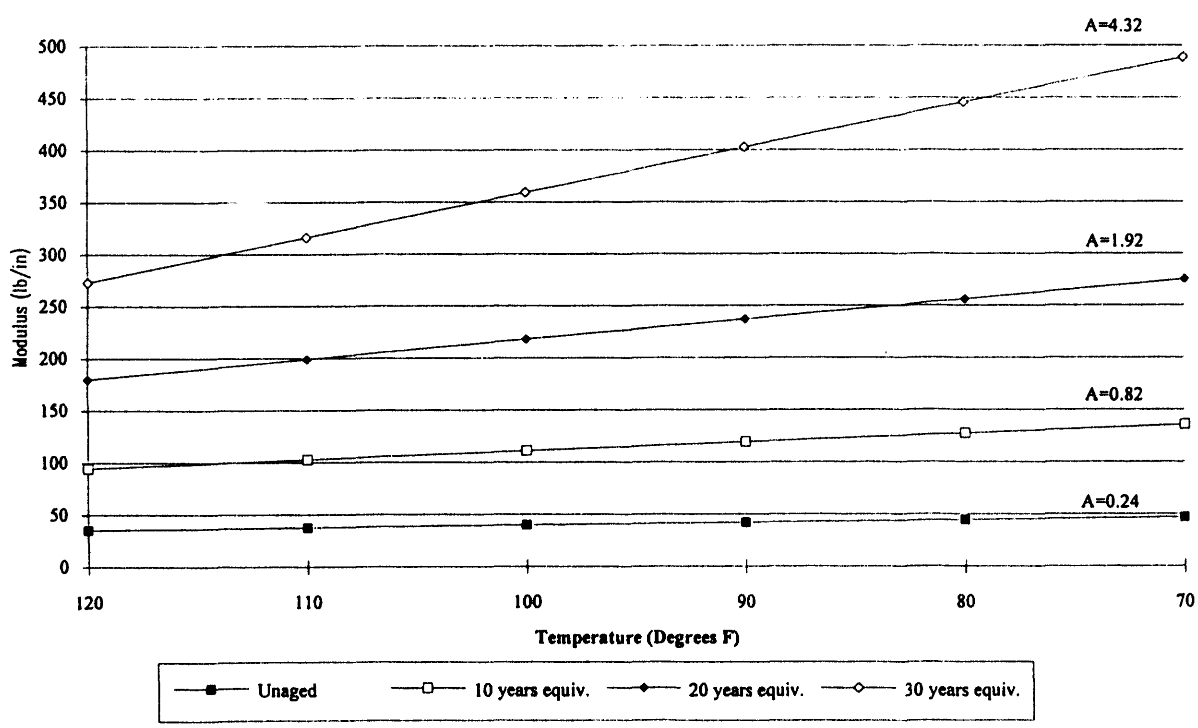


Figure 2. Effect of Jacket Temperature on Okonite Outer Jacket Modulus
Thermal Aging and Irradiation



(Note: Data presented in Figure is linear regression of actual experimental data.)

Figure 3. Indenter Modulus versus Percent Age Conditioning Limit
Okonite Okolon Individual Conductors

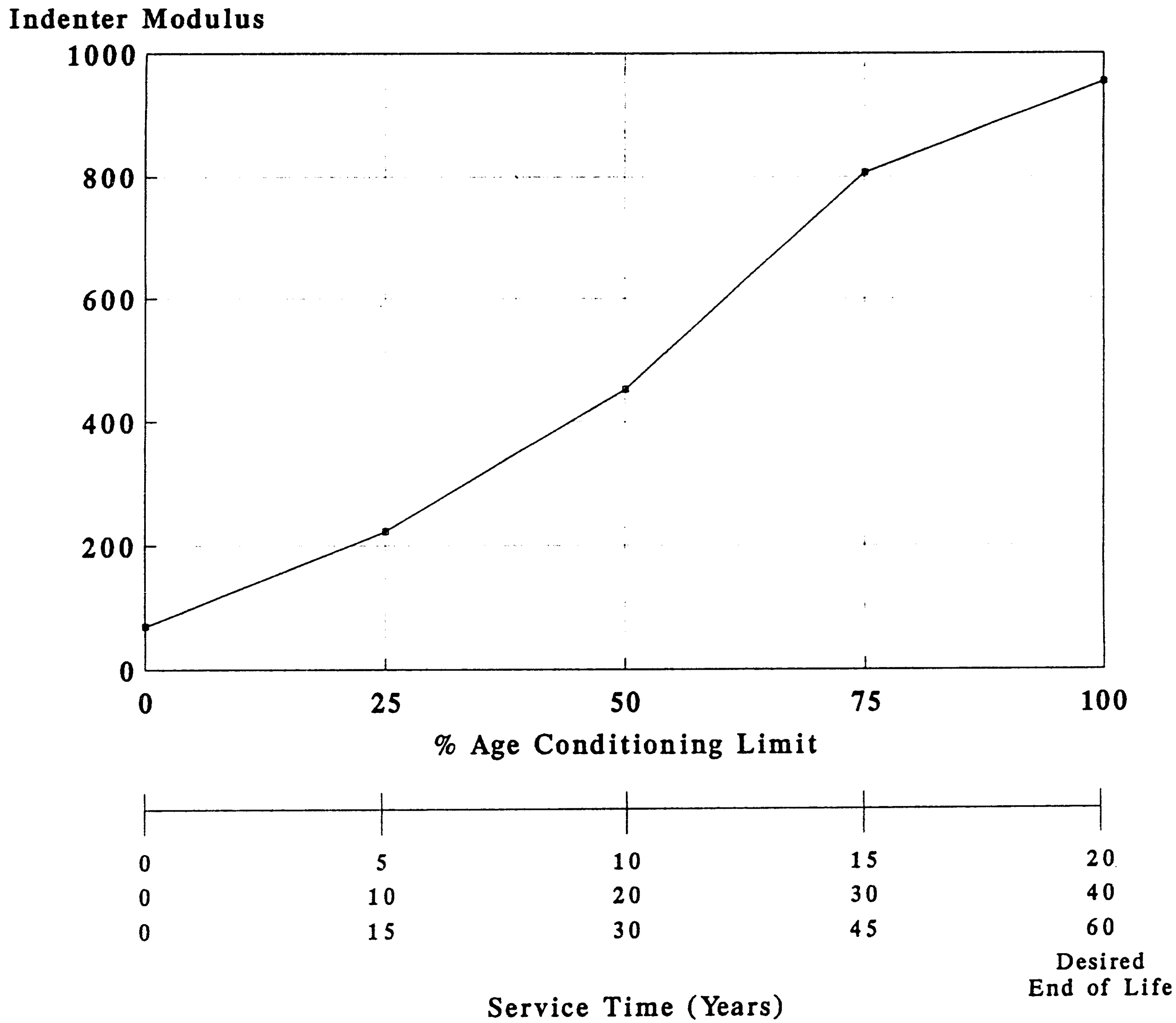


Table 1. Comparison of Dresden Unit 3 Okonite In-plant Indenter Moduli with Accelerated Aging Results

CABLE NO.	JACKET/ COND.	SIZE	TEST TEMP °F	MODULUS DATA				
				TEST AVERAGE	70°F TEMP CORRECTED[1]	UNAGED	ACCEL. 10 YEAR[2]	ACCEL. 20 YEAR[2]
34169	Jacket	7/C #14	88.3	59.2	74.0	44.2	112	238
34170	Jacket	2/C #14	85.3	74.2	86.5	42.8	93.5	251
39870	Jacket	3/C #14	88.3	58.7	71.0	48.6	132	224
39871	Jacket	3/C #14	88.3	63.5	75.8	48.6	132	224
39873	Jacket	3/C #14	88.3	56.5	68.8	48.6	132	224
39876	Jacket	3/C #14	88.3	66.6	78.9	48.6	132	224
39876	Jacket	3/C #14	79.5	58.2	66.4	48.6	132	224
57125	Jacket	3/C #14	73	59.6	62.1	48.6	132	224
57127	Jacket	12/C #14	73	118.2	120.7	47.8	135	292
57127	Conductor (red/black)	12/C #14	73	66.3	66.3	99.2[3]	113	388
57127	Conductor (black)	12/C #14	73	68.5	68.5	99.2[3]	113	388
57127	Conductor (green/black)	12/C #14	73	61.8	61.8	99.2[3]	113	388

Notes:
1. Corrections are based on linear regression of temperature effect results.
2. Acceleration factors for aging are based on insulation. Jacket aging may be in excess of actual 10-year and 20-year theoretical values.
3. This value is higher than expected and is most probably caused by residual compression from being cabled.

OXIDATION INDUCTION TIME CONCEPTS

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Oxidation induction time (OIT) testing is currently being developed for use in monitoring the condition of insulation and jacket materials of cables in nuclear power plant service. OIT testing is an established test methodology. The efforts underway at the University of Virginia for the Electric Power Research Institute will provide a standard methodology and acceptance criteria for nuclear power plant cable. OIT is a means of evaluating aging by measuring the period of time before a small sample of insulation experiences rapid oxidation when subjected to a continuous elevated temperature in an oxygen environment. The test evaluates the amount of anti-oxidants remaining in an insulation material. The anti-oxidants are materials that react with oxygen from the atmosphere surrounding the cable before it can react with the polymers of the insulation. As long as the anti-oxidants are not depleted entirely in the material, the mechanical properties (and therefore the electrical properties) remain relatively stable. Even a few percent of the initial anti-oxidant is sufficient to prevent oxidation of the polymers. When the anti-oxidants are depleted, the material properties will begin to degrade, in some cases relatively rapidly.

To perform an OIT test, a small sample of insulation or jacket must be removed from the cable. The test requires about 8 milligrams of material. OIT testing is performed using a differential scanning calorimeter. The material is heated to approximately 215°C in oxygen and held at this temperature. The energy required to sustain the temperature is monitored. When the energy required to maintain temperature begins to decrease, the material has begun an exothermic reaction, indicating that the antioxidants have been depleted and that rapid oxidation is occurring. The period from the start of the test until the point of rapid oxidation is the oxidation induction time. Figure 1 shows the OIT for a cross-linked polyethylene sample. The intersect of the slope of the stable heat flow region and that of the decreasing heat flow region is used to determine the OIT.

The OIT of a new material is approximately 45 minutes to an hour, depending on the test temperature that is selected. The OITs of materials with advanced aging are on the order of minutes. OIT results for cross-linked polyethylene are relatively easy to evaluate in that there is a clear change in the OIT plot when the transition of exothermic reaction occurs. Some materials such as highly filled ethylene propylene rubbers have plots that are more difficult to interpret in that there are smaller amounts of polymers in the material and they are mixes of polymers that react in a less orderly fashion than single polymers do.

With regard to removal of samples from plant cables, the test can be considered to be semi-non-destructive; although samples have to be removed, they are small enough that cables do not have to be destroyed or removed to obtain samples. Samples are expected to be taken by removal of terminal lugs, stripping a small segment of insulation (0.5 cm or less) and relugging the conductor. Where information is required about the cable at some point other than the termination, scrapings of the jacket or insulation can be taken. It may be possible that the scrapings may be shallow enough that repairs to the insulation are not necessary.

Figure 2 provides examples of OIT results for an cross-linked polyethylene (XLPE) insulation aged at various temperatures. OIT changes in an orderly manner in proportion to the degree of aging. Acceptance criteria for OIT will be developed in a manner similar to that for the Indenter. The aging portion of the environmental qualification program for the cables will be repeated, and the OITs will be taken to achieve a limit for the cable materials. The report of the University of Virginia OIT developmental efforts is expected to be published in 1994.

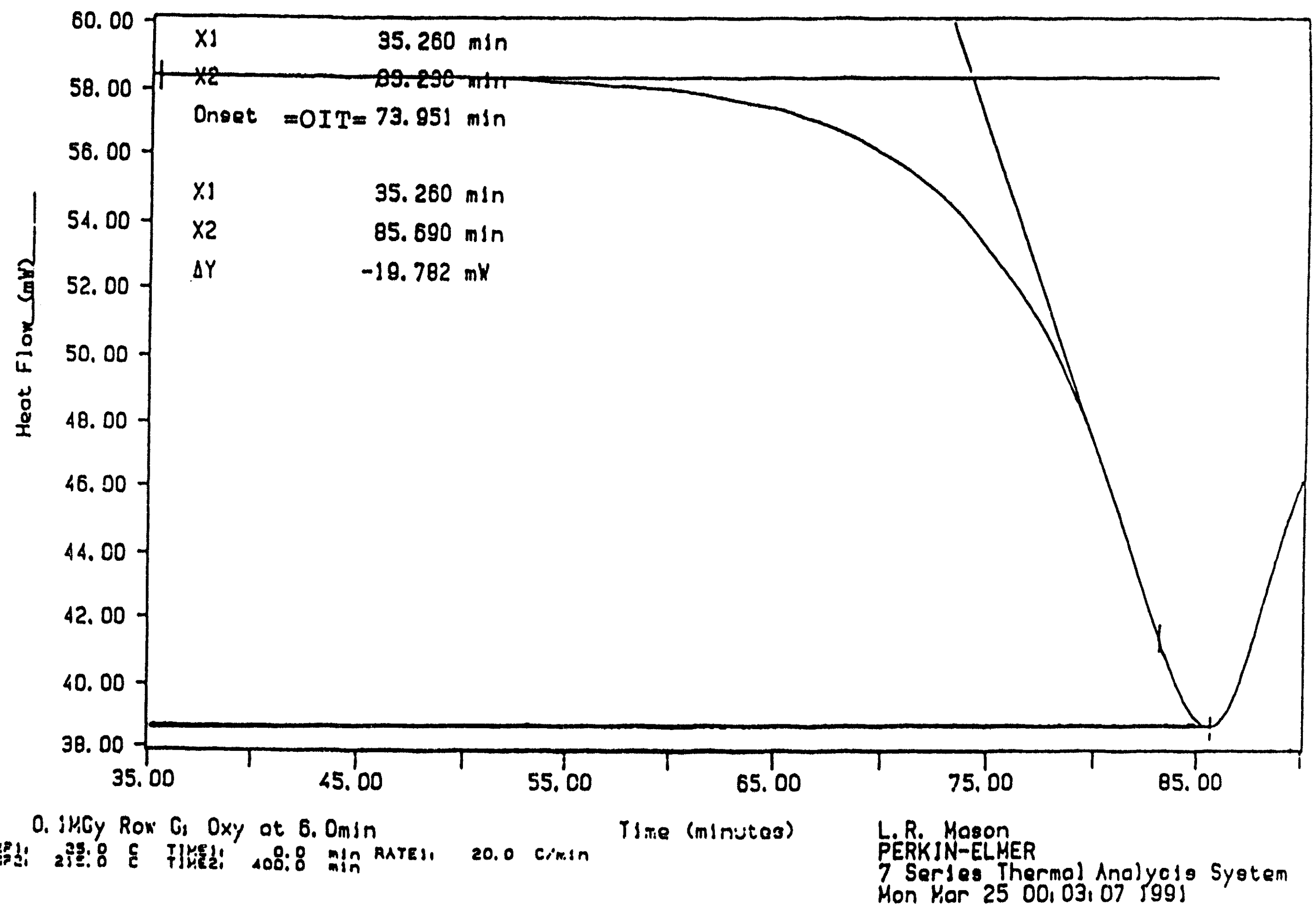


Figure 1. Differential Power Curve and OIT Extrapolation for an XLPE Material Aged to 0.1 MGy (DSC Temperature of 215°C) (Courtesy of Dr. A. Reynolds, University of Virginia)

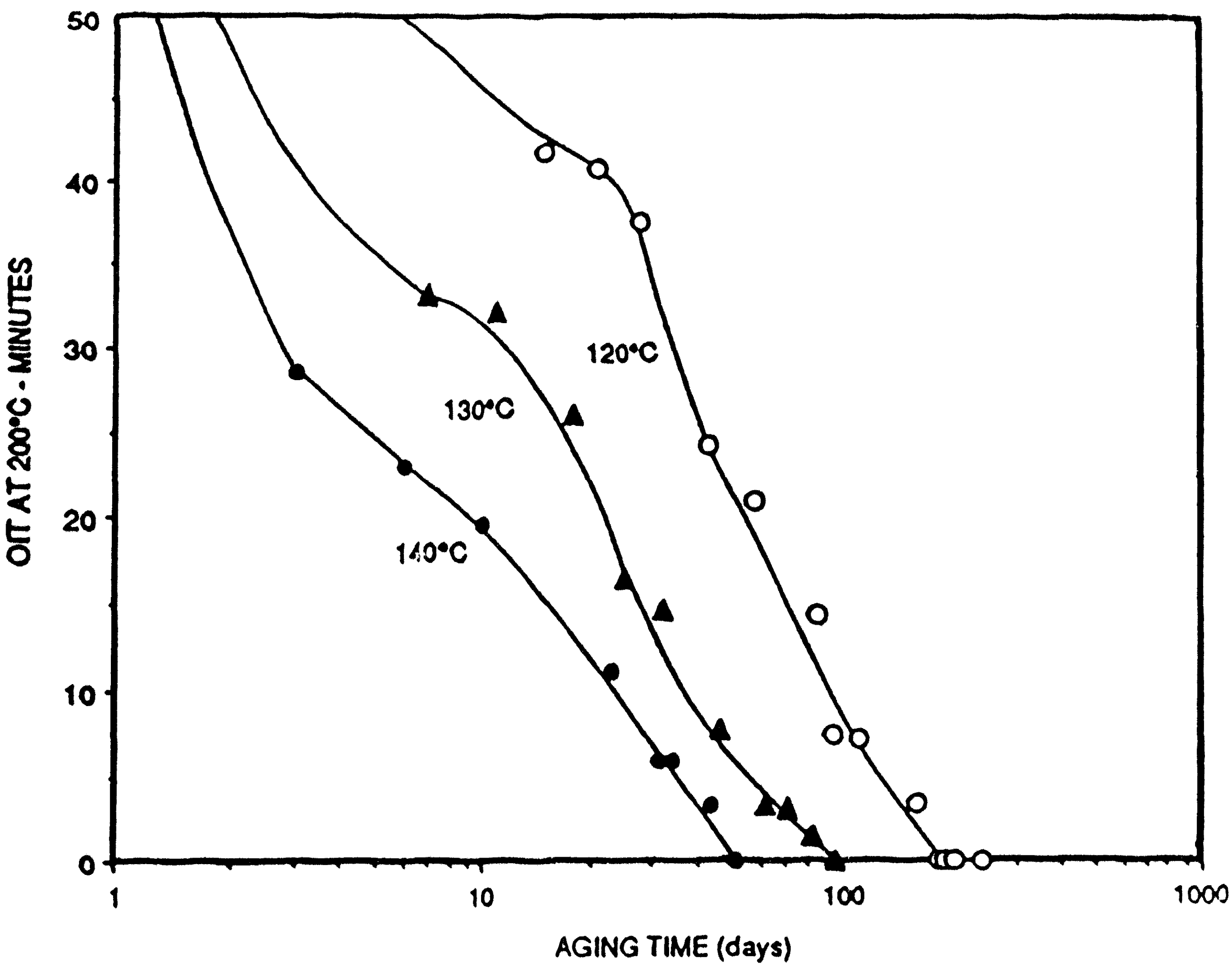


Figure 2. Oxidation Induction Time at 200°C after Aging at 120, 130, and 140°C for XLPE Samples

AEA

NRC Workshop on Environmental Qualification
of electric equipment

Nov 15 - 16, 1993
Holiday inn Crowne Plaza
Rockville, Maryland, USA

"An overview of the current status of cable condition monitoring techniques"

S G Burnay

AEA Technology
Harwell, UK

USNRC4

AEA

Current initiatives in cable aging & monitoring

- EPRI cable monitoring workshop (Feb 1993)
- IEC guide for in-service monitoring (SC15B WG2)
- IEC technical report on aging of cables
- IAEA coordinated research programme on cable aging

USNRC1

AEA

IEC Technical Report

* **Guide for in-service monitoring of radiation aging of insulating materials**

- a summary of worldwide experience on cable monitoring techniques
- including limitations and current status

[draft report will be circulated to member states in early 1994]

USNRC2

AEA

Cable monitoring techniques

Requirements:

- Preferably non-destructive
- Can be used in-plant
- Unaffected by variations in -
  - temperature
  - dose rate
  - moisture
- Sensitive to state of degradation (preferably before failure)
- Applicable to wide range of cables
- Reproducible
- Capable of identifying 'hot-spots'

AEA

Cable condition monitoring - techniques available

* Local tests - no sampling
  - indenter
  - sonic velocity
  - near IR reflectance
  - torque tester
* Local tests - with microsampling
  - IR spectroscopy
  - oxidation induction time/temperature (OIT)
  - plasticiser content
  - density
* Global tests - with spatial resolution
  - time domain reflectometry (TDR)
  - partial discharge
* Global tests - without spatial resolution
  - dielectric loss
  - time domain spectrometry (TDS)

SGB/REV6

AEA

Cable condition monitoring techniques - current status

* Promising
  - indenter
  - oxidation induction time/temperature (OIT)
  - dielectric loss
  - density
* Some promise
  - IR spectroscopy
  - torque tester
  - plasticiser content
  - time domain spectrometry (TDS)
* Limited promise (at present)
  - near IR reflectance
  - partial discharge
  - sonic velocity
* Trouble shooting
  - time domain reflectometry (TDR)

SGB/REV6

AEA

IEC Technical Report

* **Determination of long term radiation aging in air**

Part 2: Procedures for predicting aging at low dose rates

- practical methodologies for lifetime prediction
- limitations of methods
- practical examples

USNRC3

AEA

IAEA coordinated research programme

Pilot studies on ageing and plant life of cables

Objectives:

- To validate predictive cable ageing models using real-time aged cables from NPP
- To provide practical guidelines for management of ageing of I & C cables in NPP

Scope:

- Limited to low voltage (<1kV) I & C and power cables
- Materials limited to XLPE, EPR and EVA

[current participants - UK, Canada, Germany, Sweden, Russia France, India, USA, Switzerland]

SGB/REV9

APPENDIX E

PRESENTATION FOR MONDAY NOVEMBER 15, 1993
PLENARY SESSION ON EQ TESTING

CONTENTS

Perspectives on Equipment Qualification Issues from Research Testing

Mark J. Jacobus
Sandia National Laboratories

Presented to:
NRC Equipment Qualification Workshop
November 15-16, 1993

Some EQ Issues Related to Testing

- Functional Performance Monitoring
  - ➞ What parameters should be monitored?
  - ➞ What are worst case values of the monitored parameters that are acceptable?
  - ➞ NUREG/CR-3863, -4728, -3691, -5772
- Similarity of Installed and Tested Specimens
  - ➞ Matching the requirements from the EQ test can be difficult or impossible
  - ➞ NUREG/CR-4728
- Sequential Versus Simultaneous Aging
  - ➞ "Sufficient" sequential aging should be adequate to conservatively simulate simultaneous conditions
  - ➞ May not be much of an issue for many plant locations where actual radiation environments are very mild
  - ➞ NUREG/CR-3629, -4091

Some EQ Issues Related to Testing (cont.)

- Sequential Versus Simultaneous LOCA
  - General evidence suggests that sequential LOCA is sufficient in most cases
  - Some jacket materials more severely degraded by simultaneous exposure
    - Could be important if jacket is bonded to insulation or if jacket integrity is required
  - NUREG/CR-3588, -3538

- Rate of Aging Simulation (Thermal and Radiation)/ Diffusion Effects/Validity of Arrhenius Aging Predictions
  - Oxygen diffusion effects limit aging during high rate accelerated aging
    - May be especially important for cable insulations that are tested as multiconductors--jacket protects cable during accelerated tests, but not in real aging
  - Effect can be significant, but depends strongly on the margin between actual environments and test environments
  - SAND88-0754, SAND90-2009, SAND91-0822

- Submergence Testing (Especially for Cables)
  - SNL submergence test (in chemical solution) after aging and LOCA--many cables "passed" test, but failed in post-test mandrel bend/high potential testing--XLPO cables performed best, with no failures during submergence
  - NUREG/CR-5655

Some EQ Issues Related to Testing (cont.)

- Level of Aging Simulation
  - General perceptions are that equipment is overaged prior to EQ testing
    - However, diffusion effects during highly accelerated testing may reduce this margin
    - More accurate environmental definition, combined with state of the art aging simulations, would give more realistic simulations, but whether this is *necessary* is uncertain
  - Is radiation aging even really necessary?
  - Accounting for hot spots (thermal and radiation)

- Saturated Versus Superheated Steam
  - May be important for some equipment
    - Materials that can dry out under high temperatures
    - Materials that can absorb water
    - Situations where condensation may contribute to failure modes
  - Important to try to match actual conditions as much as possible
    - However, qualification enveloping (meeting conditions for many plants simultaneously) implies that a choice has to be made--should use whichever is most conservative
  - NUREG/CR-2558 Versus NUREG/CR-4536

- Fragility Testing
  - SNL test indicated that *some* cables are capable of surviving to very high temperatures (well above their qualification limits), even after aging and LOCA testing
  - NUREG/CR-5655

Some EQ Issues Related to Testing (cont.)

- Statistical Testing Considerations
  - Multiple samples certainly better than single sample (many tests do include more than one sample)
  - Practicality issues for large equipment
  - Cost issues for all equipment
  - Argument that margin accounts for production variations, etc., obviating the need for statistical tests
- Common Mode Versus Random Failures
  - Purpose of EQ is to identify common mode failures
  - Test failures (under appropriate environmental test conditions) can be dismissed only if failure is not common mode
  - Can be very tempting to dismiss single failures as random--deeper analysis will sometimes reveal potential common mode failures
- Changes to Equipment Design or Production--Induced Failure Modes May Not be Obvious in an Analysis
  - Example is change to pressure transmitter potentiometer lubricant that results in test failure of unaged transmitters in LOCA
  - NUREG/CR-3863

Some EQ Issues Related to Testing (cont.)

- LOCA Testing of Aged Versus Unaged Specimens
  - Normally believed that testing of aged equipment is conservative
  - However
    - In pressure transmitter example, it was believed that failure mode would not apply to aged equipment
    - Some cable materials swell less during LOCA if they have been aged--if swelling contributes to a failure mode, aging may mask the failure mode (note that IEEE383-1974 does require testing of aged and unaged samples)
  - NUREG/CR-3863, -5772
- Importance of Cable Jacket Integrity inTesting
  - May be important for shielding in some cases ???
  - May be important for preventing moisture ingress into connections ???
- Importance of Simulating Humidity During Aging
  - Historically considered unimportant

Some EQ Issues Related to Testing (cont.)

- Conservatism of Mandrel Bend/High Potential Test for Cables After LOCA
  - SNL testing has indicated that cables that otherwise pass EQ testing can fail the post-LOCA testing--However, failing the post-LOCA testing seemed indicative of cables that were not too far from failing during the LOCA test in some cases--Clearly the test is conservative, but this does not imply that it should necessarily be discontinued
  - NUREG/CR-5775

- Qualification of Product Families
  - *Generally appears to be an acceptable qualification methodology*
    - However, must use great caution to ensure that worst configuration (or combination of configurations) is tested--different configurations might be worst for different failure modes
  - Issues of practicality

- Many other general issues and issues specific to particular equipment

Possible Recommendations for Future

- Testing of some complete installed systems (e.g., real cable lengths, typical connectors/junctions, end device with appropriate interfaces, etc.) to determine whether any failures or system accuracy problems might result from unanticipated interactions in the system

- Testing of bonded-jacketed cables under realistic aging environments (using state of the art combined environments simulation) and simultaneous accident environments (radiation + steam)

- Determine accurate, realistic aging environments in plants (some activities in progress by utilities)

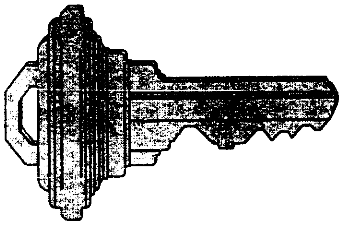
- Compile detailed information from available sources and experts on particular pieces of equipment/attempt to resolve discrepancies among tests and whether any additional research is warranted on the equipment (cables might be a good starting point since there are dozens, if not hundreds of tests, that have been done, with technical issues still remaining--amazing for such a "simple" piece of equipment).

EQ TESTING CONSERVATISMS

James F. Gleaso
GLS Enterprises, In

EQ TESTING

EVOLUTION



FROM EARLY ANOMALIES LEARNED IMPORTANCE OF

- Material Aging Capability
- Interfacing / Splicing Techniques
- Leakage Currents
- Loop Accuracies
- Simulating Installed Conditions
- Moisture Sensitivity
- Chemical Compatability
- Air Exchanges in Aging Chambers
- Air Exchange in Pressure Vessels
- Saturated & Superheated Tests

GLEASON

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EQ TESTING

CONSERVATISMS

- **WORST CASE ENVELOPE**
  - Accident Enveloping
  - Plant Enveloping
  - Multiple Plant Enveloping
  - Generic Testing
- **WORST CASE ORIENTATION**
- **WORST CASE MOUNTING**
- **WORST CASE LOADING**

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EQ TESTING CONSERVATISMS

NORMAL & ACCIDENT RADIATION

- ✓ SOMETIMES APPLIED PRIOR TO THERMAL AGING
- ✓ ALWAYS APPLIED PRIOR TO ACCIDENT SIMULATION
- ✓ ACCIDENT DOSE BASED ON SEVERE ACCIDENT
- ✓ DBE SCENARIOS TYPICALLY HAVE SEVERE STEAM / TEMPERATURES PRIOR TO RADIATION ACCIDENT DOSE, IF AT ALL
- ✓ SEVERE DEGRADATIONS COULD BE AN ARTIFACT OF THE TESTING

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EQ TESTING CONSERVATISMS

- **PRE-AGING PRIOR TO DBA TEST**
  - **VAST MAJORITY OF EQUIPMENT**
  - **NEARLY ALL CABLES**
  - **DOR/0588/50.49**
  - **DAMAGED CABLE TESTS**
- **WEAR OUT MODEL & AGING BASED ON MOST SENSITIVE MATERIAL**
- **CONTAINMENT INERTING**
- **SAME MODEL TESTED BY MANY LABS**
- **MULTIPLE TEST SPECIMENS**

GLEASON

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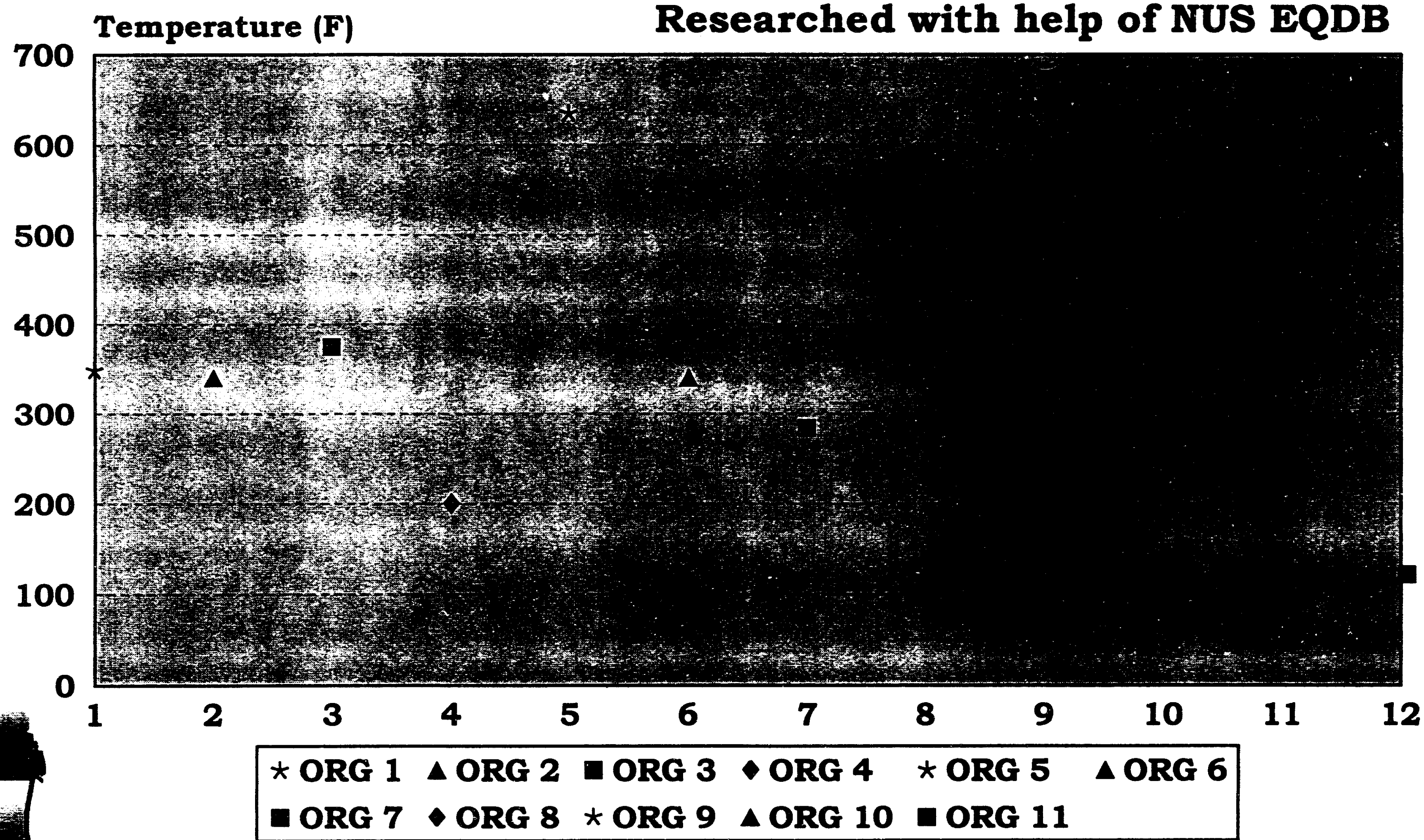
LIMIT SWITCHES

Peak Accident Temperatures

Researched with help of NUS EQDB



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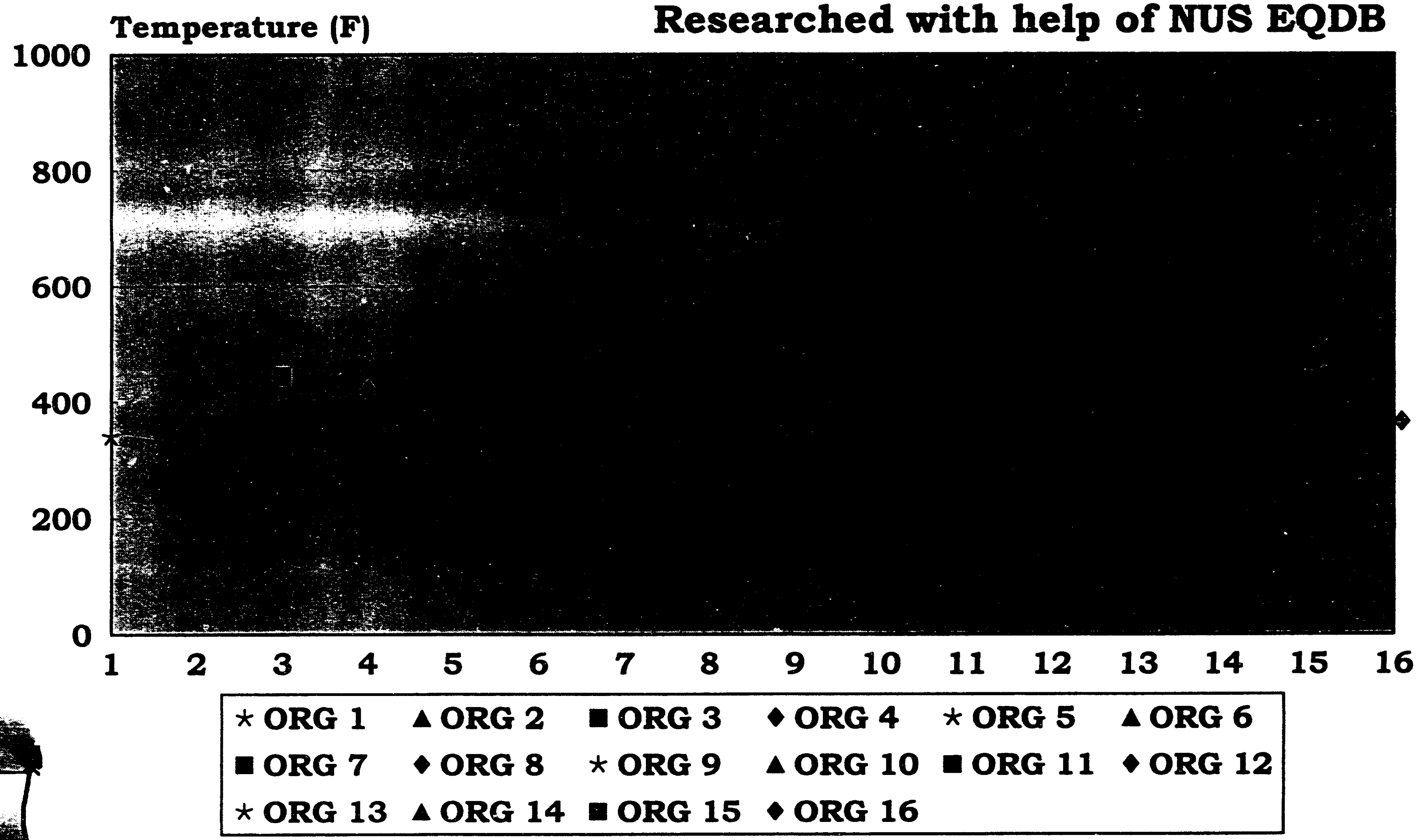
SOLENOID VALVES

Peak Accident Temperature



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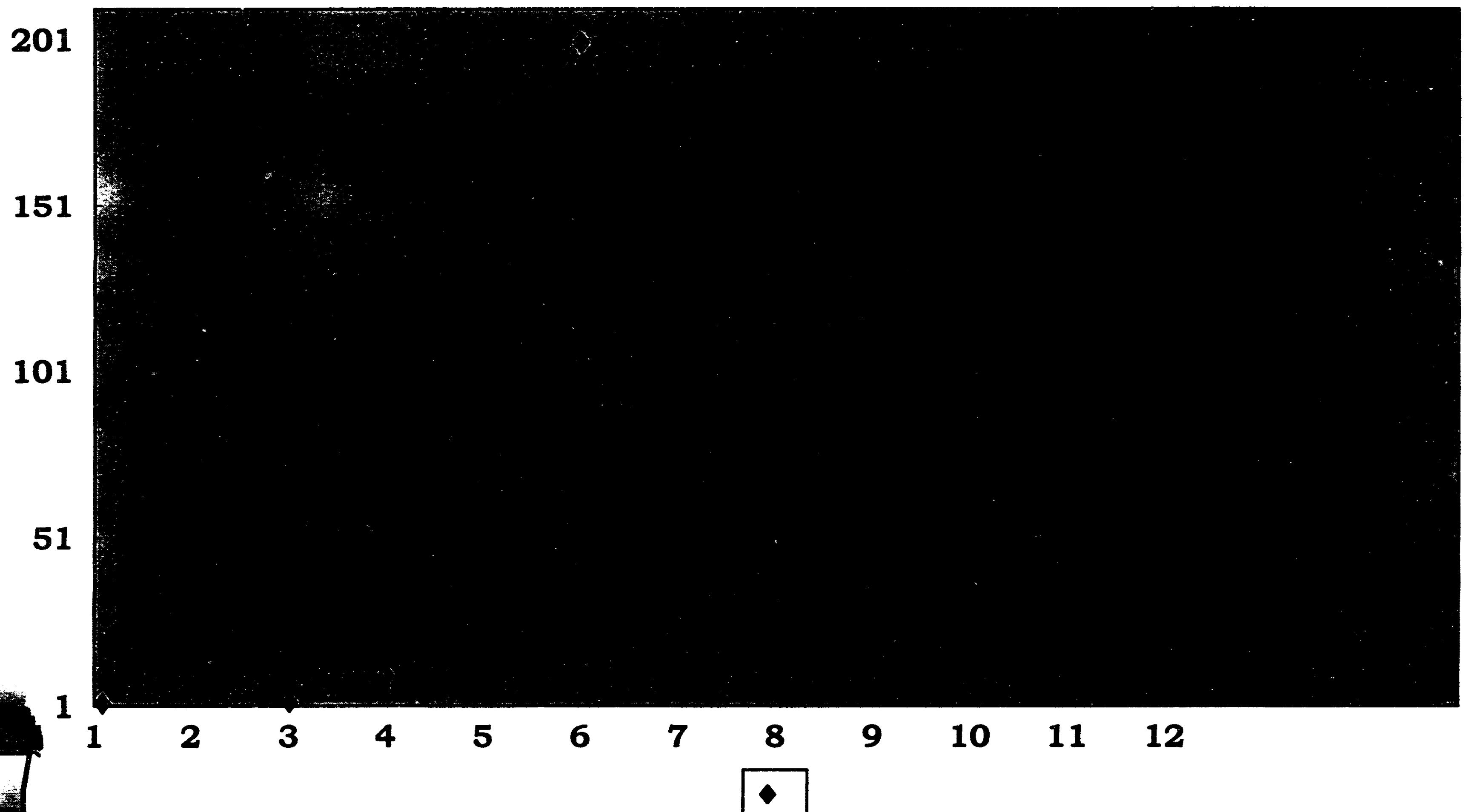
SOLENOID VALVES

Radiation Total Integrated Dose

Researched with help of NUS EQDB



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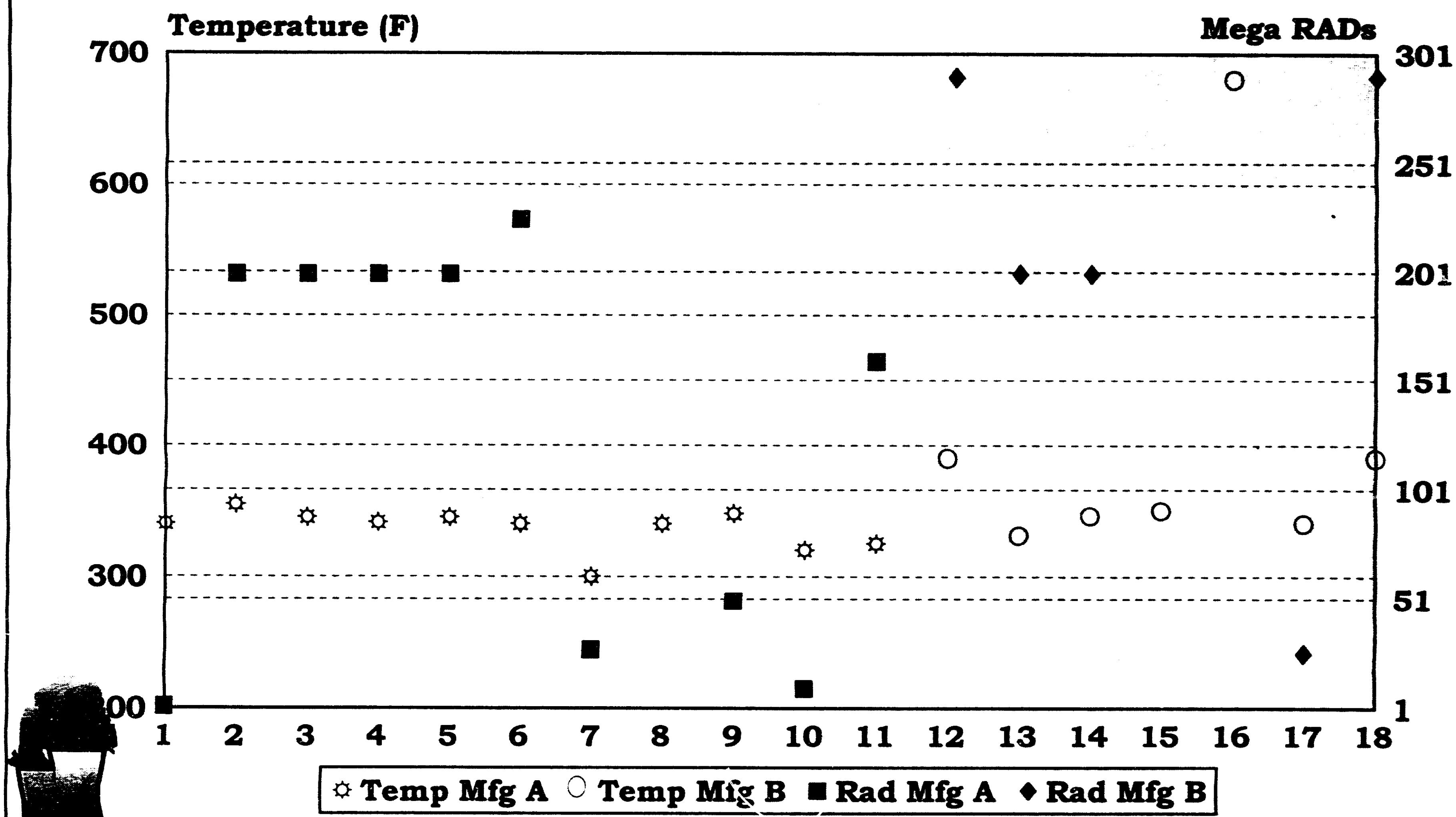
CABLES

Accident Conditions



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Researched with help of NUS EQDB

EQ TESTING RECOMMENDATIONS

PRIOR TO UNDERTAKING ADDITIONAL RESEARCH TESTING

- ✓ UNDERSTAND RESULTS IN LIGHT OF APPARENTLY DIFFERENT EQ PERFORMANCE.
- ✓ WERE RESULTS PREDICTED BY PREVIOUS KNOWLEDGE?
- ✓ HAVE TEST SIMULATIONS PROGRESSED TO THE POINT OF CONSERVATISMS ON TOP OF CONSERVATISMS AND SHOULD A REALITY CHECK BE CONSIDERED?
- ✓ ARE ACCEPTANCE CRITERIA REALISTIC AND ACCOUNT FOR INHERENT DIFFERENCES IN ENVIRONMENTS AND PERFORMANCE FOR POWER, CONTROL AND INSTRUMENT CABLES?

THERE MAY BE A NEED FOR PEER REVIEW AND COMPARISON OF RESEARCH AND SPECIFIC EQ RESULTS.

GLEASON

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CONDITION MONITORING

TWO MAJOR EFFORTS

- **EPRI NP-5024 (1987)**
  Systematic Review of Most age Sensitive Components - excluding cables

- **NRC NPAR (July 1985 to Present)**
  Systematic Research on Safety Structures, Systems and Components

CONDITION MONITORING

Research Results

EPRI NP-5024 "Seismic Ruggedness"
Principal Investigator : J. Gleason

Effective

- Setpoint
- Dead Band

Ineffective

- Insulation Resistence
- Polarization Index

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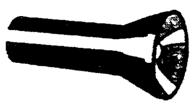
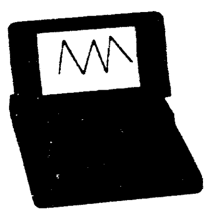
CONDITION MONITORING

WHAT'S CHANGED?

U.S. N.R.C. NPAR PROGRAM

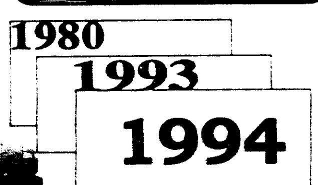


ENHANCED DIAGNOSTICS



PC CAPABILITIES

PREDICTIVE MAINTENANCE



AGING DEGRADATION MANAGEMENT

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CONDITION MONITORING

Research Results

NRC NPAR 5762 "Relays & Breakers"
Principal Investigator : J. Gleason

Effective

- **Infrared Thermography**
- **Vibration Signatures**
- **Current Signatures**

Ineffective

- **Insulation Resistence**

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CONDITION MONITORING

CABLE CONDITION

- **MOST LIKELY TO FAIL AT TERMINATION / END DEVICE**

- **ACCESSIBILITY MAXIMIZED AT TERMINATION / END DEVICE**

- **COMMON SYMPTOM : EXCESSIVE HEAT**

- **PREDICTIVE MAINTENANCE TOOL : INFRARED THERMOGRAPHY**

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TEST SIMULATIONS

HOW THEY ACCOUNT FOR INSTALLED CONDITIONS

Michael P. Saniuk
Nuclear Services Manager
NATIONAL TECHNICAL SYSTEMS

FOR

NRC WORKSHOP ON ENVIRONMENTAL QUALIFICATION OF ELECTRIC EQUIPMENT
November 15-16, 1993
Rockville, Maryland

REQUIREMENTS ACCOUNTING FOR INSTALLED CONDITIONS

DOR GUIDELINES

Paragraph 5.2.6 Installation Interfaces

- seals
- orientation
- field verification

NUREG 0588

Section 2.2(5)

- submergence
- watertight enclosures

REQUIREMENTS ACCOUNTING FOR INSTALLED CONDITIONS

<u>IEEE 323-1974</u>

Section 5(6) Principles of Qualification

- Must demonstrate qualification of any interfaces associated with Class 1E equipment.

Section 6(3) Qualification Procedures & Methods

- The installation requirements including mounting method and configuration.

REQUIREMENTS ACCOUNTING FOR INSTALLED CONDITIONS

IEEE 323-1974 (continued)

Section 6.3.1.1 Test Plan

- mounting and connection requirements

Section 6.3.1.2 Mounting

- Manner & position that simulates expected installation
- Manner
  - bolting
  - welds
  - clamps
- Position
  - spatial orientation

REQUIREMENTS ACCOUNTING FOR INSTALLED CONDITIONS

IEEE 323-1974 (continued)

Section 6.3.1.3 Connections

- Manner that simulates expected installation
  - wiring
  - connectors
  - cables
  - conduit
  - terminal blocks
  - service loops
  - piping
  - splices

10CFR50.49

Section (f)(1)

- Testing an identical item . . . under identical conditions

QUALIFICATION TESTING & INTERFACES

VENDOR GENERIC TESTING

- Mounting simulated installation
- Connections defined via qualification
- Left responsibility to utilities to duplicate "as tested" condition

CONNECTOR QUALIFICATION TESTING

- Vendors developed and tested connectors/seals
- Utilized own cables/wiring
- Others qualified with site specific cables/wiring

UTILITY TESTING

- Included site specific mounting & connections
- Utilized results of field verification activities

QUALIFICATION TESTING & INTERFACES

INDUSTRY TESTING

- Shared cost approach
- Example Raychem splice issue

SYSTEM REQUIREMENTS

- Most testing did not test entire loop as a system
- Industry utilized results from individual tests
- Instrument accuracy studies account for entire loop inaccuracies
- Some specialized testing has been performed - individual results are worst case/conservative

QUALIFICATION TESTING & INTERFACES

CONCLUSION

- Industry has appropriately accounted for installed conditions, through detailed as built inspection, testing and engineering analysis

RESEARCH PROGRAM PLAN

AREAS OF POTENTIAL STUDY

- Activation Energy Basis

- Aging Correlation and Ability to Withstand DBE's
  - testing of equipment removed from actual plant service
  - testing of accelerated aged equipment

"HOW SYNERGISMS ARE ACCOUNTED FOR IN THE TYPICAL TEST PROGRAM"

- **SYNERGISM AS IT PERTAINS TO EQ**
- **TECHNICAL BACKGROUND**
- **SYNERGISTIC EFFECTS ON KNOWN MATERIALS**
- **SIMULTANEOUS VERSUS SEQUENTIAL TESTING**
- **NORMAL 40 YEAR ENVIRONMENT**
- **ACCIDENT ENVIRONMENT**
- **ADDITIONAL CONSERVATISM**
- **REALITY CHECK**

MIKE KOPP
FARWELL AND HENDRICKS, INC

SYNERGISM

- CHEMICAL DEFINITION
    - JOINT ACTION OF AGENTS THAT WHEN TAKEN TOGETHER INCREASE EACH OTHERS EFFECTIVENESS

- EPRI DEFINITION (EP-2129)
    - AN EFFECT ON THE MATERIAL OF TWO OR MORE STRESSES APPLIED SIMULTANEOUSLY WHICH IS DIFFERENT IN MAGNITUDE OR TYPE THAN THAT OF THE SAME STRESSES APPLIED SEPARATELY

- SIMULTANEOUS APPLICATION OF ENVIRONMENTAL STRESSES

- IN EQ SYNERGISM IS ADDRESSED BY SEQUENTIAL (RADIATION/THERMAL) TEST SEQUENCE

- DOSE RATE EFFECTS

TECHNICAL BACKGROUND

- **POLYMER**
  - **MOLECULE MADE UP OF REPEATING STRUCTURAL GROUPS OR MERS. FOR EXAMPLE, POLYETHYLENE IS MADE UP OF $-CH_2-CH_2-$ GROUPS**

- **MER**
  - **A UNIT CONSISTING OF RELATIVELY FEW ATOMS JOINED TO OTHER UNITS TO FORM A POLYMER**

- **PROPERTIES**
  - **LENGTH**
  - **CROSSLINKED**

- **OXYGEN IMPORTANT TO DEGRADATION**

- **RADIATION ACCELERATION/OXIDATIVE DEGRADATION**
  - **DOSE RATE DEPENDENT IN SOME CASES**

SYNERGISTIC EFFECTS ON KNOWN MATERIALS

- **MATERIALS SUSCEPTIBLE TO DOSE RATE EFFECTS**
  - **ETHYLENE PROPYLENE RUBBER (EPR)**
  - **POLYVINYL CHLORIDE (PVC)**
  - **LOW DENSITY POLYETHYLENE (LDPE)**
  - **CHLOROSULFONATED POLYETHYLENE (HYPALON)**
  - **CHOLROPRENE**

- **MATERIALS SUSCEPTIBLE TO SYNERGISTIC EFFECTS BETWEEN RADIATION AND THERMAL AGING**
  - **LOW DENSITY POLYETHYLENE**
  - **POLYVINYL CHLORIDE**

SIMULTANEOUS TESTING VERSUS SEQUENTIAL TESTING

- **SIMULTANEOUS TESTING IS NOT PRACTICAL FROM AN ECONOMICAL PERSPECTIVE**

- **PREVIOUS TESTS SUPPORT THAT SEQUENTIAL TEST RESULTS ARE EQUIVALENT TO SIMULTANEOUS TEST RESULTS**

- **NO KNOWN EVENT OR TEST WHERE SIMULTANEOUS TESTING IDENTIFIED FAILURES THAT WERE NOT IDENTIFIED BY SEQUENTIAL TESTING**

- **HISTORY HAS DEMONSTRATED THAT MOST ITEMS PASSED PROPERLY STRUCTURED SEQUENTIAL TEST PROGRAMS**

- **FOR RARE CASES WHERE SIMULTANEOUS TESTS MIGHT IDENTIFY FAILURES, COMBINED THERMAL AND RADIATION EXPOSURE SHOULD BE PERFORMED BUT ONLY AFTER THE ITEM HAS FAILED A PROPERLY STRUCTURED SEQUENTIAL PROGRAM**

NORMAL 40 YEAR ENVIRONMENT

- **IN PLANT AGING ASSESSMENTS HAVE DEMONSTRATED LESS DEGRADATION THAN THAT OF ACCELERATED SEQUENTIAL AGING**

- **PRELIMINARY DATA ON NATURALLY AGED CABLES HAVE SHOWN LESS DEGRADATION THAN THAT OF ACCELERATED AGING METHODOLOGY**

- **PLANT INSPECTIONS OF ITEMS WITH 3 TO 5 YEARS OF QUALIFIED LIFE INDICATE THAT THE COMPONENTS ARE NOT AT THEIR END OF LIFE**

    - **SEQUENTIAL TEST CONSERVATIVE ASSUMPTIONS (i.e. E_A, AGING TIME)**

    - **LIFE OF RHR PUMP MOTOR INSULATION SYSTEMS ARE BEING EXTENDED FROM 10 YEARS OF LIFE TO 40 YEARS BY ASSESSMENTS**

    - **QUALIFIED LIFE EXTENSION OF AGASTAT RELAYS**

- **IN MANY CASES IN-PLANT TEMPERATURES ARE LESS THAN MANUFACTURERS PUBLISHED TEMPERATURES FOR THAT ITEM**

- **40 YEAR STRESSES ARE TYPICALLY WITHIN DESIGN STRESSES**

ACCIDENT ENVIRONMENT

- CONSERVATIVE SEQUENTIAL TEST APPROACH

- IRRADIATION OF ITEMS AT SEVERE DOSE RATES AND EXPOSURE TO NORMAL PLUS ACCIDENT DOSE (TID)

  - RADIATION STRESS EMBRITTLED TO MAXIMUM VALUE

- THERMAL AGING

  - THERMAL STRESS OF ITEMS GENERALLY AGED AT 115°C TO 120°C PER ARRENHIUS METHODOLOGY TO GET 40 YEARS OF AGING

  - USUALLY ABOVE PUBLISHED TEMPERATURE BUT WITHIN DESIGN MARGIN FOR SUB-COMPONENT MATERIALS OF CONSTRUCTION

  - THERMAL DEFORMATION AND/OR FURTHER EMBRITTLEMENT

- SEISMIC TESTS/MATERIAL FAILURES

- LOCA TESTS

  - SUBJECTED TO +300°F
  - STRESSES MATERIAL FOR SHORT DURATION
  - CONSERVATIVE OVER TESTING

- **DEGRADATION MONITORED THROUGHOUT TO IDENTIFY CAUSE OF FAILURE**

- **EXTREME CONSERVATISM IN TEST METHODOLOGY. SINCE 1980'S MOST ITEMS HAVE PASSED RIGOROUS SEQUENTIAL TEST PROGRAMS WHEN PROPERLY CONDUCTED VERSUS NUMEROUS FAILURES IN THE 1970'S DUE TO EVOLUTION OF LAB PRACTICES AND KNOWLEDGE OF CRITICAL CHARACTERISTICS, THRESHOLD OF MATERIALS PROPERTIES ETC.**

- **CURRENT PROGRAMS ARE BASED ON HISTORICAL TEST DATA, THEREFORE, FAILURES ARE MINIMIZED BY PROPER REVIEW OF CAPABILITIES, COMPATABILITY AND REFINEMENT OF TEST TECHNIQUES**

ADDITIONAL CONSERVATISM

- **FSAR DESIGN PARAMETERS**
  - **CONSERVATIVE GENERATION OF EQ PARAMETERS**
  - **RADIATION POINT DISPERSION VERSUS TIME HISTORY**
  - **LOCAL HOT SPOTS, THERMAL AND RADIATION ACCOUNTED FOR IN ROOM CALCULATIONS AND IS AN ON-GOING PROCESS**

REALITY CHECK

- FOR FEW CASES THAT FAIL CONSERVATIVE SEQUENTIAL TESTS THEN A MORE REALISTIC TEST SHOULD BE PERFORMED

- REALISTIC SEQUENCE OF EVENTS DURING NORMAL OPERATIONS

    - SIMULTANEOUS OR SEQUENTIAL TESTS WITH RADIATION AND THERMAL STRESSES APPLIED OVER LONGER DURATION TO MINIMIZE STRESSES VERSUS THE TYPICAL SHORT DURATION EXPOSURE IN CURRENT EQ PROGRAMS

- SEISMIC TESTING PRIOR TO ACCIDENT

    - DBE IS SHORTEST ACCIDENT DURATION EVENT, APPROXIMATELY 30 SECONDS

- LOCA ACCIDENT SHOULD BE CONDUCTED PER TIME HISTORY MODEL OF THE LINE BREAK

    - PRECEDES RADIATION ACCIDENT EXPOSURE

- APPLY REALISTIC ACCIDENT RADIATION LEVEL BASED UPON TIME MODELING OF THE EVENT

- EXPENSIVE DESIGN BASED ANALYSIS BUT COST EFFECTIVE VERSUS MAJOR REPLACEMENT OF CRITICAL ITEMS SUCH AS CABLES

SENSOR ENVIRONMENTAL UNCERTAINTIES

R. B. Miller
WESTINGHOUSE

SETPOINT METHODOLOGY

- **ENVIRONMENTAL TERMS TYPICALLY TREATED AS BIASES**

- **ENVIRONMENTAL TERMS MAY BE THREE OR FOUR TIMES LARGER THAN THE SRSS OF THE STEADY STATE ERRORS**

- **CONFIDENCE LEVEL**
  - **FOR MOST ERROR COMPONENTS A HIGH CONFIDENCE CAN BE JUSTIFIED**

  - **FOR ENVIRONMENTAL ERRORS A HIGH CONFIDENCE MAY RESULT IN UNACCEPTABLE ERRORS**

ESTABLISHING CONFIDENCE - 1

- TWO REASONABLE METHODS TO DETERMINE UNCERTAINTIES

    - RIGOROUS ASSESSMENT OF MECHANICAL AND ELECTRICAL DESIGN FEATURES OF SENSOR

    - RIGOROUS STATISTICAL ANALYSIS OF TEST PROGRAM RESULTS UTILIZING A SIGNIFICANT SAMPLE SIZE

ESTABLISHING CONFIDENCE - 2

- RIGOROUS ASSESSMENT OF MECHANICAL AND ELECTRICAL DESIGN FEATURES OF SENSOR
  - FORMULATION OF MATHEMATICAL ALGORITHM
  - BOUNDING ENVIRONMENTAL TEST PROGRAM
  - TEMPERATURE COMPENSATION OF EACH DEVICE
  - ALLOWS CALCULATION OF REDUCED ERRORS AT REDUCED TEMPERATURES
  - LIMITS ABILITY TO SEPARATE RANDOM AND BIAS ERROR COMPONENTS

ESTABLISHING CONFIDENCE - 3

- RIGOROUS STATISTICAL ANALYSIS OF TEST PROGRAM RESULTS UTILIZING A SIGNIFICANT SAMPLE SIZE

  - DETERMINES MEAN AND STANDARD DEVIATION

  - ALLOWS USE OF APPROPRIATE ONE AND TWO-SIDED TOLERANCE FACTORS

  - UNLESS TESTING PERFORMED AT LOWER TEMPERATURES, DIFFICULT TO DETERMINE ERRORS FOR REDUCED TEMPERATURES

UTILIZING QUALIFICATION TEST DATA

- **THERMAL AGING**
  - **INITIAL RESULTS MAY BE USED TO VERIFY ACCURACIES AT LOWER TEMPERATURE CONDITIONS**

- **RADIATION AGING**
  - **CALIBRATION CHECK AT PRE-TRIP CONDITION AND FOR POST-ACCIDENT MONITORING**
  - **SOMEWHAT LARGER SAMPLE SINCE ELECTRONICS ARE IDENTICAL**

SEISMIC

- **POST EVENT RESIDUAL EFFECTS**

HELB ELEVATED TEMPERATURES

- **VERIFY THAT ERROR IS LESS THAN PREDICTED BOUNDING CONDITION**

- **CONFIRM MODEL BY TESTING AT LOWER TEMPERATURE**

- **MAY PROVE REDUCED DYNAMIC EFFECTS**

- **POSITIVE EFFECT ON PLANT AVAILABILITY**

VENDOR DOCUMENTATION

USERS NEED THE FOLLOWING FROM VENDORS

- **PROBABILITY AND CONFIDENCE LEVEL**
- **MEAN AND STANDARD DEVIATION, IF POSSIBLE**
- **TEST CONDITIONS**

AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5

CONCLUSIONS

- **APPROACHES TO DETERMINING ENVIRONMENTAL UNCERTAINTIES**

  - **DESIGN WITH MATHEMATICAL ALGORITHM**

  - **STATISTICAL ANALYSIS OF A SIGNIFICANT POPULATION**

- **SAMPLE SIZE BASED ON DATA REQUIRED FROM QUALIFICATION PROGRAM**

APPENDIX F

LIST OF REGISTRANTS

List of Registrants

LAST NAME	FI	ORGANIZATION
ADAMS	J.	NAMCO CONTROLS
AGGARWAL	S.	U.S. NUCLEAR REGULATORY COMMISSION
AHMAD		TU ELECTRIC COMPANY
AL-HUSSAINI	T.	DUKE POWER COMPANY
ALEXION	T.	U.S. NUCLEAR REGULATORY COMM.
ALLAN	G.	ECAD
ALLEN	M.	ALLEN ENGINEERING SERVICES
ALLEN	R.	PACIFIC NORTHWEST LAB.
AMATO	A.	ROCKBESTOS
ANAND	R.	U.S. NUCLEAR REGULATORY COMMISSION
ANTONESCU	C.	U.S. NUCLEAR REGULATORY COMMISSION
APARICIO	L.	NUCLEAR LOGISTICS INC.
ARNOLD	R.	ROCHESTER GAS & ELECTRIC
ARP	D.	TENNESSEE VALLEY AUTHORITY
ATTIYEH	G.	NIAGARA MOHAWK POWER CORP.
BACANSKAS	V.	RIVER BEND STATION
BAILEY	S.	SOUTH CAROLINA ELEC & GAS
BAR	K.	ADVANCED SCIENCE & TECH. ASSOC.
BAUER	S.	ARIZONIA PUBLIC SERVICE CO.
BECK	J.	CONSOLIDATED EDISON, IP2
BECKJORD	E.	U.S. NUCLEAR REGULATORY COMMISSION
BEHERA	A.	KCI
BERGER	B.	FAUSKE & ASSOC. INC.
BERKSHIRE	R.	SO. CAL. EDISON, SAN ONFRE
BHATIA	R.	U.S. NUCLEAR REGULATORY COMM.
BLUM	A.	PUBLIC SERVICE ELECTRIC & GAS
BONNER	J.	YANKEE ATOMIC
BOUCHER	P.	GPU NUCLEAR
BOYUM	B.	WASHINGTON PUBLIC POWER SUPPLY SYS.
BRAZANT	J.	IOWA ELECTRIC LIGHT & POWER
BREON	J.	UNITED ENERGY SERVICES CORP.
BROWN	K	TENNESSEE VALLEY AUTHORITY
BROWN	R.	ABB IMPELL CORP.
BURELL	D.	TENNESSEE VALLEY AUTHORITY
BURNAY	S.	AEA TECHNOLOGY
BUTZ	C.	DUPONT
CANTOR	M.	BECHTEL
CARFAGNO	S.	CONSULTANT
CARRITTE	R.	MPR
CARTWRIGHT	B.	BALTIMORE GAS & ELECTRIC
CASO	L.	AMERICAN ELECTRIC POWER
CASTALDO	P.	ONTARIO HYDRO
CLAUSS	J.	SANDIA NATIONAL LAB.
CLUNE	W.	PHILADELPHIA ELECTRIC CO.
COIL	G.	IOWA ELEC.LIGHT & POWER-DUANE ARNOLD

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CRAIG	J.	U.S. NUCLEAR REGULATORY COMMISSION
CRUMBO	S.	SOUTH CAROLINA ELEC & GAS
CURREN	M.	WASHINGTON PUBLIC POWER SUPPLY SYS.
DAS	P.	ROCKBESTOS
DAVID	M.	SCIENTECH
DAVIS	J.	SCIENCE APPLICATIONS INTERNATIONAL
DEMARS	C.	GENERAL PHYSICS
DENNY	B.	OGDEN CO.
DIBENEDETTO	P.	DIBENEDETTO ASSOC.
DRANKHAN	D.	COMMONWEALTH EDISON
DUMMER	A.	U.S. NUCLEAR REGULATORY COMMISSION
DVONG	Q.	DETROIT EDISON
EDSON	J.	IDAHO NATIONAL LAB
ELDRIDGE	G.	NIAGARA MOHAWK
FARAMARZI	A.	THE MITRE CORP.
FARGO	W.	PACIFIC GAS & ELECTRIC CO.
FARMER	W.	NRC, RETIRED
FERGUSON	R.	AECL TECHNOLOGIES
FERO	A.	WESTINGHOUSE ELECTRIC CORP.
FORKELL	C.	ROCHESTER GAS AND ELECTRIC
FRIER	L.	MET LABS
FROSCH	F.	EPRI
FUKUSHIMA	T.	S. LEVY, INC.
GARDNER	J.	CONSULTANT
GARG	H	U.S. NUCLEAR REGULATORY COMMISSION
GARTEN	G.	WINSTON AND STRAWN
GEHM	R.	ROCKBESTOS
GELSTON	H.	FLORIDA POWER CORP.
GILLEN	K.	SANDIA NATIONAL LAB.
GLEASON	J.	GLS ENTERPRISES, INC.
GRADIN	L.	ECO TECH/RAM-Q INDUSTRIES
GRANEY	K.	BECHTEL
GRATTON	C.	U.S. NUCLEAR REGULATORY COMMISSION
GROEGER	J.	ALTRAN MATERIALS
GUNTHER	W.	BROOKHAVEN NATIONAL LAB.
HANAN	N.	ARGONNE NATIONAL LAB.
HARTMAN	D.	NPPD
HAUSEMAN	G.	U.S. NUCLEAR REGULATORY COMMISSION
HENLEY	J.	UNITED ENERGY SERVICES CORP.
HENRY	G.	APPLIED POWER ASSOC., INC.
HEROUX	T.	EPRI
HICKMAN	R.	WASHINGTON PUBLIC POWER SUPPLY SYS.
HODGDON	A	YANKEE ATOMIC ELECTRIC CO.
HOLZMAN	P.	STRATEGIC TECHNOLOGY & RESOURCES

LAST NAME	FI	ORGANIZATION
HORIN	B.	WINSTON AND STRAWN
HOUGHTON	J.	U.S. NUCLEAR REGULATORY COMMISSION
HUBBARD	G.	U.S. NUCLEAR REGULATORY COMMISSION
HUTCHINSON	J.	NUS
IEPSON	K.	IEPSON CONSULTING ENTERPRISES
ISGRO	J.	EBASCO SERVICES, INC.
JABS	R.	WESTINGHOUSE
JACKSON	D.	NAMCO CONTROLS
JACOBUS	M.	SANDIA NATIONAL LAB.
JOHNSON	E.	TOLEDO EDISON
JONES	D.	SOUTHERN NUCLEAR OPERATING
JORDAN	P.	NUS
KARIMIAN	S.	PUBLIC SERVICES ELEC. & GAS
KASTURI	S.	MOS
KELLER	C.	DUGUESNE LIGHT CO.
KILPATRICK	J.	BALTIMORE GAS & ELECTRIC
KNUETTEL	T.	TENNESSEE VALLEY AUTHORITY
KOPECKY	G.	OMAHA PUBLIC POWER DIST.
KOPP	M.	FARWELL AND HENDRICKS
KORSAH	K.	OAK RIDGE NATIONAL LAB.
KOWKABANY	S.	GPU NUCLEAR
KRATT	T.	DC COOK
KRUGER	D.	COMMONWEALTH EDISON
KULANGARA	J.	TU ELECTRIC CO.
KUO	P.	U.S. NUCLEAR REGULATORY COMMISSION
LANKENAU	B.	IMAGING AND SENSING TECHNOLOGY
LASKY	J.	OKONITE
LE GOULLON	K.	NORTHERN STATES POWER,
LEE	B.	BROOKHAVEN NATIONAL LAB.
LEFKOWITZ	S.	ECAD DIVISION OF CM TECH.
LEUNG	H.	ATOMIC ENERGY OF CANADA LIMITED
LITCHFIELD	S.	CLEVELAND ELECTRIC, PERRY NPP
LOBBIN	F.	GENERAL PHYSICS CORPORATION
LOCZI	V.	U.S. DEPARTMENT OF ENERGY
LOFARO	R.	BROOKHAVEN NATIONAL LABORATORY
LOVE	N.	ROCHESTER GAS AND ELECTRIC
LYNCH	J.	IMAGING AND SENSING TECHNOLOGY
MACDONALD	G.	U.S.NUCLEAR REGULATORY COMM.
MAKATURA	L.	TOLEDO EDISON
MARINOS	E.	U.S. NUCLEAR REGULATORY COMMISSION
MARION	A.	NUMARC
MARTZLOFF	F.	NATIONAL INSTITUTE OF STANDARDS & TECHNOL
MAZZONI	O.	SRI
MCCOY	D.	SOUTHERN NUC OPERATING CO.
MCCRACKEN	C.	U.S. NUCLEAR REGULATORY COMMISSION

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METRO	B.	WESTINGHOUSE
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MILLER	C.	STONE & WEBSTER ENG.
MOORE	R.	SOUTHERN CO. SERVICES
MORA	M.	NY POWER
MULVEHILL	J.	SOUTHERN CO. SERVICES
MURMELLO	M.	PENNSYLVANIA POWER AND LIGHT
NAYLOR	R.	COMMONWEALTH EDISON CO.
NELSON	C.	SANDIA NATIONAL LAB.
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PAPKEN	R.	YANKEE ATOMIC
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PETRUSICH	F.	COMMONWEALTH EDISON DRESDEN NS
PINION	M.	VIRGINIA POWER
POLLARD	R.	UNION OF CONCERNED SCIENTISTS
PRIBEK	B.	WISCONSIN PUBLIC SERVICE CORP.
QUINN	F.	SCIENTECH
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ROURK	C.	U.S. NUCLEAR REGULATORY COMMISSION
RULAND	W.	U.S. NUCLEAR REGULATORY COMM.
SANIUK	M.	NATIONNAL TECHNICAL SYSTEMS
SARLITTO	M.	ABB IMPELL CORP.
SATES	E.	WYLE LABORATORIES
SAVINO	S.	ECOTECH/RAM-Q INDUSTRIES
SCHOPPMAN	M.	SOUTHERN TECHNICAL SERVICES, INC.
SERKIZ	A.	U.S. NUCLEAR REGULATORY COMMISSION
SHAFII	A.	ABB IMPELL CORP.
SHEMANSKI	P.	U.S. NUCLEAR REGULATORY COMMISSION
SHYMLOCK	M.	U.S. NUCLEAR REGULATORY COMM.
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SLITER	G.	EPRI
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SMITH	K.	WASHINGTON PUBLIC POWER SUPPLY SYS.
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STEINER	J.	AVO BIDDLE INSTRUMENTS
STEINMAN	B.	ENTERGY OPERATIONS, INC.

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TAYLOR	J.	BROOKHAVEN NATIONAL LAB.
TEST	L.	CONSULTANT
THADANI	A.	U.S. NUCLEAR REGULATORY COMMISSION
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THIBAULT	C.	WYLE LABORATORIES
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WALTERS	D.	NUMARC
WARD	S.	DOMINION ENGINEERING, INC.
WEINACHT	R.	BALTIMORE GAS & ELECTRIC
WISE	R.	CONSULTANT, SO CAL EDISON, SAN ONFRE
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WOODWARD	N.	TENERA
WOOMER	P.	SPECTRUM TECHNOLOGIES
WU	G.	NUMARC
WYLIE	M.	ADVENT ENGINEERING SERVICES
YAGER	B.	ROCHESTER GAS & ELECTRIC
YATES	B.	UNION ELECTRIC CO.
YOUNG	C.	CAROLINA POWER AND LIGHT
ZACHARIAS	E.	GDS ASSOCIATES
ZOTTER	J.	WESTINGHOUSE

APPENDIX G

PREPARED QUESTIONS FOR PANEL DISCUSSION

NRC ENVIRONMENTAL QUALIFICATION WORKSHOP
PANEL QUESTIONS

Session A: Preaging

1. What is the technical basis for preconditioning components, prior to LOCA testing, to simulate a qualified life?

2. How do temperatures and radiation doses used in preconditioning analyses compare to the values observed in operating experience?

3. Does accelerated thermal aging based on the Arrhenius methodology adequately simulate natural age-related degradation caused by thermal stressors?

4. How has the Arrhenius approach been misapplied?

5. What are the limitations of the Arrhenius approach for electrical assemblies, such as SOVs, relays, electrical penetration assemblies, motors, and transmitters, which include parts with different thermal degradation rates and are subject to several failure mechanisms?

6. Do existing preconditioning methods adequately simulate age-related degradation caused by radiation?... by equipment operation?

7. Do existing preconditioning methods encompass the degradation effects of humidity, non-seismic vibration, and electrical and other stressors?

   What is the state-of-the-art for simulating the effects of such stressors?

   Is there a need to upgrade conventional preconditioning methods with respect to such effects?

8. Do known preconditioning synergisms (i.e., the sequence of thermal and radiation aging, and dose rate effects) significantly affect the adequacy of preconditioning methods?

9. Can the uncertainties of existing preconditioning practices be reduced by including margins in the assumed service conditions?

10. Can conservatisms in LOCA testing account for uncertainties in preconditioning?

11. What age management methods are available to address significant aging mechanisms?

12. In addition to the approaches mentioned in Questions 9, 10, and 11, what other alternatives to existing preconditioning methods can be considered?

13. Is analysis in accordance with DOR Guidelines and NUREG 0588/Category II adequate for age-related degradation?

14. Is it feasible to use probabilistic risk assessments to guide the selection of equipment of which to focus preaging?

15. Do available aging research results, qualification experience, and operational data indicate ways to improve the conventional approach to preconditioning?

16. Giving consideration to time, cost, and the prospect for success, what additional research related to preaging is needed to guide the improvement of existing regulatory requirements for demonstrating reasonable assurance that safety-related equipment can function as specified throughout its service life?

Session B: Operating Experience

1. Have there been premature (before end of EQ life) failures of safety-related electric equipment during normal operation?

   Do utilities track the failure of safety related electric equipment and are root cause analyses performed for such failures? What records are maintained?

   Does operating experience provide insight into what are the significant aging mechanisms? Are these addressed as part of EQ?

2. What are the root causes of premature (or unanticipated) failure of electric equipment during normal service conditions, and how do these failures relate to environmental qualification? Are any of the root causes age-related? Are EQ programs intended to eliminate these failures?

3. Is there evidence of degradation from actual field conditions such as thermal and radiation hot spots, cable/connector interfaces, or other unusual physical constraints such as long cable overhangs that are not usually accounted for in the preaging and/or testing process? Should provision be made for these effects?

4. Are containment temperatures and radiation levels being monitored in operating plants to identify hotspots, and to what extent?

   How are containment temperatures and radiation levels being monitored to ensure they are not more severe than assumed for EQ. Does this monitoring identify hot spots and to what extent?

5. For older plants, what electric equipment is typically being upgraded to the current EQ requirements when it is replaced?

6. Has ongoing EQ upgrading improved equipment qualification and performance? What types of equipment are typically upgraded and what types are typically not upgraded? What are the pros and cons of upgrading. Should more equipment be upgraded?

7. Are there any other sources of data related to the industry's EQ experience to supplement existing (eg EQ, NPRDS) databases? How could such sources be acquired, or accessed?

8. What preventive maintenance techniques are being used to verify cable system integrity? Are there other maintenance techniques that could be used to verify cable integrity?

Session C: Condition Monitoring

1. What is situ testing and condition methods are typically employed on EQ equipment?

2. What are the effectiveness and limitations of in-situ testing and condition monitoring methods that are available (and employed) to determine the state of electric equipment, especially cables?

3. What results are available from electrical tests such as insulation resistance, capacitance, dissipation factor, loop resistance, time domain reflectometry, partial discharge, ionized gas technique, AC and/or DC high potential withstand, and polarization index? Are there any other techniques? For what types have these methods been used on?

4. What results are available for non-electrical test techniques such as mechanical indenter, elongation, chemical analysis, oxidation induction time, flexing, visual examination, and infrared adsorption? What cable types have these methods been used on?

5. Are there any on-going research programs which can be expected to provide practical condition monitoring methods in the near future?

6. What role does surveillance and condition monitoring play in traditional EQ? Could it play an enhanced cost-effective role in the future?

7. Should equipment/condition monitoring be part of EQ programs? Why and for what type of equipment or aging stressors?

Session D: Testing

1. Does experience continue to support the validity of the hypothesis that the proper application of sequential testing can simulate natural in-plant aging? If not, would simultaneous testing be more appropriate?

2. How have the following bee accounted for in EQ testing?
   Cable to connector interfaces? Thermal/radiation hot spots? Long cable overhangs?
   Are additional EQ testing requirements or margins needed?

3. Are techniques used to impose combined thermal and radiation aging in current EQ testing still valid? How are synergistic and dose rates affects accounted for?

4. What tests could be performed on naturally-aged cables in situ to substantiate EQ tests?

5. In view of the increasing use of PRA techniques, is it still justifiable to use the deterministic, single sample approach used in traditional EQ space? What are possible alternatives?

6. How do current EQ methods account for unanticipated modes of failure (i.e., moisture intrusion failure paths, interface relaxation/creep effects).

7. The post LOCA simulation test of IEEE standards demonstrates margin by requiring mechanical durability (mandrel bend) for cables and immersing them in water while being energized. Is needed margin adequately accounted for in this test or is the test considered to be too conservative (and on what basis?).

9. The LOCA simulation test includes exposure to two cycles of the predicted LOCA environment. The additional peak transient is intended to assure performance margin. How realistic is this test profile in terms of demonstrating that adequate margin exists?

10. LOCA chambers have exhibited difficulty in controlling steam pressure and internal temperature such that temperature overshoots in excess of the test profile plus 15 degree margin often occurs. What is the impact on the qualification test results when equipment is exposed to these conditions? How adequately is the LOCA accounted for?

11. What gives you confidence that cables have been qualified to accident conditions. What conservatisms are typical in qualification testing?

12. How have synergisms been addressed in cable qualification? What about other devices?

APPENDIX H
PUBLIC COMMENTS

Submitted by J.B. Gardner, Consultant

This writer was impressed by the degree of openness and relative lack of adversarial discussion of issues during the workshop. However, I, and perhaps others, were well aware of public, press, and intervenor potential or actual presence and so deliberately avoided raising issues for which there was no evidence that they were even being addressed by the industry.

With the writer there have been cases where, during NPP audits with NRC staff, issues arose that were side-stepped because "all NPPs have the same problem so one can't hold this utility to task for in." The issue was deemed "generic." Recent inquiry to NRC staff has indicated that there are, in fact, no open generic cable system or cable EQ issues. It appears to mean that no one has pursued the rather elaborate bureaucratic steps to establish the official question of such generic issues or that no cable issue raised has survived the equally elaborate evaluation process in order to be deemed worthy of resolution effort. The issues seem to float about in a state of "If you don't shout about it, it won't be addressed." Several of the issues noted below have been articulated in the Proceedings of the February 1993 Cable Conditioning Monitoring Workshop, the NPEC Ad hoc Working Group February 27, 1991 report on IEEE 383 revision issues, and in the writer's response to the NRC's EQ Survey in September 1993.

The reason for renewed attention to EQ concerns at this time is apparently the removal by the Commission of EQ issues from utilities' license renewal programs. EQ issues had been smoldering for some time and license renewal had evidently been looked at as a pivotal point to reconsider them. This being so, it appears that now is the appropriate time to speak out about presently understood serious cable system issues. I believe all the issues noted below can and should be presently addressed or merit investigation or research to find the proper means of doing so. The writer would be happy to discuss his own and other reported experience supporting his allegations of these issues and suggested approaches to their resolution but makes no attempt to pursue these aspects in this memo.

Despite few outright statements to the contrary and several strong implications made orally at the workshop, it is very clear that past and even the most recent cable EQ programs do not verify that cables and connections (cable systems) will operate properly in a harsh environment under the actual conditions (stresses) of installation. The conditions referred to are:

1. The compressive and shear stresses imposed by the many controlled and uncontrolled means of supporting vertical cable runs. Not only are design and control of supporting vertical runs subject to great variation within given plants and between plants but in no case to the writer's knowledge have the resultant stresses been ascertained and then applied to cables during EQ Tests. Softening and creep flow of polymers is promoted by high temperature excursions and for many polymers by prolonged steam or hot water exposure - a clear risk for common cause failures.

2. Stresses resulting from minimum existing bend radii. Well recognized in the industry is that actual (as found and practical) minimum bending radius of installed cables in large installations is frequently far below the cable manufacturers recommended value. Not required in industry standards and certainly not part of most (or any?) EQ program is deliberate bending of cable to the minimum recommended. Early in our EQ testing experience it was observed that failures occurred in samples at locations of unplanned over-bending or pressure points due to cramped space in autoclaves or movement due to heat expansion of cables. Failures ascribed to such "improper test conditions" was not considered a significant (reportable) EQ failure.

3. Stresses on insulation and creation of moisture leakage paths from jacket ruptures. Compromise of jacket integrity is usually alleged to be a non-problem. If damaged during installation, "it's done its job and isn't needed anymore." If cracked from aging, "it doesn't perform any electrical function so who cares - and the insulation has much better aging characteristics." Thus EQ testing with intentionally split or ruptured jackets has never been practiced despite our knowing that for bonded materials, a rupture in one may readily propagate into and through the other due to extreme sheer/tensile stresses at the interface. Additionally, for non-bonded jackets and especially multi-conductor cables, a jacket opening allows immediate intrusion of water into and along a cable to spuriously ground or corrode open thin shielding materials or more seriously, if near a connection, may flow into the interiors of connector or equipment with their consequent failure. Again, this writer is not aware of any EQ program for cable/connector or cable/equipment interface qualification where jacket compromise was a given condition of test. Is this not another significant exposure to common cause failures?

4. Mechanical seals to cable for environmental (hermetic) protection of connected equipment. The writer is not currently with all presently installed seal constructions in NPPs but is aware that several gasket types were in use in past years. At that time he made known orally his concerns for the effectiveness of such seals after even a few years of aging. Many different non-adhesive seal constructions used on equipment sensitive to moisture have been found to fail when simply subject to atmospheric level pressure changes. For this reason, <u>any</u> mechanical seal to cable in containment should be suspect after a few years' service and be subject to hermetic verification. Just how to test for hermeticity may be worthy of investigation or research. Other resolution could be to supplement or replace such seals as they are found to exist. As with nonshielded cables, there is no commercial practice available today for ready detection of seal degradation conditions that create potential for common cause failures when exposed to NPP harsh environments.

The present non-testability of many (non-shielded) cables for complete jacket/insulation rupture raises another generic cable system issue which, though not directly EQ-related, does relate to the effectiveness of maintenance/surveillance programs. The problem is that the cable system design does not apparently comply with the single failure design criteria as given in IEEE 379. It seems clear that a nonshielded cable with ruptured insulation and jacket in air (tray) or a dry conduit and with ruptured insulation susceptible to failure in the event of a harsh environment is a classic case of an "identified but nondetectable failure" as used in the SFC text. Have safety system designers assumed all nonshielded cables in harsh environments have failed in analyzing their designs? No. When this question has been raised by the writer several times in the last two decades within small engineering groups, the response has either been silence and a rapid change of subject or an impassioned outburst of (to me) incomprehensible arguments that involved EQ, QA, arm waiving, maintenance, redundancy, etc. Despite requests, I have never received a written response to allow me to consider a response rationally. Is this not a generic cable-related issue affecting safety? Some types of cable jacket failure or installation damage or seal failures as noted above also would impact this SFC issue.

Lastly, the writer would add a post script to the challenge made in his panelists' presentation at the Workshop to focus our constructive attentions on the highest safety priority areas of risk. One means of doing so is to classify safety-related systems and components in degrees of importance - not simply as a single 1E class. Since the workshop, and through the assistance of your John Gallagher, I have viewed a copy of IEC 1226, 2/6/93 Draft International Standard "The Classification of I & C Systems Important to Safety for NPPs." It has subclassified into three categories what in the U.S.A. would all be 1E. Having struggled in this classification issue over a decade ago with John Gallagher, I was delighted to see this impressive step while regretting that the effort had to gel overseas, not here. I fear that the issues noted herein and others discussed at length in the public workshop will likely end in great debates and little action to improve safety post-accident if we continue to look at safety-related cables primarily as all or nothing. If it's too costly, a safety issue becomes a non-issue - safety is "adequate."

Submitted by A. Marion, NUMARC

General

NUMARC commends the NRC staff for its efforts at soliciting industry input and continuing interactions with the industry in implementing the Environmental Qualification (EQ) Task Action Plan (TAP), including the development of the research effort in support of the TAP. We believe that the workshop provided an excellent opportunity for the staff to obtain industry input regarding specific issues involved with EQ of safety-related electric equipment. Based on comments expressed by utility representatives at the workshop, NUMARC would like to provide the following input for consideration by the staff in the development of a research plan.

Extensive discussion occurred at the workshop on four major topics including testing, preaging/preconditioning, operating experience, and condition monitoring. Concerns expressed primarily involved cable performance. Based on these discussions, our comments focus primarily on the following three areas: safety significance of EQ equipment; condition monitoring; and cable performance following prolonged aging.

Potential Research Areas

1. Safety Significance of EQ Equipment

Several comments expressed at the workshop indicated that probabilistic risk (or safety) assessments (PRAs) may be used for identifying the safety significance of EQ equipment, and that PRAs can provide insights on the relative significance of such equipment in the mitigation of or recovery from accidents. These insights may then provide the basis either for investigations to be directed toward equipment that have the most safety significance and identify priorities for further consideration, or for minimizing EQ efforts for non-risk significant equipment. We agree with this concept and suggest that the NRC develop research in the PRA area to evaluate the safety significance of EQ equipment. For example, we believe that existing PRA information contained in utility submittals of Individual Plant Examinations can be used to facilitate this research effort.

Further, since limited data exists on performance of qualified electric equipment in harsh environments due to actual accidents, and since data from operating experience to date are limited to routine operation, we believe that some investigation may be warranted to relate equipment performance in normal plant operation to performance of safety functions during accident situations. We believe that PRAs would be useful in such investigations.

In addition, some discussion occurred at the workshop on failure data recently generated in EQ testing of cables. We note that while a few data points may provide added information on equipment failures in harsh environment for deterministic evaluations, a much larger volume of similar test data (including manufacturers' EQ test) exists where the equipment have performed adequately under harsh conditions. Such data may provide substantial input to the development of a data base eventually necessary to a PRA and relevant information should be gathered.

2. Condition Monitoring

There was substantial discussion at the workshop regarding the expected performance of qualified cables in harsh environments following prolonged aging in service conditions. The NRC's interest in the condition monitoring area appeared to be primarily concerned with the reassurance of cable qualification after a period of service time, and with the degrees of verification of cable condition that can be provided by monitoring techniques. Although we agree that such topics warranted technical interest and discussion, there did not appear to be any identified safety issue in this area.

While we are confident that the use of aging models is adequate to establish qualified life in compliance with regulations, and that existing maintenance and surveillance programs are sufficient for ensuring the continued performance of EQ equipment, we believe that research in the area of condition monitoring may be useful toward developing information for assessing the actual service life of equipment. We believe that the results of such research can be used to quantify the levels of conservatism provided by existing aging qualification techniques.

In particular, we suggest that research be performed to identify monitoring techniques that can provide information on actual equipment conditions following prolonged service in routine plant operation, and that can provide data for specifically quantifying aging qualification conservatisms. However, we see limited value from condition monitoring in directly contributing further toward plant safety, since we believe the existing aging qualification techniques are conservative and adequately comply with regulations. Use of condition monitoring may also allow the extended use of cables, which in some cases may currently have a qualified life of less than 40 years in plant areas with relatively severe normal temperature and radiation environments, due to the conservatisms in the aging qualification techniques. Accordingly, we suggest that the practical benefits of research in this area may be more useful to extending cable life in hot plant areas and to plant life extension rather than safety improvements.

Several monitoring techniques were discussed at the workshop, including some that are being developed and some that are currently available. We believe that the cable indenter technique that was developed in an EPRI effort appears to be a technique that may warrant further development along with others as appropriate. We also suggest that any NRC research into condition monitoring be pursued in cooperation with EPRI so that unnecessary duplication of effort can be avoided.

3. Cable Performance Following Prolonged Aging

Based on discussions at the workshop and on research efforts to date, we believe that there may be some benefit from further research into two specific areas of cable performance in harsh environment. Specifically, we believe that useful information may be generated in the areas of cable performance after prolonged aging in a service environment, and on identifying the impact of bonded jackets on such performance, particularly composite insulations consisting of dissimilar conductor jacket and conductor insulation materials.

More specifically, we note that the NRC aging research program already underway includes investigations into cable performance after prolonged artificial aging, some for more than 40 years of simulated life. Further, we understand the NRC plans to obtain in situ cable samples for testing from plants currently being decommissioned. We support the staff's efforts in this regard, in that cables from different plants can provide a diverse source of samples that represent different aging conditions. We believe that comparison of artificial aging data with cables naturally aged in service at nuclear plants can enhance understanding of actual aging mechanisms. Further, we believe that appropriate research may be useful for determining how cables perform in harsh environments after prolonged in-situ aging in actual plant environments. We also suggest that this research may be suitable as a cooperative effort between the NRC and EPRI.

In addition, we note that cable performance questions had been identified from recent tests conducted for the NRC by Sandia National Laboratories on bonded jacket cables. While we do not believe that the test results to date indicate a significant safety concern, we believe that those results show a need for further research in this area. We therefore support further research to determine the significance of any long term impact from bonded jackets on cable performance in a harsh environment.

Conclusion

In conclusion, NUMARC supports NRC research to investigate specific problems that may challenge the performance of safety-related electric equipment during exposure to design basis accident conditions. We believe this research can be focused in the three following areas: PRA investigations to provide insights on the safety significance of EQ equipment; development of condition monitoring techniques for identifying equipment aging qualification conservatisms; and continued research into cable performance in a harsh environment after prolonged service aging. We appreciate the opportunity to interact with the staff in the development of a research plan.

Submitted by Louis D. Test, Consultant

Regarding Highlight 3 on waiving of enforcement requirements for utilities supplying cable for research; I listened to this during the workshop and could not believe what I was hearing. If operational, real time data shows that our qualification margins or preaging methods were far too conservative, wouldn't the industry expect revisions to standards and regulations to so reflect? I would think so for no other reason than to reduce the cost of replacements and upgrades. One of the major complaints about EQ over the years is that qualification expense precludes modernization. Therefore, if the opposite is true, shouldn't the standards and regulations also be changed? There is ample precedence.

Regarding Highlight 7 on radiation and temperature hot spots; I feel the last sentence of this paragraph should be strengthened. Not being as familiar with plant operating practices as with equipment design and testing, I was surprised to find that there apparently was no requirement to monitor and report on harsh environment operating levels to confirm safety related equipment was not being operated beyond qualified limits. It seems a requirement NRC would have logically imposed and it seems a natural step to be taken by the owner and operator of very expensive equipment. Such a requirement would aid in proving that the present requirements are not only adequate but may be excessively conservative.

Regarding Highlight 12 on sample size; there are additional reasons for limiting the sample size which were considered when IEEE 323 and 344 were written. Aside from the cost of the larger components (motors, generators, large valve operators, etc.) we felt we should take credit for the QA programs (design control, change control, manufacturing QA) to produce sufficiently exact replicas of the tested sample. The "commercial grade" subject caused us worry but that has been covered subsequently by the "dedication" process with which I've had enough experience to believe it works.

Regarding Highlight 14 on validation of the preaging process; In addition, if you can live with the concern that some installations may be jeopardizing the Eq status of equipment by possibly exceeding predicted operating conditions because of the cost of monitoring harsh volumes, then I suggest EPRI monitor selected equipment in many plants to get (as inexpensively as possible) a large data base on real time aging vs currently applied accelerated aging techniques. Spreading the data over many plants would tend to provide a layer of anonymity to the participating plants while giving a broad picture of the technology.

Regarding Highlight 21 on indentor and ECAD testing; I agree with the concept but fail to understand the apparent paranoia that rejects out of hand what might prove to be a cost effective action to not only maintain safety levels but to protect a major investment.

Regarding S. Aggarwal's comment on vendor testing in Section 2.4, Question 5; The comment regarding vendor testing may be accurate in some cases, but my experience differs. It is true that equipment which failed was retested but that is not the whole story. Our EQ program was run in accordance with Appendix B as all such programs have been. Therefore, if there was a failure, the fact was noted in the test report, the test halted until the cause was investigated, and appropriate corrective action taken. If it was determined that a random failure occurred, the test sample could be repaired and the test continued. If a design change was indicated, the test was usually aborted and restarted with an upgraded test sample. I cannot remember any instances where the case described occurred in our program.

Regarding P. Boucher's comment in Section 2.4, Question 11; Paul Boucher's comment is also true for most vendor programs. The program I mentioned above included five plants owned by different utilities with different AEs. Each owner had the AE and plant personnel generate environmental profiles for each piece of equipment in the program. We then had our environmental experts envelope all the inputs for each piece of equipment and we utilized the results in the testing. Needless to say, this resulted in conservatism on conservatism.

Submitted by P. Holzman, STAR

Mr. Thadani's presentation and slides indicate that 84 plants "do not have to consider preaging effects." This statement is factually incorrect and the perception it provides must be corrected. The factually correct statement is:

> All operating nuclear power plants are required to consider the effects of aging during plant operation (preaging) for all equipment within the scope of their 10 CFR 50.49 programs. However, for equipment whose qualification is evaluated under the criteria of NUREG-0588 Cat. II or the DOR Guidelines, regulatory flexibility permits somewhat greater reliance on aging analysis in lieu of qualification test program aging simulations (preconditioning) prior to the accident simulation.

It is also critically important for those reading the proceedings to recognize that, both as a practical matter and per the upgrading provisions of 10 CFR 50.49, the vast majority of currently installed EQ equipment at all plants (including the 60 "DOR Guidelines" plants have had the effects of aging predominantly addressed by aging simulations. This is confirmed by recent survey results provided by NUMARC to the NRC.

Mr. Craig indicates that in the Sandia NPAR program (NUREG/CR 5772) on cables "30% of the cables tested under that program failed" and "some of them failed after 20 years". At a minimum, this appears to be an overstatement of that test's failures. This misconception may be significant since such a view regarding the Sandia test results appears to be part of the NRC's motivation for the EQ TAP and additional cable research. IN 93-33 indicates that out of

128 tested cables, only 8 cables (6.25%) "failed" while 24 (18.75%) exhibited potentially significant low insulation resistance (IR) readings. Even the inappropriate assumption that all these cables constitute failures only results in a 24% "failure" value.

Importantly, the IR data for 11 of the 24 "low IR" cables are virtually identical to the IR data currently used by the industry and developed by the manufacturers during their qualification tests. These results can hardly be viewed as test failures or EQ issues since they confirm existing qualification conclusions and were already considered in licensees' cable applications. Similarly, 3 of the 8 cable failures (as defined in IN 83-33) involved Kapton insulated specimens. Sandia notes (see NUREG/CR 5772 Vol. 3, pg. 39) that all 3 exhibited abnormal properties during aging and were damaged during the testing program's installation or handling activities. The appropriate elimination of all these 14 cables from the "failure" category reduces the failure value to 14%. If one also removes the remaining 13 specimens with low IRs from the "failure" category, then the "failure" percentage decreases to less than 4% of the specimens. Importantly, all these 13 "low IR" specimens were the same cable style supplied by a single manufacturer and the EQ impact, if any, of the low IRs is likely limited to a few instrument circuits in some plants. Regarding the remaining 5 non-Kapton failures, 4 occurred for the specimens subject to the 60 year aging program. The remaining single failure occurred during the 20 year program.

I suggest that the NRC clarify the basis for the "30% failure" statement and indicate that the percentage of specimens considered as failures can vary widely (e.g., 4% to 24%) depending on the performance criteria applied.

Submitted by W. Fargo, Pacific Gas and Electric Co., Diablo Canyon

The overhead slide presented by A. Thadani on "Comparison of EQ Requirements" is very misleading and can easily be misinterpreted. This slide identifies the minimum level of qualification required by original licensees. It is used elsewhere in the NUREG as a basis to state that 86 operating reactors (OR) have not addressed preaging of test specimens in implementation of 50.49. This outdated perception is not accurate. Diablo Canyon is licensed to NUREG-0588, Category II and is therefore two of those 86 ORs. Yet, ~ 95% of our EQ files document qualification to Category I of NUREG 0588 and include preaging of the test specimens.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

Questions concerning the Environmental Qualification (EQ) of electrical equipment used in commercial nuclear power plants have recently become the subject of significant interest to the U.S. Nuclear Regulatory Commission (NRC). Initial questions centered on whether compliance with the EQ requirements for older plants were adequate to support plant operation beyond 40 years. After subsequent investigation, the NRC Staff concluded that questions related to the differences in EQ requirements between older and newer plants constitute a potential generic issue which should be evaluated for backfit, independent of license renewal activities.

EQ testing of electric cables was performed by Sandia National Laboratories (SNL) under contract to the NRC in support of license renewal activities. Results showed that some of the environmentally qualified cables either failed or exhibited marginal insulation resistance after a simulated plant life of 20 years during accident simulation. This indicated that the EQ process for some electric cables may be non-conservative. These results raised questions regarding the EQ process including the bases for conclusions about the qualified life of components based upon artificial aging prior to testing.

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