NUREG/CR-6704, Vol. 2
BNL-NUREG-52610

Assessment of Environmental Qualification Practices and Condition Monitoring Techniques for Low-Voltage Electric Cables

Condition Monitoring Test Results

Brookhaven National Laboratory

**U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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Condition Monitoring Test Results

Manuscript Completed: December 2000
Date Published: February 2001

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NRC Job Code W6465

ABSTRACT

This report documents the results of a research program addressing issues related to the qualification process for low-voltage instrumentation and control (I&C) electric cables used in commercial nuclear power plants. Three commonly used types of I&C cable were tested: Cross-Linked Polyethylene (XLPE) insulation with a Neoprene® jacket, Ethylene Propylene Rubber (EPR) insulation with an unbonded Hypalon® jacket, and EPR with a bonded Hypalon® jacket. Each cable type received accelerated aging to simulate 20, 40, and 60 years of qualified life. In addition, naturally aged cables of the same types were obtained from decommissioned nuclear power plants and tested. The cables were subjected to simulated loss-of-coolant-accident (LOCA) conditions, which included the sequential application of LOCA radiation followed by exposure to steam at high temperature and pressure, as well as to chemical spray. Periodic condition monitoring (CM) was performed using nine different techniques to obtain data on the condition of the cable, as well as to evaluate the effectiveness of those CM techniques for in situ monitoring of cables.

Volume 1 of this report presents the results of the LOCA tests, and Volume 2 discusses the results of the condition monitoring tests.

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EXECUTIVE SUMMARY

As a licensing requirement for commercial nuclear power plants, electric equipment important to safety must be qualified for use in a harsh environment. Environmental qualification (EQ) requirements have evolved over the years, becoming more strict as new knowledge was gained about the aging process. The current requirements for qualification are specified in the Environmental Qualification Rule, which is documented in Title 10 of the Code of Federal Regulations, Part 50, Section 49 (10 CFR 50.49).

During a review of EQ requirements to address issues related to license renewal, questions arose as to the technical bases for allowing plants to have equipment qualified to different requirements. In addition, research in which certain types of cable failed loss-of-coolant-accident (LOCA) tests raised questions about their qualification. As a result, the issues related to EQ requirements were identified as Generic Safety Issue (GSI) 168, and a task action plan was developed to resolve them.

In support of the task action plan on EQ, and for the resolution of GSI-168, the NRC's Office of Nuclear Regulatory Research (RES) sponsored the research reported herein to resolve issues related to the process used for environmental qualification of certain electric components used in commercial nuclear power plants. Brookhaven National Laboratory (BNL) was selected as the lead laboratory to assist the RES. The initial focus of this program was on low-voltage electric cables used for instrumentation and control (I&C) applications, which is the subject of this report.

The objective of this research program was to provide information to help resolve specific issues related to the EQ process for low-voltage I&C electric cables. Initially, a comprehensive list of 43 issues was developed. Based on a thorough review and analysis of the literature, 24 issues were resolved by considering past research results, and 19 issues remained unresolved. Of the latter, six issues were identified that required additional analysis and testing of cables to resolve. These issues are summarized as follows:

- How do the properties of cables subjected to accelerated aging techniques used in the original qualification compare with the properties of naturally aged cables of equivalent age?
- What are the limitations in using an estimated value of the activation energy to predict the chemical degradation during thermal aging?
- Do multiconductor cables have different failure mechanisms than single conductor cables, and, if so, are these unique failure mechanisms properly accounted for in the qualification process?
- Do bonded jacket cables have different failure mechanisms than unbonded jacket cables, and, if so, are these unique failure mechanisms properly accounted for in the qualification process?
- Are there any effective condition monitoring techniques for determining cable condition in situ?
- Can condition monitoring techniques be used to predict LOCA survivability?

In addition to the six issues for which new testing was undertaken, six issues were categorized as unresolved with no further research recommended, and seven were identified for which the new information from the tests might help resolve. The later seven relate to addressing hot spots, impingement, physical damage, and improper installation in the qualification process. Also, the information gained from the new testing might help resolve issues related to extending the qualified life of I&C cables to 60 years.

To provide information that will assist in resolving the EQ issues of interest, the following three types of I&C electric cables commonly used in commercial nuclear power plants were tested:

- Cross-Linked Polyethylene (XLPE) Insulation with Neoprene® jacket,
- Ethylene Propylene Rubber (EPR) Insulation with unbonded Hypalon® jacket, and
- EPR Insulation with bonded Hypalon® jacket.

Testing was performed on unused cables that had undergone accelerated aging to simulate 20, 40, and 60 years of qualified life based on their original qualification parameters. Naturally aged cables from two nuclear power plants also were included. For comparison, unaged cable of the same type as the naturally aged cables received accelerated aging, using currently accepted accelerated-aging models, to match the service conditions to which the naturally aged cables had been exposed. Cables with no pre-aging were also included in all of the tests as controls. Six pre-aging/LOCA test sequences were performed to address the six EQ issues of interest. The performance results of the cables during the LOCA tests are reported in Volume 1 of this report.

Hold points were incorporated into the program to monitor the condition and performance of the cables at preselected points throughout the pre-aging and LOCA testing process. Various condition monitoring (CM) techniques were used at each hold point to obtain data on the cables, as well as to evaluate the effectiveness of those CM techniques for monitoring cable condition. Elongation-at-break (EAB) was used as a reference CM technique, against which other techniques were compared and correlated. The findings of this evaluation are reported in Volume 2 of this report.

Conclusions on EQ Issues:

Based on the results of the testing, the following conclusions are drawn:

Accelerated Aging Techniques:

- The data obtained suggest that the accelerated aging predictions using the Arrhenius model for thermal aging, with limitations, and the equal-dose/equal-damage model for radiation aging provide adequate estimates of the degradation experienced due to actual service aging. In six-out-of-six cases, material that received accelerated aging had a lower EAB, indicating more degradation than naturally aged material of equivalent age. Also, as the duration and severity of the natural aging simulated increased, the difference in degradation simulated by the models also increased. These results suggest that currently accepted artificial aging techniques provide conservative estimates of service aging, however, the limitations in the assumptions made, along with uncertainties in the data available, prevent a definitive conclusion from being drawn regarding the accuracy of the aging models.

Activation Energies:

- The data from these tests demonstrate that, for the two cable insulation materials tested, the activation energies used in the original qualification tests were representative of the materials being tested.

Multiconductor Cables:

- Test results show that differential swelling of jacket and insulation materials due to moisture absorption can occur during a LOCA. This phenomenon can contribute to rupture or cracking of the materials during steam exposure. If the insulation on the conductors of a multiconductor cable expands faster and to a greater degree than the outer jacket, the resulting stresses imparted on the outer jacket may be significant enough to cause it to rupture. While these results might suggest a potential common cause failure for multiconductor cables, it must be noted that, of the 15 cables pre-aged to 40 years and LOCA tested, 3 experienced performance anomalies that could impact their safety function.

Bonded Jacket Cables:

- The results of this study demonstrate that the bonded jacket/insulation configuration has a potential for catastrophic failure under LOCA conditions. This catastrophic failure can occur if the composite bonded jacket/insulation is first exposed to severe aging conditions, causing it to embrittle and shrink significantly, prior to its sudden exposure to steam. The steam causes swelling stresses that can initiate failure. While this phenomenon was observed for single conductor bonded jacket cables from one manufacturer in this program, it could be problematic for similar cables from other manufacturers.

Extending Qualified Life:

- The results indicate that degradation due to aging beyond the qualified life of the cables, based on extrapolation of the aging parameters used in the original qualification to a 60 year service life, may be too severe for the insulation material to withstand and still be able to perform adequately during a LOCA. For life extension purposes, the aging protocols used to establish the qualified life of the cables should be reviewed and compared to actual service environments in a plant. A determination then can be made as to whether the additional exposure to aging stressors during a period of extended operation will be acceptable for the cable materials.

Observations:

From the results of the tests, the following observations are made regarding the qualification process for electric cables:

- The currently accepted standards for qualifying various configurations of cable based on similarity to cables of the same material or construction that have already passed qualification type tests should be re-evaluated. Specifically, cables that are being qualified for use in applications requiring a multiconductor configuration should be tested in a multiconductor configuration. Similarly, cables with bonded individual jackets should be type tested in the configuration for which they are being qualified. The similarity argument may not be appropriate in all cases.

- Consideration should be given to developing more definitive acceptance criteria for determining if a cable passes a qualification type test. Currently, the qualification test results are analyzed to determine if the cable is qualified for its particular application. Typically, as long as one cable specimen passes the mandrel bend/submerged voltage withstand test at the end of the type test, and all other anomalies are determined not to be caused by global degradation of the insulation, the cable can be considered qualified. Guidance should be provided in qualification standards for the number of data points required, the number of permissible cable failures during the qualification test and how they should be addressed, and the required statistical confidence level to consider a cable qualified.

- Test sequence 5 indicated that cables with a composite EPR insulation with bonded CSPE individual jackets may exhibit catastrophic failure under LOCA conditions if they previously were exposed to severe aging, causing them to become brittle and shrink. Additional research is recommended to quantify the degree to which this type of cable can be aged before its ability to function during a LOCA is compromised. The research should determine if this observation is specific to the materials and construction of the cables of the one manufacturer for which it was observed, or if the phenomenon is generic to all cables of this construction.

- In thermally aging cables with a bonded CSPE individual jacket, consideration should be given to using an activation energy representative of the CSPE since it appears to dominate the failure mechanism for this type of cable.

- For safety-related cables, the electrical performance during accident peak conditions is a critical criteria for establishing qualification. However, current qualification standards do not provide any guidance on what electrical characteristics should be monitored or the frequency at which data should be obtained. Consideration should be given to including this information in the qualification standards (e.g., IEEE Std. 383).

- During the testing performed in this program, problems were observed on multiple occasions with moisture intrusion into splices applied to cables that had undergone preaging. In all cases, the cable jackets were degraded and cracked due to the preaging, and the moisture intrusion lead to a deterioration of cable performance. On the basis of these results, consideration should be given to evaluating the condition of a cable and developing an acceptance criterion prior to allowing the application of splices.

- For the Samuel Moore bonded jacket cables tested in this program, localized failures were observed on several of the test specimens after preaging to simulate 40 and 60 years of service, followed by simulated accident testing. While global degradation was not noted for these cables, the localized failures do raise uncertainties related to the accident performance of these cables after being in service for extended periods. On the basis of these results, consideration should be given to identifying and closely monitoring localized adverse environments in plants, and performing condition monitoring of electric cables located in those areas.

Conclusions on Cable Condition Monitoring Techniques:

It should be noted that most of the condition monitoring (CM) data evaluated in this study were obtained in a laboratory setting; therefore, conclusions regarding the application of the techniques in an actual plant setting cannot be drawn from this work. Additional testing is warranted to determine the impact of plant operating environments and logistics on the feasibility of performing these techniques in situ.

Eleven testing techniques were used throughout this research program. Nine were evaluated as potential methods for use as in situ condition monitoring techniques directly on plant cables or on in-plant sacrificial cable specimens. The remaining two techniques, the functional performance test and the post-LOCA voltage withstand test, were designed primarily to monitor cable performance during and after the LOCA exposure test. The effectiveness of each of the techniques for in situ CM is summarized below.

Visual Inspection:

- Based on the results of this study, visual inspection should be considered for inclusion in any cable CM program. While it does not provide quantitative data, it does provide useful information on the condition of the cable that is easy and inexpensive to obtain and that can be used to determine if further investigation of the cable condition is warranted. A significant limitation of this technique is that the cable must be visually accessible.

Elongation-at-Break (EAB):

- Elongation-at-break was found to be a reliable technique for determining the condition of the polymers studied. It provides trendable data that can be directly correlated with material condition. It is useful as a reference technique; however, its destructive nature prevents it from being used as an in situ means of monitoring electric cables unless sacrificial cable specimens are available.

Oxidation Induction Time (OITM):

- OITM was found to be a useful technique for monitoring the condition of electric cables. Results show that aging degradation can be trended with this technique for both XLPE and EPR insulation. Since a small sample of cable material is needed to perform this test, OITM is considered an effective in situ technique.

Oxidation Inducution Temperature (OITP):

- While it is related to OITM, OITP was found to be less sensitive to the detection of aging degradation for the polymers studied. It can be considered an in situ technique; however, OITM is preferred at this time.

Fourier Transform Infrared Spectroscopy (FTIR):

- FTIR was found to provide inconclusive results in terms of its ability to trend aging degradation in the polymers studied. Although the results show a consistent trend with aging, the technical basis for the trend remains questionable. Further research is warranted on this technique; however, it is not currently considered effective as an in situ technique for monitoring cable degradation.

Indenter:

- The indenter was found to be a reliable device that provided reproducible, trendable data for monitoring the degradation of cables in situ. While it is limited to accessible sections of cables, it was found to be effective for monitoring the condition of some cable jacket and insulation materials. Therefore, the indenter is considered an effective in situ technique for monitoring low-voltage electric cables.

Hardness:

- This technique was evaluated since it is a simple, inexpensive technique to perform. The results indicate that, over a limited range, the hardness can be used to trend cable degradation. However, different probes must be used to accommodate the change in material hardness. Also, puncturing of the cable insulating material is a potential concern with this technique. This technique is not considered to be effective as an in situ CM technique.

Dielectric Loss:

- This technique was found to provide useful data for trending the degradation of cable insulation. As the cables degrade, a definite change in phase angle can be detected at various test frequencies that can be correlated to cable condition. This technique is considered effective as an in situ CM technique.

Insulation Resistance:

- This technique was found to provide useful data for trending the degradation of cable insulation. As the cables degrade, a definite change in insulation resistance can be detected that can be correlated to cable condition. Using 1-minute and 10-minute readings to calculate a polarization index enables the effects of temperature and humidity variations to be accounted for. This technique is considered effective as an in situ CM technique.

Functional Performance:

- The use of functional performance data as a means of monitoring the condition of electric cables was evaluated since it is a simple, inexpensive technique to perform. While useful information can be obtained to determine if further CM is needed, this technique alone does not provide sufficient data to determine the degraded condition of a cable. This technique is not considered effective for in situ trending of degraded cable condition.

Voltage Withstand:

- This technique is performed as part of the currently accepted qualification process to determine the ultimate condition of the cables under test. At high voltage levels it is a potentially destructive technique that can impart damage to the cable due to the high voltage used. At low voltage levels, the technique can be non-destructive, however, its effectiveness is undetermined. It is not considered effective as an in situ condition monitoring technique.

Conclusions on the Use of CM to Predict LOCA Survivability

On the basis of this study it is concluded that no single, non-intrusive, cost effective, currently available CM method alone can be used to predict the survivability of electric cables under accident conditions. A plant instrumentation and control circuit may traverse a number of environments and localized conditions along its length. Many condition monitoring techniques are localized indicators of condition at the specific location along a cable circuit where the measurement is made. The criteria used to define survivability for a particular safety-related circuit are application-specific. Consequently, engineering judgements concerning the integrity and soundness of an electric cable must be made by experienced personnel based upon several condition monitoring tests, including visual, electrical, physical and chemical techniques. A suite of such condition monitoring tests, with periodic measurements referenced to baseline values, may then be used to make survivability assessments.

ACKNOWLEDGMENTS

The authors wish to thank the NRC Program Manager, Satish Aggarwal, for his technical guidance in the performance of this research program and in the review of this document. We would also like to thank Jit Vora of the NRC, along with Robert Hall and John Taylor of Brookhaven National Laboratory for their technical review and comments on this and past documents, as well as their managerial direction and support, which enabled the successful completion of this program.

Special thanks and acknowledgments are extended to Sal Carfagno, formerly of Franklin Institute Research Laboratory, Jim Gleason of GLS Enterprises, and Don Stonkus of DJS Associates for their numerous consultations, insights on past practices, and input in the development of test plans and interpretation of results. Their assistance was instrumental in the successful completion of this test program and is greatly appreciated.

The authors also wish to thank Louis Gerlach for providing timely and high quality support on the preparation of test specimens, as well as for setting up and maintaining the test laboratory and his assistance in performing the cable tests.

Our appreciation is also extended to the various members of the BNL staff who provided support to the program over the years, including Jay Adams, Biays Bowerman, Richard Deem, Victor Gutierrez, Don Horn, Sonny Kasturi, Bom Soon Lee, Mano Subudhi, and Helen Todosow and the staff of the Research Information Resources Library. We also thank David Diamond and Avril Woodhead for their review of this report.

We would also like to acknowledge the contributions made by the various students that provided support on this program, including Colleen Nathan, Sadia Hameedi, Jason Sese, Victor Gao, Un Mei Pan, Carmen Jenkins and Suly Palacio.

We also thank Susan Signorelli and Jean Frejka for their assistance in the preparation of this document, along with Patricia Van Gurp and Janice De Pass for their assistance in the preparation of past reports.

The authors also thank the staff of Wyle Laboratories, Huntsville, Alabama for their excellent support in the performance of the aging and LOCA testing of the cable specimens, including Bobby Hardy, the LOCA Testing staff, Don Smith and Claude Thibault.

Our appreciation is also extended to the staff of the Georgia Institute of Technology, Neely Research Center for the successful irradiation of the test specimens, including Peter Newby, Dwayne Blaylock, Rodney Ice, Ratish Karam and Nolan Hertel.

ABBREVIATIONS

BNL	Brookhaven National Laboratory
CM	Condition Monitoring
CSPE	Chloro-Sulfonated Polyethylene (also known as Hypalon®)
DBE	Design Basis Event
DOR	U.S. NRC, Division of Operating Reactors
EPDM	Ethylene Propylene Diene Monomer
EPR	Ethylene Propylene Rubber
GPM	Gallons Per Minute
EQ.	Environmental Qualification
I&C	Instrumentation and Control
IE	Inspection and Enforcement
LOCA	Loss of Coolant Accident
NRC	U.S. Nuclear Regulatory Commission
PSIG	Pounds per Square Inch Gauge
QA	Quality Assurance
RES	U.S. NRC, Office of Nuclear Regulatory Research
XLPE	Cross-Linked Polyethylene
XLPO	Cross-Linked Polyolefin

1. INTRODUCTION

1.1 Background

As a licensing requirement for commercial nuclear power plants, safety-related electric equipment must be qualified for use in a harsh environment. Environmental qualification (EQ) requirements have evolved over the years, starting with the U.S. Nuclear Regulatory Commission (NRC) Division of Operating Reactors Guidelines for Environmental Qualification of Class 1E Equipment (DOR Guidelines), which were issued as part of Inspection and Enforcement (IE) Bulletin 79-01B. These were followed by NUREG-0588 requirements (Szukiewicz, 1979) which essentially established two categories of qualification, one for older plants and one for newer plants. The current requirements for qualification are specified in the Environmental Qualification (EQ) Rule, which is documented in Title 10 of the Code of Federal Regulations, Part 50, Section 49 (10 CFR 50.49). As knowledge was gained in the area of equipment aging, the EQ requirements were modified to reflect this new knowledge, and, in general, became more stringent. As an example, early EQ requirements did not specifically call for equipment to receive accelerated aging to reflect its end of qualified life condition prior to being tested, whereas the current requirements do.

During a review of qualification requirements to address issues related to license renewal, questions arose as to the technical bases for allowing plants to have equipment qualified to different standards. In addition, testing in which certain cable types failed LOCA tests raised questions related to the qualification of these cable types. As a result, the issues related to EQ requirements were identified as Generic Safety Issue 168, and a task action plan was developed to resolve them.

In support of the task action plan on EQ, the NRC's Office of Nuclear Regulatory Research (RES) has sponsored research to resolve issues related to the process used for the qualification of certain electric components used in commercial nuclear power plants. Brookhaven National Laboratory (BNL) was selected as the lead laboratory to assist RES in this effort. The initial focus of this program was on low-voltage electric cables used for instrumentation and control (I&C) applications. This report focuses on the research results specifically for I&C cables.

1.2 Program Objective

The objective of this research program was to provide information to help resolve issues related to the EQ process for low-voltage I&C electric cables. Initially, a comprehensive list of issues of interest was developed based on a workshop held in November 1993. At this workshop, national and international experts in the area of cable qualification participated in technical discussions and provided their insights on specific topics related to cable qualification that should be addressed. The results of this workshop are documented in NUREG/CP-0135 (Lofaro, et al., 1993). Using the information obtained at this workshop, a total of 43 issues related to the EQ process were identified.

Subsequent to this workshop, a thorough literature review and analysis was performed in an attempt to resolve as many of the issues as possible using prior research results before resorting to new cable testing. The literature review and analysis, which is documented in NUREG/CR-6384, Volume 1 (Subudhi, 1996) and Volume 2 (Lofaro, 1996), along with BNL Technical Report TR-6169-9/97 (Lofaro, 1998), categorized each of the issues and was very successful at resolving many of them. The results were as follows:

Category 1:	Resolved by past work; no new research recommended	24 issues
Category 2:	Unresolved by past work; no new research recommended	6 issues
Category 3:	Unresolved by past work; new research recommended	6 issues
Category 4:	Unresolved by past work; no new research recommended but may be addressed by work performed on other issues.	7 issues

As noted, 24 issues were resolved by reviewing and analyzing past research results, and 19 issues remained unresolved. Of those issues that were unresolved, six issues (Category 3) were identified that required additional cable testing to resolve. These issues are summarized as follows:

- How do the properties of cables subjected to accelerated aging techniques used in the original qualification compare with the properties of naturally aged cables of equivalent age?
- What are the limitations in using an estimated value of the activation energy to predict the chemical degradation during thermal aging?
- Do multiconductor cables have different failure mechanisms than single conductor cables, and, if so, are these unique failure mechanisms properly accounted for in the qualification process?
- Do bonded jacket cables have different failure mechanisms than unbonded jacket cables, and, if so, are these unique failure mechanisms properly accounted for in the qualification process?
- Are there any effective condition monitoring techniques for determining cable condition in situ?
- Can condition monitoring techniques be used to predict LOCA survivability?

In addition to the six issues for which new testing was performed, the literature review identified seven issues which the information gained from the new testing might help to resolve. These issues relate to addressing hot spots, impingement, physical damage and improper installation in the qualification process. Also, it was felt that the information gained from the new testing might help resolve issues related to extending the qualified life of I&C cables.

To facilitate future literature reviews on this or related subject areas, a computerized database was developed by BNL as part of this effort. In this database, each document reviewed is listed, along with publication information and a summary of the information included in the document. The database, along with a user's manual for the database, is available in BNL Technical Report TR-6169-06-96 (Hsu, 1998).

1.3 Research Approach

To provide information that would assist in the resolution of the six EQ issues of interest, BNL designed a research program in which three types of I&C electric cables commonly used in commercial nuclear power plants were tested. The cable types tested are:

- Cross-Linked Polyethylene (XLPE) Insulation with Neoprene® jacket,
- Ethylene Propylene Rubber (EPR) Insulation with unbonded Hypalon® jacket, and
- EPR Insulation with bonded Hypalon® jacket

These cable types were selected for study since they represent the most popular types of in-containment cables currently used in U.S. commercial nuclear power plants. In a study performed by EPRI (1994), it was found that approximately 89 percent of the currently operating plants in the U.S. had cables with XLPE insulation in containment, and approximately 73 percent had cables with EPR insulation. Other insulation materials used to a lesser degree in containment are silicone rubber (27 percent), chloro-sulfonated polyethylene (24 percent), ethylene tetrafluoroethylene copolymer (15 percent) and polyvinyl chloride (6 percent).

Testing for the research program reported herein was performed on unused cables that received accelerated aging to simulate 20, 40, and 60 years of qualified life based on their original qualification parameters. Naturally aged cables from two nuclear power plants were also tested. As a comparison, unaged cable of the same type as the naturally aged cables received accelerated aging, using currently accepted accelerated aging models, to match the service conditions to which the naturally aged cables were exposed. Unaged cables with no pre-aging were also included in the tests as controls.

The BNL test program was structured such that selected unaged cable specimens first received accelerated thermal and radiation aging to the desired equivalent qualified life, then they were exposed to high radiation doses followed by high temperature and high pressure steam and chemical spray, which simulated the first 7 to 10 days of a design basis loss-of-coolant-accident (LOCA). Unaged and naturally aged cables were also exposed to the same LOCA simulations, after which comparisons were made of their physical properties. Both the accelerated aging and LOCA simulation were performed in accordance with IEEE Standard 323-1974, which is the standard endorsed by the NRC in Regulatory Guide 1.89 to qualify Class 1E electric equipment for use in harsh environments in commercial nuclear power plants. The accelerated aging parameters were chosen to match those used in the original qualification of the cables.

Hold points were incorporated into the program to allow the condition and performance of the cables to be monitored at preselected intervals throughout the pre-aging and LOCA testing process. Various condition monitoring (CM) techniques were used at each hold point to obtain data on the cables, as well as to evaluate the effectiveness of those CM techniques for monitoring cable condition. Elongation-at-break (EAB) was used as a reference CM technique, against which other techniques were compared and correlated. The preliminary pre-aging/LOCA test plan is described in BNL Technical Report TR-6168/69-04-95 (Villaran, 1996). The preliminary condition monitoring research plan is described in BNL Technical Report TR-6168/69-03-95 (Lee, 1996).

Six pre-aging/LOCA test sequences were performed to address the six EQ issues of interest. In each sequence, one or more of the three cable types being studied were tested. Condition monitoring measurements were made at preselected hold points, after which the aging/LOCA testing continued, as appropriate. The CM data obtained were used to determine the condition of the cable, as well as to evaluate the CM techniques being studied. The objectives of each test sequence are presented in Table 1.1.

The pre-aging/LOCA testing parameters varied for each type of cable tested, however, each was based on the original qualification test for the cable being tested. In tests where more than one type of cable was tested, the cables were pre-aged separately, when necessary, to allow using parameters consistent with their original qualification. The LOCA test profile was selected to envelop the profiles used in the original qualification for all cables in the test. Sequential pre-aging was used with thermal aging preceding radiation aging. The LOCA tests were also performed sequentially with LOCA radiation preceding steam exposure.

Throughout this research program, periodic public meetings were held to obtain industry input and insights on the testing being performed, and to disseminate the results being obtained. Each of the program plans and test reports was made available for public review and comment. Test results were presented and discussed as they were obtained, and insights gained were incorporated into subsequent tests, as appropriate.

Table 1.1 Objectives of the six test sequences

Test Objectives	Test Sequence					
	1	2	3	4	5	6
Primary Objectives						
1. Evaluate pre-aging techniques by comparison of artificially aged cables with naturally aged cable	X	X	X			
2. Determine if any unique failure mechanisms exist for multiconductor cables as compared to single conductor cables.				X		
3. Determine if any unique failure mechanisms exist for bonded jacket cables as compared to unbonded jacket cables.					X	
4. Evaluate the effectiveness of promising cable condition monitoring techniques and determine if they can be used to predict LOCA survivability.	X	X	X			X
Secondary Objectives						
5. Provide information related to cable performance during the period of extended service past 40 years.						X
6. Provide confirmatory information on the qualification basis for the cables tested.			X	X	X	

Note: LOCA testing was not required to address the issue related to activation energies, as discussed in Section 3.7 of this report.

1.4 Quality Assurance

To ensure that the results of this research are traceable and defensible, a Quality Assurance (QA) program was developed by BNL. The BNL QA program is based on the requirements specified in Title 10, Part 50, Appendix B of the Code of Federal Regulations (10 CFR 50, Appendix B). All work was performed under this QA program, which required the development and approval of detailed test procedures for all testing activities, as well as periodic audits, both by BNL staff and by NRC. Work performed by subcontractors to BNL was also performed according to these QA requirements. The BNL QA plan is described in BNL Technical Report TR-6169-05-95 (Grove, 1996).

The results of test sequences 1 through 3 are reported in a series of interim BNL technical reports (Lofaro, et al. 1998B, 1998C, 1999A, 1999B), while those for tests 4 and 5 are documented in letter reports (Lofaro, 2000A, B). This final program report, which is comprised of two volumes, combines the results of all test sequences to provide information and draw conclusions that can be used to help resolve the issues discussed in Section 1.2. The results of the LOCA tests are presented in Volume 1 of this report. The results of the CM techniques evaluated in the program are discussed in Volume 2.

2. TESTING PROTOCOL

2.1 Cable Test Specimens

As previously discussed, this research effort involved testing of both unaged and naturally aged cable specimens, which were obtained from decommissioned nuclear power plants. There are many factors which influence the acquisition of cable samples, including cable type, installation, configuration, degree of aging, and jacket and insulation materials. Once the cables were selected, special handling precautions were implemented to insure no damage occurred to the cables during removal and testing. Also, an identification system was developed to uniquely identify each cable specimen and maintain traceability throughout the testing process. A Cable Acquisition Plan (Deem, 1995) was prepared to identify the cable types of interest, as well as the steps and precautions to be taken to mitigate handling damage to the samples during removal and transport.

2.1.1 Acquisition of Cable Samples

During the initial phases of the acquisition process, many nuclear power utilities were contacted to determine cable availability and their willingness to supply cables for this program. Naturally aged cables were requested, along with unaged cable of the same type and manufacturer, if available. Detailed plant information on the service environment seen by the naturally aged cables was also requested. Once a plant indicated a willingness to supply cables, meetings were held with utility representatives to review the types of cables available, and the environmental data available for the cables. By contacting numerous sources, BNL was successful in obtaining sufficient lengths of both unaged and naturally aged cables to meet the program objectives.

In obtaining cables from the plants, candidate cables were first identified from a review of the plant database, then located in a plant walk-down to assess the location and physical installation characteristics. Installation characteristics of interest included installation method (trays or conduits), location (potential hot spots), bends and overhangs. Special attention was given to selecting cables from areas where ambient data were available (temperature, humidity, and radiation).

Emphasis was also placed on obtaining cables from severe environmental stress areas, such as locations within the bio-shield (i.e., close vicinity to reactor coolant pumps, pressurizers, steam generators, etc.). Plant files, including EQ documentation, maintenance work requests and radiation survey reports for the candidate cable locations, were reviewed to obtain historical data on the cables. Specific information of interest included the original purchase specifications, manufacture and installation date, environmental data, and initial EQ test reports.

In addition to obtaining naturally aged cables, unaged cables of the same specifications (manufacturer, material) were also obtained from the plants. These cables were used for comparative analysis with the naturally aged specimens. Typically, these cables were obtained from warehouse stock, or mild environment areas (i.e., computer rooms, cable spreading rooms, control room).

To ensure that the cables selected for removal from the plant site were in good condition initially and after removal, in situ insulation resistance (IR) tests and visual examinations were conducted before and after the removal process. Once the acceptability of the cables was established, special precautions were taken to minimize the physical handling of the cables. The cable tray (or conduit) containing the desired cables was cut and removed as a unit. Following transfer to a lay-down area, the tray (or conduit) was carefully removed from around the cable, as opposed to physically pulling the cable. In addition to protecting the cable from physical damage, this also maintained the as-installed configuration. Procedures for cleaning and bagging the cables were also implemented.

Depending upon the cable (unaged or naturally aged), different types of packaging were utilized to protect the cables during transport between the plant site and BNL. Naturally aged cables which were installed in a straight configuration were transported in PVC tubes which were capped at both ends. Naturally aged cables with bends were attached to sheets of plywood to immobilize them and maintain their installed configuration, then placed in wooden crates to protect them during shipping (Figure 2.1). Unaged cables were coiled according to acceptable handling practices, and shipped in barrels, crates, or on pallets. Prior to removal from the plant site, each cable was radiologically surveyed to detect any fixed or loose contamination.

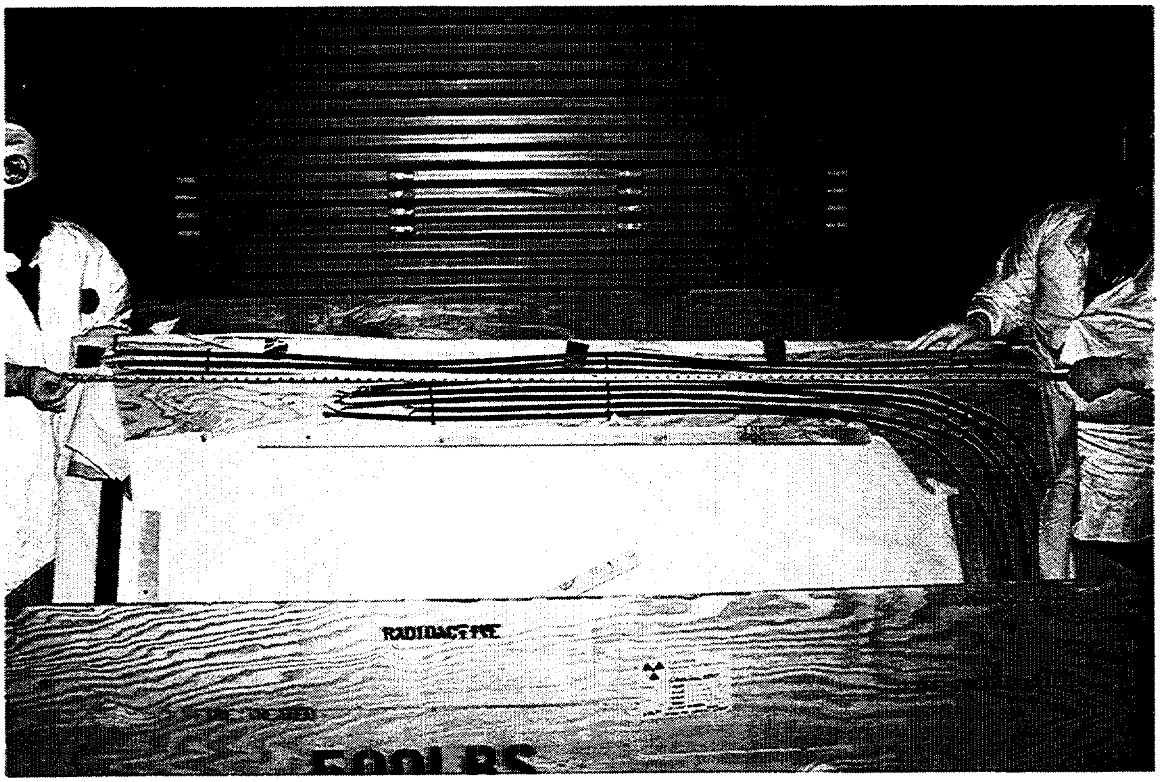

Figure 2.1 Naturally aged cables installed on plywood boards to protect them during shipping

Transportation between plant sites and testing facilities was accomplished using dedicated shippers. This minimized the required handling, and ensured that the cables were protected from damage or exposure to adverse environmental conditions.

Upon receipt at BNL (or the test site), the cable samples were inspected to ensure that there were no visible signs of damage. They were then unloaded, inventoried, and placed in a secure storage area. The temperature and humidity in the storage area were monitored continuously using a calibrated chart recorder to verify that moderate storage conditions were maintained to protect the cables from adverse environmental conditions.

In addition to the cables obtained from decommissioned plants, several cable types were acquired from Sandia National Laboratories to address two specific issues in the program. These cables, manufactured by Okonite and Samuel Moore, had been tested by Sandia in previous research programs and had exhibited performance anomalies. Samples from the same lots tested by Sandia were obtained to re-evaluate the anomalies experienced in past tests.

The cables tested in each of the six LOCA test sequences are listed in Table 2.1.

Table 2.1 Cable types used in each test sequence

Cable Manufacturer	Cable Type	Cable Description	Test Sequence					
			1	2	3	4	5	6
Rockbestos	I&C	• 2/C #14 AWG Firewall® III • 30 mil XLPE insulation • 45 mil Neoprene® overall jacket • 600 V	X		X			X
		• 3/C #16 AWG Firewall® III with ground • 30 mil XLPE insulation • 45 mil Neoprene® overall jacket • 600 V	X		X			
American Insulated Wire (AIW)	I&C	• 3/C #16 AWG with ground • 30 mil EPR insulation • 15 mil CSPE unbonded individual jacket • 45 mil CSPE overall jacket • 600 V		X				X
		• 4/C #16 AWG with ground • 30 mil EPR insulation • 15 mil CSPE unbonded individual jacket • 45 mil CSPE overall jacket • 600 V		X				X
Anaconda	P	• 3/C #12 AWG • 30 mil EPR insulation • 15 mil CSPE unbonded individual jacket • 45 mil CSPE overall jacket • 1,000 V				X	X	
		• 1/C #12 AWG • 30 mil EPR insulation • 15 mil CSPE unbonded individual jacket • 1,000 V				X		
Samuel Moore	I&C	• 2/C #16 AWG with shield and ground • 20 mil Dekoron® (EPDM) insulation • 10 mil Dekorad® (CSPE) bonded individual jacket • 45 mil Dekorad® (CSPE) overall jacket • 600 V				X	X	X
		• 1/C #12 AWG with shield and ground • 20 mil Dekoron® (EPDM) insulation • 10 mil Dekorad® (CSPE) bonded individual jacket • 600 V				X		
Okonite	I&C	• 1/C #12 AWG • 30 mil Okonite® (EPR) insulation • 15 mil Okolon® (CSPE) bonded individual jacket • 600 V					X	X

I&C = Instrumentation and Control EPR = Ethylene Propylene Rubber EPDM = Ethylene Propylene Diene Monomer
XLPE = Cross-linked Polyethylene P = Power CSPE = Chlorosulfonated Polyethylene AWG = American Wire Gauge

2.1.2 Preparation of Test Specimens

Upon selecting a specific cable for testing, it was retrieved from the cable storage area, and cut to length in accordance with approved program procedures. For this testing program, the cable samples were cut into both long (10-foot or 30-foot) and short (6-inch) specimens for testing. The long specimens were energized during the steam exposure and monitored for cable functional performance. Short specimens, made from the same source as the long specimens, were used for destructive testing to determine the physical and material condition of the cable at various hold points.

Several of the long cable specimens were placed in individual steel Unistrut® channels to simulate a typical physical configuration of cables installed in a power plant, i.e., straight horizontal cable trays or conduit. The Unistrut® channels also served to protect the cable specimens from damage during handling. Approximately one inch of insulation was removed from the conductors on both ends to allow splices to be made to facility wiring to energize the long specimens. The cables were held in place using Tefzel® tie wraps, which were applied by hand just tight enough to hold the cable snugly and prevent it from moving. Figure 2.2 is an end view of four typical Unistrut® channels with individual long cable specimens on a test fixture in the thermal aging chamber.

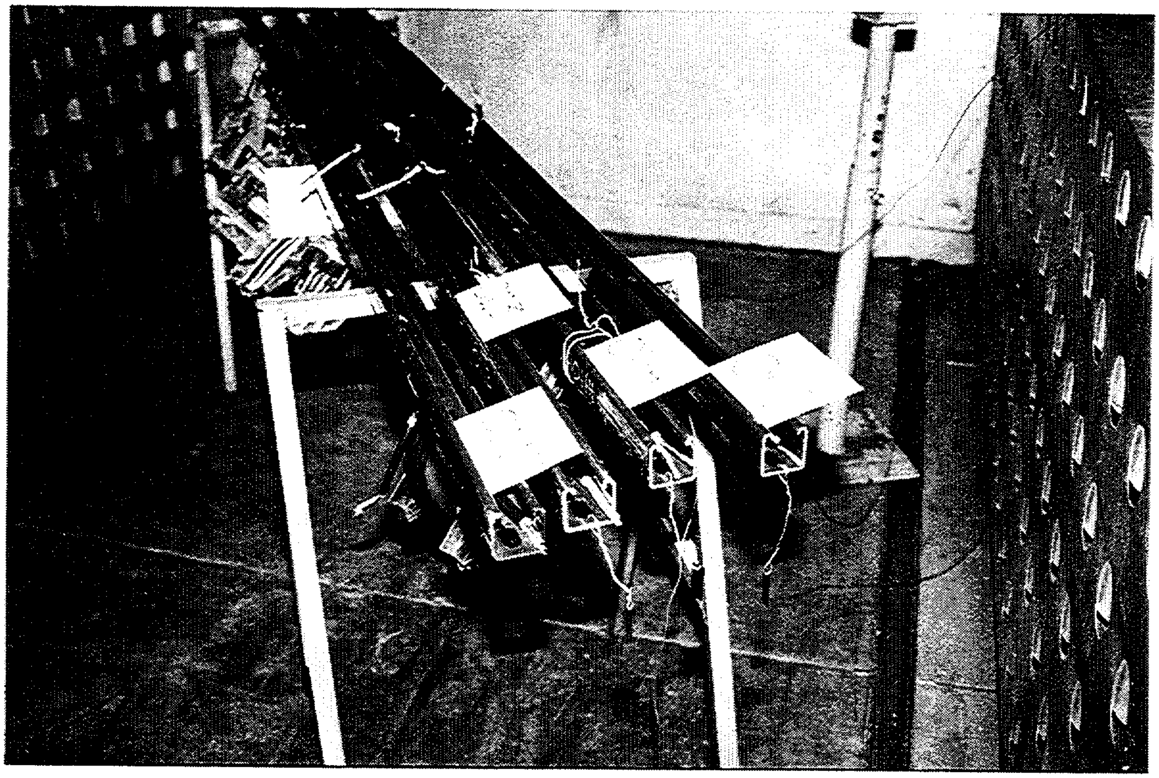

Figure 2.2 Typical long specimens installed in Unistrut® shown in thermal aging oven

The remaining long specimens were installed on stainless steel mandrels to simulate actual qualification testing. The specimens were tied to the mandrel using stainless steel wire, which was also applied by hand just tight enough to hold the cable snugly and prevent it from moving. A piece of fiberglass tape was placed between the stainless steel wire and the test specimen to prevent the wire from cutting into the test specimen jacket. Figure 2.3 shows a typical long specimen mounted on a mandrel.

Figure 2.3 Typical long specimen installed on a mandrel

For test sequences 1, 2 and 3, un-insulated butt-splice connectors were crimped to the conductors for later connection to test leads. The facility test leads were connected to the test specimens using Raychem® nuclear grade splices after thermal aging, radiation aging and LOCA irradiation of the test specimens were completed. This procedure was modified for test sequences 4, 5 and 6 to further minimize the potential for handling damage to the specimens during splice application. In the later test sequences, the mandrels were modified to include a 2-foot arm to support the ends of the test specimen as they were routed away from the mandrel. In addition, short (2-foot to 3-foot) Teflon®-insulated pigtails were spliced to the test specimens using Raychem nuclear grade splices prior to any accelerated aging to further mitigate the potential for handling damage to the test specimens. The pigtails were shielded from the thermal and radiation aging, to the extent possible, to keep them from becoming brittle. After aging, the facility lead wires were connected to the pigtails using a second splice. Figure 2.4 shows a typical specimen mounted on the modified mandrel with pigtails attached, as used for tests 4, 5 and 6.

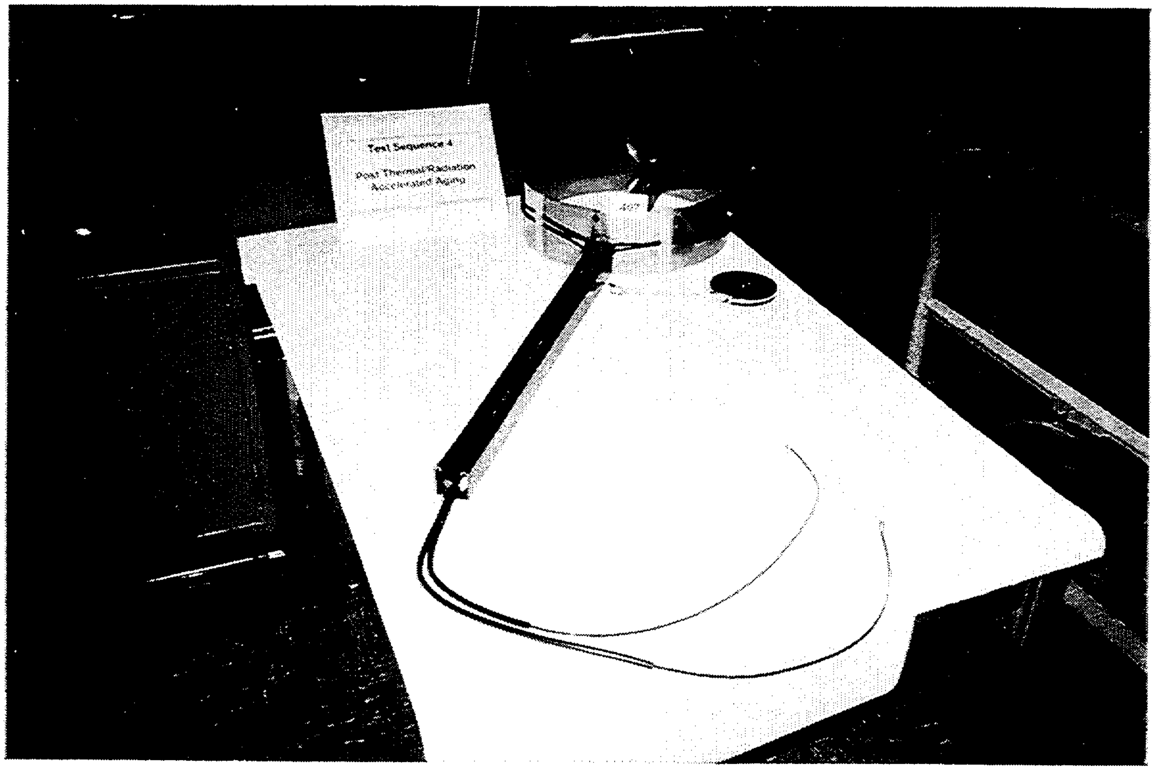

Figure 2.4 Typical specimen mounted on a mandrel with a modified design for tests 4, 5 and 6

Preparation of the 6-inch short specimens involved separating the cable outer jacket from the individual conductors, and removing the copper conductors from the insulation in accordance with approved program procedures. This allowed for tensile and hardness testing of individual jacket and conductor insulation materials. The outer jacket material specimens were punched into a standardized "dog bone" configuration for elongation-at-break (EAB) testing. The insulation was left in a tubular configuration for testing. The short specimens were placed in stainless steel mesh baskets during pre-aging and LOCA testing. Typically, seven to ten short cable jacket and insulation specimens were inserted into each basket. The baskets were then labeled for removal at specific CM points for materials testing. The exact number of long specimens and baskets prepared for each LOCA test was dependent upon the number of different cable types and CM points included in each test. Figure 2.5 shows a typical basket containing short specimens.

In order not to damage the long specimens, an additional two foot specimen was prepared from the same source as each long specimen to be used specifically for indenter testing. This 2-foot specimen followed the "parent" long specimen throughout the test sequence. Approximately 6 inches of outer jacket material was removed from both ends of the 2-foot specimen to allow indenter testing of the underlying insulation material. Figure 2.6 shows a typical 2-foot specimen used for indenter testing.

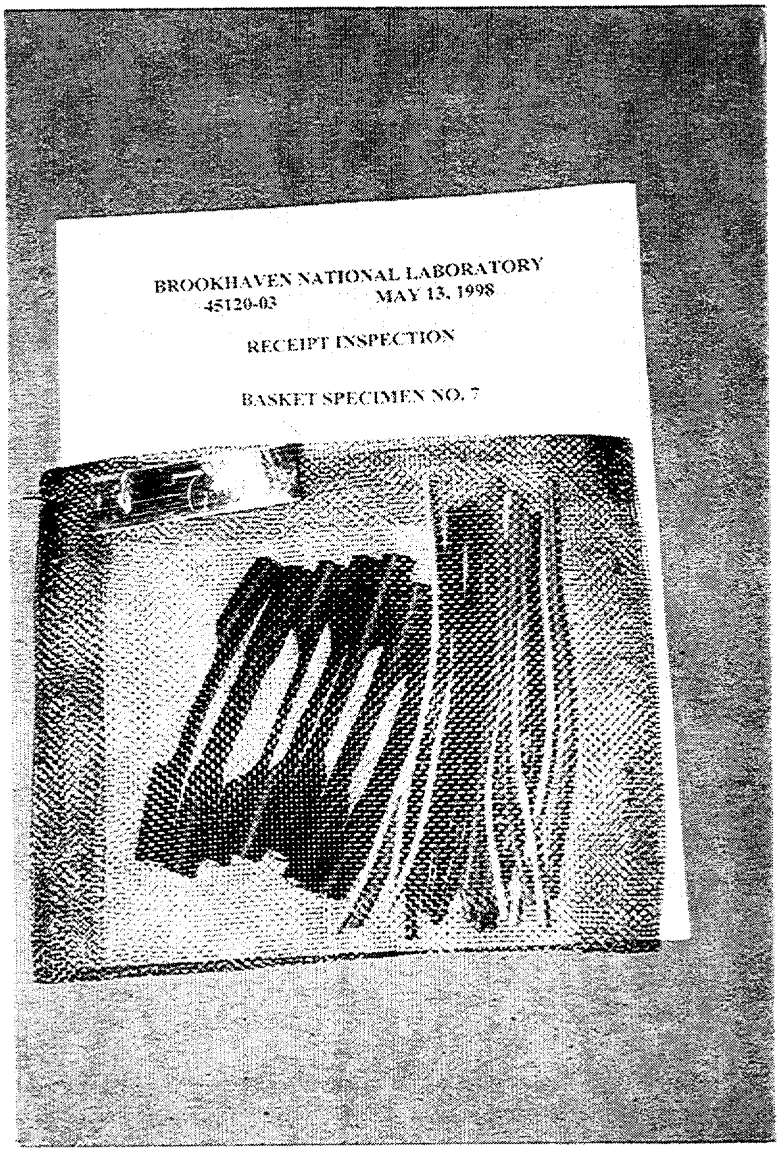

Figure 2.5 Typical basket of short specimens

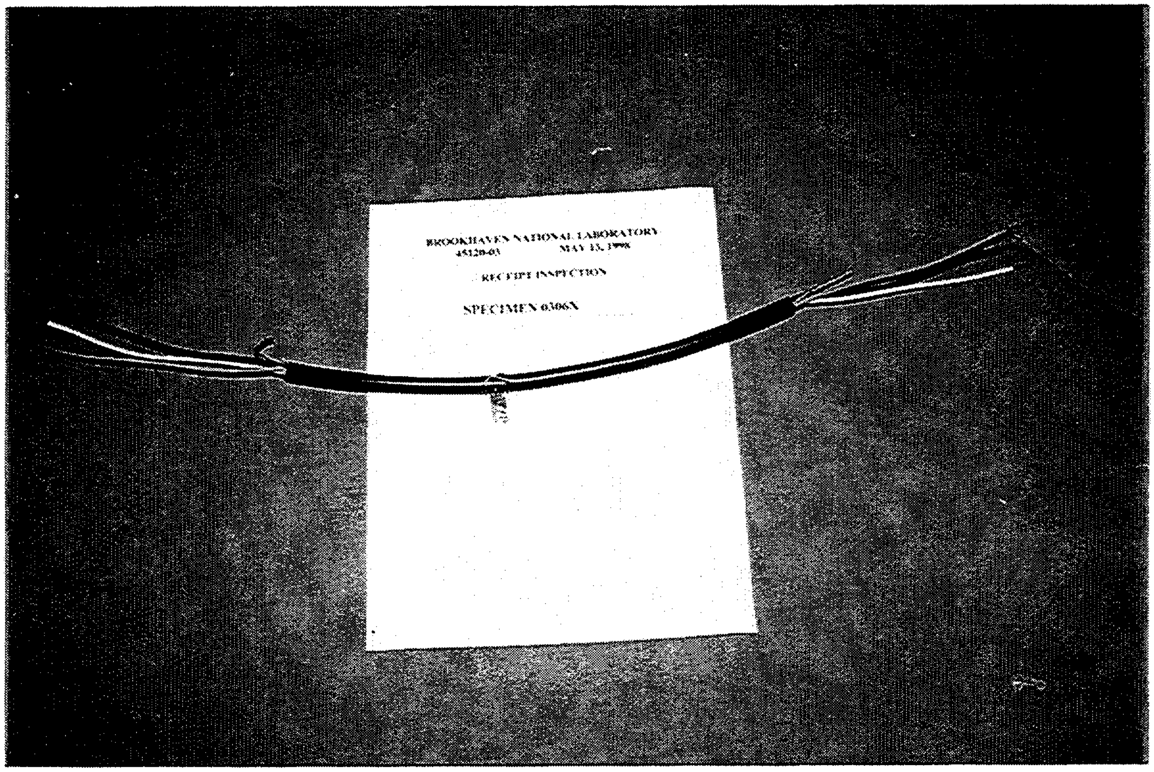

Figure 2.6 Typical 2-foot specimen for indenter testing

2.1.3 Identification of Test Specimens

Throughout this program, hundreds of different cable specimens were prepared and tested. It was critical that each specimen be properly and uniquely identified to allow traceability of test results to the proper specimen, and to draw accurate conclusions. To accomplish this, a procedurally-controlled identification scheme was developed to assign a unique identification number to each specimen. These identification numbers are used throughout this report to identify cable specimens and their test results. The scheme is described in the following paragraphs.

New or unused cables were obtained from nuclear facilities, and were typically long coils or reels of cable from warehouse stock. These are used as the "unaged" cables for this program since they were not in service and the aging degradation from storage is expected to be minimal compared to service in the plant. Naturally aged cables from both mild and harsh environments were also obtained and were typically delivered in their installed configuration. Both the unaged and naturally aged source cables obtained are referred to as cable "samples" and were used as the source cable for preparing the test specimens. The cable test "specimens" are the long (30-foot or 10-foot) and short (2-foot or 6-inch) pieces of cable cut from the source cable samples.

The cable samples are identified by a 10-digit identification number, such as "PNI85RB191." Each digit provides information about the sample, as follows:

Position	Description
1	Code indicating the source of the cables: "P" for PWR, "B" for BWR, "M" for manufacturer, "D" for DOE facility, "L" for National Laboratory.
2	Code indicating the aging of the cable when it was obtained by BNL: "A" for naturally aged, "N" for new or unused, or "U" for used (installed but not energized or not exposed to harsh environments).
3	Code for cable type: "I" for instrumentation, "P" for power, "C" for control.
4 & 5	Year of installation for naturally aged or used cable, or year of manufacture for new or unused cable.
6 & 7	Code indicating the cable manufacturer: "RB" for Rockbestos, "OK" for Okonite, "AI" for American Insulated Wire, "AN" for Anaconda, or "SM" for Samuel Moore.
8, 9 & 10	Sequential number of sample (e.g., 001, 002, etc.).

Each long cable specimen was assigned an identification number consisting of the 10-digit ID code from the parent sample from which it was made, followed by a 4-digit number, such as "0101." The first two digits represent the pre-aging/LOCA sequence in which they were tested. The last two digits are the sequential number of the specimen. Two stainless-steel tags with the specimen's 4-digit number engraved on it were tied to each long specimen using stainless-steel wire to ensure positive identification through all phases of testing. The tag wire was wound loosely around the test specimen to prevent it from damaging the test specimen jacket.

A 2-foot specimen was prepared to accompany each long specimen throughout the pre-aging and LOCA testing process for indenter testing, as previously discussed. These specimens carried the same 4-digit number as the "parent" specimen, but with an "X" suffix; e.g., 0101X. A stainless-steel tag with the specimen's 4-digit number engraved on it was tied to each specimen using stainless-steel wire to ensure positive identification through all phases of testing. The tag wire was wound loosely around the test specimen to prevent it from damaging the test specimen jacket.

The 6-inch specimens were prepared from the same source as the long specimens. Therefore, their identification code is linked to the parent specimen. The small specimen identification consists of the 4-digit code from the long specimen, with one prefix and one or two suffix codes attached, such as "I0101AW." The 4-digit core number (i.e., 0101) indicates it was prepared from the same sample cable used to make the long specimen "0101." The prefix indicates the part of the cable used for the specimen; either "I" for insulation, or "J" for jacket. The first suffix indicates the CM hold point at which the specimen was tested; "A", "B", "C", etc. For insulation specimens, a second suffix indicates the color of the insulation; "B" for black, "R" for red, "G" for green, or "W" for white. Each basket of small specimens was labeled with two stainless-steel tags engraved with the identification number to ensure positive identification throughout all phases of testing.

2.2 Accelerated Aging Protocol

As part of this research program, various new or unused cables were aged using accelerated thermal and radiation aging techniques to simulate actual service conditions. In all cases, sequential thermal aging followed by radiation aging was used. The following sections describe the process used to perform this accelerated aging. The development of this accelerated aging process is described in detail in the Pre-Aging and LOCA Test Plan (Villaran, 1996).

2.2.1 Accelerated Aging Parameters

The accelerated aging parameters (i.e., activation energy, thermal aging temperature, radiation dose rate) were selected to match those used in the original qualification tests of the cables for the plant from which they were obtained. The thermal aging time and total integrated dose were then adjusted using a linear extrapolation to achieve the qualified life being simulated (i.e., 20 years, 40 years, or 60 years). This approach was selected to avoid exposing the cables to any aging stresses in excess of what they were originally designed and qualified to withstand, with the exception of the 60-year tests. Since the parameters used in this test program are the same as those to which the cables were originally qualified, the cables can be expected to perform acceptably with a high level of confidence. Also, using the same aging parameters as those for the original qualification allows comparisons to be made with, and extrapolation of test results to, cables used in the plants.

Table 2.2 lists the qualification test reports obtained and reviewed for the pre-aging information. Table 2.3 presents the pre-aging parameters used in the original qualification tests, along with the accident conditions simulated. Included in Table 2.3 is the equivalent qualified life at an assumed service temperature of 140°F (60°C). This information facilitates comparison of the pre-aging for each of the test specimens and illustrates the differences in pre-aging used by the different cable manufacturers in the qualification tests.

2.2.2 Accelerated Aging Procedure

Prior to thermal aging, the test specimens were prepared and installed on their test fixture (Unistrut® or mandrel), as discussed previously. Accelerated thermal aging was then performed by Wyle Laboratories in Huntsville, Alabama. All specimens with the same specified aging temperature in a particular test sequence were loaded into one oven. The specimens were not energized during the thermal aging exposure. Oven temperature was controlled to +5, -0°F with a thermal trip setting +10°F above the specified aging temperature. Thermal aging duration was controlled to +2, -0 percent of the specified duration. In cases where some specimens in the oven had different required thermal aging durations, the oven was shutdown to remove specimens, then restarted to continue the thermal aging run. The shutdown and startup ramps were typically not credited as aging time for the specimens since they were of relatively short duration (approximately 1 hr.). A continuous circular chart recording was used to monitor the thermal aging process. All work was performed in accordance with Wyle Laboratories' pre-aging procedure under a 10 CFR 50, Appendix B Quality Assurance program.

Table 2.2 Qualification reports used to determine test parameters

Cable Tested	Test Laboratory	Test Report Title	Report Number	Report Date
AIW	Franklin Institute Research Laboratories	Qualification of Electrical Cables for a Loss-of-Coolant Accident	F-C4197-2	12/75
Anaconda	Franklin Institute Research Laboratories	Tests of Electrical Cables Subjected to Thermal Aging, Gamma Radiation and a Loss-of-Coolant Accident Simulation	F-C4350-3	7/76
Okonite	The Okonite Company	Nuclear Environmental Qualification Report for Okonite Insulated Cables	NQRN-1A	Rev. 5 10/24/88
Samuel Moore	Isomedix Inc.	Qualification Test of Electric Cables Under a Simulated LOCA/DBE by Sequential Exposure to Environments of Radiation, Thermal Aging, Steam and Chemical Spray	LOCA XLPO/ EPDM	6/78
Rockbestos	The Rockbestos Company	Report on Qualification Tests for Firewall III Irradiation Cross-Linked Polyethylene Constructions for Class 1E Service in Nuclear Generating Stations	QR-1806(a) QR-5805(a)	5/1/81 5/22/86

(a) Rockbestos report QR-1806 was used to determine the pre-aging parameters for the cables in test sequences 1 and 3, while report QR-5805 was used for test sequence 6.

Table 2.3 Parameters used in original qualification tests

Cable Tested	Qualified Life	Activation Energy (eV)	Service Pre-aging		Accident Simulated	Equivalent Qualified Life at 140°F (60°C) (d)
			Thermal	Radiation		
AIW	40 yr.@122°F (50°C) (a)	1.18 (b)	168hr.@ 250°F (121°C)	25Mrad@ 0.55Mrad/hr.	75 Mrad + 1 Peak Steam Exposure	11 yrs.
Anaconda	40 yr.@156°F (69°C) (a)	1.18 (b)	168hr.@ 302°F (150°C)	50Mrad@ 0.36Mrad/hr.	150 Mrad + 1 Peak Steam Exposure	120 yrs.
Okonite	40 yr.@194°F (90°C)	1.44 (c)	504hr.@ 302°F (150°C)	50Mrad@ 0.65Mrad/hr.	150 Mrad + 2 Peak Steam Exposure	2,495 yrs.
Samuel Moore	40 yr.@136°F (58°C) (a)	1.36 (b)	168hr.@ 250°F (121°C)	25Mrad@ 0.75Mrad/hr.	175 Mrad + 2 Peak Steam Exposure	30 yrs.
Rockbestos (QR#1806)	40 yr.@194°F (90°C)	1.33 (c)	1,300hr.@ 302°F (150°C) (e)	50Mrad@ 0.50Mrad/hr.	150 Mrad + 2 Peak Steam Exposure	2,847 yrs.
Rockbestos (QR#5805)	40 yr.@194°F (90°C)	1.33 (c)	909.5hr.@ 302°F (150°C) (e)	50Mrad@ 0.40Mrad/hr.	150 Mrad + 2 Peak Steam Exposure	1,992 yrs.

(a) Service temperature calculated based on thermal aging performed and activation energy stated.
(b) Activation energy obtained from literature (Holzman and Sliter, 1992).
(c) Activation energy calculated based on thermal aging performed and qualified life simulated.
(d) Equivalent qualified life of the insulating material at a service temperature of 140°F (60°C) calculated using the Arrhenius model and the activation energy stated, based on thermal aging only.
(e) Thermal aging duration includes margin above calculated duration of 850 hr.

After completion of thermal aging at Wyle Laboratories, accelerated service radiation and LOCA radiation exposures were performed at the Neely Nuclear Research Center located at the Georgia Institute of Technology in Atlanta, Georgia. The accelerated service radiation exposure was used to simulate service radiation conditions. This was followed by a LOCA radiation exposure simulating the design basis accident radiation dose used in the original cable qualification tests. Specimens were not energized during either of the radiation exposures.

A photograph of the hot cell in which the specimens were irradiated is shown in Figure 2.7. As shown, the hot cell is large enough to accommodate the long specimens in their Unistrut® support channels. Figure 2.8 presents a schematic of the hot cell with a typical arrangement of long specimens in Unistrut® stacked upon each other, with the open portion of the channels facing the sources. The individual source holders without the sources were first positioned on the test bench at the required distance to provide the desired dose rate. For the mandrel mounted specimens, several mandrels were stacked on top of each other and the source holders were placed at the appropriate distance around the outside circumference of the specimens to irradiate them. The individually identified Cobalt-60 sources are kept in a source storage pool adjacent to the hot cell. After the specimens and source holders were properly placed, the designated sources were transferred from the storage pool into the hot cell by the operator using manipulator arms. The specific sources to be used, and the positions of the sources with respect to the target cable specimens, were calculated and verified by the hot cell engineer prior to the irradiation run. All irradiations were performed in accordance with Georgia Institute of Technology procedures under a 10 CFR 50, Appendix B Quality Assurance program.

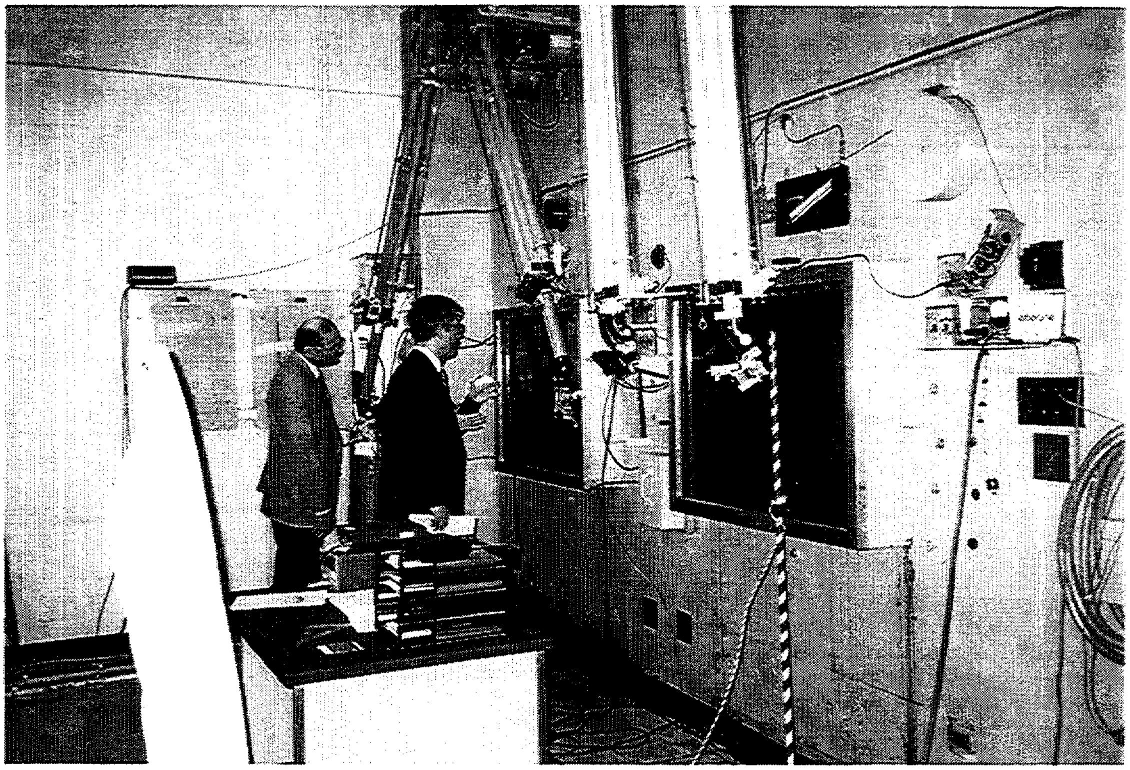

Figure 2.7 Hot cell used for irradiation of specimens at Georgia Institute of Technology

2.3 LOCA Testing Protocol

The LOCA steam/chemical spray exposure testing was performed by Wyle Laboratories in Huntsville, Alabama. All work was performed in accordance with Wyle Laboratories' LOCA test procedure under a 10 CFR 50, Appendix B Quality Assurance program.

2.3.1 LOCA Profile

As for the pre-aging parameters, the LOCA test profile was selected to be consistent with the original qualification test for the cables in performing test sequences 1 through 3, and with the generic BWR/PWR LOCA profile suggested in Appendix A to IEEE Standard 323-1974 in performing test sequences 4 through 6. While the original qualification tests were 30 to over 100 days in duration, the LOCA tests for this program were shortened to simulate only the first 7 to 10 days of the LOCA since post-LOCA duration was not an issue being addressed in this program. The qualification test profiles included either a single or double peak to maximum temperature and pressure, as specified in the qualification report for the cable. In general, a double peak LOCA profile is considered more severe and can cause more degradation to the test cables. Chemical spray was included during the steam exposure for all test sequences. The qualification reports used are listed in Table 2.2.

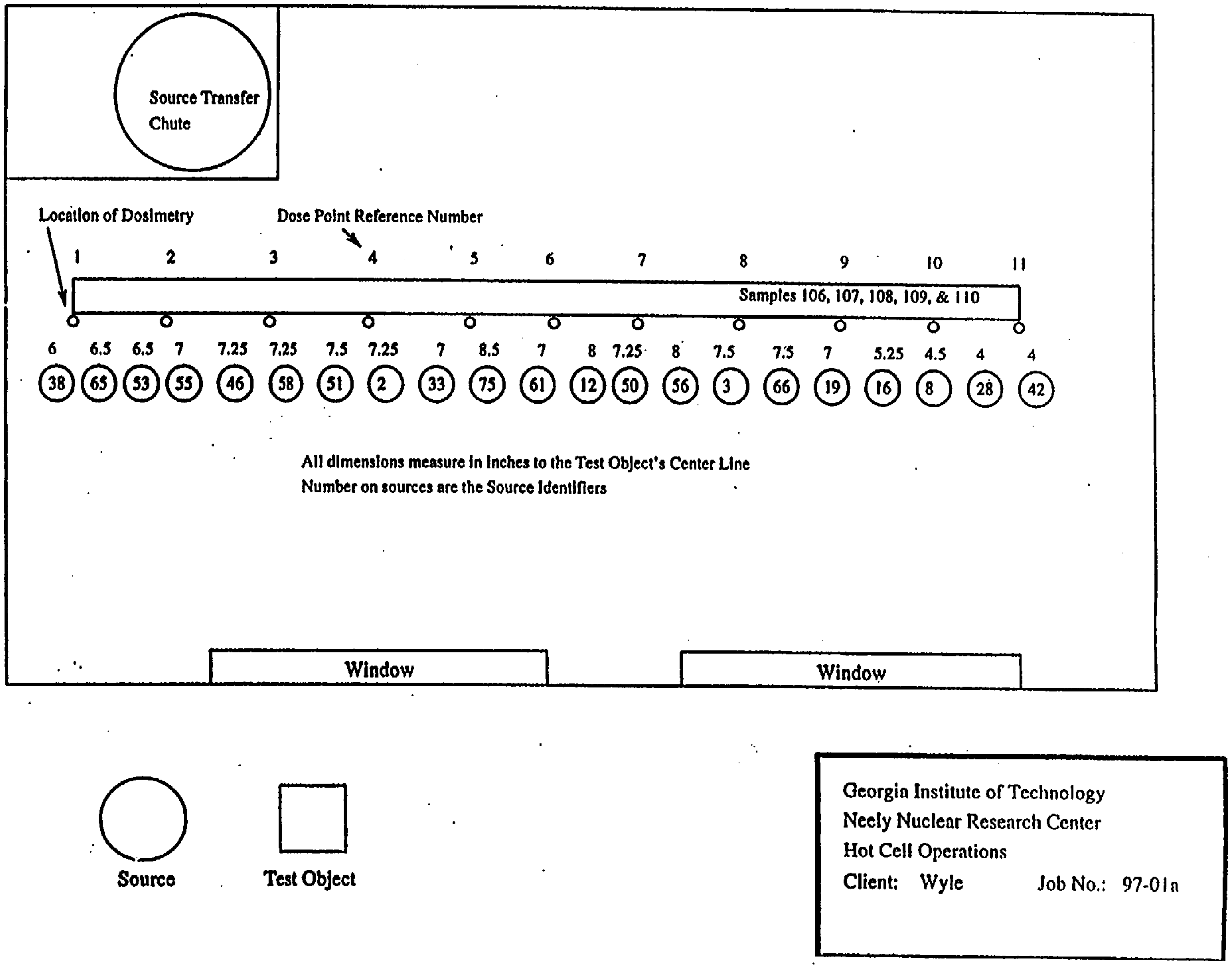

Figure 2.8 Diagram of the Hot Cell at Georgia Institute of Technology with typical arrangement of long specimens

2.3.2 LOCA Test Setup

Two different LOCA test chambers were used in this program. One LOCA test chamber was a 30-inch diameter cylindrical chamber that can accommodate the 10-foot long straight cable specimens mounted in the Unistrut® support channels. Figure 2.9 shows a side view photograph of this chamber with the specimens inside and the end bell unattached, along with a dimensional schematic of the chamber. Figure 2.10 shows the open end of the chamber with specimens loaded. This chamber was used for test sequences 1, 2 and 3. The second chamber, which was used for test sequences 4, 5, and 6, is a 59-inch diameter vessel, which was more suitable for loading mandrel mounted specimens. Figure 2.11 shows a front view of this chamber.

Thermocouples were mounted in the test chambers to monitor chamber temperature distribution in the horizontal direction and the vertical direction. The chamber temperature distribution in the area of the specimens was monitored by placing five thermocouples within one inch of the cable specimens along their length. Two other thermocouples, placed at the top and bottom of the vertical central axis of the chamber, provided the temperature distribution in the vertical direction. The average chamber temperature was calculated and recorded. The pressure in the test chamber was monitored and recorded throughout the test by means of a pressure transducer connected to the chamber.

The boilers used to provide steam to the LOCA test chamber are capable of providing saturated steam at up to 20,000 lbs/hr at 150 psig; superheat capability is also available. A chemical spray system consisting of a 140-gallon tank, recirculating pump, control valves, flow monitoring, and level instrumentation injects a chemical spray to the chamber through one or more full-cone spray nozzles.

The energized cable specimens were connected to Teflon®-insulated facility lead wires prior to being placed in the LOCA simulation chamber. This was accomplished by connecting the lead wires to the un-insulated butt-splices on the test specimens, which were previously attached during the initial specimen preparation for test sequences 1, 2 and 3. For test sequences 4, 5 and 6, the facility lead wires were connected to the pigtails that were installed prior to accelerated aging. Raychem® Nuclear Grade Heat Shrink was finally applied to all of the splice areas. The specimens were then placed in the LOCA test chamber. Typically, the facility lead wires exited the LOCA chamber through fittings that were sealed with 3M® Scotchcast potting compound[1]. The nuclear grade splices attaching the facility lead wire to the test specimen were exposed to the internal environment of the chamber and were not part of the chamber's pressure boundary. Figure 2.12 shows the typical Wyle penetrations on the end of the LOCA chamber with the facility lead wires extending through them.

2.3.3 LOCA Test Procedure

Prior to initiating the LOCA transients, the test chamber was preheated to a temperature of approximately 140°F (60°C) and held for approximately 30 to 60 minutes to allow temperatures to stabilize. Following preheat, saturated steam was admitted to the test chamber and was controlled to simulate the LOCA profile desired. The initial transients were continued until the specified peak conditions were reached, after which conditions were held for approximately 3 hours. After completing the transients, the LOCA chamber temperature and pressure enveloped the LOCA test profile specified. The total duration of the LOCA exposure was 7 to 10 days.

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[1] Several of the energized specimens in test 4 exited directly through the LOCA chamber with no facility lead wire attached, and Swagelock penetration assemblies were installed (see discussion of LOCA test 4).

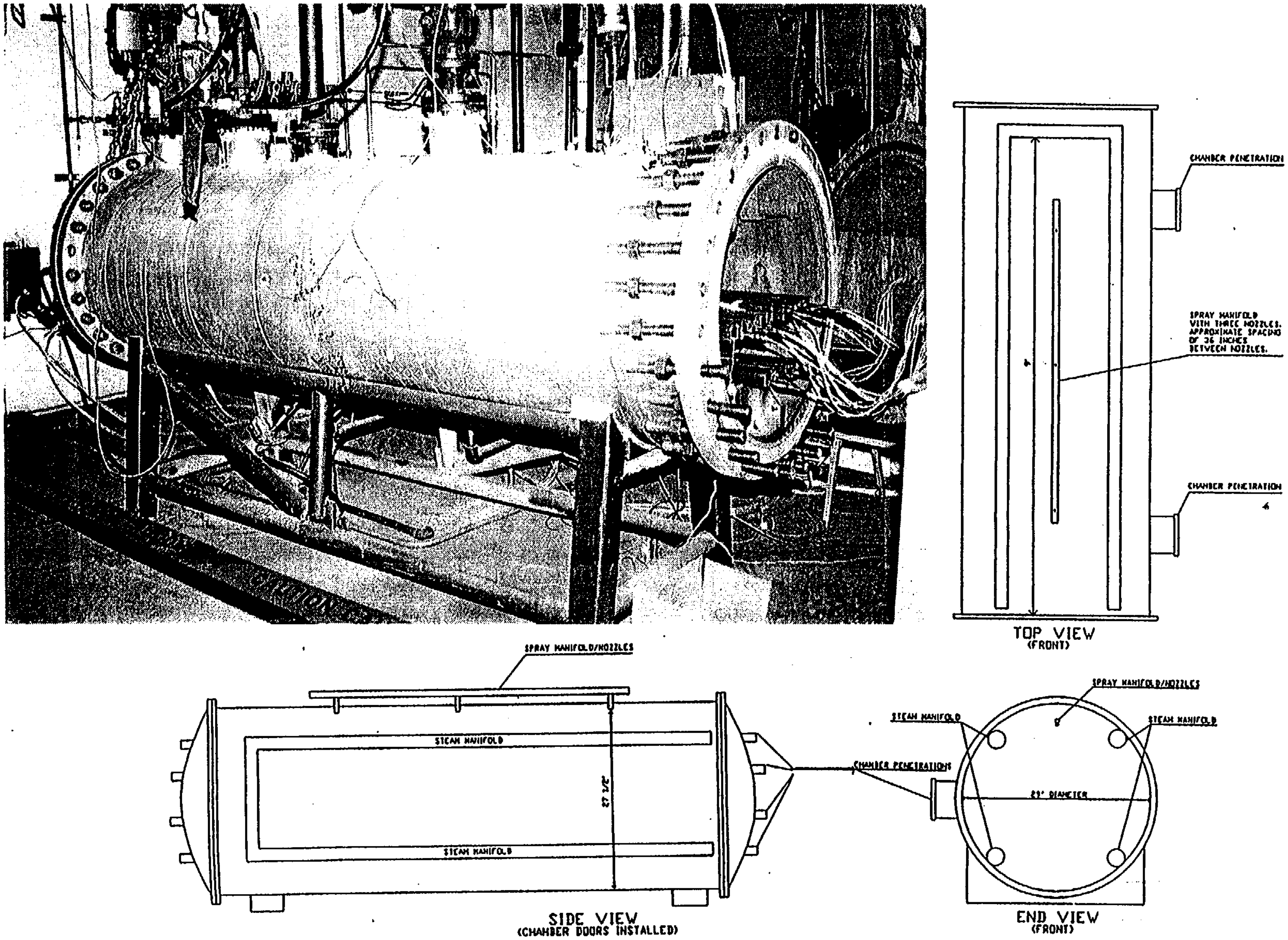

Figure 2.9 Photograph and diagram of the LOCA test chamber at Wyle Laboratories used for Tests 1, 2 and 3

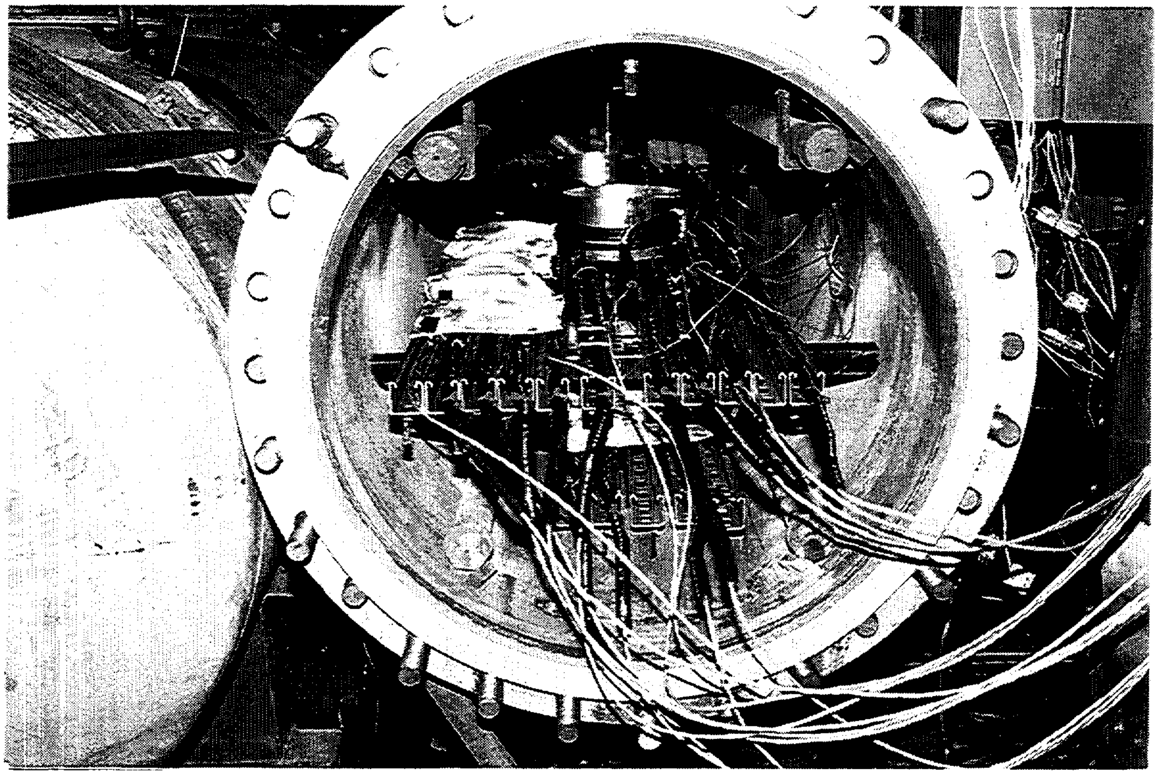

Figure 2.10 End view of the LOCA test chamber with the cable specimens loaded prior to testing

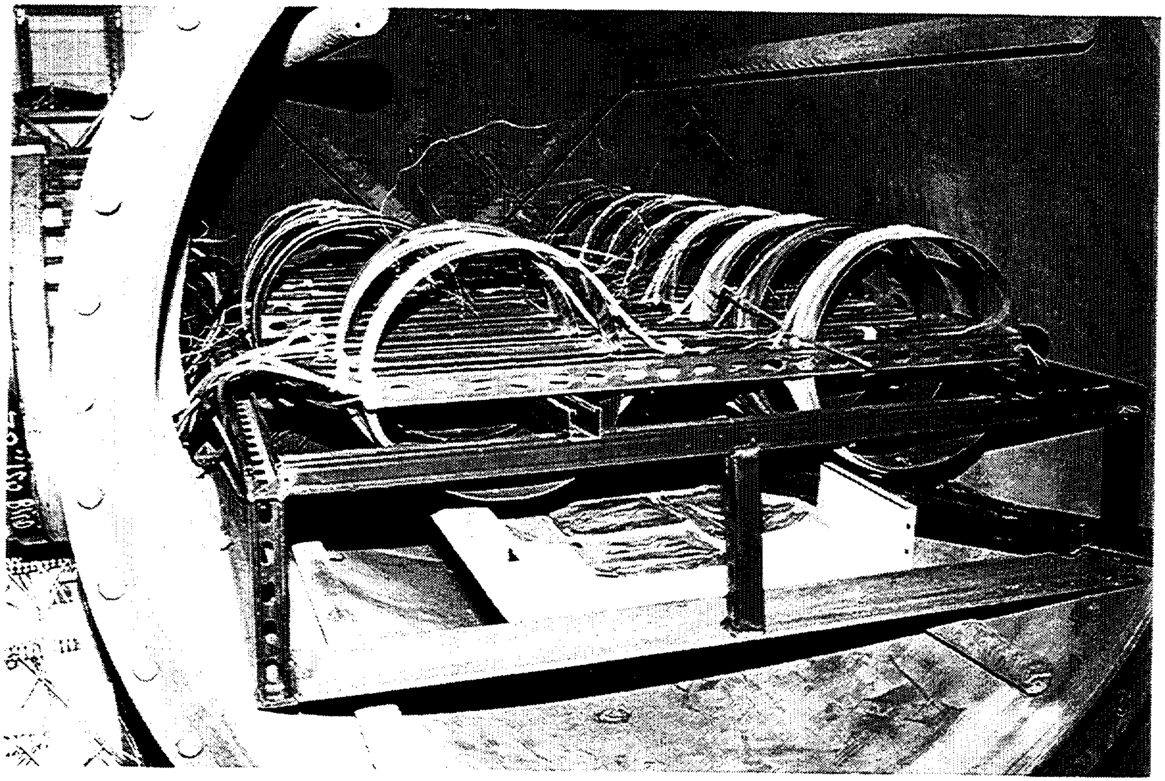

Figure 2.11 End view of large diameter LOCA chamber used for tests 4, 5 and 6

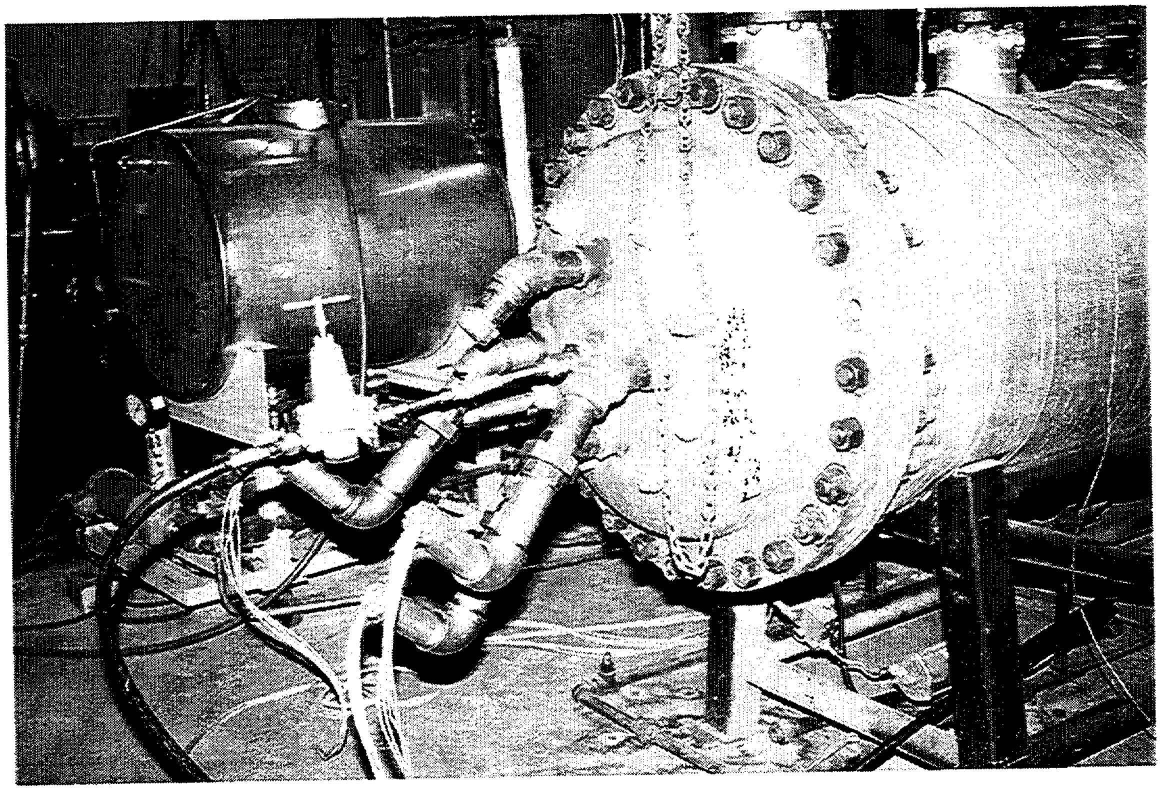

Figure 2.12 Facility lead wires extending through the penetrations on the end of the LOCA test chamber

Once the LOCA chamber pressure had decreased to approximately 32 psig, the chemical spray was initiated. The chemical spray flow rate was approximately 0.15 gpm per ft^2 of projected area[2], as recommended by IEEE Standard 323-1974. Chemical spray solution and steam condensate were captured and recirculated to the spray header for 24 hours, after which the flow was terminated. The chemical spray flow was monitored and recorded during the chemical spray portion of the exposure. The initial chemical spray solution consisted of deionized water with 0.28 molar H_3BO_3 (3000 ppm Boron), 0.064 molar $Na_2S_2O_3$, and NaOH to make a pH of 10.6 at the start of the spray test. Dilution of the recirculated chemical spray solution by condensate lowered the pH to approximately 8.5 by the end of spray test.

2.3.4 Functional Performance Monitoring

The long specimens (except the sacrificial specimens that were cut up for archiving at each hold point) were individually powered and loaded as detailed in Figures 2.13 and 2.14 for the Unistrut® mounted and mandrel mounted specimens, respectively. Each of these specimens was powered separately with 28 Vdc. A pressure transmitter was connected to

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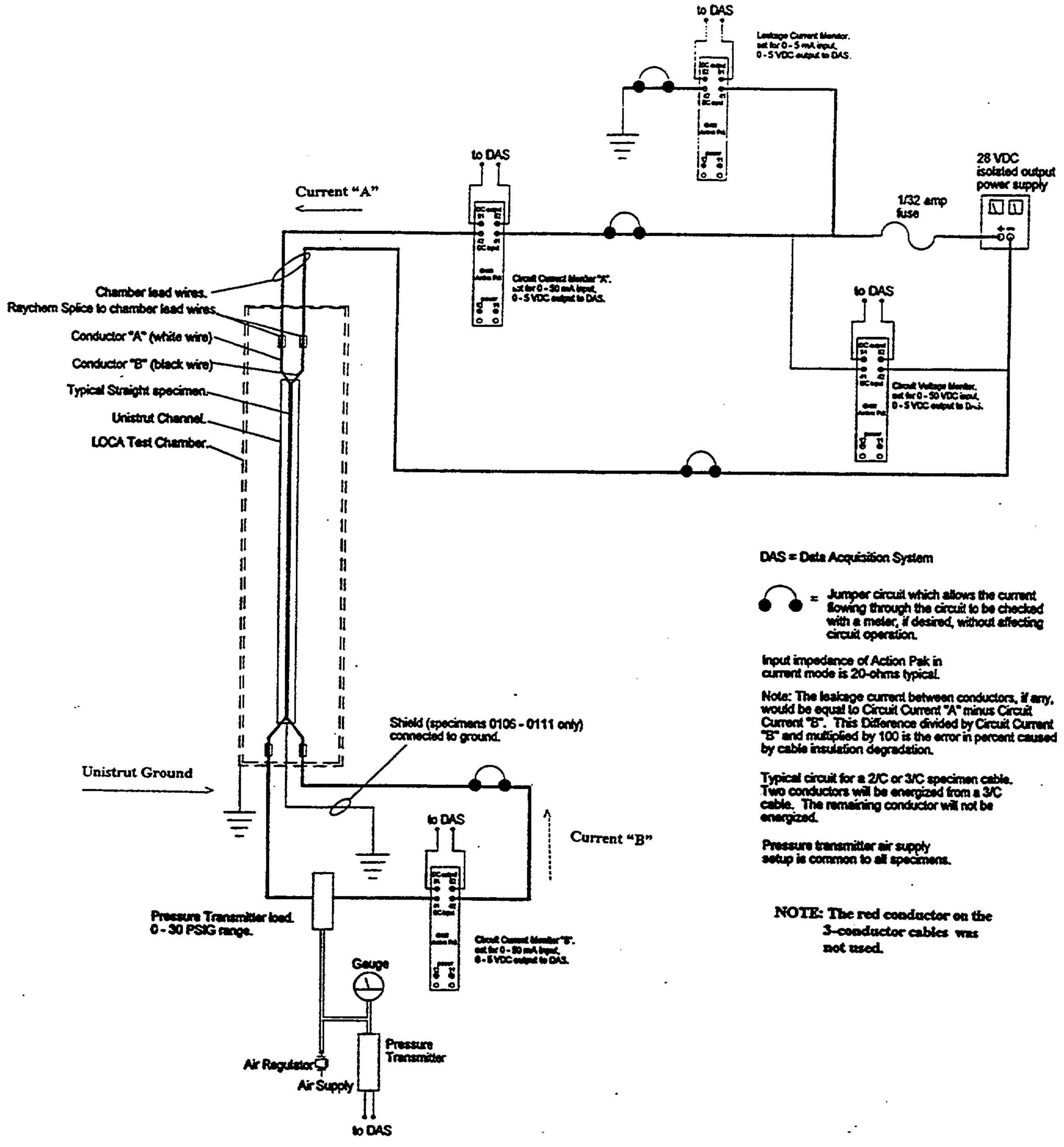
[2] The "projected area" for determination of the chemical spray flow rate is the area projected by the test cables in a plane perpendicular to the spray direction. For the tests reported herein, the projected area was approximately 26.7 ft^2 resulting in a chemical spray flow rate of 4 gpm.



DAS = Data Acquisition System

= Jumper circuit which allows the current flowing through the circuit to be checked with a meter, if desired, without affecting circuit operation.

Input impedance of Action Pak in current mode is 20-ohms typical.

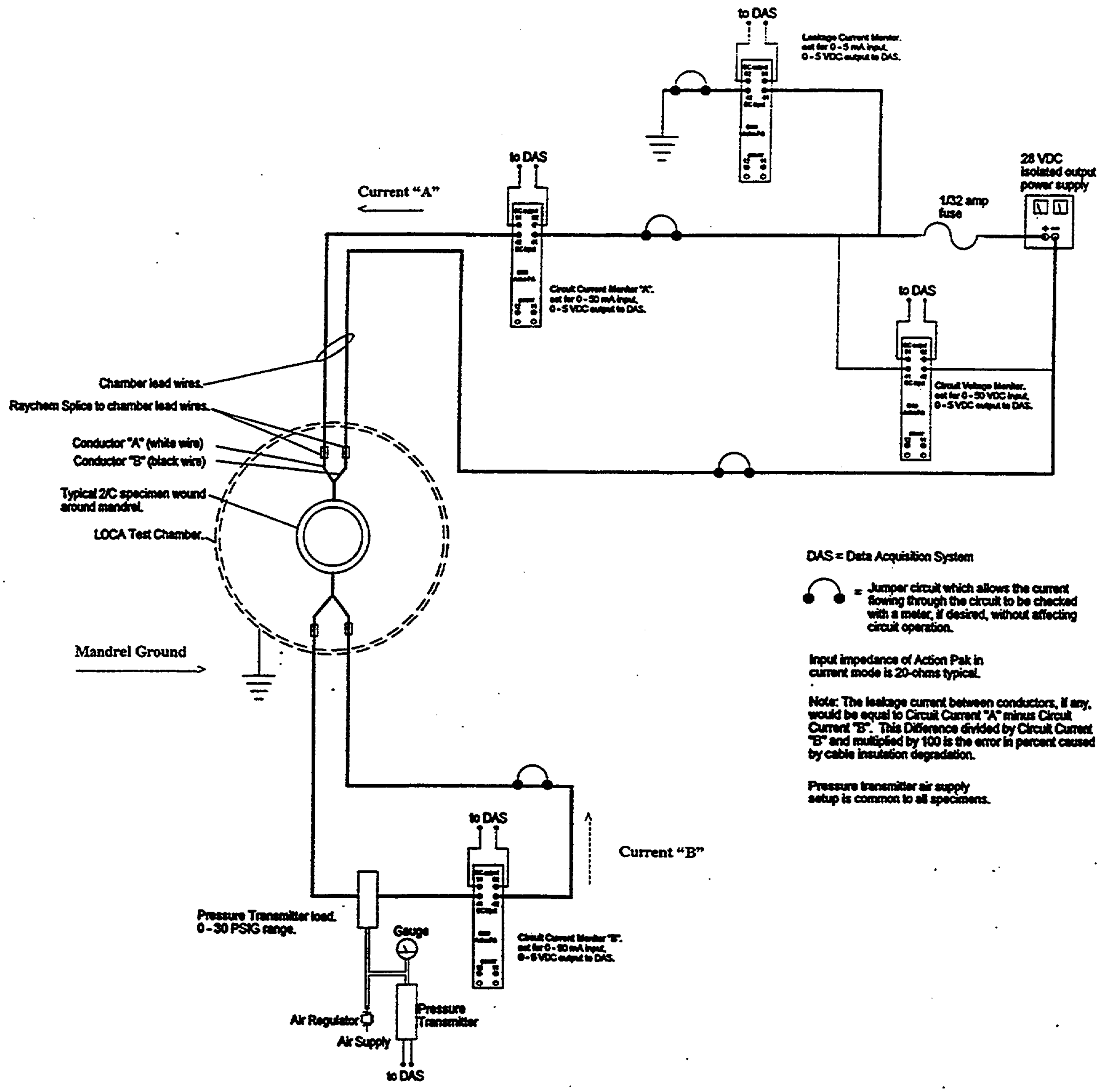
Note: The leakage current between conductors, if any, would be equal to Circuit Current "A" minus Circuit Current "B". This Difference divided by Circuit Current "B" and multiplied by 100 is the error in percent caused by cable insulation degradation.

Typical circuit for a 2/C or 3/C specimen cable. Two conductors will be energized from a 3/C cable. The remaining conductor will not be energized.

Pressure transmitter air supply setup is common to all specimens.

NOTE: The red conductor on the 3-conductor cables was not used.

Figure 2.13 Monitoring circuit diagram for straight Unistrut® mounted specimens



DAS = Data Acquisition System

⌒ = Jumper circuit which allows the current flowing through the circuit to be checked with a meter, if desired, without affecting circuit operation.

Input impedance of Action Pak in current mode is 20-ohms typical.

Note: The leakage current between conductors, if any, would be equal to Circuit Current "A" minus Circuit Current "B". This Difference divided by Circuit Current "B" and multiplied by 100 is the error in percent caused by cable insulation degradation.

Pressure transmitter air supply setup is common to all specimens.

Figure 2.14 Monitoring circuit diagram for mandrel mounted specimens

the chamber leads of each long cable specimen to simulate a 4-20 mA instrumentation loop circuit. The pressure source tank and header with sixteen pressure transmitters can be seen under the test bench in Figure 2.15. The short specimens in the stainless steel baskets were not powered since they were to be used for materials condition monitoring.

Each of the powered specimens was monitored for applied voltage, circuit current, and leakage current throughout the LOCA steam exposure simulation. Circuit current was monitored for each conductor to facilitate troubleshooting. These currents are identified as "A"and "B" on the circuit diagram. Nominal values for the initial healthy circuits are 28 volts dc applied voltage, 12.0 milliamps for "A" and "B" currents, and 0 milliamps for leakage current. These circuit values correspond to the pressure source being maintained at approximately 15 psig. The test specimen powering and monitoring equipment are shown in Figure 2.16.

2.3.5 Post LOCA Inspection and Voltage-Withstand Test

Upon completion of each of the LOCA steam/chemical spray exposures, the test chamber was opened and the specimens were inspected. The specimens were then removed from the test chamber and post-LOCA condition monitoring tests were performed. Following these CM tests, the long cable specimens were submerged in tap water at room temperature while still mounted in their Unistrut® or mandrel, and a voltage withstand test was performed at 80 Vac/mil of insulation thickness, in accordance with IEEE Standard 383-1974. For cables with, as well as without an individual jacket on top of the insulation, only the insulation thickness (30 mils) was considered in determining the test voltage. The one exception was the Samuel Moore cables for which both the thickness of the insulation (20 mils) plus the thickness of the individual jacket (10 mils) were used to be consistent with the original qualification test. Therefore, a test voltage of 2,400 volts was used for all test specimens.

In performing this test, the test voltage was initially set to zero volts, then was gradually increased to 2,400 volts. The acceptance criteria used was for the test specimen to hold 2,400 volts for five minutes without exceeding a leakage current of 10 milliamps, which was the maximum leakage current measurable with the test equipment used. If the leakage current exceeded 10 mA during the rise to 2,400 volts, or during the hold period, the test was terminated and the specimen was considered failed. The test setup for performing the submerged voltage withstand test on the straight specimens is shown in Figure 2.17.

2.4 Condition Monitoring (CM) Protocol

2.4.1 CM Tests Evaluated

As previously mentioned, two of the issues being studied in this program are related to condition monitoring techniques for installed low-voltage instrumentation and control electric cables. To address these issues, several promising CM techniques were selected for evaluation in this program. Each of these techniques was performed at prescribed times throughout the testing to obtain data for evaluation. The selection process and planned CM evaluation approach are described in detail in the BNL Condition Monitoring Research Plan, BNL Technical Report TR-6168/69-03-95 (Lee, 1996). The CM tests evaluated in this program are listed below.

Mechanical CM Tests
- Elongation-at-break
- Indenter (Compressive Modulus)

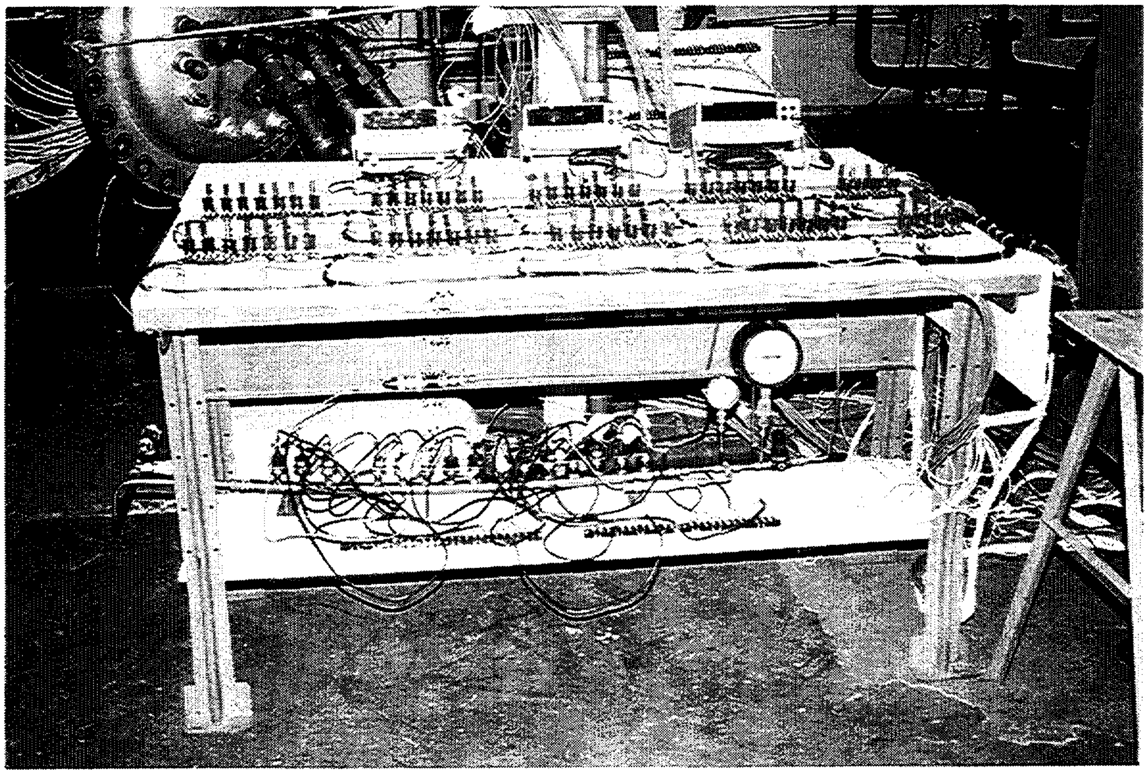


Figure 2.15 Test bench with hard-wired monitoring circuits and simulated pressure instrumentation loops

Chemical CM Tests

- Oxidation Induction Time
- Oxidation Induction Temperature
- Fourier Transform Infrared Spectroscopy

Electrical CM Tests

- AC Impedance/Dielectric Loss
- Insulation Resistance

Simple/Inexpensive CM Tests

- Visual Inspection
- Hardness

2.4.2 Condition Monitoring Points

Periodically throughout the test sequence, testing was halted and condition monitoring data were obtained. These data were used to determine the condition of the test specimens at each stage of the test and to evaluate the effectiveness of the different CM techniques. Each of these hold points, identified by a capital letter, corresponds to a different condition for the cable specimens. The test results reported herein are presented based on these condition monitoring (CM) points, which are defined in Table 2.4.

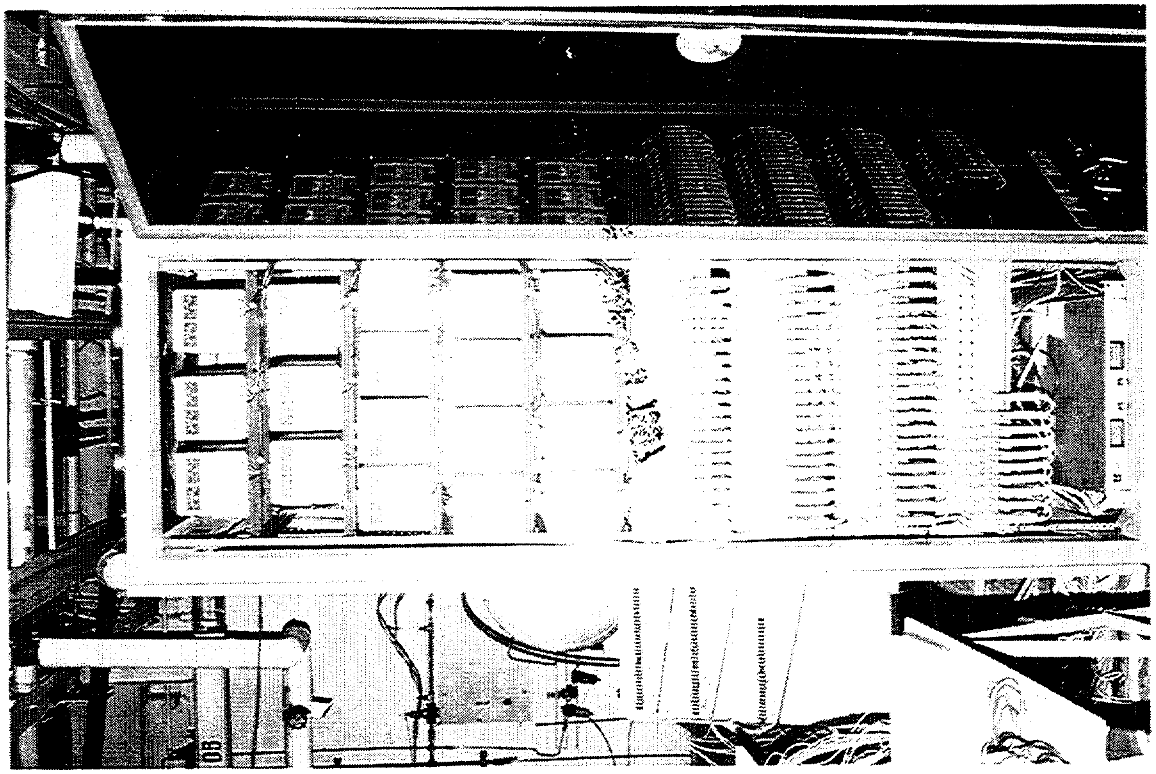


Figure 2.16 Specimen powering and monitoring equipment

Typical specimen CM hold points in test sequences 1, 2, and 3 were A-B-D-F-G-H for specimens that were being tested to match naturally aged cables, or A-C-E-F-G-H for specimens that were being tested to simulate a specific service age. The CM hold points for the control specimens and the naturally aged specimens were A-F-G-H, since no accelerated aging was applied to these specimens.

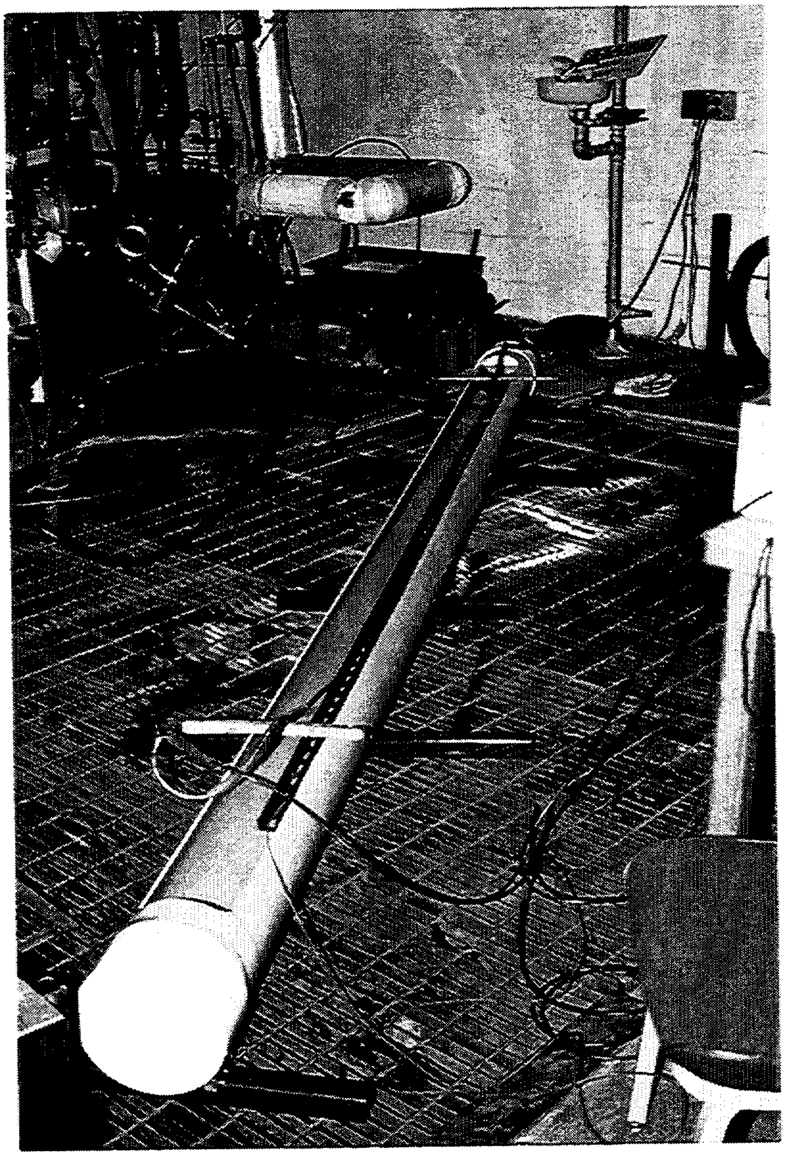


Figure 2.17 Test setup for the submerged voltage withstand test

Table 2.4 Definition of lettered CM hold points

CM Hold Point	Condition of Cable Specimens	Test Sequence
A	Baseline as-received condition	All
B	Completion of thermal aging to match condition of naturally aged cable specimens	1, 2, 3
	Completion of thermal aging to simulate 20 years of qualified life	4, 5
	Completion of thermal aging to simulate 40 years of qualified life	6
C	Completion of thermal aging to simulate 20 years of qualified life	1, 2
	Completion of thermal aging to simulate 40 years of qualified life	3, 4, 5
	Completion of thermal aging to simulate 60 years of qualified life	6
D	Completion of thermal and radiation aging to match condition of naturally aged cable specimens	1, 2, 3
	Completion of thermal and radiation aging to simulate 20 years of qualified life	4, 5
E	Completion of thermal and radiation aging to simulate 20 years of qualified life	1, 2
	Completion of thermal and radiation aging to simulate 40 years of qualified life	3, 4, 5
	Completion of thermal and radiation aging to simulate 60 years of qualified life	6
F	Completion of 75 Mrad of the simulated LOCA accident radiation	All
G	Completion of 150 Mrad of the simulated LOCA accident radiation	All
H	Completion of steam/chemical spray LOCA exposure simulation	All

3. DESCRIPTION OF CONDITION MONITORING TECHNIQUES

Condition monitoring of an electric cable involves the observation, measurement, or trending of one or more indicators, which can be correlated to the condition or functional performance of the cable, with respect to an independent parameter, such as time or cycles. Ideally, a CM technique would have the following attributes:

- non-destructive and non-intrusive (i.e., does not require the cable to be disturbed or disconnected),
- capable of measuring property changes or indicators that are trendable and can be consistently correlated to functional performance during normal service,
- applicable to cable types and materials commonly used in existing nuclear power plants,
- provides reproducible results that are not affected by, or can be corrected for the test environment (i.e., temperature, humidity, or radiation),
- inexpensive and simple to perform under field conditions,
- able to identify the location of any defects in the cable,
- allows a well defined end condition to be established,
- provides sufficient time prior to incipient failure to allow corrective actions to be taken,
- available to the industry immediately

CM measurements are intended to provide information that can be used to determine the current ability of a cable to perform within specified acceptance criteria, as well as to make predictions about its future performance and accident survivability. To predict future performance, it is most important to have a trendable indicator and a well defined end point. A trend curve can then be used to estimate the time remaining before the end point is reached.

In this program, a number of promising condition monitoring techniques were evaluated to determine their effectiveness for in situ use. Each technique was performed periodically throughout the accelerated aging and accident testing of the cable specimens to obtain data for this evaluation, as well as to track the condition of the test specimens. The data obtained for the baseline condition of the cables and the service aging portion of the program are the most representative of actual applications of CM techniques in service, and were principally used for evaluating the effectiveness of the various CM techniques. Conditions during the accident exposures were also observed, and are reported herein, to gain a better understanding of cable performance, even though these observations are not relevant to the use of CM in operating nuclear power plants.

In this section, each of the condition monitoring techniques studied is described in terms of the theory behind it and how it was performed. Information is also provided on any special equipment that was used. In all cases, a detailed procedure was developed and approved to provide step-by-step instructions on how to perform the test.

3.1 Visual Inspection

Visual inspection of the cable test specimens was an integral part of the research program. In comparison to the other CM methods, which produce quantitative results, visual inspections provide a qualitative assessment of cable condition. However, visual inspection is an in situ test that is inexpensive and relatively easy to perform, and can provide useful information for determining cable condition. Therefore, it is considered an important element of any condition monitoring program, and was evaluated as part of this research effort. For this evaluation, visual inspections of the test specimens were performed prior to testing (baseline), as well as periodically throughout the pre-aging and LOCA simulation processes. The results obtained throughout the research program are compared to those obtained from the baseline visual inspection to determine if visible changes in the cable can be correlated to degradation occurring as a result of aging.

The visual inspections were performed in a standardized, detailed manner in accordance with a BNL-approved test procedure. The only pieces of equipment used were a flashlight, magnifying glass and a tape measure. Cable attributes that were inspected visually include: 1) color, including changes from the original color and variations along the length of cable, and the degree of sheen; 2) cracks, including crack length, direction, depth, location, and number per unit area; and 3) visible surface contamination, including any foreign material on the surface. Also, the rigidity of the cable was qualitatively determined by squeezing and gently flexing it.

3.2 Elongation-at-Break

Elongation-at-break (EAB) is a measure of a material's resistance to fracture under an applied tensile stress. It is often termed the "ductility" of a material and is defined as the percent increase in elongation at the time of fracture:

$$\text{EAB (\%)} = \frac{\text{Final length - Original length}}{\text{Original length}} \times 100$$

Therefore, if the specimen's original deformable length (the gage length) is 2.5 inches (63.5 mm), and it deforms to a final length of 6 inches (152.4 mm), then the EAB is 100 x (6.0 - 2.5)/2.5, or 140 percent.

It is well known that cable insulation and jacket materials, like most polymers, lose ductility as they age. In a nuclear power plant environment the aging process is a combination of thermal oxidation and gamma radiation effects. The oxidation process is accelerated by elevated temperatures. EAB has long been used to quantify the degradation of plastics. Much of this work has been for reactor cable evaluation. Therefore, in the current program, the EAB test was used as the standard procedure for estimating the integrity of cable materials. It was also used in this program as the reference against which other CM techniques were compared.

The EAB tests were carried out using a calibrated Instron tensile tester (model 4202) using ASTM Standard D638-91 for guidance. The tests were performed using 6-inch (152.4 mm) material specimens, which were prepared from the cable insulation and jackets, as described in Section 2.1.2. The standard gage length was 2.5 inches (63.5 mm), however, in a few cases a smaller gage length of 1.5 inches (38.1 mm) was used to avoid testing specimens that deformed during pre-aging. The jacket specimens were in the form of a "dog bone" shape with a 1.25-inch (31.75 mm) gage length and a width of 0.25 inches (6.35 mm). These were prepared by flattening the material to the extent possible, and stamping out the dog bones with an ASTM-approved die. For cables constructed with a composite insulation and bonded individual jacket, EAB measurements were obtained on the composite specimens. Therefore, the ductility is a measure of the overall integrity of the composite insulation and bonded individual jacket.

The standard cross head velocity during the tests was 20 in./min. (508 mm/min.). All tests were performed at room temperature. Three to five replicate specimens were normally tested at each applicable CM hold point. Data that deviated by a large margin from the average value were discarded.

After pre-aging, several of the specimens became very brittle. In order to grip these specimens for testing it was necessary to reinsert a conductor wire into the gripping ends of the insulation to prevent the specimen from being crushed in the grips.

3.3 Oxidation Induction Time

A Shimadzu Model DSC-50 differential scanning calorimeter (DSC) was used to measure the time at which rapid oxidation of the test material occurred at a predetermined constant test temperature in a flowing oxygen environment. This is termed the oxidation induction time (OITM). The DSC is an apparatus that supplies heat to an approximately 10 mg sample of insulation or jacket material that is placed in a small aluminum pan. The sample is cut into small pieces, each less than about 1 mg in mass. An empty pan is placed in the heating chamber adjacent to the test specimen to act as a control. The difference in heat supplied to the two pans is, therefore, the heat supplied to the sample. The onset of oxidation is usually considered to occur when the sample has become depleted of antioxidants, which allows the main polymer backbone to suffer rapid attack.

At the beginning of the test, the temperature of the pans is raised to the predetermined test temperature in flowing nitrogen, which takes about 20 minutes. When the temperature approaches the test temperature, the nitrogen is replaced by oxygen flowing at a rate of 50 ml/min. The OITM is the time from the start of oxygen flow to the time that rapid oxidation of the sample occurs, which is manifested by the appearance of a large exothermic peak in the oxidation curve (the thermogram). The OITM is measured using software supplied with the DSC. Usually, at least two replicate samples are tested to assure reproducibility. The OITM is measured for the cable materials as a function of the various aging treatments that each specimen receives.

The calorimeter was calibrated every month when it was used intermittently. During periods of heavy use it was given a high-temperature cleaning using a N_2/H_2 gas mixture to remove "sooty" deposits. Temperature and enthalpy were calibrated using tin and indium standards.

3.4 Oxidation Induction Temperature

As with the OITM measurements, the oxidation induction temperature (OITP) is measured using a DSC. The test specimen is prepared in an identical way to those for OITM However, the OITP is determined as the temperature of the sample is increased at a rate of 18°F/min (10°C/min) in oxygen flowing at 50 ml/min. The temperature at which the exothermic peak commences is the OITP, and is measured by software supplied with the DSC.

3.5 Fourier Transform Infrared Spectroscopy

Fourier Transform Infrared (FTIR) Spectroscopy is an important technique for analyzing the structure of molecules. The principle involves the measurement of absorbance or transmittance of infrared radiation by molecular structures, including those for polymers. As the radiation passes through a polymer, atoms absorb radiation and begin to vibrate. For a particular chemical bond, maximum vibration occurs for a specific wavelength of radiation. Therefore, by irradiating a specimen with a continuous spectrum of infrared radiation, and measuring the peaks (wavelengths) at which maximum absorbance or transmittance occurs, the chemical bonds that are vibrating may be identified from standard wavelengths that are available from the open literature.

The FTIR spectroscope used in the current study is a Spectra-Tech Model 410. During test sequence 1 of this program a zinc selenide crystal was used against which the specimen was held in optical contact using a pressure plate. The infrared radiation passes through the crystal and is refracted into the specimen and is then reflected back into the crystal. The amount of absorbance (or transmittance) of the infrared radiation as it passes through the surface layers of the specimen is automatically measured as a function of the wavenumber, which is the inverse of the wavelength of the radiation.

In studying the oxidation of cable materials two of the more important wavenumbers in the FTIR spectrum occur at 1730 and 2916 cm^{-1}. The presence of the carbonyl (C=O) peak at 1730 cm^{-1} is a direct indication that the polymer is undergoing oxidation and carbonyl bonds are being generated. The 2916 cm^{-1} peak represents the $-CH_2$ bond that is part of the specimen's backbone structure. These bonds could also be present in other constituents that are added to the polymer.

As will be described in Section 4.5 of this report, difficulties were experienced in the use of the zinc selenide crystal. This centered on the difficulty of obtaining adequate optical contact between the crystal and specimens that had become stiff from aging. To overcome this problem, a new selenium crystal assembly was purchased from Spectra-Tech Inc.

that had the advantage of using only a 2 mm diameter area of the specimen for examination. By providing a "pressure tower" that forced the specimen against the crystal at a predetermined pressure, reproducible optical contact could be obtained even for specimens that were relatively stiff. After the purchase of the so called "Thunderdome®" crystal attachment, it was used exclusively in all of the FTIR spectroscopy work.

The Spectroscope was calibrated every month by first aligning the infrared beam. Then, the accuracy of the wavenumbers of the peaks in the spectrum were confirmed by comparing values measured on a vendor-supplied control material with standard values listed in the computer's software library.

3.6 Compressive Modulus (Indenter)

Compressive modulus is a material property defined as the ratio of compressive stress to compressive strain below the proportional limit. As cable insulation and jacket materials age they tend to harden, which will cause the compressive modulus of the materials to increase. By monitoring this change in compressive modulus, an estimate of the degradation rate of the material can be made.

To monitor changes in the compressive modulus, the Ogden Indenter Polymer Aging Monitor (Indenter) was used. This device presses a probe into the material being tested and measures the force required for the resulting displacement. These values are then used to calculate the compressive modulus of the material. The probe is controlled by a portable computer and appropriate software, which controls the travel of the probe to prevent damage to the cable.

Indenter measurements for both the cable jacket and conductor insulation materials were performed during the initial baseline testing, and at the pre-determined CM hold points discussed previously. For the baseline testing, jacket measurements were conducted at 2-foot (0.61m) intervals along each of the long specimens, and at four different angles (0°, 90°, 180°, and 270°) circumferentially at each location. Measurements were obtained at the four different angles to account for the differences in the readings taken directly above a conductor, as opposed to readings taken above the space between conductors. The additional measurements also account for any variations in the materials. Each of the individual modulus measurements at the different angles were arithmetically averaged to obtain the mean compressive modulus for each cable specimen. For the insulation measurements, a minimum of three locations were tested for each conductor, and the results averaged to obtain the mean compressive modulus for each color of insulation.

A similar methodology was used at each of the subsequent CM hold points, with some minor modifications. In order to preclude the possibility of damaging the long cable specimens as a result of the handling required to perform the indenter measurements, a 2-foot (0.61 m)specimen was prepared from each of the original long specimens, as discussed in Section 2. Both the long specimen and the 2-foot piece were exposed to the same test conditions so each would receive the same aging exposure.

All compressive modulus measurements were obtained at room temperature. For modulus measurements on softer materials (modulus < 100 N/mm), a probe speed of 0.5 in./min. (12.7 mm/min.) was used. For harder materials (modulus > 100 N/mm), a probe speed of 0.2 in./min. (5.1 mm/min.) was selected. Semi-annually, a full calibration of the indenter was performed. Between full calibrations, a calibration "quick-check" was performed prior to, and after use at each CM hold point. This ensured no damage occurred during shipping or use that would affect measurement accuracy.

3.7 Hardness

As a comparison to the indenter, simple hardness measurements were performed on the jacket and insulation specimens, and evaluated as a potential condition monitoring technique. In theory, as the cable materials harden with age, a hardness test may be useful for correlating age degradation with changes in hardness readings. Hardness measurements are similar to the indenter measurement in that a probe is pressed against the cable and the cable surface deforms. The difference between the simple hardness measurement using a Shore Durometer and the indenter is the level of sophistication of the test, and the sensitivity of the instrument in taking measurements. The Durometer hardness is based on the penetration of the tip into the material being tested. The hardness is then inversely related to the penetration depth, and is dependent on the elastic modulus and viscoelastic behavior of the material.

The Shore Durometer is a simple, inexpensive device, however, its sensitivity is not equal to that of the indenter. A needle-like steel tip is spring loaded against the test material surface, and the depth of penetration is read on a calibrated vernier indicator. The Shore-D durometer used in this evaluation is recommended for use on rigid and some semi-rigid materials. The focus of this evaluation was to determine if the Durometer is sensitive enough to be useful as a condition monitoring tool on electric cables. All the hardness measurements on the jacket and the insulation were performed in accordance with a BNL-approved test procedure. Periodically during the testing process, the Durometer was calibrated against a vendor supplied polymer test block with a pre-determined hardness of 82.

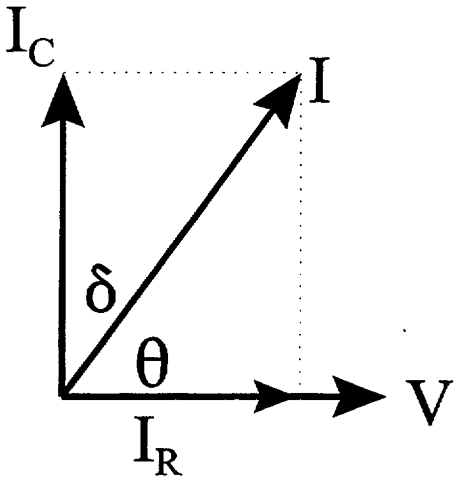
The hardness tests were conducted on the basket specimens that were removed at pre-determined hold points during the testing process. While these samples were prepared primarily for EAB testing, they were also used for hardness, OITM, OITP and FTIR measurements. In order to ensure accurate results, the hardness measurements were not performed on samples that had already been used for EAB testing. For the jackets, the measurements were obtained from the narrow gage length area of the tensile specimens. This area of the specimens was relatively flat and did not require straightening, which could have induced compressive forces that might affect the hardness readings.

3.8 Dielectric Loss

When a steady-state ac test voltage (V) is applied to an insulated cable, the resulting apparent total current (I) that flows consists of a charging current (I_C) due to the capacitance of the cable insulation and a leakage current (I_R). The relationships among the applied test voltage and the current components are shown in Figure 3.1 The phase angle θ between the applied test voltage (V) and the total current (I) is known as the dielectric phase angle. The compliment of the phase angle is called the dielectric loss angle δ.

The leakage current for electric cables is normally much smaller than the charging current, but it is more sensitive to the condition of the insulation. As insulation deteriorates, it is expected that the leakage current will increase, while the capacitive current remains approximately constant. Thus, the ratio of the magnitudes of (I_R) and (I_C) will increase. As can be seen from Figure 3.1, this ratio is the tangent of the dielectric loss angle (tan δ). It is called the dielectric dissipation factor and is commonly used as a measure of insulation condition. Similarly, another means of describing insulation condition is the dielectric power factor, expressed as the cosine of the dielectric phase angle (cos θ). At very low power factors (<10 percent), the dielectric power factor (cos θ) is approximately equal to the dielectric dissipation factor (tan δ).

The dielectric loss measurement was performed according to a BNL-approved test procedure, which measures the dielectric phase angle of the cable insulation for the long cable specimens when a test voltage of 5Vac (peak) is applied over a range of frequencies from 0.1 to 5000 Hz. The baseline and final measurements were made from conductor-to-conductor and conductor-to-ground in all the conductor combinations. Measurements at intermediate CM points were made between the black and white insulated conductors, and between the black and white insulated conductors and the ground.



I	**Total measured current**
I_C	**Capacitive component of I**
I_R	**Loss component of I**
V	**Applied ac voltage**
θ	**Dielectric phase angle**
δ	**Dielectric loss angle**
cos θ	**Dielectric (insulation) power factor**
tan δ	**Dielectric (insulation) dissipation factor**
Δ tan δ	**Power factor tip-up**

Figure 3.1 Insulation power factor relationship

Dielectric loss measurements for the cable specimens were made using a calibrated two-channel Hewlett Packard HP 35670A Dynamic Signal Analyzer with swept sine option. An internal source provided the applied ac voltage signal to the test specimens, and an internal disk drive allowed the data to be stored for later analysis. A simplified diagram of the test setup with this instrument is given in Figure 3.2.

3.9 Insulation Resistance

Insulation resistance measurements are commonly performed to determine the current condition of cable insulation. By applying a voltage from the conductor-to-ground, the resistance of the insulation separating them can be measured. The advantages of this test are that it is relatively easy to perform and requires inexpensive equipment. If the insulation resistance decreases in a predictable manner as the insulation ages, trending of this parameter could be useful as a condition monitoring technique for electric cables. This program evaluated insulation resistance as it is used to monitor the condition of cable specimens that are aged in a controlled series of steps.

When a dc voltage is applied to a test specimen, the total current flowing in the insulation from the conductor-to-ground is equal to the sum of the capacitive charging current, leakage current, and dielectric absorption current. These three component currents change with time. The capacitive charging current and the dielectric absorption current will initially be relatively high when the test voltage is first applied to the test specimen. Once the insulation, which behaves like a capacitor, is energized and charges have aligned across the insulation, these currents will taper off and eventually approach zero. However, leakage current will typically start at zero and gradually increase. In high integrity insulation, leakage current will reach and maintain a steady value after a certain amount of time. If the insulation is badly deteriorated, wet, or contaminated, the leakage current will be greater than that found in good insulation and it could continue to increase over time.

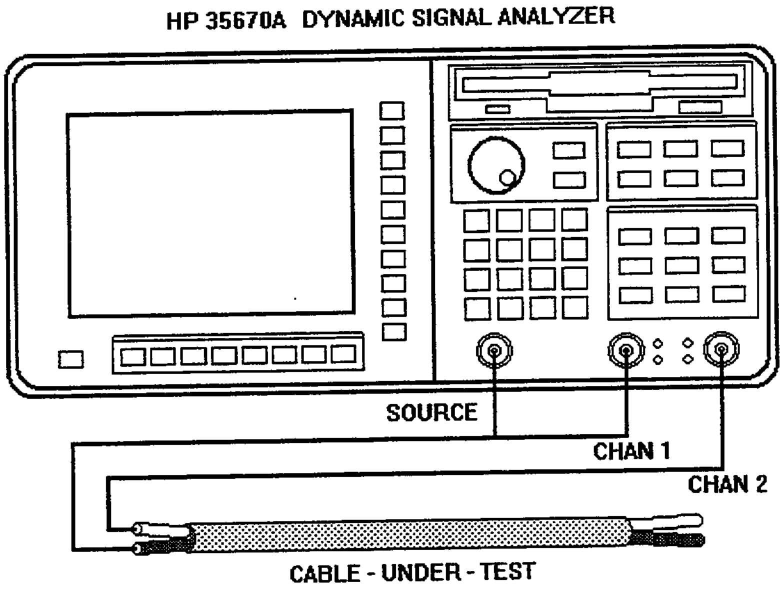


Figure 3.2 Test setup for dielectric loss measurement

As a result, the total current flowing in a test specimen will start out high when a test voltage is first applied, and taper off in different ways over the next several minutes depending on the condition of the insulation. In high integrity insulation the insulation resistance will gradually increase after the test voltage is applied, then a steady value will be reached. Because of this behavior, insulation resistance measurements are taken using an ohmmeter first at one minute and again at ten minutes. The ratio of the insulation resistance at ten minutes to the value measured at one minute is called the polarization index.

An additional factor that must be considered when making these measurements is that insulation resistance is very sensitive to temperature. It is common practice to correct the readings to a single temperature, such as 60°F (15.6°C) for electric cables, in order to compare measurements taken at different times and to trend the data over an extended period. Another advantage of using the polarization index is that it is not temperature dependent since the temperature correction factor drops out of the calculation.

In test sequence 1, a calibrated Biddle model 210600 digital Megger® was used following a BNL-approved test procedure. This instrument was capable of measuring IR values up to 2 gigaohms, which was found to be too low a range to provide quantitative values. For subsequent tests, a calibrated General Radio model 1864 megohmmeter with the capability of measuring IR values up to 200 teraohms ($200 \times 10^{12}\Omega$) was used. IR measurements were made at a test voltage of 500 Vdc in air. The IR values were taken from conductor-to-conductor or conductor-to-ground and recorded at 1 minute after application of the test voltage and again at 10 minutes. Temperature and humidity at the time of the test were also recorded. This provided direct IR values at two intervals of time and allowed calculation of the polarization index of the insulation. This method of IR measurement is similar to what would be performed in the field by plant maintenance technicians.

3.10 Functional Performance Test

The ultimate objective of qualification testing is to verify that a cable, at the end of its qualified life, is capable of performing its intended function in a given application under design basis accident conditions. The functional test provided a direct means for evaluating the performance of a cable test specimen while configured into a typical plant instrumentation application. The information thus gathered on the accuracy of the simulated instrumentation circuit, and the magnitudes and pathways of observed leakage currents, provided real-time quantitative research data regarding the LOCA exposure performance of cable test specimens. To perform this evaluation, the test specimens were powered and loaded as shown in Figures 2.13 and 2.14. Each of the long specimens were powered separately with 28 volts DC. A pressure transmitter was connected to the LOCA chamber leads from each long specimen to act as a load. All of the pressure transmitters were connected to a common manifold connected to a source of regulated compressed air so that they monitored the same pressure.

During the simulated LOCA test, the powered specimens were monitored for applied voltage, circuit current, and leakage current. Manifold pressure, as measured by the test specimen pressure transmitters, was compared to actual pressure, as measured by an external pressure transmitter connected directly to the manifold. Circuit current was measured on both sides of each test circuit (current "A" and current "B") to aid in evaluating the source of any anomalies. Nominal instrument readings for a healthy circuit were 28.0 volts DC, 12.8 milliamps for currents "A" and "B", and 0 milliamps for leakage current. Since currents "A" and "B" are for the same circuit, they should be equal for a healthy circuit. A 1/32 amp fuse was placed in the circuit to prevent overloading the power source in the event of a short circuit. Potential anomalies for which the circuits were monitored include: a leakage current greater than 0, indicating a short circuit from conductor-to-ground; a mismatch between currents "A" and "B", indicating a short circuit from conductor-to-conductor; and a blown fuse, indicating a short circuit from conductor-to-ground or conductor-to-conductor.

The performance of a cable specimen's test circuit during the accident exposure test can thus be evaluated by identifying the maximum error indicated by the pressure transmitter loop circuit in which the specimen was connected The magnitude of leakage current measured and the time at which it occurred was also recorded. If the circuit current exceeded 1/32 ampere, causing the protective fuse on the power supply to blow, the time at which this occurred was also noted, along with the success of any attempts to replace the fuse to return a circuit to operation.

3.11 Voltage Withstand

After each accident exposure test was completed, the insulation resistance of each long specimen was checked prior to its removal from the LOCA test chamber, and then measured again after the cables were removed from the chamber. At this time post-LOCA visual inspection was performed, and condition monitoring tests were repeated to provide final post-LOCA values for research information purposes.

Once the post-LOCA tests and visual inspection were completed, the long cable specimens were then subjected to a submerged voltage withstand test. While this test is not considered to be a candidate for in situ cable testing, the voltage withstand test was used in the BNL research program as an indicator of whether a cable had survived an end-of-life LOCA exposure. Since this is a high potential test, it was possible that the specimens could have been damaged during the performance of the test. For this reason, all other post-LOCA inspections and tests were completed before the voltage withstand test was performed. (The submerged voltage withstand test is also performed in the final step in cable qualification testing in accordance with IEEE Std. 383-1974.)

The post-LOCA submerged voltage withstand test was performed by Wyle Laboratories personnel using a calibrated Hippotronics Model 760-2HVT high potential test set. Each specimen was individually submerged in a trough, for straight Unistrut®-mounted specimens, or a large tank, for mandrel-mounted specimens, containing tap water at room temperature (73°F/23°C) while being subjected to a test voltage of 80 Vac/mil of insulation thickness for a period of 5 minutes. Based on the thickness of the insulation for the cable specimens tested in this program, the voltage used was 2,400 Vac at 60 Hz. The straight cable specimens remained in their Unistrut® supports, and the mandrel-mounted specimens were left on the mandrels during the voltage withstand testing. Splices on the test specimens (to connect the specimen to the facility test leads) were not submerged during this test to ensure that only the insulation system of the test specimen was being subjected to the conditions of the submerged voltage withstand test. Figure 2.17 shows a typical test setup for voltage withstand testing a straight cable mounted on Unistrut® channel in a water-filled trough.

As the test voltage was applied to each individual conductor of the cable specimen for five minutes, the leakage current between the conductor and electrical ground was recorded. The maximum leakage current that may be measured by the Hippotronics Model 760-2HVT high potential test set is 10 mA. If the applied test voltage could not be achieved or maintained for the entire five minutes of the test without exceeding the maximum leakage current of the test set, the cable specimen was then considered to have failed the test. The cable was visually monitored to note any sparking, electrical discharges, bubbling, corona noise, or smoke that occurred during the test.

This test is similar to the post-LOCA voltage withstand test performed in many manufacturers' original qualification tests and in the qualification type tests described in the IEEE Std. 383-1974 for electric cable qualification. The major difference is that, in the typical original qualification, as well as in the IEEE standard, the cable specimens were removed from their test mandrels, straightened, and rewound on the mandrels prior to the final submerged voltage withstand test.

4. CONDITION MONITORING RESULTS FOR CROSS-LINKED POLYETHYLENE CABLES

This section presents the results of the condition monitoring tests on cables with cross-linked polyethylene insulation. Each CM technique is evaluated based on how well it was able to detect and trend the degradation caused by the pre-aging administered to the test specimens. In some cases, degradation caused by the accident exposure (radiation plus steam/chemical spray) is also discussed since it provides supplemental data and additional insights into how well the CM technique, as well as the polymer being tested, performed.

4.1 Visual Inspection

As discussed previously, the visual inspections were performed in accordance with a BNL-approved procedure that provided a standardized method of inspection. Attributes that were examined included discoloration, surface contamination, cracking and stiffness. Table 4.1 presents a sample tabulation of the visual inspection results for the Rockbestos XLPE-insulated cable specimens from test sequence 1, Group 1.1 (0101, 0102, 0118, 0104, 0105). These specimens received no pre-aging prior to accident irradiation and LOCA steam testing. The table shows the level of detail used in obtaining and reporting visual inspection findings. Results for all groups are discussed individually below.

For the test sequence 1, Group 1.1 specimens , which received no pre-aging prior to LOCA testing, the baseline data show the cables were initially in excellent condition, with no visible signs of degradation. The application of 150 Mrad of radiation had little noticeable affect on the cables. After exposure to simulated LOCA conditions, areas of white/brown residue, along with small, white, powdery spots were noted on the jackets. The white insulation became slightly brown in color. The cables also felt slightly more rigid than their baseline condition, however, they were still somewhat flexible. In general, the specimens appeared to be in good physical condition.

As noted in Table 4.1 for surface contamination, an area of reddish/brown residue was found on specimen 0104. This is believed to be a marking made by the utility using spray paint and is not representative of degradation. Similarly, under "Comments", flat spots were noted on several of the specimens. These are believed to be inherent to the manufacturing process and also do not represent degradation.

The visual inspection results for the Group 1.2 Rockbestos cable specimens (0106, 0107, 0108, 0109, 0110), which were pre-aged to simulate the service conditions experienced by the naturally aged specimen in Group 1.3 (0111), show these specimens were also initially in excellent condition with no visible signs of degradation. After thermal aging at 120°C for 2.86 hours to simulate the naturally aged specimen (0111), the specimens showed a slight yellowing of the white insulation, and the cables became slightly more rigid than initially. The subsequent application of 0.6 Mrad of radiation had little visible effect on the specimens. Application of an additional 150 Mrad of accident radiation also caused little noticeable change in the specimens, with the exception that one circumferential crack was noted on the jacket of specimen 0109. Exposure to the simulated LOCA conditions resulted in the white insulation becoming light brown in color, and a white/brown residue formed on the jackets. The specimens were slightly more rigid than previously.

Visual inspection of the naturally aged specimen in test sequence 1 (0111) found that initially the specimen was in excellent condition with uniform black jacket color, and slight yellowing of the white insulation. No cracks were observed in either the jacket or the insulation. A sticky residue was noted on the jacket initially. The specimen was slightly more rigid than a new cable, however, the insulated conductor had good flexibility. Application of 150 Mrad of radiation to simulate an accident had no visible effect on the specimen. Exposure to the simulated LOCA steam conditions left the jacket with some areas of white/brown residue, and small, white, powdery spots. The white insulation appeared light brown in color. Both the jacket and the insulation felt more rigid than they did previously, however, they still had some flexibility remaining. In general, the specimen appeared to be in good physical condition.

Table 4.1 Sample tabulation of visual inspection results for Rockbestos XLPE/Neoprene® specimens in Group 1.1

Hold Point	Cable Characteristics Noted During Visual Inspection				
	Color	Cracks	Surface Contamination	Flexibility	Comments
"A" Unaged	Jacket: 1. Uniform black color; low sheen. Insulation: 1. Uniform black/white color.	Jacket: 1. No visible cracks. Insulation: 1. No visible cracks.	Jacket: 1. Area of reddish/brown residue on specimens 0104 at 0.9 - 1.0 m. Insulation: 1. No visible contamination.	Jacket: 1. Good Insulation: 1. Good	1. Specimens inspected prior to installation in Unistrut®. 100% of jacket surface examined; insulation examined at exposed sections on each end of cable.
B, C, D, E	No change - specimens not exposed to any additional pre-aging after last hold point.				
"F" 75 Mrad	Jacket: 1. Uniform black color; low sheen. Insulation: 1. Uniform black/white color.	Jacket: 1. No visible cracks. Insulation: 1. No visible cracks.	Jacket: 1. Area of reddish/brown residue on specimens 0104 at 0.9 - 1.0 m, and 0105 at 0.5 - 0.6 m. Insulation: 1. No visible contamination.	Jacket: 1. Good Insulation: 1. Good	1. Specimens installed in Unistrut®. Top 50% of jacket inspected. Insulation examined at exposed sections on each end of cable. 2. Flat spots noted on various portions of jacket surface for specimens 0102, 0104, 0105, 0118
"G" 150 Mrad	Jacket: 1. Uniform black color; low sheen. Insulation: 1. Uniform black/white color.	Jacket: 1. No visible cracks. Insulation: 1. No visible cracks.	Jacket: 1. Area of reddish/brown residue on specimens 0104 at 0.9 - 1.0 m, and 0105 at 0.5 - 0.6 m. Insulation: 1. No visible contamination.	Jacket: 1. Good Insulation: 1. Good	1. Specimens installed in Unistrut®. Top 50% of jacket inspected. Insulation examined at exposed sections on each end of cable. 2. Flat spots noted on various portions of jacket surface for specimens 0102, 0104, 0105, 0118.
"H" 150 Mrad + LOCA	Jacket: 1. Mostly uniform black color; low sheen. Some portions of white/ brownish color on all specimens. Insulation: 1. Uniform black/white color. 2. White insulation light brown	Jacket: 1. No visible cracks. Insulation: 1. No visible cracks.	Jacket: 1. Small (1 mm dia.) white powdery spots on sections of cable jacket for specimens 0102, 0105, 0118. Insulation: 1. No visible contamination.	Jacket: 1. Slight rigidity Insulation: 1. Slight rigidity	1. Specimens installed in Unistrut®. Top 50% of jacket inspected. Insulation examined at exposed sections on each end of cable.

Visual inspection results for the Group 1.4 Rockbestos cable specimens (0112, 0113, 0114, 0115, 0116) showed the specimens were initially in excellent condition with uniform jacket and insulation colors, no cracks and no visible signs of degradation. At hold point "C" after thermal aging, all of the specimens showed significant visible signs of degradation. The jackets had areas of grey/silver coloring, while the white insulation was dark brown in color. Numerous cracks were noted in the jackets, however, no cracks were found in the insulation. The jacket cracks were circumferential in nature, with most tightly closed and several opened 1-2 mm exposing the insulation underneath. Small, white, powdery spots were noted near the ends of the jacket on all specimens. The jackets felt brittle with little or no flexibility remaining. The insulation felt moderately rigid, however, it still had some flexibility remaining.

Application of 75 Mrad of radiation had little visible effect on the Group 1.4 specimens, with the only change being the number of circumferential cracks in the outer jacket increasing slightly. It is observed that there is some variability in the number of cracks noted. This is believed to be due to different inspectors performing the visual inspections. Typically, some of the cracks are not well defined and identification becomes subjective. In general, however, the number of cracks appeared to increase with additional aging.

Exposure to the simulated LOCA caused additional degradation to the Group 1.4 specimens. The jackets were badly damaged with numerous circumferential cracks and longitudinal splits. Some sections of the jackets were missing completely. Areas of grey/silver and white/brown residue were noted on the jackets. Both the black and white insulation were very dark brown/black, as if they were burnt, such that it was difficult to distinguish between the two. The jacket remained brittle with no flexibility, while the insulation was moderately rigid with some flexibility remaining.

The corresponding EAB readings for the 20 year pre-aged specimens in Group 1.4 had all been reduced to <5 percent. Additional pre-aging to simulate 40 and 60 years of service at 194°F (90°C), therefore, produced little if any further visible change in the appearance of the cable. This explains why the pre-aged Rockbestos cables all seemed to have a very similar physical appearance.

Similar results were obtained in test sequences 3 and 6, which also included Rockbestos XLPE-insulated cable specimens. The Group 3.2 specimens, which were pre-aged to match the service exposure of the 10-year naturally aged specimens, were found to be in good condition throughout the pre-aging process. No cracking was visually evident in the jacket or insulation of these specimens. The specimens were flexible with no significant hardening noted.

The Group 3.4 specimens were pre-aged to simulate 40 years of qualified life. As for the specimens in Group 1.4, significant degradation was noted on the cable jackets. The jacket material was embrittled and severely cracked with the cracks extending through the entire jacket thickness. No cracking was noted in the insulation and it was not embrittled, however, it was slightly stiffer than the baseline condition.

The thermal pre-aging for the Rockbestos specimens in test sequence 6 was similar to that received by the specimens in test sequence 3; the major difference in pre-aging was the 50 percent greater total integrated dose of service radiation administered to the test sequence 6 cables. As a result, the two groups of preaged specimens were in similar physical condition. Severe cracking of the jackets was noted after pre-aging, however, the insulation appeared to be in good physical condition.

4.2 Elongation-at-Break (EAB)

Elongation-at-break (EAB) measurements were performed on the XLPE/Neoprene® cables manufactured by Rockbestos that were included in test sequences 1, 3 and 6 to quantify the condition of the specimens at each CM hold point. These measurements were also used as a reference for comparison with other CM techniques being evaluated in this program. The complete set of EAB values are presented in Appendix A. Selected data are discussed below to characterize the behavior of the XLPE-insulated cables.

In test sequences 1, 3 and 6, two different samples of XLPE-insulated cable specimens were studied. They are designated as PNI79RB188 (2-conductor) and PNI85RB191 (3-conductor), which were manufactured in 1979 and 1985, respectively. Figure 4.1 shows EAB results for the 2-conductor cable. The unaged insulation and jacket materials had EAB values in excess of 500 percent. After the LOCA irradiations (CM Points F and G) and steam/chemical spray (CM Point H), the ductilities were greatly reduced. However, the cable materials were far from brittle.

Figure 4.2 shows data for the three-conductor cable that was artificially aged to simulate the 10-year naturally aged cable in Group 1.3. The Neoprene® shows small losses in EAB after the simulated thermal and irradiation aging (CM Points B and D, respectively). However, the XLPE shows a small increase in EAB after thermal aging, and a decrease after the irradiation. When the two LOCA radiation doses were administered (CM points F and G) there was a large loss in ductility. After the LOCA steam/chemical spray, the EAB for the Neoprene® jacket again decreased; however, the XLPE showed a small increase. This could be due to penetration of water into the specimen, which could act as a plasticizer or, perhaps, because some of the aging damage was repaired during high-temperature spray testing. One interesting point to note is that the white XLPE consistently showed a larger EAB than the black and red insulation. The differences were usually small, however, and one may use the EAB values from one color of insulation to illustrate the trend for all colors during aging. Alternately, one may use an averaged value for all colors to illustrate general XLPE behavior.

Figure 4.3 shows EAB data for the 10-year naturally-aged cable in test sequence 1. Note that for this cable, CM Point A represents the EAB for the naturally-aged condition; for most other specimens in this program CM point A represents unaged cable. When the naturally-aged cable is compared to specimens that were artificially-aged to simulate 10 years of service, the results are consistent (compare results for CM Point A in Figure 4.3 with those for CM Point D in Figure 4.2). The reasonable agreement is obviously connected with the fact that, for a 10-year aging period, whether artificial or natural, cable degradation is minimal. Therefore, the EAB values for 10-year-aged cable remain very close to those for unaged materials. LOCA irradiation causes a major loss in EAB for the naturally-aged cable, which is slightly more severe than that for the artificially-aged materials. This could be because the two cables are from different production lots, and may have different responses to LOCA testing.

Figure 4.4 shows EAB results for the two-conductor cable sample (PNI78RB188), which was artificially aged under conditions that were equivalent to one-half of the manufacturer's 40-year cable qualification test protocol. After the thermal aging given in CM Point C in Figure 4.4, the EAB dropped to a value of less than 5 percent. The materials remained embrittled for all subsequent service irradiation and LOCA exposures. Based on these findings, the qualification test conditions appear to be very conservative and lead to cable embrittlement after only one-half of the 40-year qualification test protocol is applied.

Table 4.2 summarizes the accelerated thermal and radiation aging carried out in this program on XLPE/ Neoprene® cables. The EAB data for the XLPE are averages for all colors of insulation. The exception is for test sequence 3 (Specimen 0303D) results for which only white XLPE was tested. The table includes thermal aging protocols that were used by the manufacturer to qualify the cables for particular service times. In some cases a safety margin was applied so that the cable is aged more severely than they would be under actual service conditions. In order to compare the qualification aging protocols, the Arrhenius equation was used to normalize all of the aging temperatures to an assumed service temperature of 140°F (60°C). The activation energy for aging of XLPE was taken to be 1.33 electron volts/molecule, as determined from the original qualification test report for these cables. The data in the fourth column show that, at 140°F (60°C), the times required to give equivalent aging to that experienced in the qualification test protocols are extremely long. This explains why the XLPE became so severely embrittled during the qualification test simulations in all three test sequences.

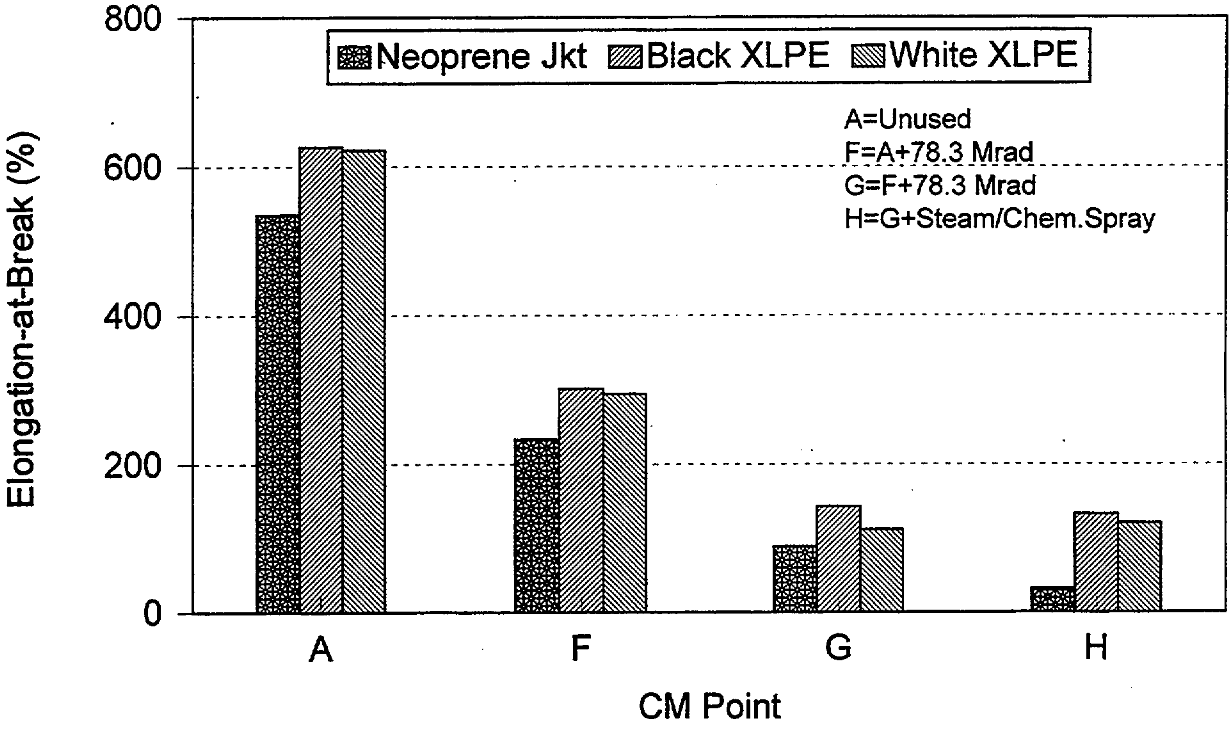


Figure 4.1 **Effect of LOCA testing on EAB for Rockbestos cable PNI79RB188 (Group 1.1, Specimen 0101)**

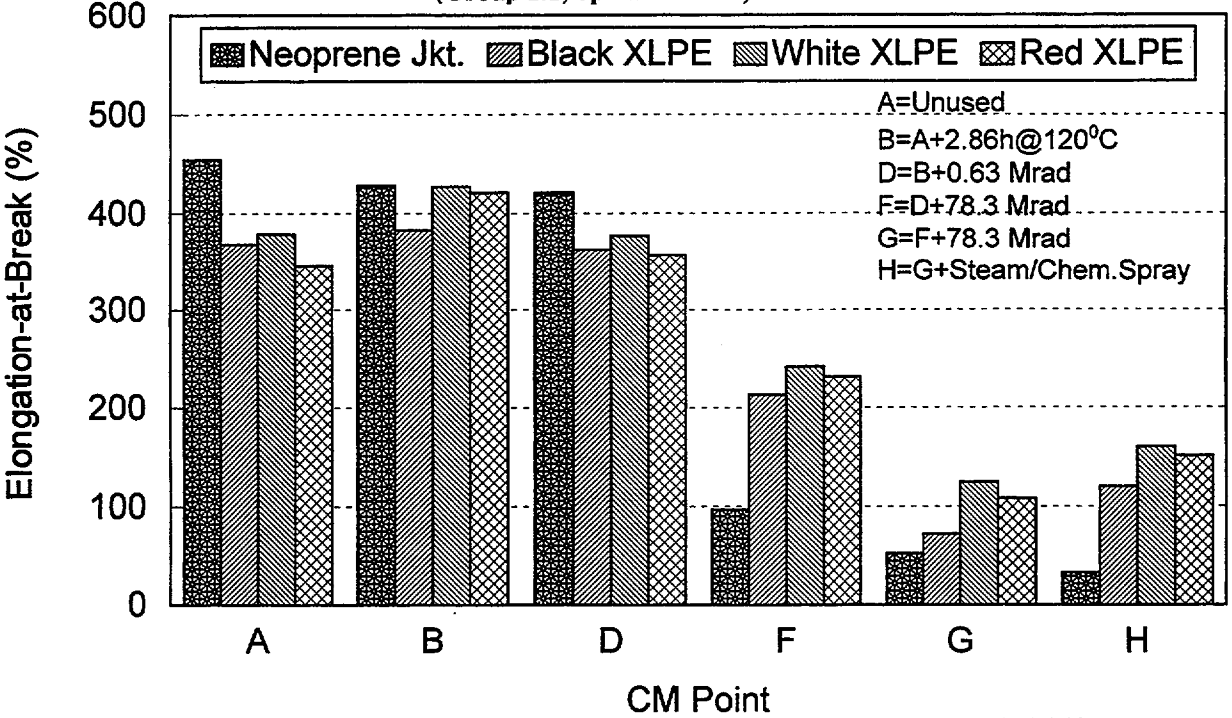


Figure 4.2 **Effect of aging and LOCA testing on EAB for Rockbestos cable PNI85RB191 (Group 1.2, Specimen 0106) artificially aged to 10 years service**

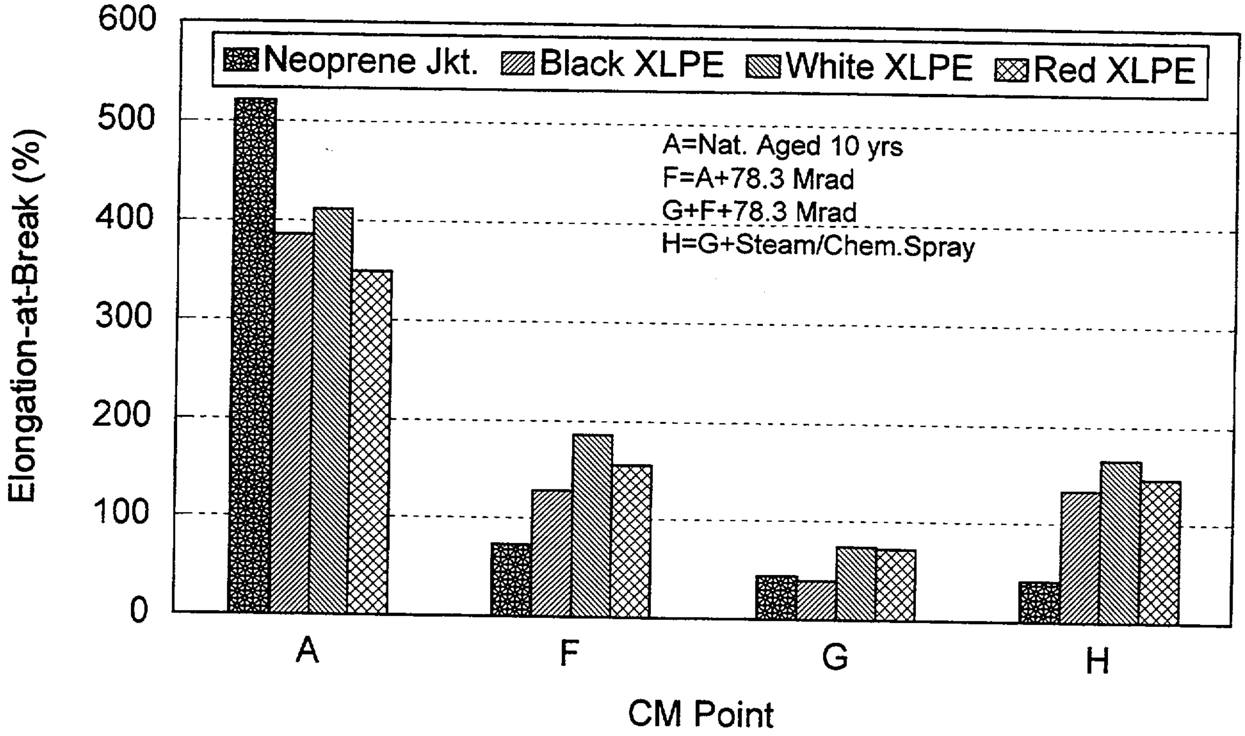


Figure 4.3 Effect of LOCA testing on the EAB of Rockbestos cable PAP86RB267 (Group 1.3, Specimen 0111) naturally aged for 10 years

Some additional research was carried out to determine more quantitatively how thermal aging affects the ductility of XLPE insulation. Figure 4.5, prepared from data taken from Appendix A, shows the EAB for white XLPE aged in air at 350°F (177°C). For the shortest aging time of 6 hours, the EAB increases by about 10 percent compared to the unaged condition. As aging continues, EAB slowly decreases with aging time up to about 75 hours. Then the ductility shows a much faster loss, and appears to become stable at about 80 percent. Experiments using a differential scanning calorimeter, which will be described later in Section 4.3 of this report, show that, at about 95 hours, all of the antioxidants in the XLPE have become depleted. At this point, rapid oxidation of the insulation begins. Since the calculated depletion time is close to the time at which the EAB begins to decrease, it is a strong indication that antioxidants, up to the point that they are completely depleted, are very effective in minimizing losses in ductility. However, as Table 4.2 and Appendix A show, severe thermal aging and heavy irradiation may eventually reduce the EAB to a few percent.

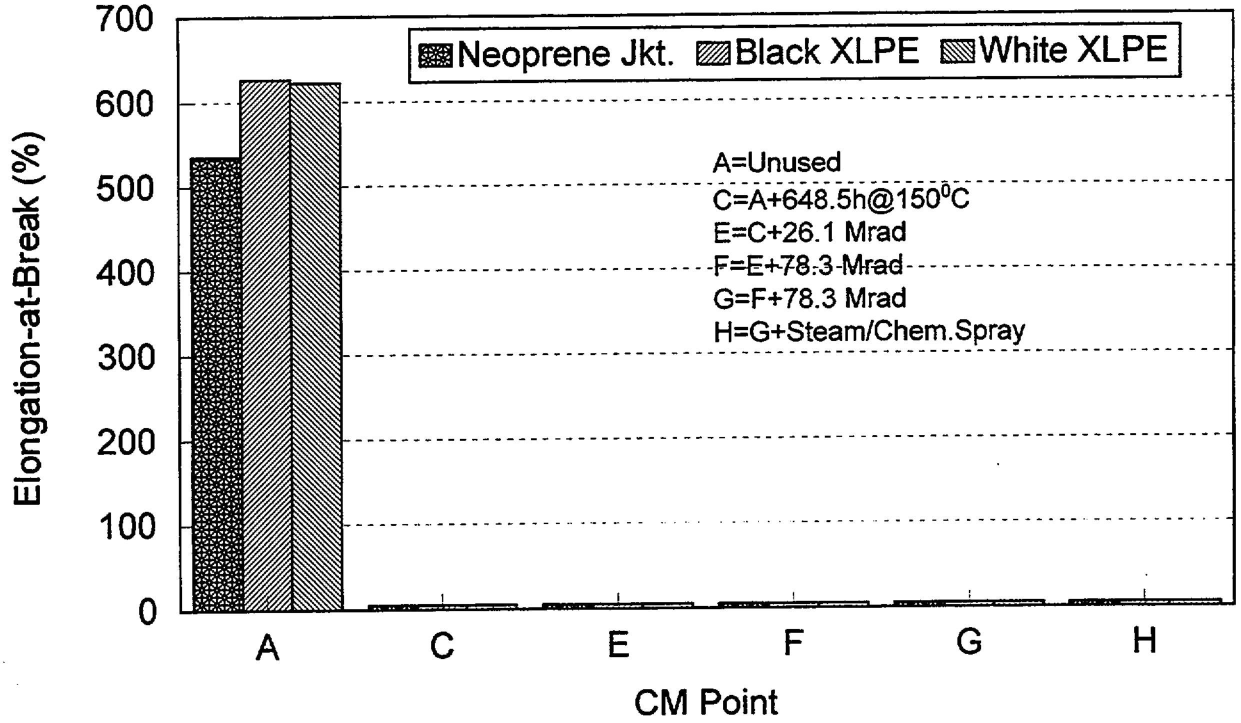


Figure 4.4 Effect of aging and LOCA testing on the EAB of Rockbestos cable PNI79RB188 (Test 1.4, Specimen 0112) artificially aged to one-half of the 40 year qualified life

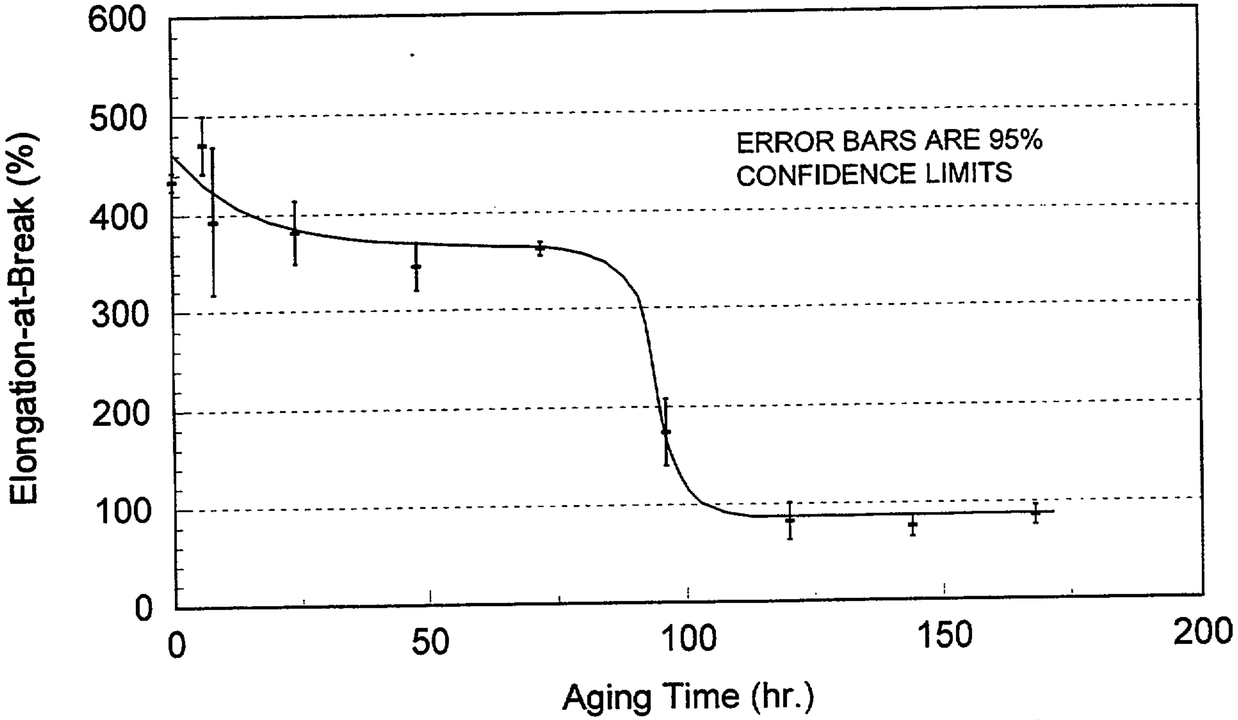


Figure 4.5 Effect of thermal aging at 350°F (177°C) in air on the EAB of Rockbestos white XLPE insulation (PNI85RB191)

Table 4.2 Effect of accelerated aging on the EAB of XLPE insulation

Cable Sample	Group (Specimen)	Accelerated Aging Treatment	Equivalent Aging Time at 60°C (y)	EAB (%)
PNI85RB191	1.2 (Specimen 0106A)	None	0	364
PNI85RB191	1.2 (Specimen 0106D)	2.86 hr.@120°C + 0.63 Mrad (Simulates a 10yr. nat. aged cable)	0.4	365
PNI85RB191	3.2 (Specimen 0303D)	9.93 hr.@120°C + 2.27 Mrad (Simulates a 10yr. nat. aged cable)	1.3	403
PNI79RB188	1.4 (Specimen 0112A)	None	0	624
PNI79RB188	1.4 (Specimen 0112E)	648.5 hr.@150°C + 26.1 Mrad (One-half of 40yr. qualified life)	1,420	≤5
PNI79RB188	6.2 (Specimen 0621D)	909.5 hr.@150°C + 51.4 Mrad (40yr. qualified life)	1,992	≤5
PNI79RB188	3.4 (Specimen 0312E)	1301 hr.@150°C + 51.5 Mrad (40yr. qualified life)	2,849	≤5
PNI79RB188	6.2 (Specimen 0621E)	1364 hr.@150°C + 77.0 Mrad (60y qualified life)	2,987	≤5

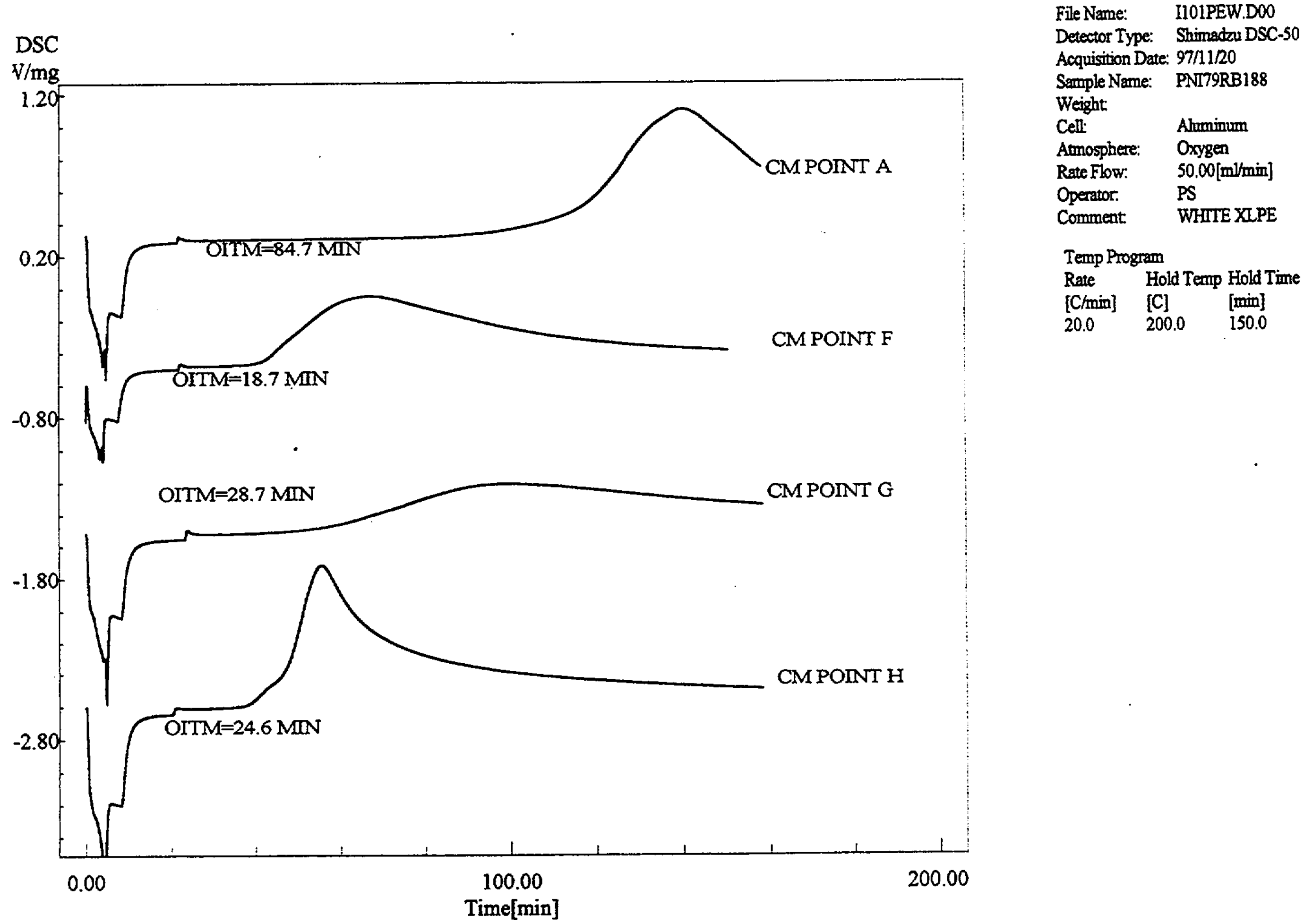
4.3 Oxidation Induction Time (OITM)

Two samples of Rockbestos XLPE/Neoprene® cable were evaluated from test sequences 1 and 3 (PNI79RB188 and PNI85RB191). Sample PNI79RB188 is a two-conductor cable, which received accelerated aging to simulate one-half of the manufacturer's 40-year qualification test protocol. Sample PNI85RB191, a three-conductor cable, received accelerated aging that was used to simulate a 10-year service aging period, comparable to a naturally-aged cable that had been in plant service for 10 years. All of the OITM results for the Rockbestos cables are tabulated in Appendix B of this report.

Figure 4.6 shows thermograms for white XLPE insulation taken from cable PNI79RB188 at a test temperature of 392°F (200°C). Sample weights for the individual tests varied from specimen to specimen in this figure so no weight values are given in the test data table. However, weights were all close to 10 mg. Note that the flat line in the figure denotes the test temperature profile with time. The unaged material (CM Point A) shows a flat region following a small "spike." This spike is the time at which oxygen was admitted to the sample chamber. When the flat region ends, and an exothermic peak appears, it shows that the antioxidants in the sample have been exhausted by oxidation and the main polymer structure begins to be destroyed by further oxidation. The duration of the flat region is measured by computer software and represents the OITM at the particular test temperature. LOCA radiation exposures of about 75 Mrads each (CM Points F and G) cause a decrease in the OITM, as does the LOCA steam/chemical spray (CM Point H). Figure 4.7 shows a bar chart for the OITM of XLPE from Group 1.1, Specimen 0101, as a function of the CM point. Note the large decrease in OITM after irradiation. This may be caused by structural changes in the insulation, or by the radiation-induced losses of antioxidant in the samples.

Figure 4.8 shows an OITM thermogram for black XLPE from sample PNI79RB188 (Group 1.4, Specimen 0112) that was thermally aged for 648.5 hrs at 302°F (150°C) to simulate one-half of the 40-year qualification protocol. As soon as oxygen was admitted to the specimen chamber, there was a continuous increase in thermal energy absorbed. This indicates that the specimen was already depleted of antioxidants and that the main polymer structure was being oxidized. As shown previously in Table 4.2, this thermal aging treatment is equivalent to a service aging time of 1,420 years at 140°F (60°C). This is in keeping with the data in Figure 3.46 of Volume 1 of this report, which confirms that this is approximately the time that the antioxidants have been depleted. Therefore, the OITM is essentially zero.

For Rockbestos sample PNI85RB191 (Group 1.2, Specimen 0106) accelerated aging was carried out to simulate a 10-year natural aging period (Figure 4.9). The thermal and radiation aging treatments (CM points B and D, respectively) cause little change in the OITM compared to the unaged insulation. Note that the black insulation has slightly less oxidation resistance (lower OITM) compared to the white and red XLPE. The OITM is reduced significantly after the LOCA testing protocols. A comparison with the data for the 10-year naturally-aged insulation in Figure 4.10 shows that there is excellent agreement with the artificially-aged XLPE (compare CM point D in Figure 4.9 to CM point A in Figure 4.10).



File Name:	I101PEW.D00
Detector Type:	Shimadzu DSC-50
Acquisition Date:	97/11/20
Sample Name:	PNI79RB188
Weight:	
Cell:	Aluminum
Atmosphere:	Oxygen
Rate Flow:	50.00[ml/min]
Operator:	PS
Comment:	WHITE XLPE

Temp Program

Rate [C/min]	Hold Temp [C]	Hold Time [min]
20.0	200.0	150.0

Figure 4.6 OITM for white XLPE at 392°F (200°C) for Rockbestos cable PNI79RB188 (Group 1.1, Specimen 0101)

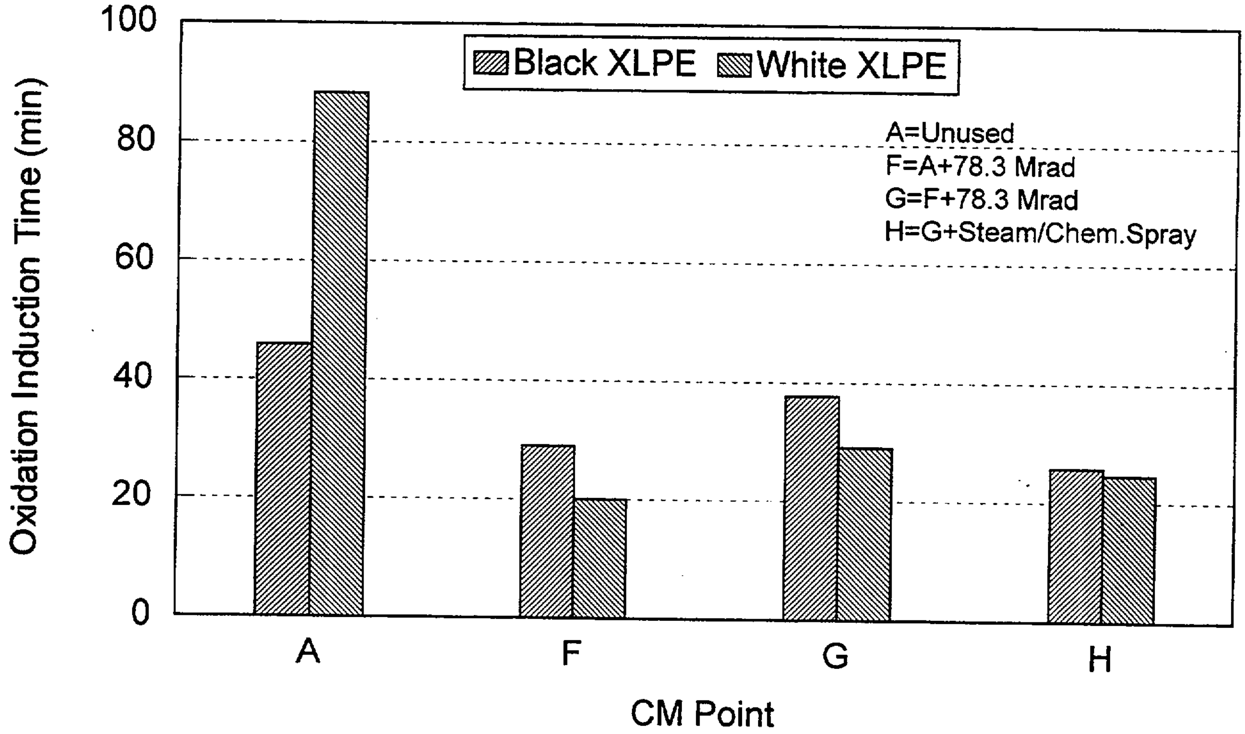


Figure 4.7 **OITM for XLPE at 392°F (200°C) for Rockbestos cable PNI79RB188 (Group 1.1, Specimen 0101) as a function of LOCA testing**

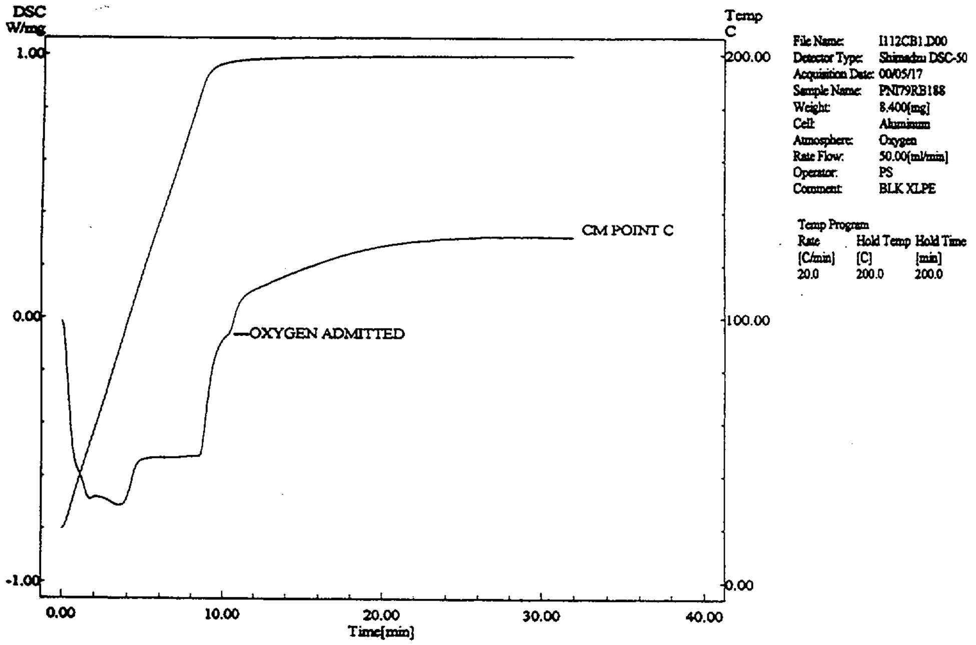


Figure 4.8 **OITM at 392°F (200°C) for black XLPE from Rockbestos cable PNI79RB188 (Group 1.4, Specimen 0112)**

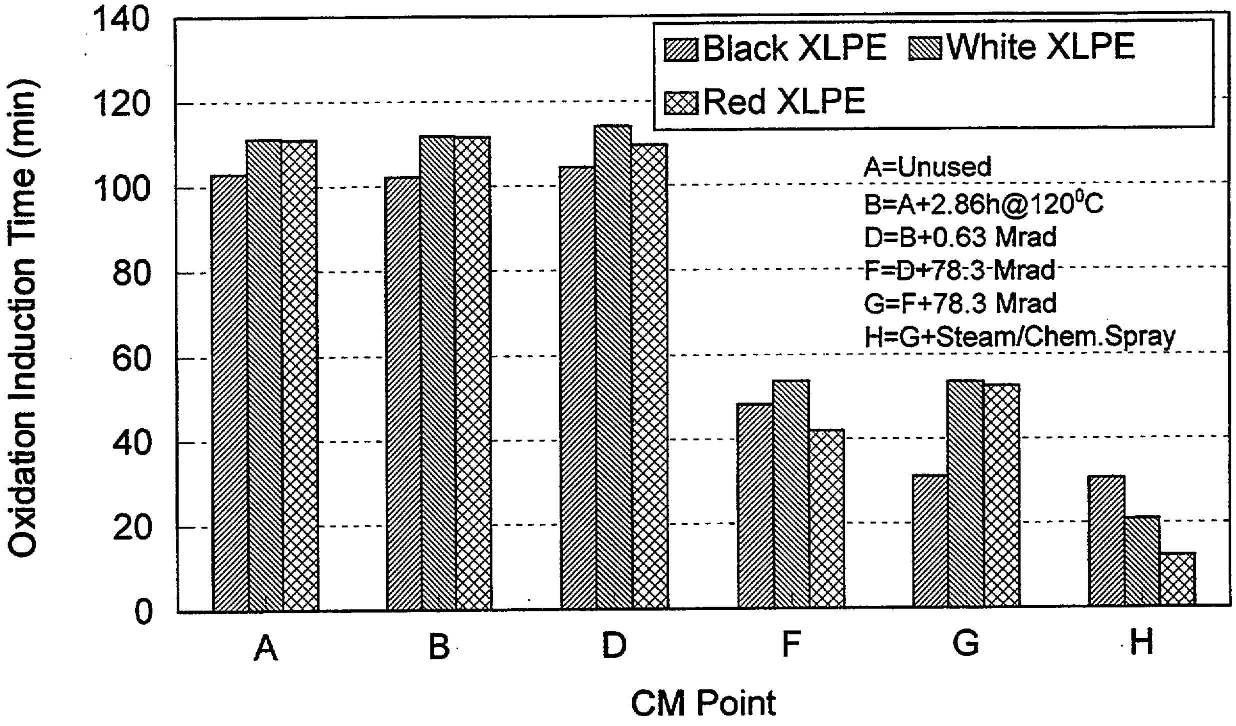


Figure 4.9 OITM for XLPE at 428°F (220°C) for Rockbestos cable PNI85RB191 (Group 1.2, Specimen 0106) artificially aged to 10-years service

To supplement the data obtained from the LOCA test specimens, several additional experiments were performed on white XLPE from Rockbestos cable PNI85RB191 at smaller thermal aging intervals to correlate changes in OITM with the elongation-at-break. Table 4.3 shows the results obtained for samples of this insulation that were aged in an oven in a flowing air environment.

Figure 4.11 shows the relationship between OITM and EAB. The times in the parentheses are the aging times in air that the specimens received prior to measuring the OITM. The OITM varies greatly with the pre-aging time and provides a sensitive estimate of the EAB for the aged XLPE. At the 96 hr. aging time, the EAB shows a very large decrease to about 175 percent, indicating that the base polymer structure has begun to be oxidized. In Volume 1, Section 3.7 it was shown that the time for the depletion of antioxidants in oxygen for white XLPE from cable PNI85RB191 is given by:

$$\ln t\,(\mathrm{min}) = 30.26/RT(^{0}K) - 25.88 \quad \ldots\ldots\ldots\ldots (1)$$

From this equation it can be shown that, for the aging temperature used in this study (350°F, 177°C), the antioxidants will be depleted after 2,864 min, or 47.7 hrs. As was also shown in Volume 1, Section 3.7, the time for depletion in air is approximately double that for oxygen. Therefore, after about 95.5 hours, it is predicted that the polymer structure begins to be attacked. The large loss in EAB at 96 hours in Figure 4.11 is, therefore, fully consistent with the prediction from this equation.

An attempt was also made to obtain OITM data for Neoprene® jackets. However, the results in Figure 4.12 show that there was not a well-defined flat portion in the thermogram that indicated that the antioxidants were preventing the oxidation of the jacket. It appears that even with unaged material (CM point A) there was a small immediate oxidation process that prevented the meaningful measurement of the OITM. Therefore, Neoprene® aging cannot be quantified by the OITM methodology. This has also been commonly observed in prior studies.

In summary, OITM measurements are useful in estimating the gradual loss in EAB as XLPE is thermally aged, as well as showing that, as the OITM tends to zero, a major loss in ductility is to be expected.

4.4 Oxidation Induction Temperature (OITP)

Two samples of Rockbestos XLPE/Neoprene® cable from test sequences 1 and 3 were evaluated (PNI79RB188 and PNI85RB191). Figures 4.13 and 4.14 show OITP themograms for sample PNI79RB188, a two-conductor cable, which received accelerated aging to simulate one-half of the manufacturer's 40-year qualification test protocol . The straight lines on each figure show the linear increase in temperature with time, whereas the curves show the thermal energy absorbed by the specimen. Note that in these composite figures the curves have been displaced along the Y axis to more clearly compare the results.

Figure 4.13 shows the changes in the OITP for XLPE caused by thermal and irradiation aging during service (CM points C and E) while Figure 4.14 shows changes during LOCA testing (CM points F, G, and H). There is a large decrease in OITP for the XLPE insulation after the thermal aging treatment (CM point C) but little change after the radiation aging step (CM point E). Examination of the thermograms in Figure 4.13 shows that the initial sharp oxidation peak for CM point A is drastically reduced by thermal aging with the oxidation peak broadened and decreased in height through CM points C and E. The reason for this dramatic change in the shape of the thermogram after the thermal aging is because the thermal aging treatment of 648.5hr. at 302°F (150°C) is equivalent to an aging time of 1,424 years at 140°F (60°C), as shown in Table 4.2 in Section 4.2. For such a long aging period it is to be expected that the XLPE would have become very heavily oxidized and degraded. Table 4.2 shows that after this long term aging protocol, the XLPE has become completely brittle with an EAB of less than 5 percent

In the case of Rockbestos sample PNI85RB191, a three-conductor cable that received an accelerated aging protocol to simulate a 10-year service aging period, the oxidation peaks remain sharp and clearly defined (Figures 4.15 and 4.16). There is, also, only a small decrease in the OITP as the XLPE is aged and LOCA tested through the various CM points. This shows that the aging received is minimal and has only a small effect on the integrity of the insulation, as would be expected.

For the Neoprene® jacket from sample PNI79RB188 (Group 1.4, Specimen 0112), the thermograms in Figures 4.17 and 4.18 for unaged material (CM points A) show two oxidation peaks. The first is broad and relatively low, whereas the second is very sharply defined. Thermal aging (CM points C and E) appears to remove the second peak, or at least delay its appearance to a longer test time. The OITP measurements were taken for the first deviation from the horizontal line.

The OITP remains essentially unchanged after the LOCA irradiations (CM points F and G in Figure 4.18), but LOCA steam/chemical spraying (CM point H) causes an increase in OITP. This apparent improvement in cable oxidation characteristics is accompanied by a very large increase in the exothermic reaction (note the major change in the gradient of the thermogram curve. It is speculated that the steam/chemical spray causes the Neoprene® to absorb compounds from the chemical spray, and it is these chemicals that oxidize and give rise to the large exothermic reaction seen for CM point H. This seems reasonable because after the LOCA irradiations the exothermic reactions are very small showing that the jacket is no longer capable of being heavily oxidized. Therefore, from a mechanistic standpoint, degradation caused by accelerated thermal and radiation aging is different from that encountered during LOCA steam/chemical spraying.

Table 4.3 Correlation Between OITM for White XLPE from Rockbestos Cable PNI85RB191 and Elongation-at-Break

Specimen	Aging Time at 350°F (177°C) (hr.)	Oxidation Induction Time (min)	Elongation-at-Break (%)
1	0	105.9 101.9 Avg = 103.9	444 426 433 Avg = 434 ± 9
2	6	106.7 101.4 Avg = 104.0	440 475 498 Avg = 471 ± 29
3	18	68.8 65.1 Avg = 67.0	447 339 Avg = 393 ± 76
4	24	49.7 46.4 Avg = 48.0	346 393 408 Avg = 382 ± 32
5	48	9.0 8.2 Avg = 8.6	357 318 362 Avg = 346 ± 24
6	72	2.6 2.2 Avg = 2.4	368 358 Avg = 363 ± 7
7	96	0.8 0.6 Avg = 0.7	213 153 157 Avg = 174 ± 34
8	120	0 (Instantaneous oxidation)	65 102 79 Avg = 82 ± 19
9	144	0 (Instantaneous oxidation)	81 84 64 Avg = 76 ± 11
10	168	0 (Instantaneous oxidation)	75 86 95 Avg = 86 ± 10

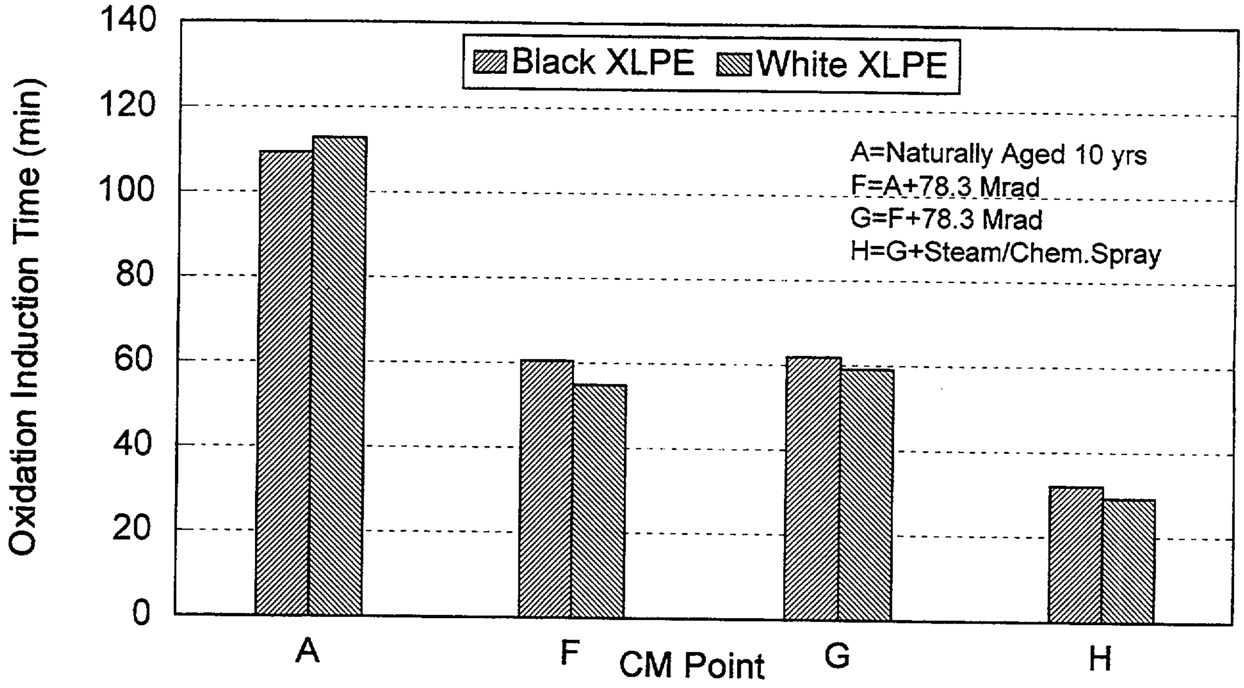


Figure 4.10 OITM for XLPE at 428°F (220°C) for Rockbestos cable PAP86RB267 (Group 1.3, Specimen 0111) naturally aged for 10 years

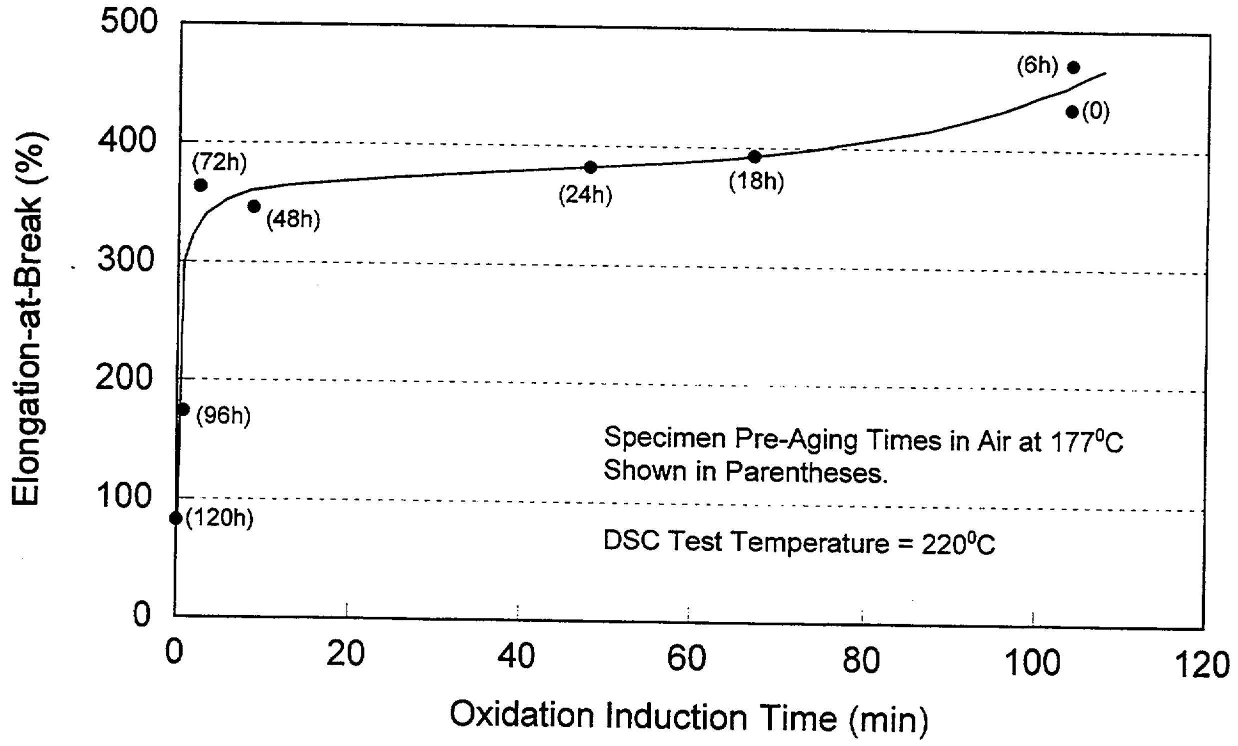


Figure 4.11 Correlation between OITM and EAB for white XLPE from Rockbestos cable PNI85RB191 as a function of thermal pre-aging time in air at 350°F (177°C)

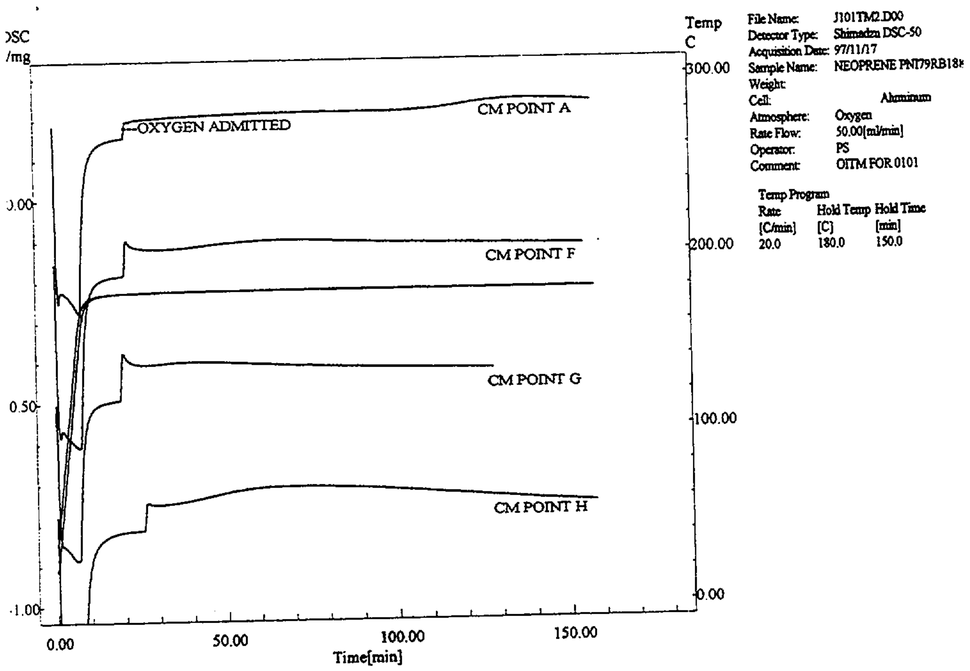


Figure 4.12 OITM thermogram for Neoprene® jacket at 356°F (180°C) from Rockbestos cable PNI79RB188 (Group 1.1, Specimen 0101)

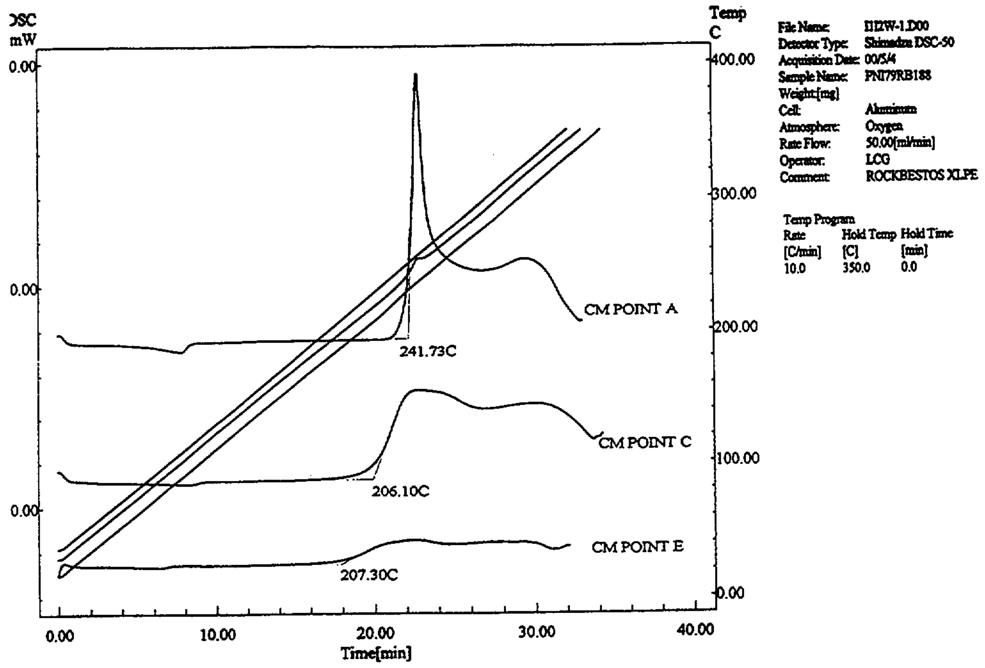


Figure 4.13 OITP for Rockbestos XLPE (Group 1.4, Specimen 0112) as a function of service aging protocols

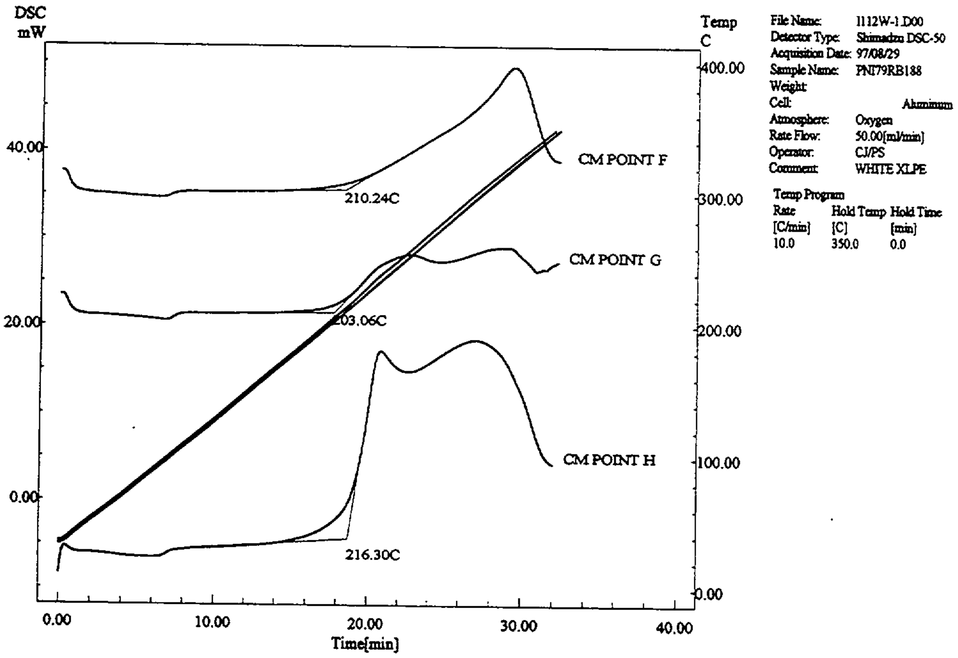


Figure 4.14 OITP for Rockbestos XLPE (Group 1.4, Specimen 0112) as a function of LOCA testing protocols

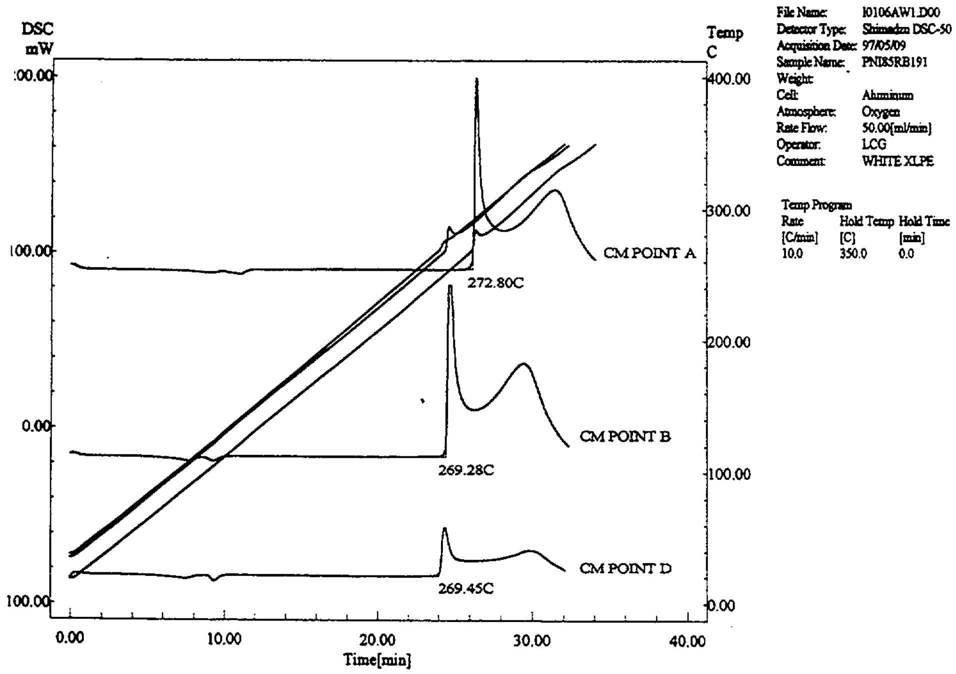
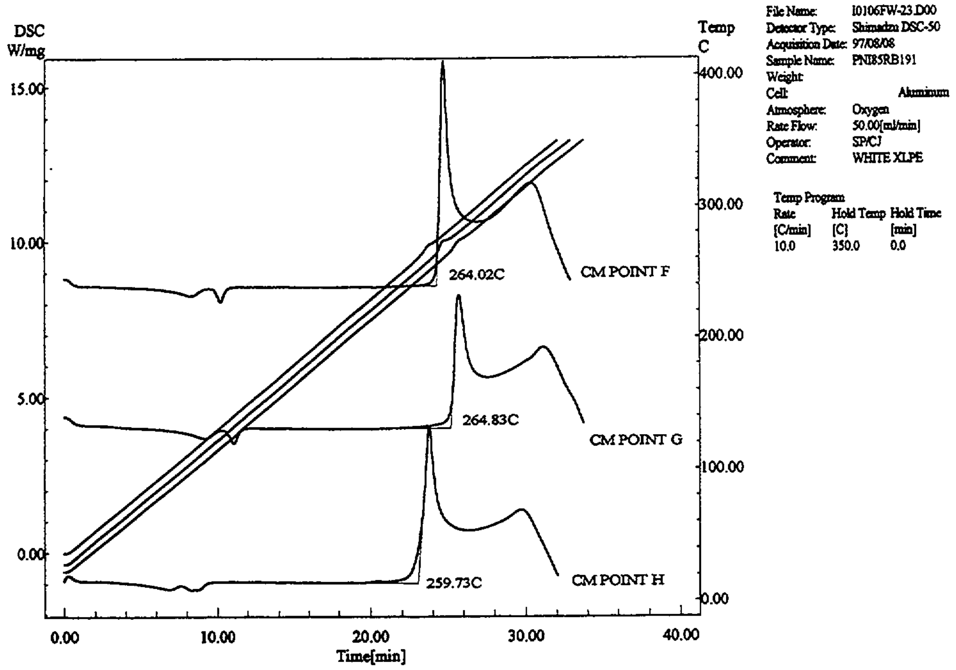


Figure 4.15 OITP for Rockbestos white XLPE (Group 1.2, Specimen 0106) as a function of service aging protocols

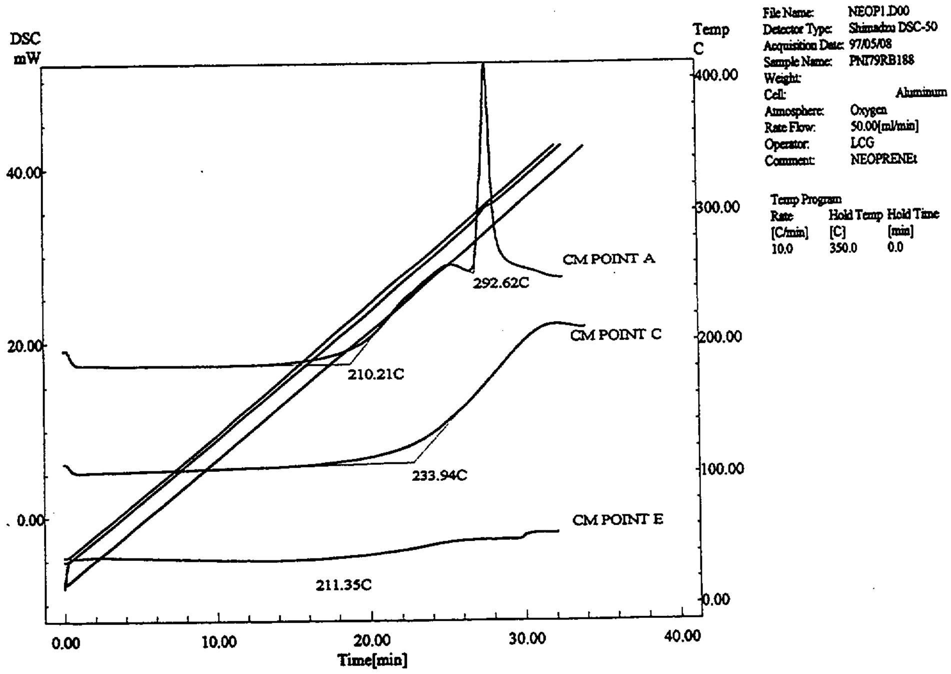


File Name: I0106FW-23.D00
Detector Type: Shimadzu DSC-50
Acquisition Date: 97/08/08
Sample Name: PNI85RB191
Weight:
Cell: Aluminum
Atmosphere: Oxygen
Rate Flow: 50.00[ml/min]
Operator: SP/CJ
Comment: WHITE XLPE

Temp Program

Rate [C/min]	Hold Temp [C]	Hold Time [min]
10.0	350.0	0.0

Figure 4.16 OITP for Rockbestos white XLPE (Group 1.2, Specimen 0106) as a function of LOCA testing protocols



File Name: NEOP1.D00
Detector Type: Shimadzu DSC-50
Acquisition Date: 97/05/08
Sample Name: PNI79RB188
Weight:
Cell: Aluminum
Atmosphere: Oxygen
Rate Flow: 50.00[ml/min]
Operator: LCG
Comment: NEOPRENEt

Temp Program

Rate [C/min]	Hold Temp [C]	Hold Time [min]
10.0	350.0	0.0

Figure 4.17 OITP for Rockbestos Neoprene® jacket (Group 1.4, Specimen 0112) as a function of service aging protocols

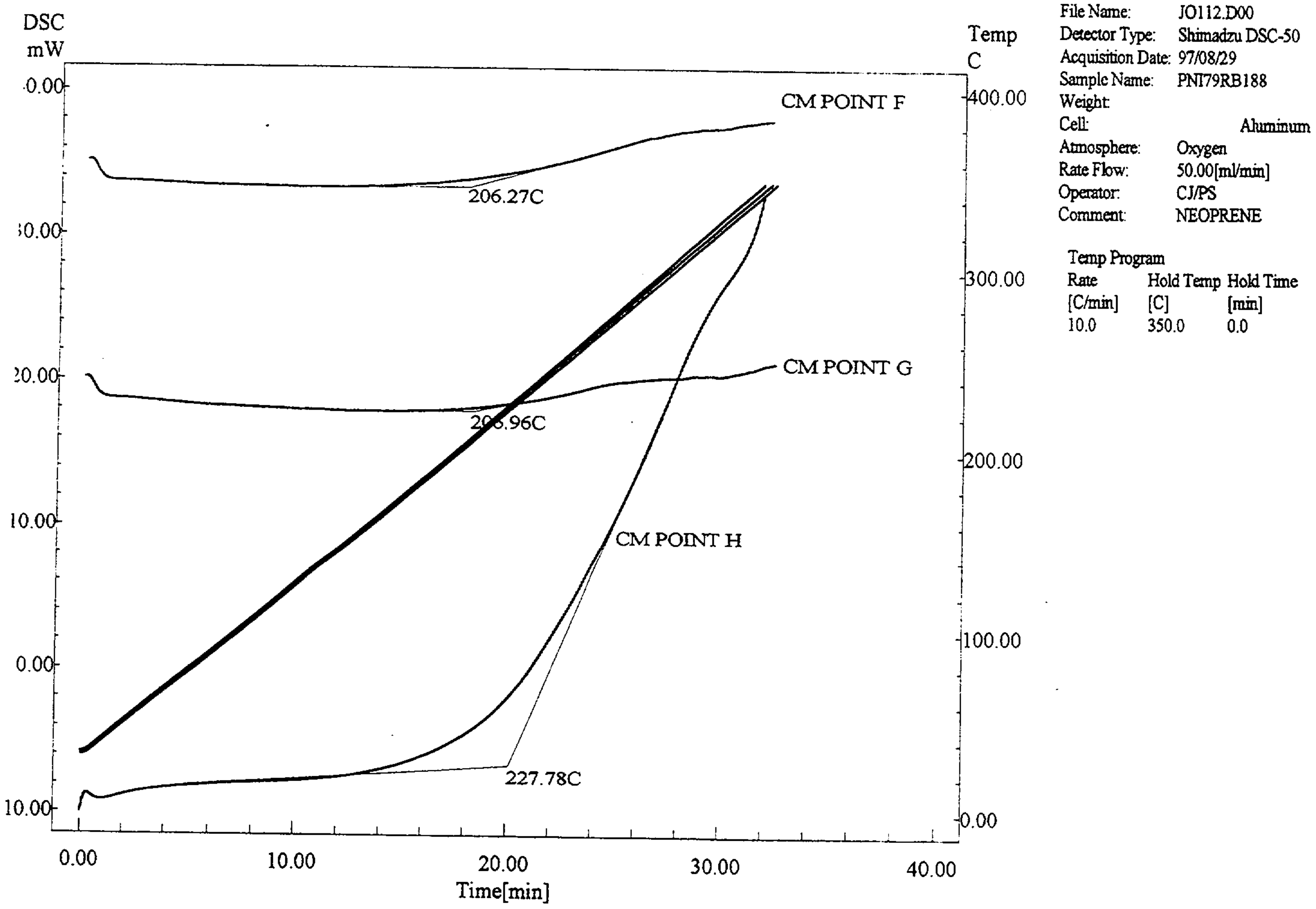


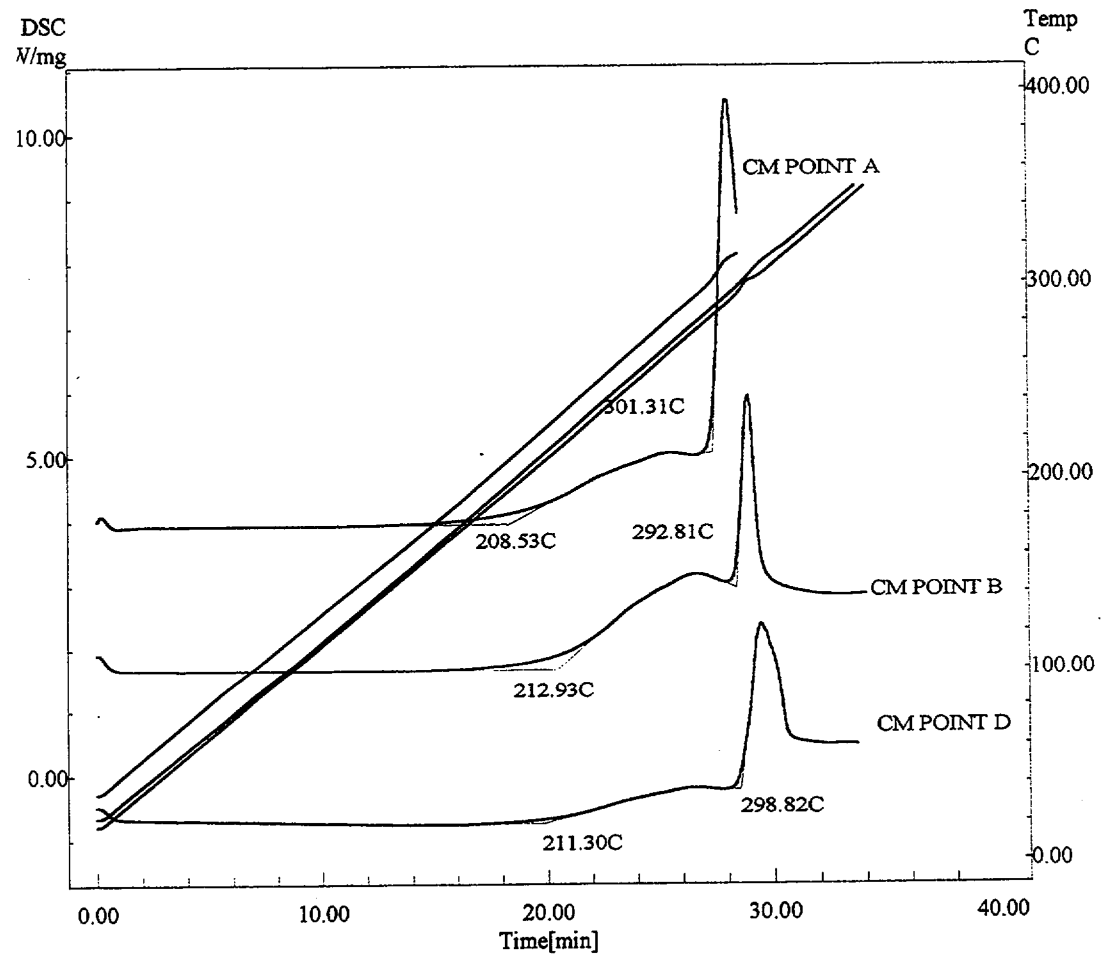
Figure 4.18 OITP for Rockbestos Neoprene® jacket (Group 1.4, Specimen 0112) as a function of LOCA testing protocols

Figures 4.19 and 4.20 for Neoprene® from cable PNI85RB191 (Group 1.2, Specimen 0106) show that the basic shapes of the thermograms are similar, with a broad initial peak followed by a sharply-defined second peak. Little change occurs in the OITP for the service aging treatments (CM points B and D). This is to be expected since the service aging protocol used was relatively mild. For the LOCA radiation doses of about 78 Mrad each at CM points F and G, the OITP shows a small decrease, but after the steam/chemical spray (CM point H) the OITP increases. Some of the changes in OITP as a function of CM point are summarized in Figures 4.21 and 4.22. The tabulated results in Appendix C show that the OITP for all colors of insulation are very similar, so the white insulation was arbitrarily selected to show the trend.

As mentioned above, the insulation for the two-conductor cable (Group 1.4, Specimen 0112 in Figure 4.21) shows a large decrease in OITP after thermal aging (CM point C) but irradiation does not cause any major additional losses. For the three-conductor cable (Group 3.2, Specimen 0303 shown in Figure 4.22) which was given a service aging protocol to simulate 10-years of natural aging, the OITP remains essentially unchanged. These observations are associated with the presence or depletion of antioxidants in the insulation. If the thermal aging treatment is insufficient to deplete the antioxidants, the OITP values do not change rapidly with aging. However, if the antioxidants are completely deleted, the OITP drops rapidly to lower values.

Figure 4.23 shows OITP results for Rockbestos cable (Group 1.3, Specimen 0111) that was naturally aged for 10-years in a power plant. A comparison of the results for CM point A in Figure 4.23 for the naturally-aged cable to CM point D in Figure 4.22, which represents cable artificially aged to simulate 10-years of service, shows close agreement.

It was not feasible to correlate the OITP for the Rockbestos® cables with service aging time and the EAB because, as Table 4.2 shows, the aging protocols that were used in the current program give aging times at a nominal 140°F (60°C) for very short times (1.4 yrs) or very long times(>1,424 yrs). Thus, the important aging period between 0-60 years is not effectively covered by the data available.



File Name:	J0106-1.D00
Detector Type:	Shimadzu DSC-50
Acquisition Date:	97/03/20
Sample Name:	PNI85RB191
Weight:	
Cell:	Aluminum
Atmosphere:	Oxygen
Rate Flow:	50.00[ml/min]
Operator:	BSB/LCG
Comment:	NEOPRENE

Temp Program

Rate [C/min]	Hold Temp [C]	Hold Time [min]
10.0	350.0	0.0

Figure 4.19 OITP for Rockbestos Neoprene® jacket (Group 1.2, Specimen 0106) as a function of service testing protocols

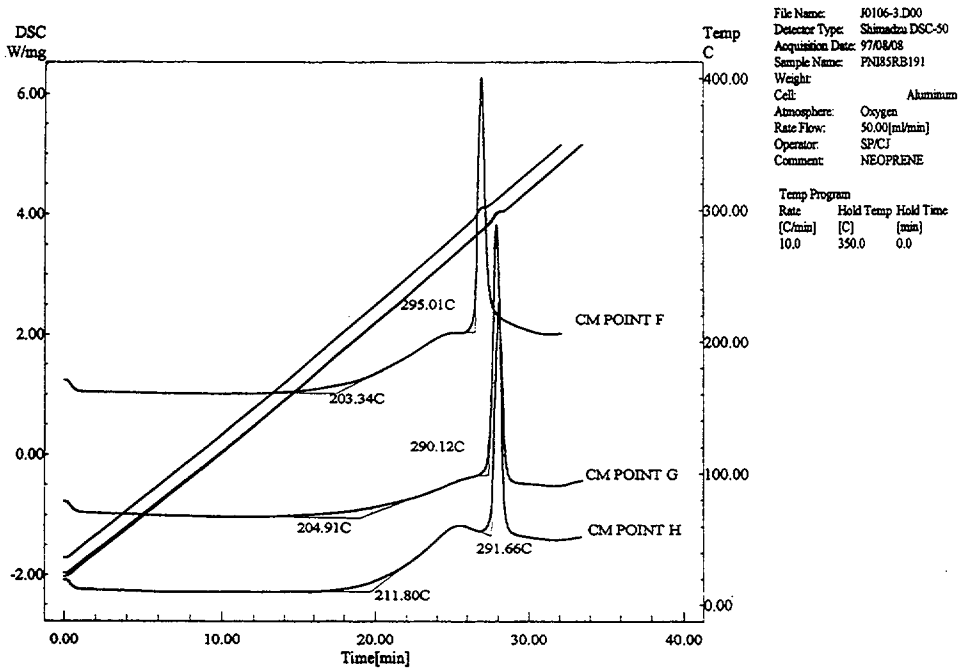


Figure 4.20 OITP for Rockbestos Neoprene® jacket (Group 1.2, Specimen 0106) as a function of LOCA testing protocols

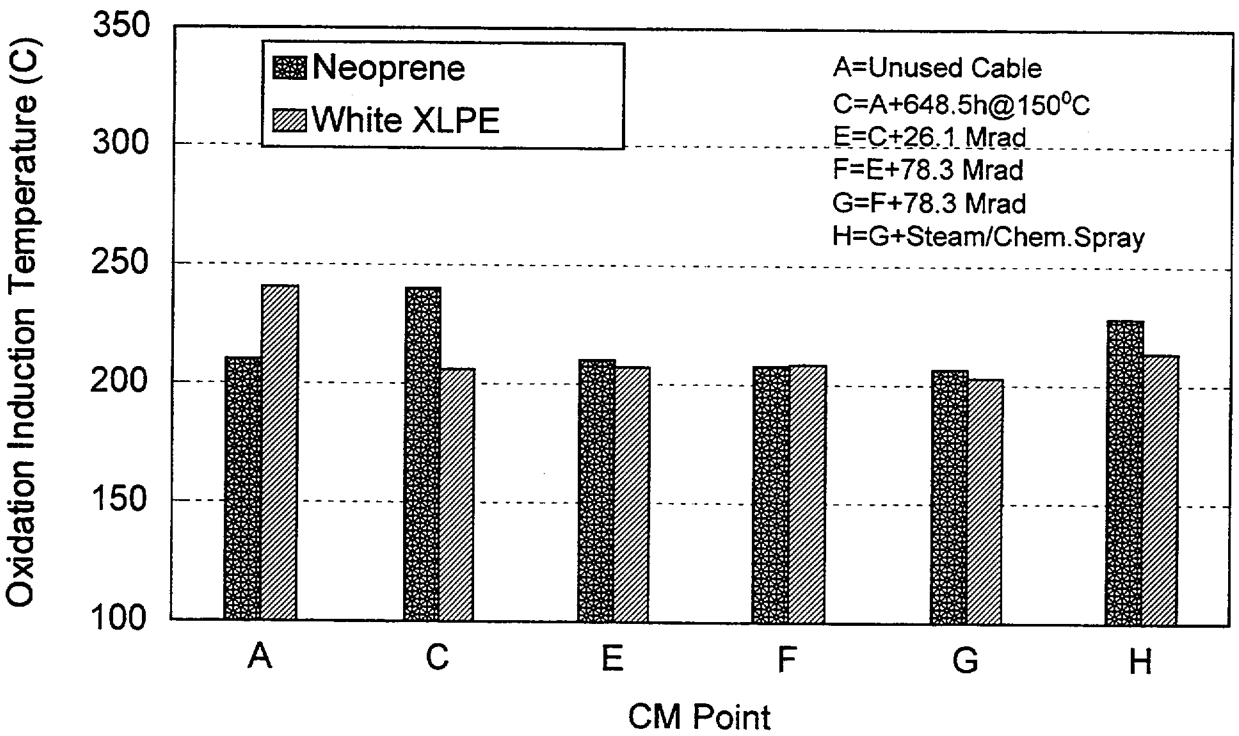


Figure 4.21 Effect of service aging and LOCA testing on the OITP of Rockbestos cable PNI79RB188 (Group 1.4, Specimen 0112)

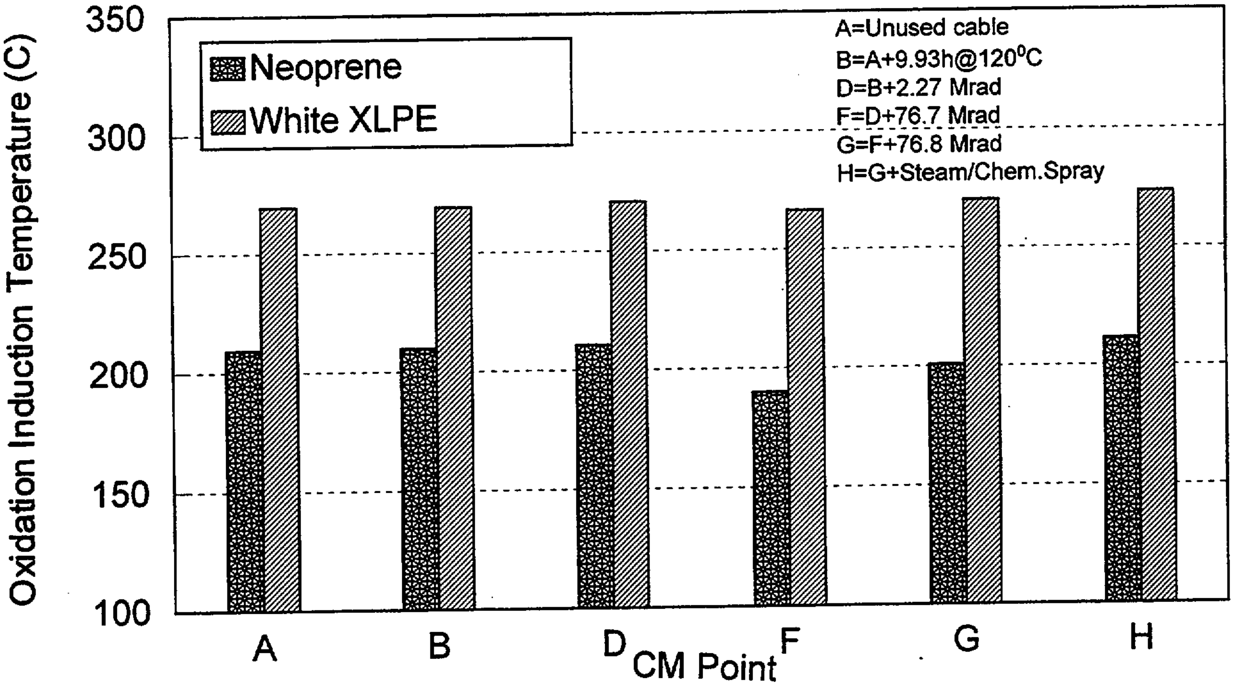


Figure 4.22 Effect of service aging and LOCA testing on the OITP of Rockbestos cable PNI85RB191 (Group 3.2, Specimen 0303)

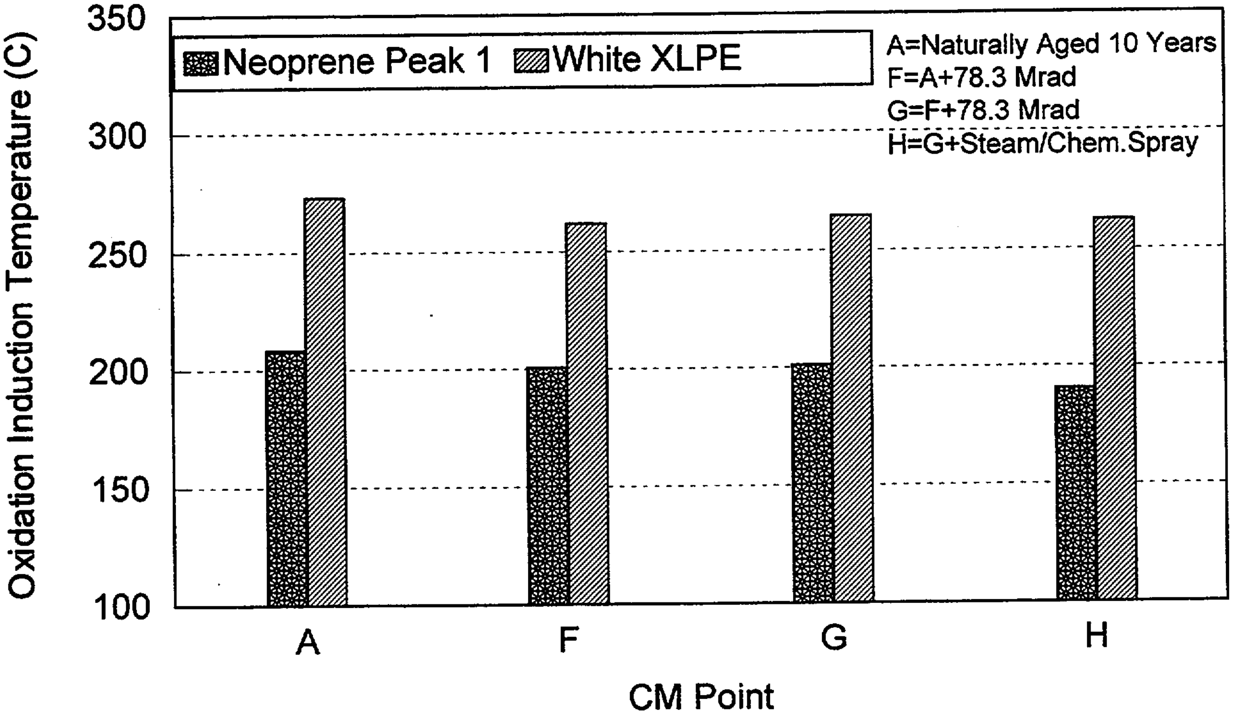


Figure 4.23 Effect of LOCA testing on the OITP of 10-year naturally aged Rockbestos cable PAP86RB267(Group 1.3, Specimen 0111)

4.5 Fourier Transform Infrared Spectroscopy

Section 3.5 describes the FTIR spectroscopy technique used in the current study. Early in the test program, the original zinc selenide crystal used to refract the infrared beam into the specimen was found to be inadequate. Figure 4.24 shows an FTIR transmittance spectrum using this crystal on white XLPE insulation (test sequence 1, Group 1.3, Specimen 0111) that was naturally aged for 10 years and given a LOCA irradiation of 157.5 Mrad, followed by a steam/chemical spray. In studying polymeric specimens, two of the more important peaks in the FTIR spectrum occur at wavenumbers of 1730 and 2916 $cm^{-1.}$ These wavenumbers represent absorptions by the carbonyl bond (C=O) and the $-CH_2$ bond, respectively. In Figure 4.24, the carbonyl bond is not clearly seen above background. Extensive tests on test sequence 1 specimens showed that the peak could sometimes be detected, but not in a consistent fashion. The $-CH_2$ peak, however, was always very prominent. In some rare cases for heavily aged specimens, the carbonyl and $-CH_2$ were reversed, which is indicative of poor optical contact between the specimen and the crystal. Discussions with the spectroscope vendor support the conclusion that the oxidized specimens were not making proper optical contact with the zinc selenide crystal. This made it impossible to obtain consistent spectra when specimens became stiff during aging and did not have flat contact with the large zinc selenide crystal, which measured about 3x0.5 cm. For some stiff specimens, there was essentially only line contact, because of the inability to press the tubular samples flatly against the crystal. Because of this problem, the use of the zinc selenide crystal was discontinued.

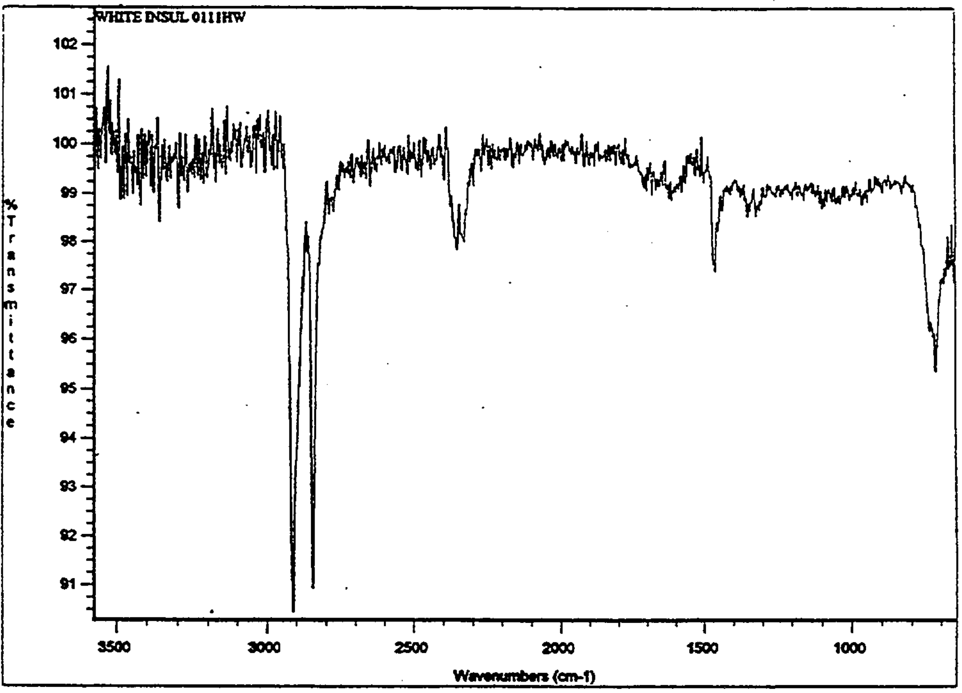


Figure 4.24 FTIR spectrum for ten-year naturally aged white XLPE from Rockbestos cable PAP86RB267 (Group 1.3, Specimen 0111) after receiving 157.5 Mrad of LOCA radiation and steam/chemical spray

In order to overcome the difficulty with poor optical contact, a new "Thunderdome®" crystal attachment for the spectroscope was purchased from the Nicolet Instrument Corp. It operates under the ATR (Attenuated Total Reflectance) mode. During test, the specimen is placed on top of the concave crystal and pressure is applied using a ratchet controlled pressure tower to force the specimen against the crystal with a large preset contact pressure. Because only about a 2 mm diameter surface disc of material is involved, excellent optical contact is obtained reproducibly. Figure 4.25 shows a typical spectrum for as-received white XLPE (test sequence 3, Group 3.2, Specimen 0303). Note the much cleaner spectrum compared to that obtained for the zinc selenide crystal shown in Figure 4.24. All subsequent tests in this program were, therefore, conducted with the "Thunderdome.®" Appendix D gives the FTIR results obtained. Note that the data are given simply as peak heights on the transmittance spectra, taking into account subtraction of the baseline value of the spectrum at the peak location. The percent transmittance is merely 100 minus the peak height given in Appendix D. Figure 4.26 shows a series of FTIR tests on white XLPE (test sequence 3, Group 3.2, Specimen 0303), which had received a service aging protocol that simulated 10 years of natural aging. This included 9.93 hrs of aging at 250°F (120°C) (CM point B), followed by 2.27 Mrad of radiation (CM point D). At CM points F and G the specimen received 76.6 and 76.7 Mrad of LOCA radiation, respectively, followed by steam/chemical spraying (CM point H). Unfortunately, the carbonyl peak at wavenumber 1730 cm^{-1} could not usually be detected by the Thunderdome®. It was, therefore, decided to measure the transmittance at wavenumber 2916 cm^{-1} to determine if it could be correlated with aging of XLPE. The service aging treatments and the LOCA radiation exposures caused small increases in transmittance indicating that the number of $-CH_2$ bonds is decreasing (see Figure 4.27). However, the steam/chemical spray causes the transmittance to drop slightly from the LOCA radiation (CM point G) value.

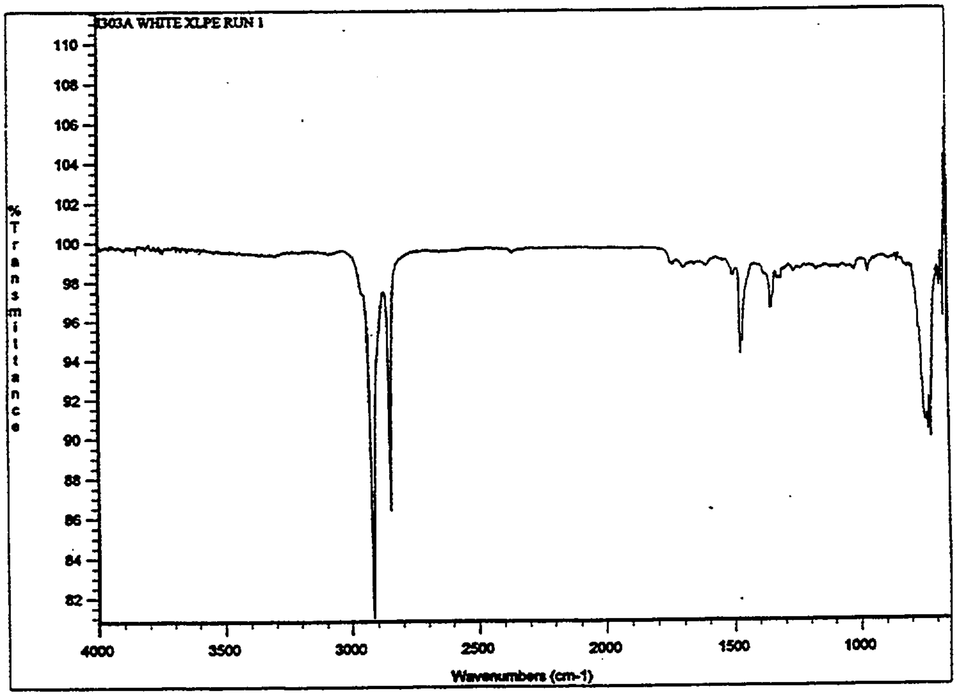


Figure 4.25 FTIR spectrum for unaged white XLPE from Rockbestos cable PNI85RB191 (Group 3.2, Specimen 0303) using the "Thunderdome®" attachment

Table 4.4 shows the very limited FTIR data available for XLPE. Values of the elongation-at-break are also given to correlate with the percent transmittance. For the small amount of service aging, the transmittance increase is small, as is the associated decrease in EAB, as would be expected.

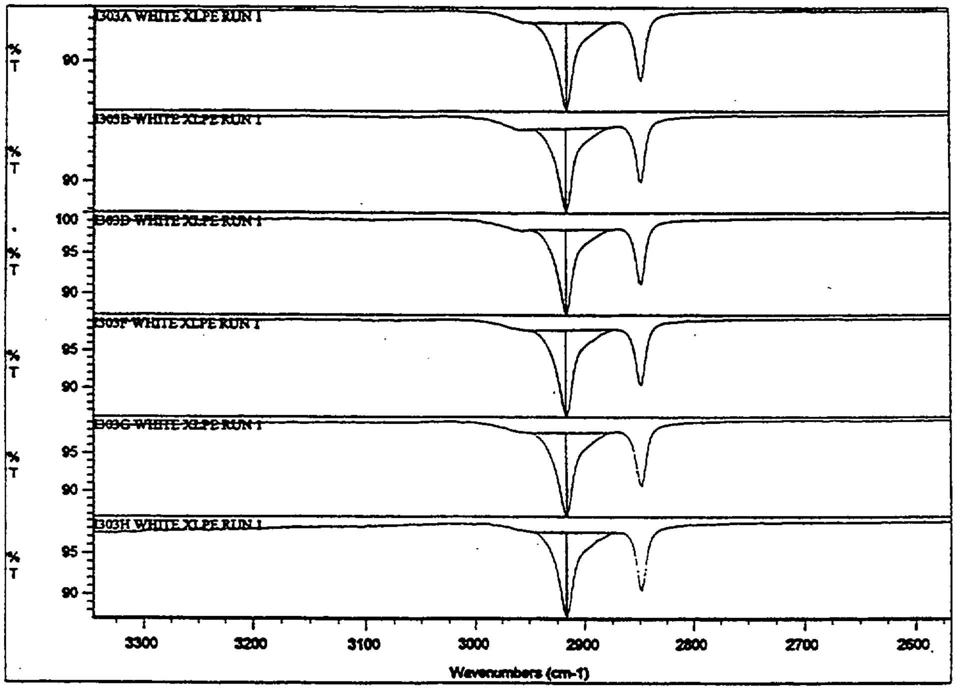


Figure 4.26 FTIR spectra for artificially aged white XLPE from Rockbestos cable PNI85RB191(Group 3.2, Specimen 0303) as a function of CM point

Figures 4.28 and 4.29 plot the FTIR transmittance against the elongation-at-break and the service aging time, respectively. The aging time was normalized to a service aging temperature of 140° (60°) using the Arrhenius equation. The data, although very limited, are consistent with the theory that oxidation reduces the number of -CH_2 bonds, thereby increasing the transmittance of infrared radiation. According to Baird (1981), free radicals (R^0) are formed that combine with oxygen to form peroxyl radicals:

$$R^0 + O_2 \ = \ ROO^0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

These radicals can remove hydrogen atoms from another portion of the polymer to form hydroperoxides and a polymer free radical:

$$ROO^0 \ + RH \ = ROOH + R^0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

This gives rise to a repetitive cyclic chain reaction as the new free radical reacts with additional oxygen according to equation (2). If the polymer free radical removes hydrogen atoms from the -CH_2 bonds in the polymer during aging then the transmittance of infrared radiation would be expected to increase, as is shown in the current data.

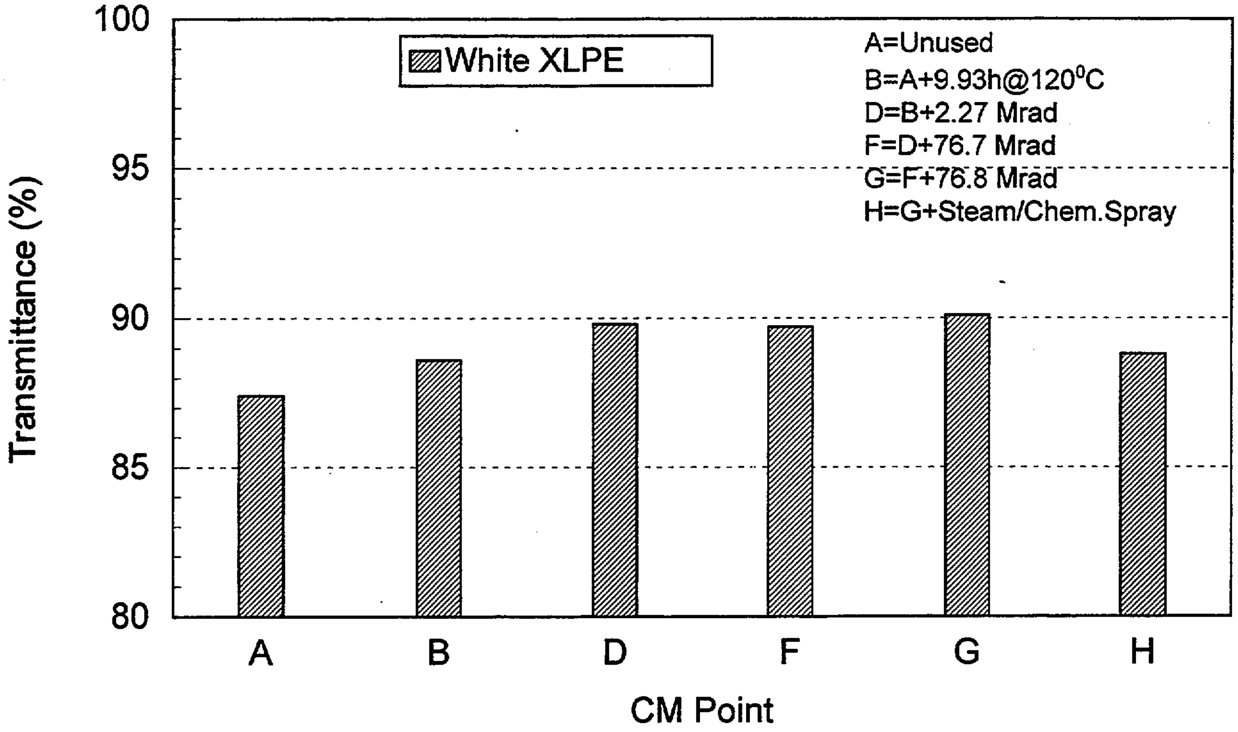


Figure 4.27 FTIR results for artificially aged white XLPE from Rockbestos cable PNI85RB191 (Group 3.2, Specimen 0303) as a function of CM point

Table 4.4 FTIR and EAB results for white XLPE insulation from Rockbestos cable PNI85RB191

Group (Specimen)	Aging Protocol	Equivalent Aging Time at 140° (60°), (years)	Transmittance (%)[a]	EAB (%)[a]
3.2 (Spec. 0303A)	None	0	87.4	426
3.2 (Spec. 0303D)	9.93 hr.@120°C + 2.27 Mrad	1.4	89.8	403

(a) Average values from at least 3 replicate tests.

It is also important to remember that FTIR spectroscopy is a surface measurement technique. Hence, it is mainly valuable in evaluating surface oxidation characteristics. If there are major differences in the degree of oxidation at the surface of a specimen and the interior, then the "average" behavior of the specimen will not be measurable. To check this possibility, a comparison was made between the percent transmittance for white XLPE naturally aged for 10 years (Group 3.3, Specimen 0307A) and similar material artificially aged to simulate this aging time (Group 3.2, Specimen 0303D). One might suspect that the oxidation profile through a naturally aged specimen would be relatively flat compared with a specimen that had been artificially aged at a higher temperature. However, the percent transmittance values from Appendix D are 89.2 percent and 89.8 percent, respectively, showing good agreement. This indicates that, for this particular accelerated aging protocol, FTIR spectroscopy appears to measure bulk behavior in thin walled insulation. This may not be true for all accelerated aging protocols. Therefore, it is likely that FTIR is most suitable for examining naturally aged polymers for which the differences between surface and internal oxidation are minimized.

To further investigate the usefulness of FTIR spectroscopy for condition monitoring, a series of tests was run to examine how transmittance is affected by gamma radiation. Specimens of black XLPE were irradiated in air at 50°F (10°C) in the BNL Gamma Irradiation Facility to different dose levels and tested with the "Thunderdome.®" Figure 4.30 shows that a sigmoidal relationship exists between the transmittance and the dose. This indicates that XLPE is initially resistant to radiation induced oxidation but, after a given irradiation dose, the rate of oxidation increases.

At even higher doses, the rate of oxidation again decreases. Figure 4.31 shows a correlation between the FTIR transmittance and the elongation-at-break. For the high-ductility specimens that had received smaller radiation doses, the transmittance increased only slightly. As the dose level increases, the transmittance displays a sharp increase.

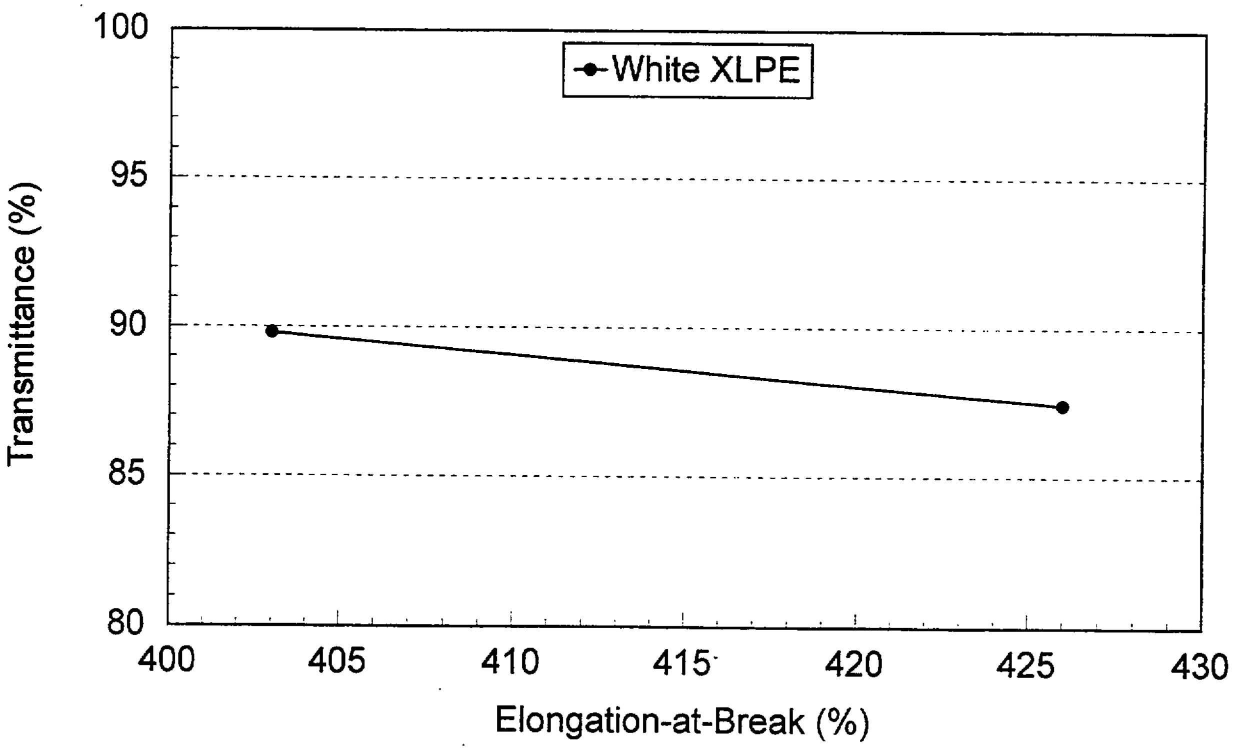


Figure 4.28 FTIR results for artificially aged white XLPE from Rockbestos cable PNI85RB191 (Group 3.2, Specimen 0303) as a function of elongation-at-break

Overall, FTIR spectroscopy appears to monitor thermal and radiation aging of XLPE by measuring changes in -CH_2 bond concentrations. The XLPE backbone contains many such bonds but one should not assume that it is only the backbone bonds that are oxidized. Other constituents in the cable may contain similar structures. However, additional work is clearly needed to check the usefulness of FTIR as a condition monitoring technique.

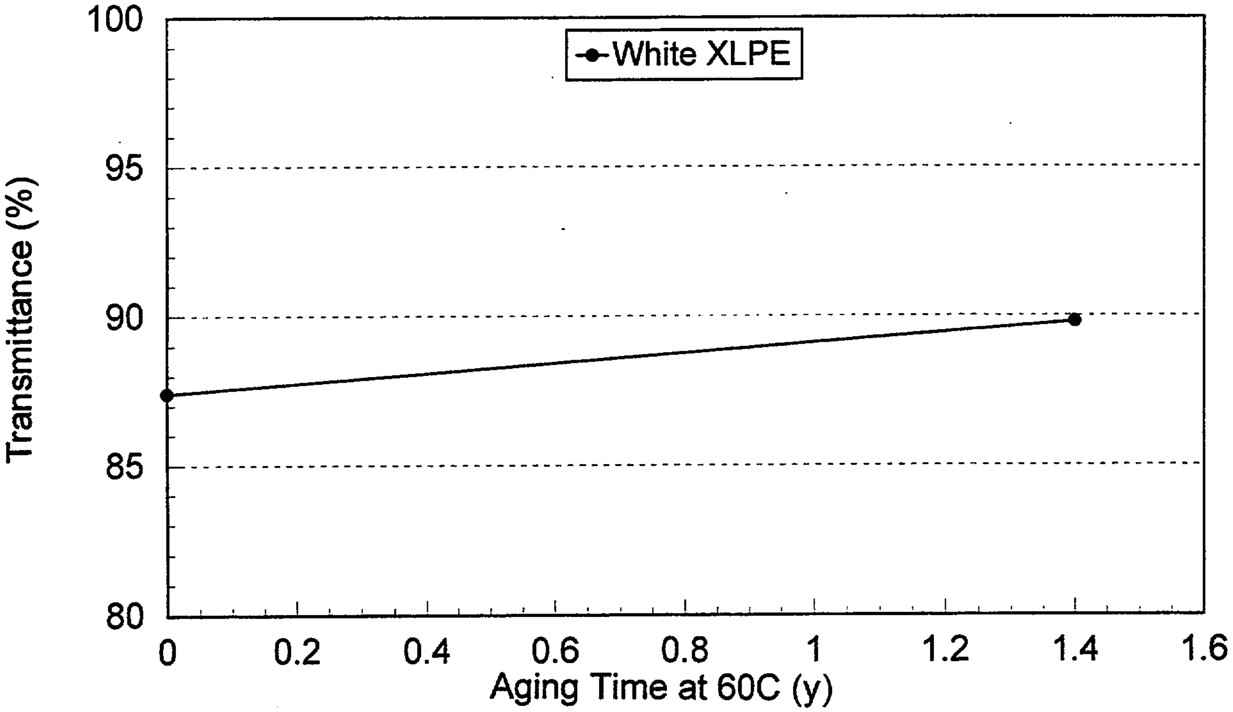


Figure 4.29 FTIR results for white XLPE from Rockbestos cable PNI85RB191 (Group 3.2, Specimen 0303) as a function of aging time at 140°F (60°C)

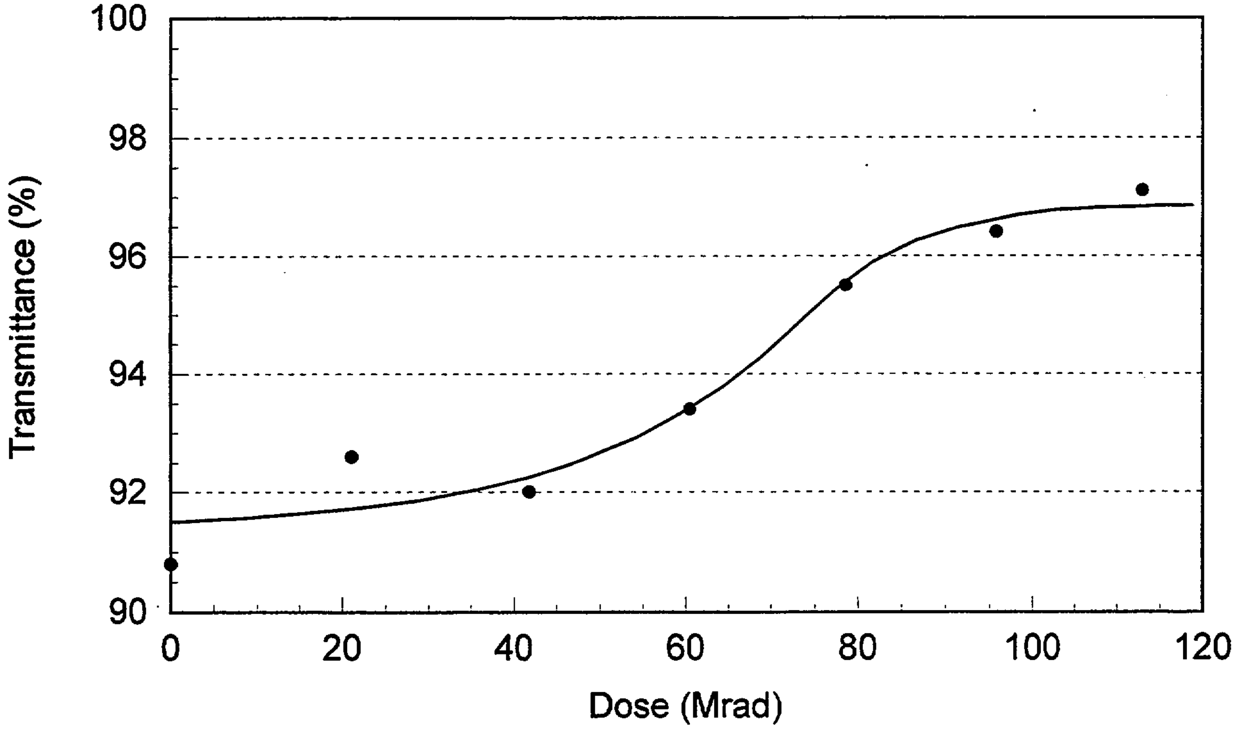


Figure 4.30 FTIR results for black XLPE form Rockbestos cable PNI79RB188 as a function of gamma radiation dose in air at 50°F (10°C)

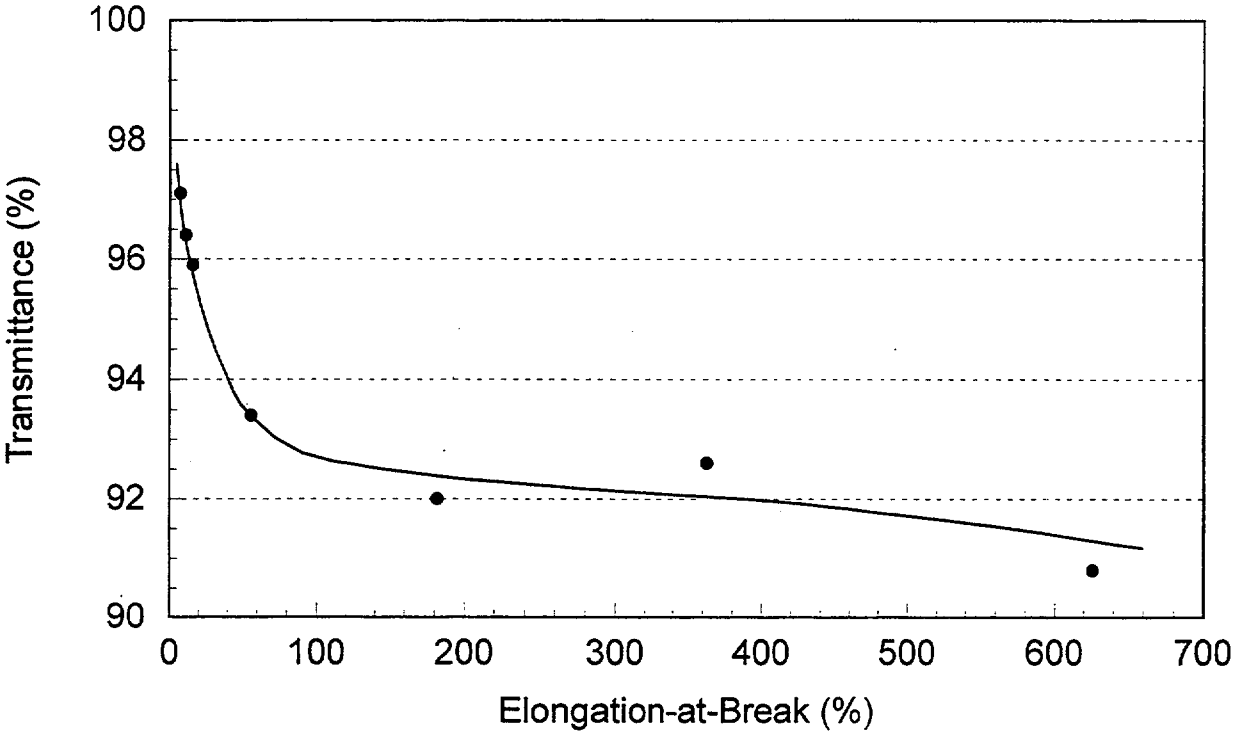


Figure 4.31 Correlation between FTIR transmittance and elongation-at-break for irradiated black cross-linked polyethylene from Rockbestos cable PNI79RB188

4.6 Indenter

Indenter testing was performed using the Ogden Polymer Indenter, as described in Section 3.6. Measurements were taken on the Rockbestos cables, with Neoprene® outer jackets and XLPE insulation, in LOCA test sequences 1, 3, and 6. Appendix E contains the compressive modulus results for all of the specimens tested. Figure 4.32 provides the compressive modulus results for the Group 1.2 specimens, which received relatively mild pre-aging to match the service conditions experienced by the naturally aged cables in Group 1.3. As shown, the compressive modulus showed no significant change as thermal and radiation pre-aging was applied. Results for the XLPE specimens in test sequences 1, 3, and 6, which received accelerated aging to simulate 20, 40, and 60 years of qualified life, respectively, are shown in Figure 4.33. For the specimens pre-aged to 20 years of qualified life, the compressive modulus did not show a continuous increase. Rather, the compressive modulus first increased after thermal aging, then decreased after service radiation. Subsequently, it increased again after accident radiation, but not to its value after thermal aging.

Figure 4.33 also shows that, for the specimens aged to 40 and 60 years of qualified life, the more severe pre-aging did result in a continuous increasing trend in the compressive modulus. These data suggest that below a certain aging degradation threshold, the compressive modulus of the XLPE material does not respond in a predictable, trendable manner. This would indicate that, for relatively low aging conditions, the changes in XLPE modulus may be too small to effectively predict aging related degradation. This observation related to small amounts of aging would support conclusions from previous indenter studies (EPRI, TR-102399), which concluded that the properties of XLPE are such that the modulus remains nearly constant over its life. For larger amounts of aging, the indenter appears to provide trendable data for XLPE.

Comparing CM hold point "A" in Figures 4.32 and 4.33, it is noted that these XLPE specimens have different baseline values for compressive modulus. The cable sample used to make the Group 1.2 specimens was a three-conductor, #16 AWG Rockbestos cable, while the sample for the specimens in Groups 1.4, 3.4 and 6.2 was a two-conductor, #14 AWG Rockbestos cable. All other specifications were the same. The two-conductor cables had an initial modulus of approximately 100 N/mm (572 lbs/in), compared to a modulus of approximately 175-200 N/mm (1000-1144 lbs/in) for the three-conductor cables. These results are consistent with the EAB data, which show the two-conductor cables are initially more ductile than the three-conductor cables.

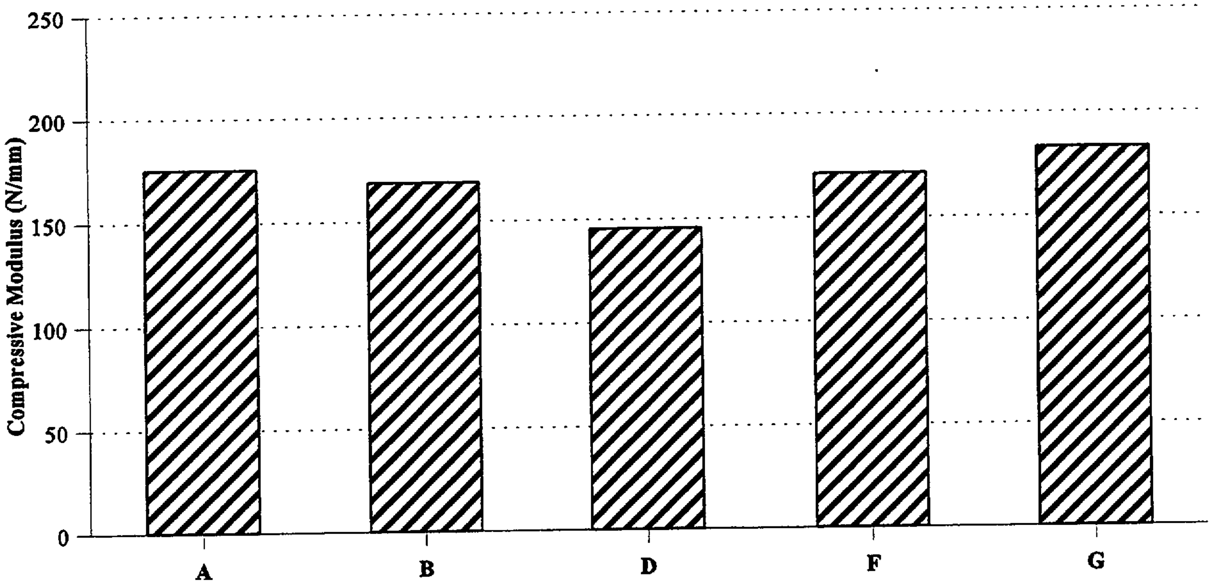


Figure 4.32 Compressive Modulus versus pre-aging for XLPE from Group 1.2 pre-aged to simulate cable naturally aged for 10 years

A = Baseline
B = Post Thermal Pre-aging
D = Post Service Radiation
F = Post half accident radiation
G = Post full accident radiation

The difference in baseline modulus values demonstrates the variation in properties that can be found among cables from the same manufacturer, but different vintages. The cause for these differences could be the result of chemical processing differences during fabrication, or it may be related to the physical design of the cables. Previous research using the indenter on insulation and jacket materials (EPRI TR-102399, June 1993) hypothesized that differences in indenter moduli for a given polymer may be related to the actual fabrication process in which the insulation may be subjected to higher compressive stresses due to the physical design of the cable. Over long periods of time, if these stresses do not completely relax, they could result in less ductile material. This study contained data limited to a single three-conductor cable (XLPE insulation) that had a baseline modulus of 130 N/mm (744 lbs./in). This data point, while less than the range observed in this study, is greater than the two-conductor baseline value observed. No other data on XLPE insulation were reported.

A review of the publicly available data on XLPE modulus identified only limited data. In a study performed by Sandia National Laboratories (Jacobus, 1992) indenter measurements were performed on a Rockbestos Firewall® III, three-conductor cable with XLPE insulation. This cable had an initial modulus of 130N/mm (740 lbs./in.). Following pre-aging, which consisted of exposure to 20 Mrad at 212°F (100°C) for three months, a 35 percent increase in modulus was

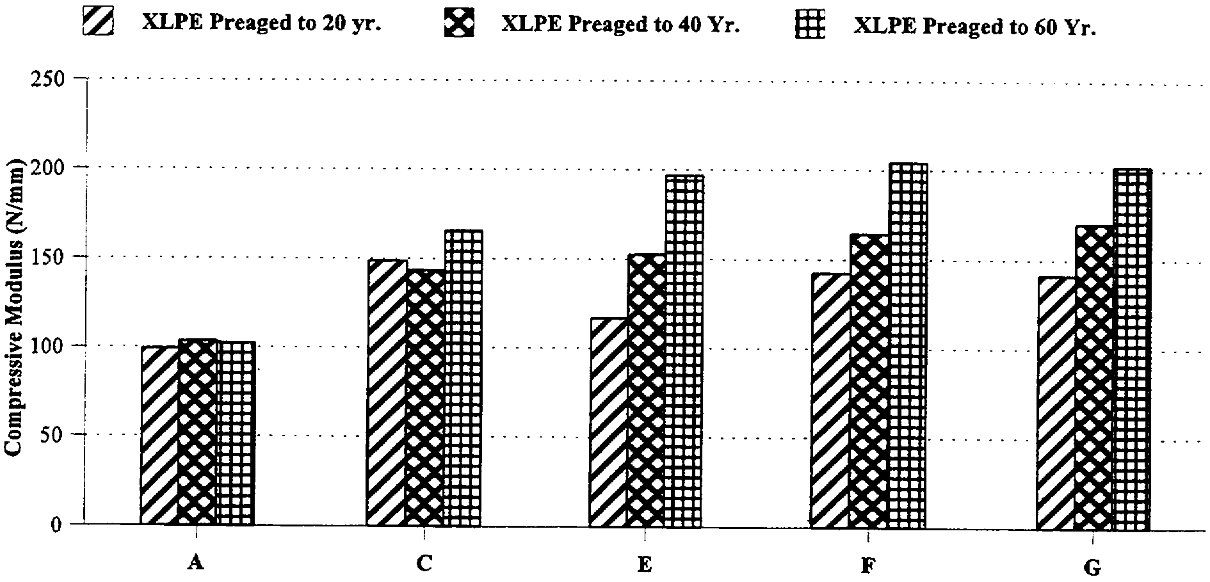


Figure 4.33 Compressive Modulus versus pre-aging for XLPE from Groups 1.4, 3.4 and 6.2 pre-aged to 20, 40 and 60 years of qualified life

A = Baseline
C = Post Thermal Pre-aging
E = Post Service Radiation
F = Post half accident radiation
G = Post full accident radiation

reported (175.5 N/mm, 1,000 lbs./in.). Other samples of the same cable, which were pre-aged for six months (40 Mrad@ 212°F), exhibited a 40 percent modulus increase (182 N/mm, 1,040 lbs./in.), while samples pre-aged for nine months (50 Mrad@ 212°F) exhibited a modulus increase of 65 percent (215 N/mm). A comparison shows that the results reported herein are in relatively good agreement with the values observed in the Sandia study.

Correlation of compressive modulus with elongation-at-break measurements was difficult for XLPE material, especially for the Group 1.4, 3.4 and 6.2 specimens. Following thermal aging, the EAB decreased quite rapidly for the XLPE insulation in these tests (<5 percent elongation remaining). This degradation was reflected by increasing modulus, however, the indenter was still able to produce compressive modulus measurements subsequent to thermal aging. For the Group 1.2 and 3.2 specimens, which received relatively mild aging by comparison, EAB was able to be compared to the compressive modulus. As shown in Figure 4.34, the relatively mild aging for these specimens resulted in little or no change in the modulus. Therefore, only a moderate correlation with EAB was found.

Figure 4.35 presents the compressive modulus values for the Neoprene® outer jackets on the Group 1.2 specimens from test sequence 1. A slight decrease in the modulus from the baseline value of approximately 10 N/mm (57 lbs./in.) was noted after service thermal and radiation aging. An increase in modulus was noted after exposure to accident radiation. A more significant increase in modulus was noted in the Group 1.4 specimens (Figure 4.36), which were pre-aged to the equivalent of 20 years of qualified life. Following thermal aging, the Neoprene® outer jackets were brittle, and this was reflected in the dramatic 1,900 percent increase in compressive modulus. Clearly, the predominant driver in this increase was the thermal aging.

The increase in modulus for the Neoprene® outer jackets was even larger following the 40 and 60 year aging in test sequences 3 and 6, where the modulus was seen to increase up to 4,750 percent. At this point, the outer jackets were very hard and contained visible cracks. The cracking was worsened during the process of clamping them in the indenter, and further testing was not possible. Because of this, modulus measurements taken after thermal aging (CM point C) for test sequences 3 and 6 are not considered to be accurate representations of the modulus of the Neoprene®.

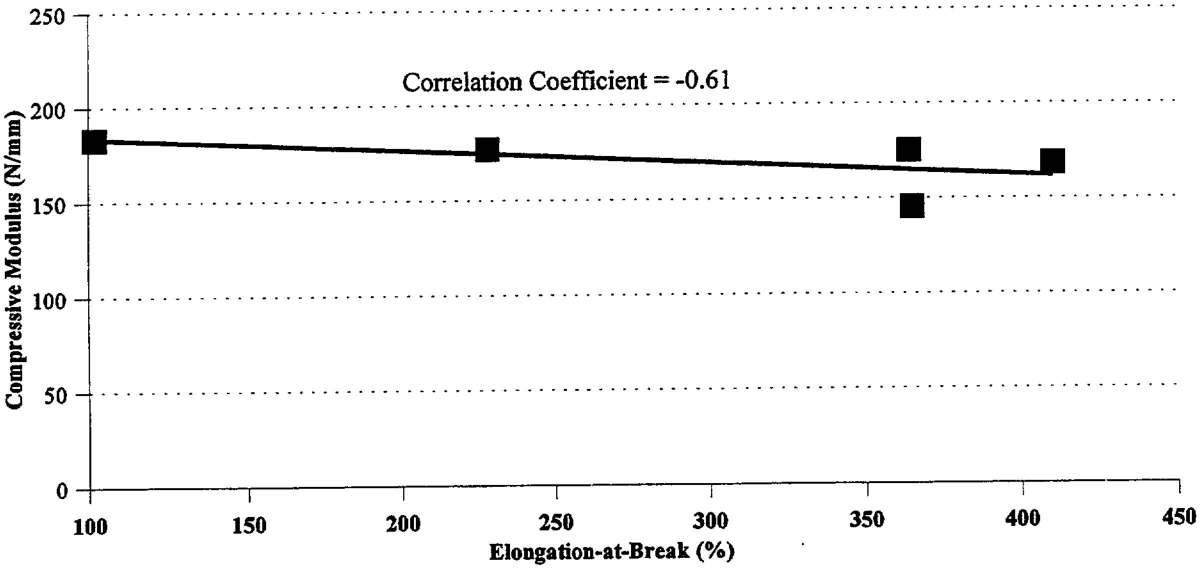


Figure 4.34 Correlation of Compressive Modulus with EAB for XLPE from Group 1.2 pre-aged to 20 years of qualified life

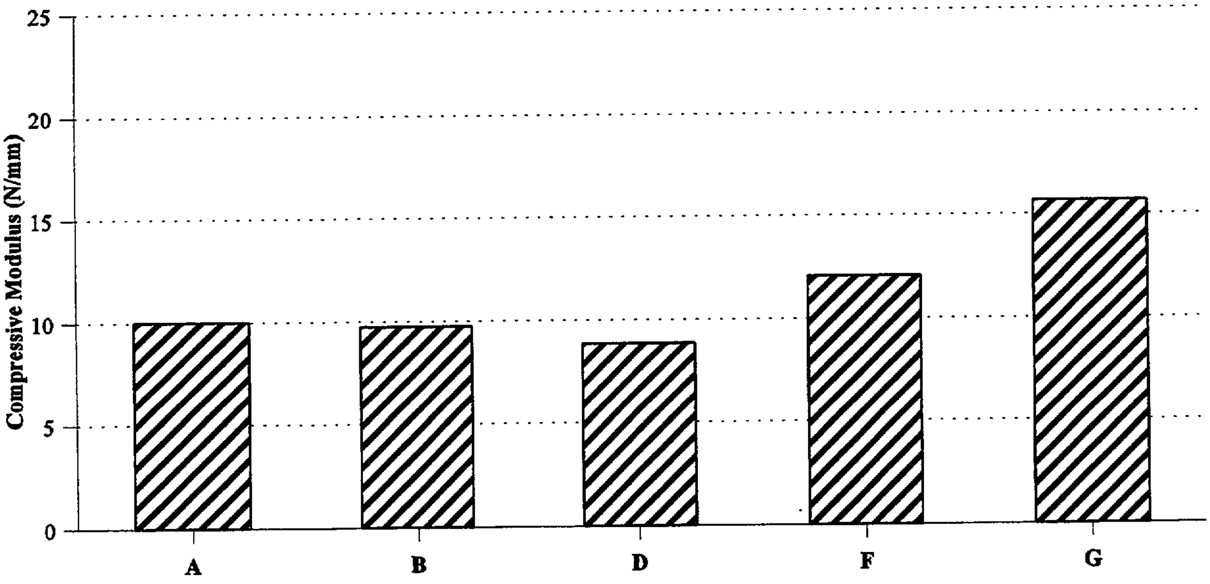


Figure 4.35 Compressive Modulus versus pre-aging for Neoprene® from Group 1.2 pre-aged to simulate cable naturally aged for 10 years

A = Baseline
B = Post Thermal Pre-aging
D = Post Service Radiation
F = Post half accident radiation
G = Post full accident radiation

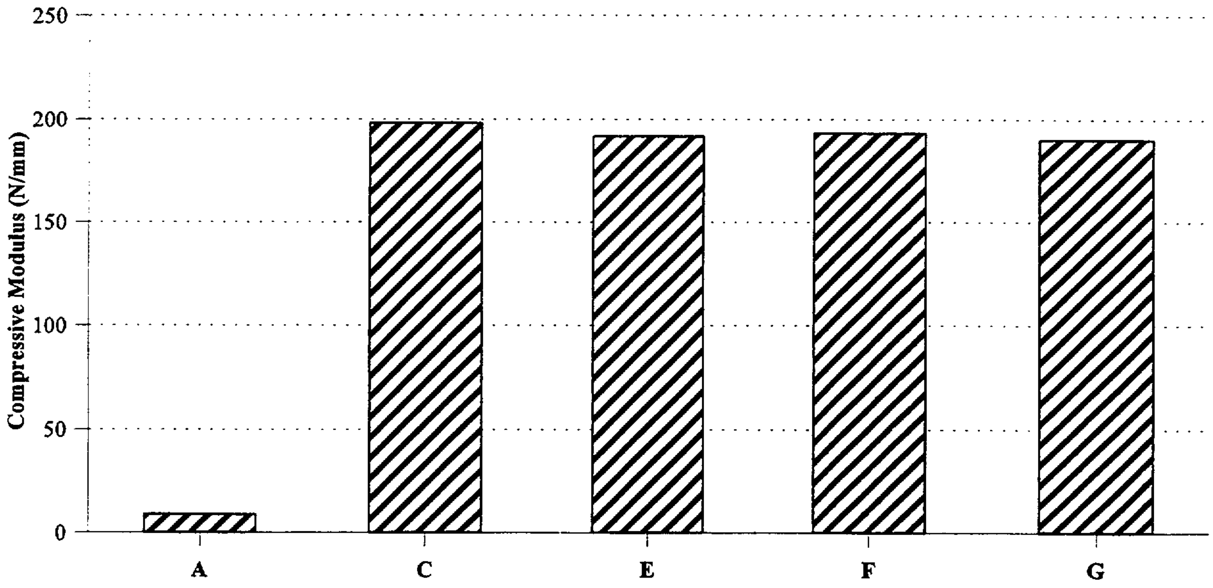


Figure 4.36 Compressive Modulus versus pre-aging for Neoprene® from Group 1.4 pre-aged to 20 years of qualified life

A = Baseline
B = Post Thermal Pre-aging
D = Post Service Radiation
F = Post half accident radiation
G = Post full accident radiation

A review of past research data for Neoprene® reveals similar large modulus increases for aged cables. In a Sandia study (Jacobus, 1992), cables with Neoprene® outer jackets received accelerated aging to the equivalent of 20, 40, and 60 years of service at 131°F (55°C). At the equivalent of 20 years, the modulus increased to 1945 lbs/in (340 N/mm), from a baseline of 99 lbs/in (17 N/mm). For the equivalent of 40 years of aging, the modulus increased to 2236 lbs/in (391 N/mm), and at 60 years of age, the modulus was 2430 lbs/in (425 N/mm). Cracking was reported for these jackets, similar to that observed in this study also. These data are consistent with the results presented herein, and show the relatively low resistance to aging for Neoprene® material.

It is recognized that the dose rates used in this study were relatively high compared to those expected in actual service. Therefore, dose rate effects were anticipated in the test samples. To investigate the impact of dose rate effects on the evaluation of the indenter as an in situ condition monitoring technique, a separate test was performed on individually irradiated cable specimens. Pieces of XLPE-insulated conductor were individually irradiated at low (0.02 Mrad/hr.), moderate (0.20 Mrad/hr.) and high (1.30 Mrad/hr.) dose rates. Indenter measurements were taken periodically to determine how the dose rate effects influenced the data for these specimens, and whether the conclusions reached related to the effectiveness of the indenter technique would be impacted. The results of this test (Figure 4.37) show that the high dose rates produced slightly less degradation of the specimens, while the low and intermediate dose rates produced similar results. However, the difference between the high dose rate values and the others was relatively small. Also, the same general increasing trend in compressive modulus with increasing aging was found for all dose rates. Therefore, these results indicate that the high dose rates used in this program should not influence the overall conclusions regarding effectiveness of the indenter.

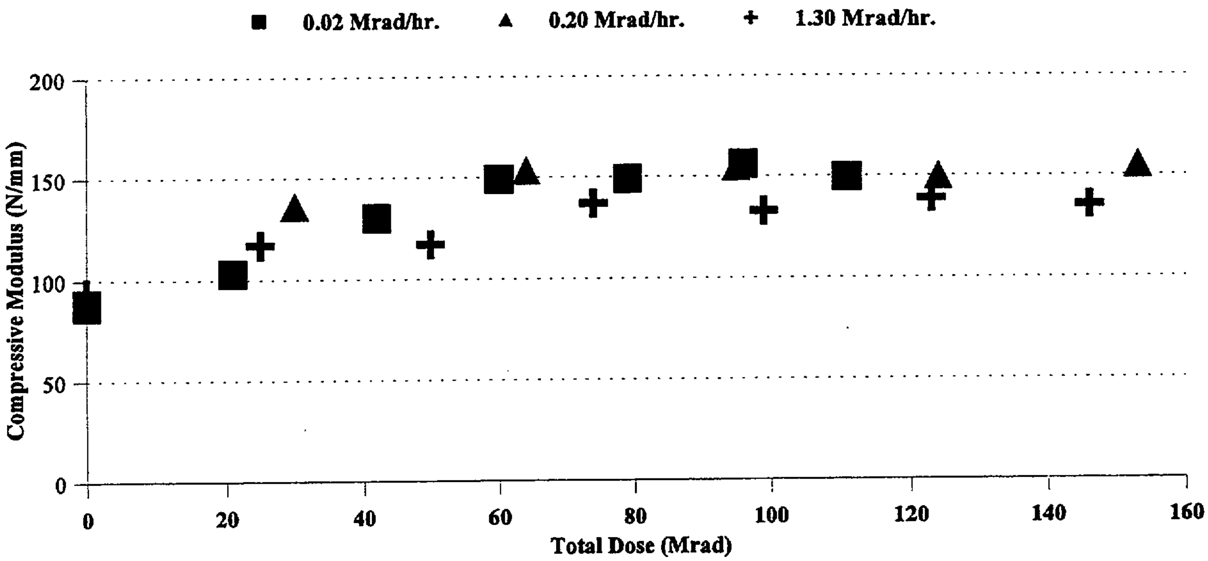


Figure 4.37 Comparison of compressive modulus versus radiation dose for XLPE as a function of dose rate

4.7 Hardness

As discussed in Section 3.7, hardness measurements were taken in accordance with a BNL approved test procedure using a hand-held Rex-D durometer. Measurements were obtained on specimens from the first three test sequences, however, this technique was ultimately discontinued due to problems encountered with the test technique and the durometer used. Hardness data for the Rockbestos XLPE-insulated specimens from test sequences 1 and 3 are shown in Figure 4.38. To obtain this data it was necessary to stack several specimens so that the 10 lb. (44.48 N) spring force from the durometer would not cause the point to totally penetrate the material. Hardness results for all specimens tested are presented in Appendix F.

For the XLPE insulation from test sequence 1, Group 1.4, which was pre-aged to simulate 20 years of qualified life, a 6 percent increase in hardness was measured from the baseline condition to the aged condition (40 to 42.5 Shore-D hardness). This relatively small change in hardness would be difficult to accurately detect in situ using the hand-held durometer. For the specimens aged to the equivalent of 40 years of qualified life in test sequence 3 a more significant, and detectable change was observed. For these specimens, a 22 percent increase in hardness was observed (41 to 50 Shore-D hardness). Following the accident radiation exposure, the hardness increased to 57.

Hardness data on the Neoprene® outer jackets from the test sequence 1 specimens were not obtainable due to the brittle condition of the jackets following thermal aging. Following the thermal aging exposure the outer jackets were found to be cracked and brittle, and, in many instances, shattered under the load from the durometer. The use of a mandrel on the test sequence 3 specimens eliminated this problem. The degree of hardening resulting from the thermal aging was evident by a marked increase in hardness from a baseline value of 28 to a value of 85 after pre-aging.

To evaluate the effectiveness of this technique, an attempt was made to correlate the hardness values with the EAB measurements for the specimens. For the Group 1.4 and 3.4 XLPE specimens in test sequences 1 and 3, this was not possible since the brittleness of the materials following thermal aging resulted in EAB values less than 5 percent. However, such a comparison was possible for the specimens in Group 1.2 and 3.2, which were aged to simulate the service conditions experienced by the naturally aged specimens in Groups 1.3 and 3.3, respectively. As shown in Figure 4.39, an excellent correlation between the two CM methods was seen. The excellent correlation between EAB and hardness seen for the XLPE insulation indicates the potential usefulness of hardness for condition monitoring. However, as discussed in Section 3.7, a specially designed hardness tester would be needed to allow the tip configuration and the spring force to be varied to accommodate the change in material hardness as a function of the amount of aging degradation experienced by the material.

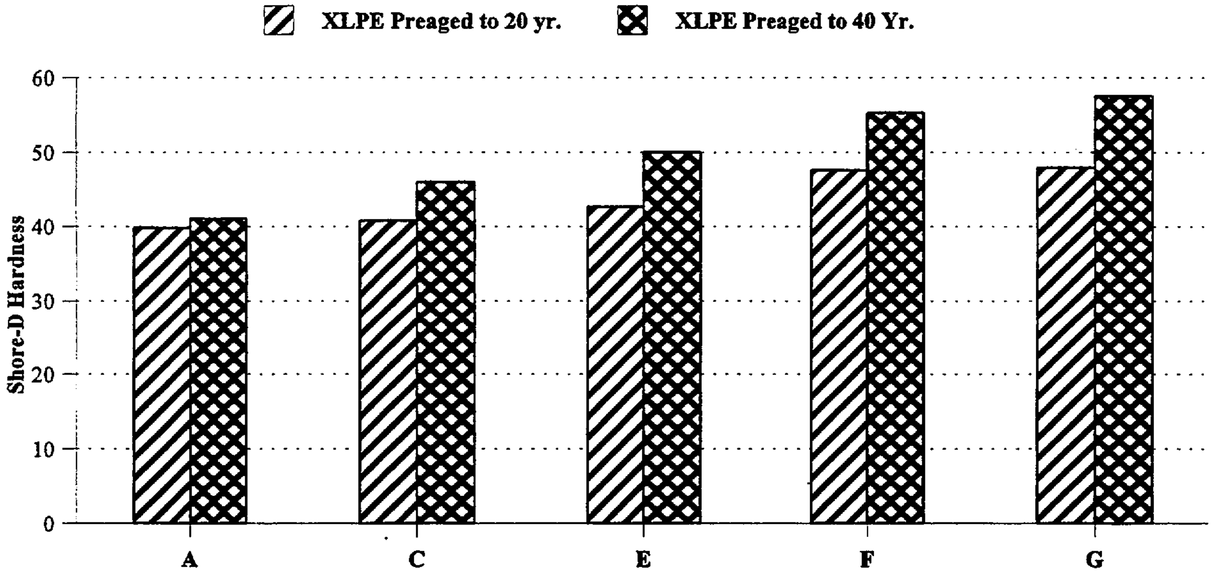


Figure 4.38 Hardness versus pre-aging for XLPE

A = Baseline
C = Post Thermal Pre-aging
E = Post Service Radiation
F = Post half accident radiation
G = Post full accident radiation

4.8 Dielectric Loss

Dielectric loss measurements were performed in accordance with a BNL test procedure using a two-channel Hewlett Packard HP 35670A Dynamic Signal Analyzer, as described in Section 3.8. The data obtained are included in Appendix G. Selected results are discussed in the following paragraphs.

Figure 4.40 presents the data for 2/C #14 AWG Rockbestos Firewall® III XLPE-insulated cables with Neoprene® outer jackets. The average dielectric phase angle measured from conductor-to-conductor as a function of the applied ac test voltage is plotted for the baseline cables (no pre-aging) and for cables pre-aged to the equivalent of 20, 40, and 60 years of qualified life. From approximately 10 to 3000 Hz, the plot generally moves toward the origin throughout the service pre-aging process compared to the baseline values.

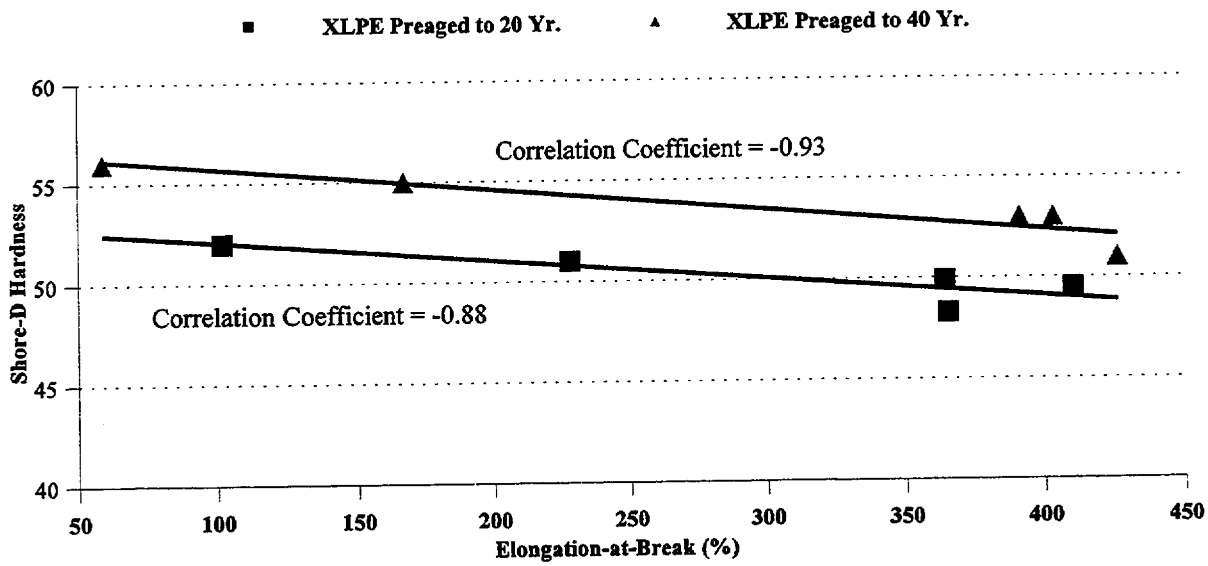


Figure 4.39 Correlation of EAB and hardness for XLPE insulation

As cable insulation deteriorates over time, either as a result of natural in-service aging or by being subjected to accelerated aging, the degradation in the dielectric properties of the insulating material can be detected, monitored, and trended. Low voltage ac applied to the test specimens at frequencies between 10 and 500 Hz were found to be the most effective in showing the effects of insulation degradation on dielectric properties. Lower frequency applied test voltage also showed the dielectric changes, especially at severe levels of insulation damage and degradation. However, the very low frequency (less than 1 Hz) measurements were much more difficult to perform, very time consuming, not consistently trendable, and results were not as repeatable.

As discussed in Section 3.8, these dielectric measurements can be presented in terms of the insulation power factor, i.e., the cosine of the dielectric phase angle, cos θ. Table 4.5 summarizes the insulation power factor values for pre-aged XLPE-insulated cables compared to the baseline values measured before any pre-aging had been performed. The insulation power factors measured at 50, 100, and 500 Hz are presented as an example, since the changes and trends were most consistently demonstrated within this range of frequencies.

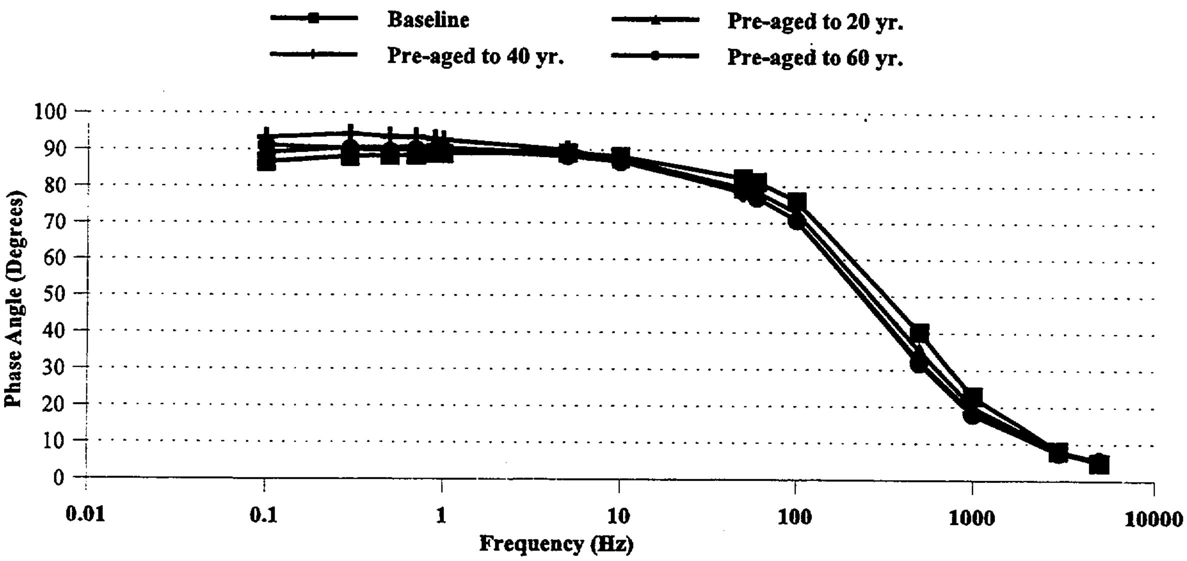


Figure 4.40 Dielectric phase angle vs test voltage frequency for aged XLPE-insulated cables

Table 4.5 Insulation Power Factor for XLPE-Insulated Cables

Insulation Power Factor - Low Voltage XLPE-Insulated Cables					
Cable Specimens	Group	Aging (Years)	Frequency of Applied ac Test Voltage		
			50 Hz	100 Hz	500 Hz
Baseline	All	None	0.13	0.24	0.77
20 Years	1.4	None	0.14	0.26	0.81
		20	0.18	0.29	0.82
40 Years	3.4	None	0.13	0.23	0.74
		40	0.20	0.33	0.84
60 Years	6.2	None	0.13	0.23	0.74
		60	0.19	0.33	0.85

The data in Table 4.5 show a measurable general trend of increasing insulation power factor from the unaged condition of the cable to the post-service aging condition. There is also good consistency in the relative insulation power factor as the total equivalent service aging, and corresponding level of insulation degradation, increased from 20 years up to 60 years.

It should be noted that the 20 year and 40 year groups were thermally aged per the parameters of Rockbestos qualification report QR #1806, i.e., 40 years service at 194°F (90°C) was simulated by 1,300 hours at an oven temperature of 302°F (150°C). The 60 year group, on the other hand, was thermally aged per the parameters of Rockbestos qualification report QR-5805, i.e., 40 years service at 194°F(90°C) was simulated by 909.5 hours at an oven temperature of 302°F (150°C). Based on qualification report QR-5805, 1,364 hours of thermal aging were required to simulate 60 years of service (150 percent of 909.5 hrs.), which is only slightly more than the 1,300 hours received for the 40 year pre-aging in the Group 3.4 specimens. Service irradiation was similar for the two test reports, therefore, the 60 year cables received 50 percent more service radiation than the 40 year cables.

The 40 year group had a slightly higher power factor than the 60 year group when measured at 50 Hz, most likely the result of the similar level of pre-aging received by the two groups of cables. Nevertheless, with the exception of the power factors measured at 50 Hz, the 60 year group followed the general trend toward higher insulation power factor as cable degradation increased because of pre-aging. Therefore, dielectric loss measurements do appear to be trendable, and may be useful for monitoring the condition of cables if a well defined limiting value can be established.

4.9 Insulation Resistance (IR)

Insulation resistance measurements were performed in accordance with a BNL test procedure using a General Radio Model 1864 Megohmmeter, as described in Section 3.9. The data obtained are included in Appendix H. Selected results are discussed in the following paragraphs.

The baseline insulation resistance readings at 10 minutes for the 2/C #14 AWG Rockbestos Firewall® III XLPE-insulated cables with Neoprene® outer jackets were generally very high, frequently exceeding the 200 Teraohm upper range of the test instrument. Pre-aging in accordance with the parameters of the original qualification test (Rockbestos Report QR #1806), which were very severe, produced large changes in the insulation resistance. The average insulation resistance, corrected to 60°F (16°C), for 40 and 60 years of qualified life at a service temperature of 194°F (90°C), dropped between one and two orders of magnitude compared to the baseline readings. No quantitative data were obtained for long specimens aged to the equivalent of 20 years of service at 194°F (90°C) because the insulation resistance, even for the specimens aged to 20 years, exceeded the 2 gigaohm maximum range of the Biddle megohmmeter used in test sequence 1.

The average insulation resistance measurements for the 60 year aged cable specimens was actually higher than for the 40 year aged specimens. It should be noted, however, that the 20 year and 40 year groups were thermally aged per the parameters of Rockbestos qualification report QR #1806, i.e., 40 years service at 194°F (90°C) was simulated by 1,300 hours at an oven temperature of 302°F (150°C). The 60 year group, on the other hand, was thermally aged per the parameters of Rockbestos qualification report QR-5805, i.e., 40 years service at 194°F (90°C) was simulated by 909.5 hours at an oven temperature of 302°F (150°C). This required 1,364 hours of thermal aging to simulate 60 years of service (150 percent of 909.5), which is only slightly more than the 1,300 hours received for the 40 year group. Radiation aging was similar for the two test reports, therefore, the specimens in the 60 year pre-aging group received 50 percent more radiation than those in the 40 year pre-aging group. Consequently, with less than a 5 percent difference in thermal aging, which was the dominant pre-aging parameter causing degradation, there was very little actual difference in the condition of these two groups of cable.

Figure 4.41 presents the polarization index data for 2/C #14 AWG Rockbestos Firewall® III XLPE-insulated cables with Neoprene® outer jackets. The polarization index, as a ratio of the 10 minute and 1 minute insulation resistance readings, minimizes the temperature and humidity effects and the differences in baseline readings among the cables, thereby providing a better relative representation of the dielectric condition of the cables. The large change from the baseline values is clearly shown in the figure. As discussed in the previous paragraph, however, the condition of the 40 year aged group is nearly the same as the 60 year aged cables. Therefore, the apparent increase in the polarization index for the 60 year aged cables is nothing more than variation in the average initial condition of the two groups. Furthermore, referring to the elongation-at-break (EAB) values for cables aged to 20 years of service at 194°F (90°C) in Table 3.3 of Volume 1 of this report, it is seen that EAB has been reduced to less than 5 percent. This means that the ductility of the XLPE insulation in the 20, 40, and 60 year cable groups has been reduced to its minimum and little difference would be expected in the insulation resistance or polarization index readings at that extreme level of degradation.

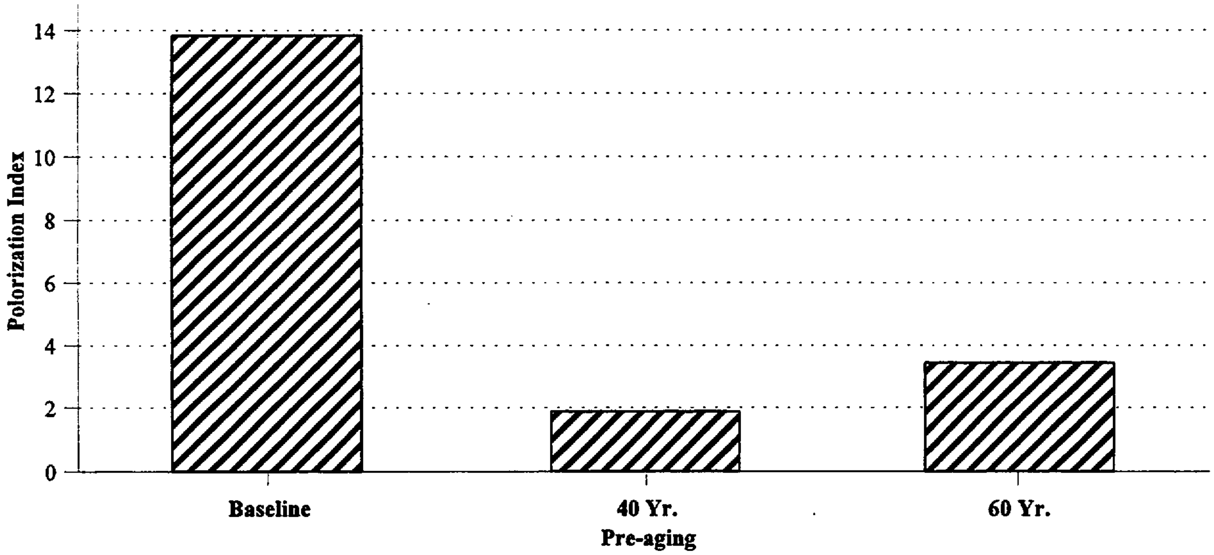


Figure 4.41 Polarization Index for aged XLPE-insulated cables

Given the large change in polarization index from the baseline to the 40 and 60 year aged cables (and to the 20 year cables, if quantitative values were available), it follows that the insulation resistance/polarization index could be a trendable parameter for increments of degradation smaller than depicted in Figure 4.41. This was in fact found to be the case in test sequence 3 (Lofaro, et.al., January 1999A) where temperature-corrected insulation resistance measurements for baseline XLPE cables, 10-year-old naturally aged cables, cables aged to match the naturally aged cables, and incrementally aged 40 year cables corresponded to the relative level of degradation for each group.

The test data for hold points in the pre-aging process, as described in Volume 1 of this report, and observations by the BNL test engineers indicate that the insulation resistance readings are a trendable parameter for smaller increments of insulation damage, as would be encountered during normal service aging in a nuclear power plant environment. Temperature-corrected insulation resistance or polarization index values, particularly when compared to a baseline measurement, are considered an electrical condition monitoring technique capable of observing incremental trends in degradation for these materials.

4.10 Functional Performance

The XLPE-insulated 2/C # 14 AWG Rockbestos cables in test sequences 1, 3, and 6 were connected into individual 4-20 mA instrumentation loop circuits in order to assess their functional performance throughout the LOCA exposure test. The test specimens were powered and loaded as shown in Figure 2.13 for cables mounted in a straight configuration in Unistrut® channels and Figure 2.14 for mandrel-mounted cables. Each of the long specimens was powered separately with 28 Vdc. A 4-20 mA output pressure transmitter was connected to the LOCA chamber leads from each of the long specimens to serve as a load. All of the pressure transmitters were connected to a common manifold pressurized by a source of regulated compressed air, so that they all monitored the same pressure.

Five specimens in Group 1.1, Specimen 0301 in Group 3.1, and Specimen 0604 in Group 6.1 were control specimens that received no pre-aging prior to the LOCA exposure test. Groups 1.4 (5 specimens) and 3.4 (5 specimens) were pre-aged to the equivalent of 20 years and 40 years of service at 194°F (90°C), respectively, in accordance with the parameters of Rockbestos qualification report QR #1806, i.e., 40 years service at 194°F (90°C) was simulated by 1,300 hours at an oven temperature of 302°F (150°C). The three specimens in Group 6.2 were pre-aged to the equivalent of 60 years of service at 194°F (90°C) in accordance with the parameters of Rockbestos qualification report QR-5805, i.e., 40 years service at 194°F (90°C) was simulated by 909.5 hours at an oven temperature of 302°F (150°C). Thus, similar amounts of thermal pre-aging were administered to the 40 year and 60 year cables.

During the simulated LOCA test, the powered specimens were monitored for applied voltage, circuit current, and leakage current, as described in Section 3.10. Manifold pressure, as measured by the test specimen pressure transmitters, was compared to actual pressure, measured by an external pressure transmitter connected directly to the manifold. A 1/32 ampere fuse was placed in the circuit to prevent overloading the power source in the event of a short circuit.

With the exception of one faulty pressure transmitter on Specimen 0105, all of the unaged XLPE-insulated cables performed adequately during the LOCA tests, with a maximum deviation from the nominal circuit current of no greater than ±2 percent of full scale and negligible leakage current. High leakage current problems were encountered on all of the 20 year aged specimens (Test Group 1.4); circuit 0212 experienced one blown protective fuse and circuit 0116 blew its protective fuse three times before being permanently removed from service. It was later determined that the splices used to connect the facility test leads to the cable specimens under test were incorrectly specified and misapplied. This problem was corrected for subsequent testing by procedurally applying nuclear grade splices that had been custom specified for this application by Raychem, the manufacturer of the splices. Despite the leakage current problems, the maximum deviation from nominal circuit current on the other 20 year cables, was still less than 8 percent of full scale, with the exception of circuit 0616 which reached 46 percent before being taken out of service. These data are summarized in Table 3.4 of Volume 1 of this report.

Problems were also encountered in the functional performance of the 40 year specimens (Group 3.4). Specimens 0313 and 0316 both had to be abandoned due to excessive leakage currents that blew protective fuses three times and one time, respectively, before being finally removed from service. Maximum deviation from the nominal circuit current for the three remaining 40 year cables was 6 percent of full scale. Maximum leakage current among the three remaining circuits was 12.4mA. These data are summarized in Table 3.13 of Volume 1 of this report.

The 60 year cables (Group 6.2) all performed adequately during the LOCA test. Maximum leakage current observed was 0.7mA. Maximum deviation from nominal circuit current was no more than 5 percent.

Referring to the elongation-a-break (EAB) values for cables aged to 20 years of service at 194°F (90°C) in Table 3.3 of Volume 1 of this report, it can be seen that the EAB had been reduced to less than 5 percent. This means that the ductility of the XLPE insulation for the 20, 40, and 60 year cable groups had all been reduced to minimum and little difference would be expected in the level of degradation among the three groups. The poor insulation resistance and insulation power factor values reinforced these EAB findings by showing that the dielectric integrity for the three groups of cables was also marginal.

Disregarding the splice-related problems of Group 1.4, leakage currents exceeded 10mA on three of the remaining eight aged XLPE-insulated specimens, and two of those had to be removed from service before the end of the LOCA test due to persistent high leakage current (blown 1/32 ampere fuse). With the exception of those two cable specimens, the maximum deviation from nominal circuit current was less than 6 percent of full scale. The functional performance of a cable specimen's test circuit during the accident exposure test can be evaluated by identifying the maximum error indicated by the pressure transmitter loop circuit that the specimen was part of. The magnitude of leakage current can also become a problem, however, if it exceeds the level of the circuit protection from the loop power supply, as was the case for Specimens 0312 and 0316.

4.11 Voltage Withstand

Upon completion of the LOCA exposure test, the XLPE-insulated 2/C # 14 AWG Rockbestos Firewall® III cables in test sequences 1, 3, and 6 were removed from the LOCA test chamber and subjected to a post-LOCA submerged voltage withstand test. This test, described in Section 3.11, is the final step of the pre-aging/LOCA test sequence followed in the BNL test program. The data obtained are included in Appendix I. Selected results are discussed in the following paragraphs.

Each long cable specimen was connected, one conductor at a time, to a Hippotronics Model 760-2HVT high potential test set and energized at 2,400Vac (80Vac per mil of insulation thickness), 60 Hz, while submerged in tap water at room temperature (~73°F/23°C). The test voltage was applied to each conductor for a total duration of 5 minutes, and the leakage current and applied test voltage were recorded. If the leakage current exceeded the maximum level that the test set is capable of measuring, 10mA in this case, or a voltage breakdown was observed, the test specimen was considered failed.

As discussed in Section 3.11, the submerged voltage withstand test is the final step in the environmental qualification type test procedure described in IEEE Std. 383-1974 for electric cables. The BNL test sequence differs from the IEEE standard in that the cable specimen is voltage withstand tested as-is, coiled on its stainless steel test mandrel, or straight, in a steel Unistrut® support channel. In the IEEE test, the cable specimen is removed from its test mandrel following the LOCA exposure, straightened, and then coiled back onto a mandrel prior to final voltage withstand testing. This process of straightening and recoiling the test specimen was judged to be unnecessarily severe, and was not included in the BNL test sequence.

The results of the post-LOCA voltage withstand test on the Rockbestos Firewall® III XLPE/Neoprene® cables are summarized in Tables 3.5, 3.14, and 3.27 in Volume 1 of this report for test sequences 1, 3, and 6, respectively. These raw data were sorted by the amount of pre-aging received by XLPE-insulated specimens prior to the LOCA exposure test, and the average leakage current measured for each pre-aging group was then plotted (Figure 4.42). The leakage currents for those specimens that successfully withstood the applied test voltage for the full 5 minute duration of the test are included in each group. The quantity of cable conductors successfully passing the test is shown above the bar representing each pre-aging group. Conductors in the 40 year pre-aging group that failed as a result of handling damage during the testing process are not included.

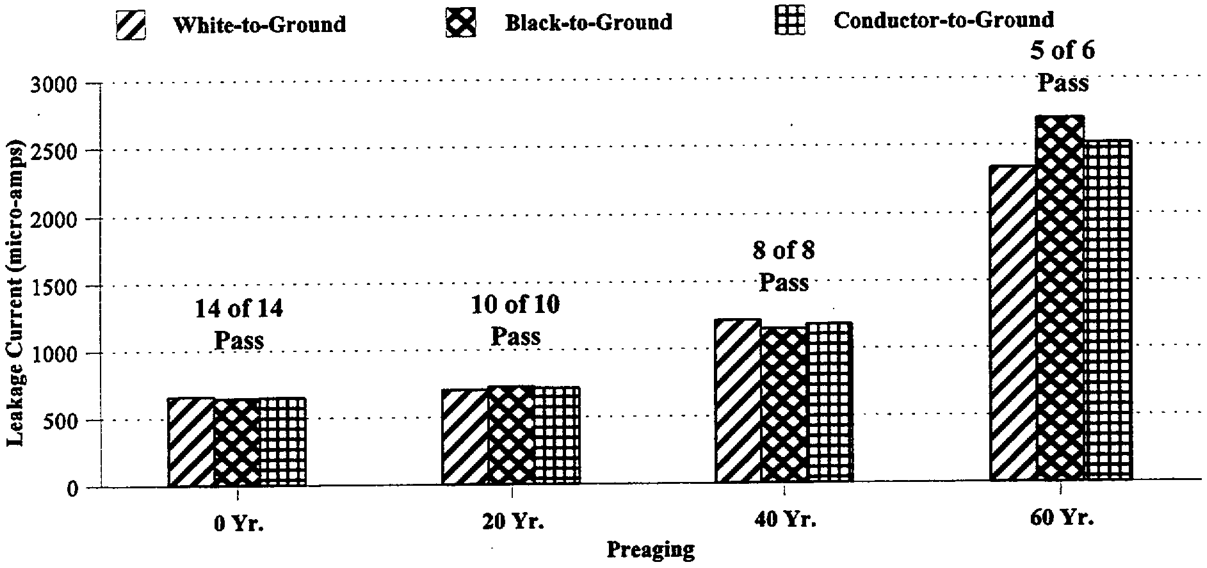


Figure 4.42 Post-LOCA submerged voltage withstand test results for pre-aged XLPE-insulated cables

Figure 4.42 clearly shows that there is a trend toward increasing leakage current observed during the voltage withstand test for XLPE-insulated cable specimens as the level of pre-aging prior to LOCA exposure increased. This trend is generally what would be expected for increased amounts of insulation degradation. Recalling the discussions in Section 4.8 and 4.9, however, that the 60 year XLPE-insulated cables received only slightly more thermal pre-aging than the 40 year cables, most of the increase in leakage current would be attributed to the additional 50 percent higher total integrated dose of radiation pre-aging administered to the 60 year cables.

Other condition monitoring methods, such as elongation-at-break, visual inspection, insulation power factor measurement, and insulation resistance measurement, showed the condition of the XLPE cable insulation to be completely deteriorated after the very severe first step of pre-aging to the equivalent of 20 years of service at 194°F (90°C). These methods did not indicate significant additional insulation degradation for cables that received further pre-aging to the equivalent of 40 and 60 years. The submerged voltage withstand test did continue to provide a trendable measure of dielectric condition at the extreme levels of insulation degradation at which some of the other conditioning monitoring methods were less sensitive to the detection of further insulation degradation.

In summary, the submerged voltage withstand test provides a measure of the electrical condition of a cable specimen's insulation following LOCA exposure testing. However, in its present protocol for this research program, it is not a true condition monitoring test. Even conducted as a dry high potential test, it would not normally be used in situ, by nuclear power plant technicians, to assess and trend the dielectric integrity of an I&C cable's insulation system. Since it is a high voltage test, it has the potential to destroy a cable if a voltage breakdown should occur. Even at lower levels of applied test voltage, within the voltage rating of the cable, the cable insulation is incrementally weakened by each high potential test. Thus, the risks of causing either catastrophic or incipient damage to cable insulation make this an unsuitable condition monitoring method.

5. CONDITION MONITORING RESULTS FOR ETHYLENE PROPYLENE RUBBER CABLES

This section presents the results of the condition monitoring tests on cables with ethylene propylene rubber insulation. Each CM technique is evaluated based on how well it was able to detect and trend the degradation caused by the pre-aging administered to the test specimens. In some cases, degradation caused by the accident exposure (radiation plus steam/chemical spray) is also discussed since it provides supplemental data and additional insights into how well the CM technique, as well as the polymer being tested, performed.

5.1 Visual Inspection

Test sequence 2 included EPR-insulated cables manufactured by AIW. Visual inspection of the Group 2.1 AIW specimens, which received no pre-aging prior to accident testing, showed that the specimens were initially in excellent condition with no visible signs of degradation. The application of 150 Mrad of radiation had little noticeable affect on the specimens. After exposure to simulated LOCA condition, areas of greyish/white residue were noted on the jackets. The white insulation became slightly yellow in color. The specimens remained very flexible and, in general, appeared to be in good physical condition.

The Group 2.2 specimens, pre-aged to match the service aging experienced by the naturally aged specimens in Group 2.3, were also initially in excellent condition with no visible signs of degradation. After thermal aging the specimens showed slight visible signs of degradation, including a greyish coloring on the jacket. The subsequent application of service radiation had only slight visible effects on the specimens, including a white dusting on the insulation and several small longitudinal splits. Application of an additional 150 Mrad of accident radiation (75 Mrad for specimens 0203 and 0204) also caused little noticeable change in the specimens. Exposure to the simulated LOCA conditions resulted in a greyish/white dusting on the cables, along with a rough surface texture.

For the naturally aged specimens in Group 2.3, the visual inspection showed they were initially in excellent condition with uniform jacket and insulation colors. No cracks we observed in either the jackets or the insulation. A waxy residue was noted on the jackets initially, which may have been cable pulling compound. The specimens were slightly stiffer than a new cable, however, the insulated conductor had good flexibility. Application of 150 Mrad of radiation to simulate an accident had no visible effect on the specimen, with the exception that several small (1mm) splits/nicks were noted in the insulation. Exposure to the simulated LOCA conditions left the jacket with some areas of greyish/white residue and a rough texture. The white insulation appeared slightly yellow in color. Both the jackets and the insulation felt slightly more rigid than they did previously, however, they still had good flexibility remaining. In general, the specimens appeared to be in good condition after the accident simulation.

The specimens in Group 2.4 were pre-aged to simulate 20 years of qualified life. After thermal aging, all of the specimens showed slight signs of degradation. The jackets retained their uniform black color, however, the white insulation was slightly yellow in color. No cracks were found in the jackets or insulation. Application of 150 Mrad of radiation had little visible effect on the specimens, with the only change being a greyish/white dusting on the jackets.

Exposure of the Group 2.4 AIW specimens to the simulated LOCA caused similar surface deposits as noted on the other specimens. Areas of grey/white residue were noted on the jackets and insulation. A rough surface texture was also noted. The jacket and insulation were slightly rigid with good flexibility remaining.

Test sequence 4 included EPR-insulated cables manufactured by Samuel Moore and Anaconda. The Group 4.2 Samuel Moore cable specimens were artificially aged to simulate 20 years of qualified life, as determined from the original qualification report. The visual inspections indicated that the Samuel Moore cables were in acceptable condition throughout the pre-aging sequence. No cracks were evident and the cables remained relatively flexible. The Group 4.3

cables were artificially aged to simulate 40 years of service. Again, the visual examinations showed that the Samuel Moore cables were in good condition and remained moderately flexible with no cracking evident. The Anaconda cables appeared degraded and were somewhat stiff, however, no cracking was evident. The accident irradiation had little effect on their visual appearance.

Following completion of the accident steam exposure, the specimens were removed from the test chamber and a visual inspection was performed. White powdery deposits were noted on the surface of the outer jackets on all of the specimens, however, no cracking was visible on any of them.

The visual inspection of the Group 4.2 cables clearly showed some degree of degradation to all of the specimens. The multi-conductor Samuel Moore specimens were still flexible and had a spongy feel to them. Large (5-10 cm) cracks were noted in the jackets, however, the underlying insulation appeared to be in good condition. Swelling was noted for the cable with the outer jacket diameter increasing approximately 21 percent and the insulation diameter increasing approximately 33 percent. The single conductor Samuel Moore specimens showed some shriveling and dis-bonding of the Hypalon® jacket on portions of the cable not attached to the mandrel. The EPR insulation appeared to be in good condition. The cable was stiff and swelling was noted with the insulation diameter increasing approximately 28 percent.

Visual inspection of the Group 4.3 cables also showed degradation on each of the specimens. The multiconductor Samuel Moore specimens had multiple large cracks in the outer jacket exposing the insulated conductors underneath. The exposed insulation appeared to be in good condition. Small water-filled bubbles were also noted in the outer jacket. The cables were stiff and swelling was noted with the jacket diameter increasing approximately 23 percent and the insulation diameter increasing approximately 29 percent. The single conductor specimens appeared similar to those in Group 4.2 with the Hypalon® jacket shriveled and dis-bonded.

The Group 4.3 Anaconda multiconductor specimens had multiple large cracks and ruptures in the outer jacket. The cable was fairly stiff and swelling was noted with the outer jacket diameter increasing approximately 21 percent and the insulation diameter increasing approximately 17 percent. The single conductor Anaconda specimens had multiple superficial cracks, or crazing in the jacket. Swelling was noted with the insulation diameter increasing approximately 12 percent.

Test sequence 5 included EPR-insulated cables manufactured by Samuel Moore, Anaconda, and Okonite. The Group 5.2 cables were artificially aged to simulate 20 years of qualified life, as determined from the original qualification report. The visual inspections indicated that the Samuel Moore and Anaconda cables were in acceptable condition throughout the pre-aging sequence. No cracks were evident and the cables remained relatively flexible. The Okonite cables in Group 5.2 appeared degraded and were relatively stiff, however, no cracking was evident.

The Group 5.3 cables were artificially aged to simulate 40 years of service. The visual examinations showed that the Samuel Moore cables were in good condition and remained moderately flexible with no cracking evident. The Anaconda cables appeared degraded and were somewhat stiff, however, no cracking was evident. The Okonite cables also appeared degraded and were very stiff. Also, minor circumferential cracking was noted in the jackets of 2 of the 3 Okonite cables in this group. The accident irradiation had little effect on the visual appearance of the specimens.

Following completion of the accident steam exposure, the test specimens were removed from the test chamber and a visual inspection was performed. All of the Group 5.1 cables appeared to be in good condition with no cracking evident. Small (1-2 mm diameter) water-filled bubbles were noted on the surface of the outer jackets on all of the specimens, however, no cracking was visible on any of the specimens.

Visual inspection of the Group 5. 2 cables clearly showed some degree of degradation to all of the specimens. The Samuel Moore specimens were still flexible and had a spongy feel to them. Small (0.75-2 in./2-5 cm) cracks were noted in the jackets. The Anaconda specimens had multiple longitudinal cracks in the outer jacket; none were through-wall. The cracks appeared to be due to swelling of the jacket. Also, one large circumferential crack was noted in the outer jacket of one of the Anaconda specimens exposing the insulated conductor. The Okonite specimens were found to have a longitudinal crack running along the length of the jacket. On one of the Okonite cables, a 5-inch (12.7 cm) section had split open exposing the bare conductor underneath.

Visual inspection of the Group 5.3 cables also showed degradation on each of the specimens. The Samuel Moore specimens were still flexible and the outer jackets felt spongy. Both of the Samuel Moore specimens had a 5 cm crack in the outer jacket exposing the insulation on the conductors underneath. The exposed insulation appeared to be in good condition. The Anaconda specimens had multiple longitudinal cracks in the outer jacket similar to the Group 5.2 specimens. In addition, a large circumferential crack was noted in the overall jacket of one cable exposing the insulation on the conductor. The Okonite specimens all had longitudinal cracking of the jacket and the underlying insulation that split open along the length of the cable exposing the bare copper conductor.

Test sequence 6 included EPR-insulated cables manufactured by Samuel Moore, AIW and Okonite that were pre-aged to simulate 60 years of qualified life. Visual inspection of the specimens at their baseline condition found that all specimens were in excellent condition with no significant anomalies. A greenish film was noted on the AIW specimens, which was probably due to cable pulling compound applied during installation. Also, several paint marks were noted on the AIW specimens, which were attributed to markings applied to identify the cable in the plant.

Following thermal aging, two of the three Okonite specimens developed circumferential cracking of the jacket. The specimens also were judged to be embrittled. The Samuel Moore specimens were somewhat stiffer than their baseline condition, however, some flexibility remained and no cracking was evident. The AIW specimens were also judged to be very stiff compared to the baseline condition, however, no cracking was evident. A white powdery coating was also noted on the outer jackets of the AIW specimens.

Application of the service radiation dose caused additional cracking to be noted on the two previously cracked Okonite specimens, as well as on the previously un-cracked Okonite specimen, leaving all three Okonite specimens containing cracks at this point. Little change was noted on the Samuel Moore specimens; the cables were stiffer than their baseline condition, however, no cracking was evident. The AIW specimens appeared to have degraded further from the previous post-thermal inspection with additional greyish/white deposits on the jackets, along with a tan colored powdery deposit on the jackets. The specimens were judged to be very stiff at this point, however, no cracking was evident.

Application of the accident radiation had little effect on the visual appearance of the specimens. Several additional cracks were noted on the Okonite specimens. No cracking was evident on the Samuel Moore or AIW specimens.

Following the LOCA steam exposure, a visual inspection showed that the pre-aged Okonite had failed catastrophically by splitting open exposing the bare conductor, similar to the results of test sequence 5. The unaged Okonite specimen appeared to be in good physical condition with no cracking evident. Cracking of the outer jackets was noted on both the Samuel Moore and AIW specimens. In some areas of the Samuel Moore specimens the cracking in the outer jacket exposed the insulated conductors underneath. On the AIW specimens, the outer jackets appeared to have expanded lengthwise causing them to rupture and travel over themselves. The AIW jacket material felt soft and spongy as if it had absorbed a large quantity of water.

5.2 Elongation-at-Break (EAB)

In this section of the report, the EAB properties of EPR and ethylene-propylene-diene monomer (EPDM) insulations are evaluated together with their associated Hypalon® jackets. All EAB results are tabulated in Appendix A.

5.2.1 Results for Ethylene-Propylene Rubber/Hypalon® Cables

The AIW and Anaconda cables evaluated consisted of EPR insulation enclosed by Hypalon® individual jackets of different colors. The overall outer jacket was also made from Hypalon®. Figure 5.1 shows the changes in EAB for AIW cable that was given thermal and irradiation aging treatments (CM points B and D, respectively) to simulate the 24 years of service that had been received by the naturally-aged cable in Group 2.3. The outer jacket consistently showed a loss in EAB with each aging step and also during the LOCA radiation and steam/chemical spraying. The individual Hypalon® jackets, however, showed an increase in EAB after the first LOCA radiation (CM point F). For subsequent steps in the LOCA cycle the EAB decreased. The ductility of the individual jackets did not seem to show any consistent differences from color to color. For the EPR insulation, the EAB showed a decrease throughout the successive service aging and LOCA treatments. The one exception was for the service aging step (CM point B) for which there was a small increase in ductility. Subsequent aging and LOCA cycles consistently reduced the EAB.

In Figure 5.2, CM point A gives the EAB results for AIW cable that was naturally aged for 24 years in a nuclear power plant. The results in Figure 5.1 (CM point D) for material artificially aged to 24 years of service show that it has a lower EAB compared to the naturally-aged material. This suggests that artificially aged cable may be used to conservatively estimate aging effects in cable materials. Such a conclusion assumes that the artificially- and naturally-aged cables, which were made by the same manufacture, had the same starting properties. This is a reasonable assumption since both cables were made in the same year (1974). It is also assumed that aging while in storage was insignificant for the artificially aged cable. The naturally-aged cable materials showed decreasing ductility after the LOCA radiation and steam/chemical spraying cycles (CM point F, G, and H in Figure 5.2). In the case of the artificially-aged cable, however, the first LOCA radiation dose of 78.7 Mrad increased the EAB. Subsequent LOCA radiation and steam/chemical spraying reduced the ductility.

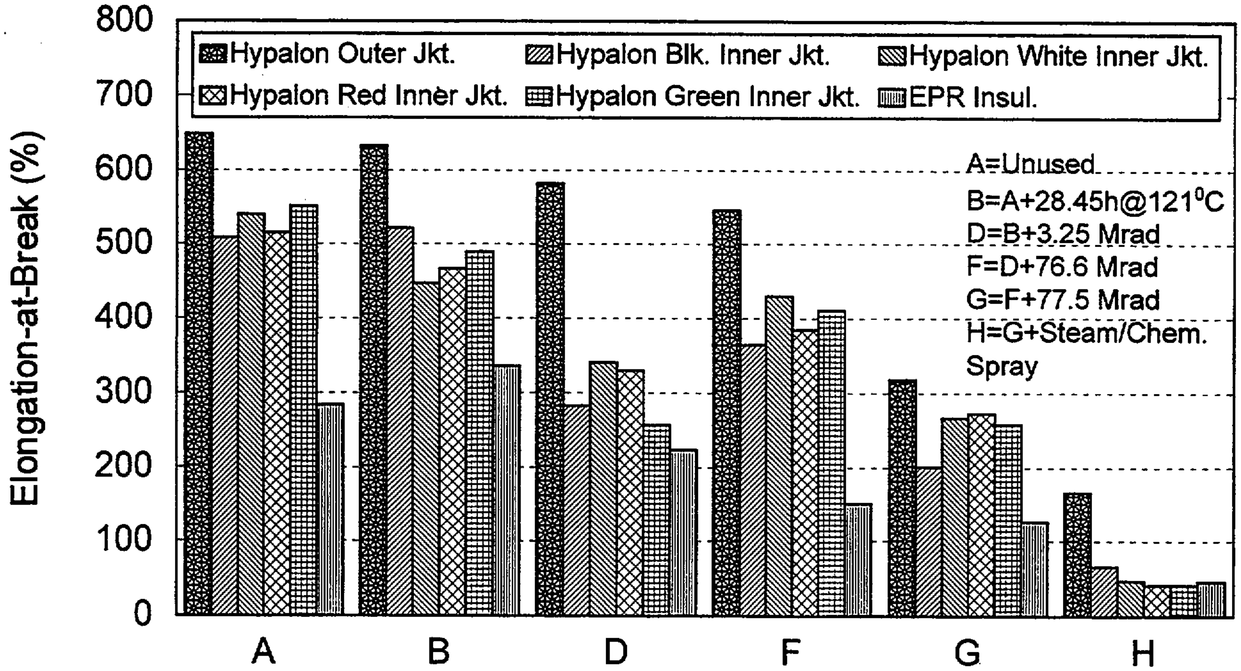


Figure 5.1 Effect of aging and LOCA testing on the EAB of AIW EPR/Hypalon® cable PNI74AI027 (Group 2.2, Specimen 0205) artificially aged to simulate Group 2.3

EAB data for Anaconda EPR/Hypalon® cable are given in Figures 5.3 and 5.4 for materials aged for 20 and 40 years of qualified life, respectively. As expected, the insulation and jacket materials suffered a loss in ductility of approximately 75 percent after the 20 year aging treatment (Figure 5.3, CM Point D); LOCA radiation and steam/chemical spraying caused further reductions in EAB, but the materials were not brittle. After the 40-year treatment (Figure 5.4, CM Point E) the ductility decreased to the 10-20 percent range. There were additional decreases after LOCA testing, and the materials became brittle.

A similar major loss in EAB was observed for Okonite® cable consisting of a Hypalon® jacket bonded to EPR insulation. After artificial aging to one-half of the manufacturer's 40-year qualification protocol, assuming a service temperature of 194°F (90°C), the EAB of the bonded Hypalon®/EPR composite specimens was reduced to approximately 8 percent (Figure 5.5, CM Point D). For the full 40-year qualification, the cable became brittle with the EAB reduced to about 5 percent (Figure 5.6).

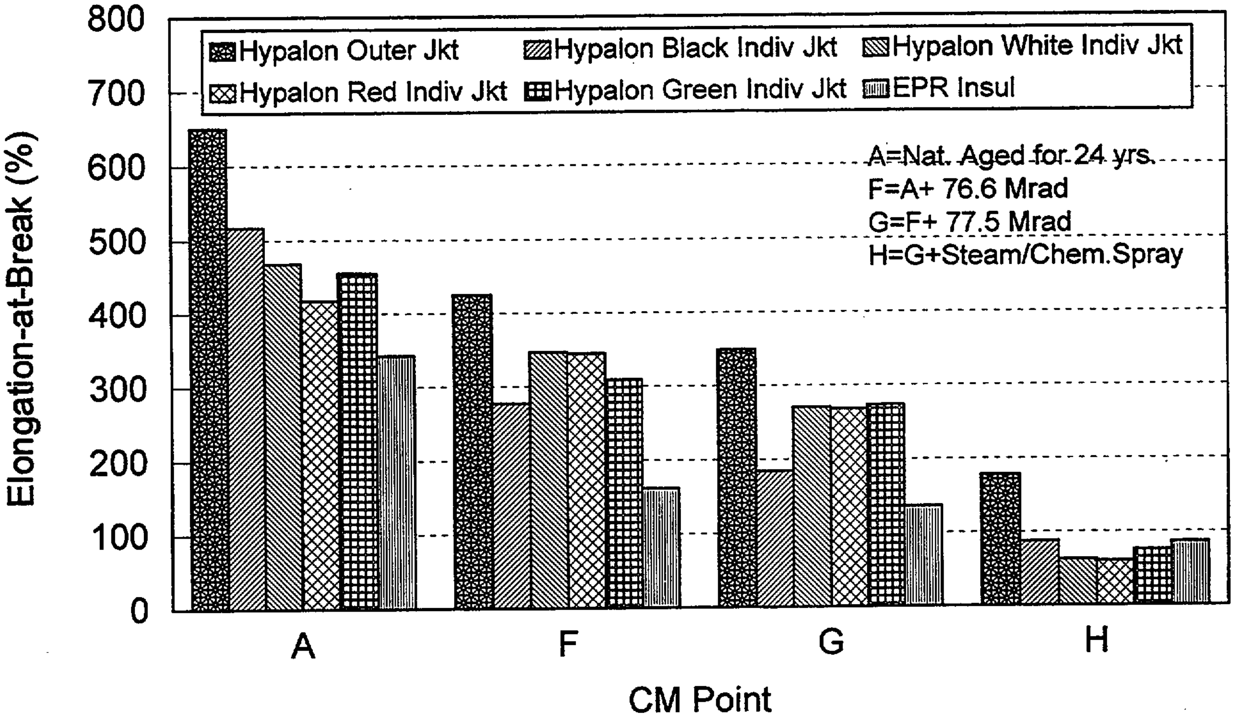


Figure 5.2 Effect of LOCA testing on the EAB of AIW EPR/Hypalon® Cable PNI74AI015 (Group 2.3, specimen 0207) naturally-aged for 24 Years

5.2.2 Results for Ethylene-Propylene-Diene Monomer (EPDM) Cables

The EPDM insulation tests were carried out on two samples of Samuel Moore cable (PNI82SM008, and DNI80SM010) both of which were of the two-conductor type. Red or purple individual jackets made from Hypalon® were bonded to the EPDM insulation. The outer jacket was also made from Hypalon.® Complete results of the EAB tests are given in Appendix A.

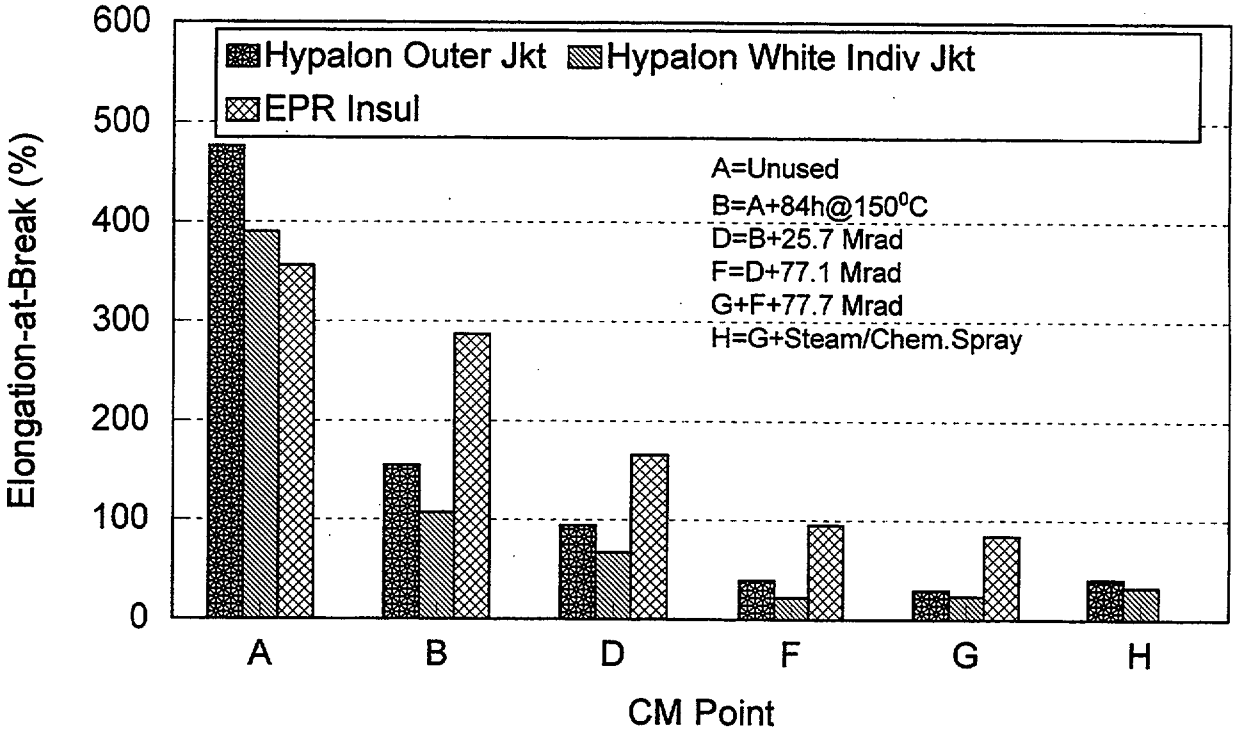


Figure 5.3 Effect of aging and LOCA testing on the EAB of Anaconda EPR/Hypalon® cable DNP78AN008 (Group 5.2, Specimen 0508)

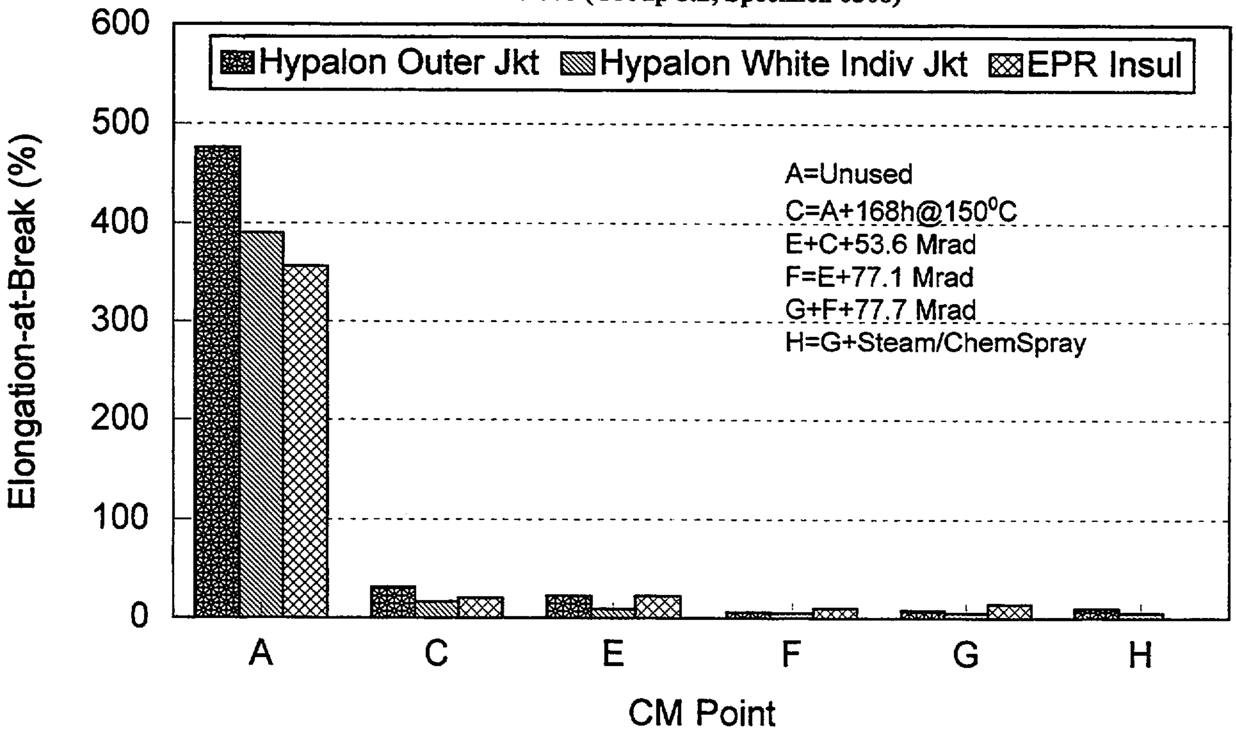


Figure 5.4 Effect of aging and LOCA testing on the EAB of Anaconda cable DNP78AN008 (Group 5.3, Specimen 0515). Specimens artificially aged to 40 Years of qualified life

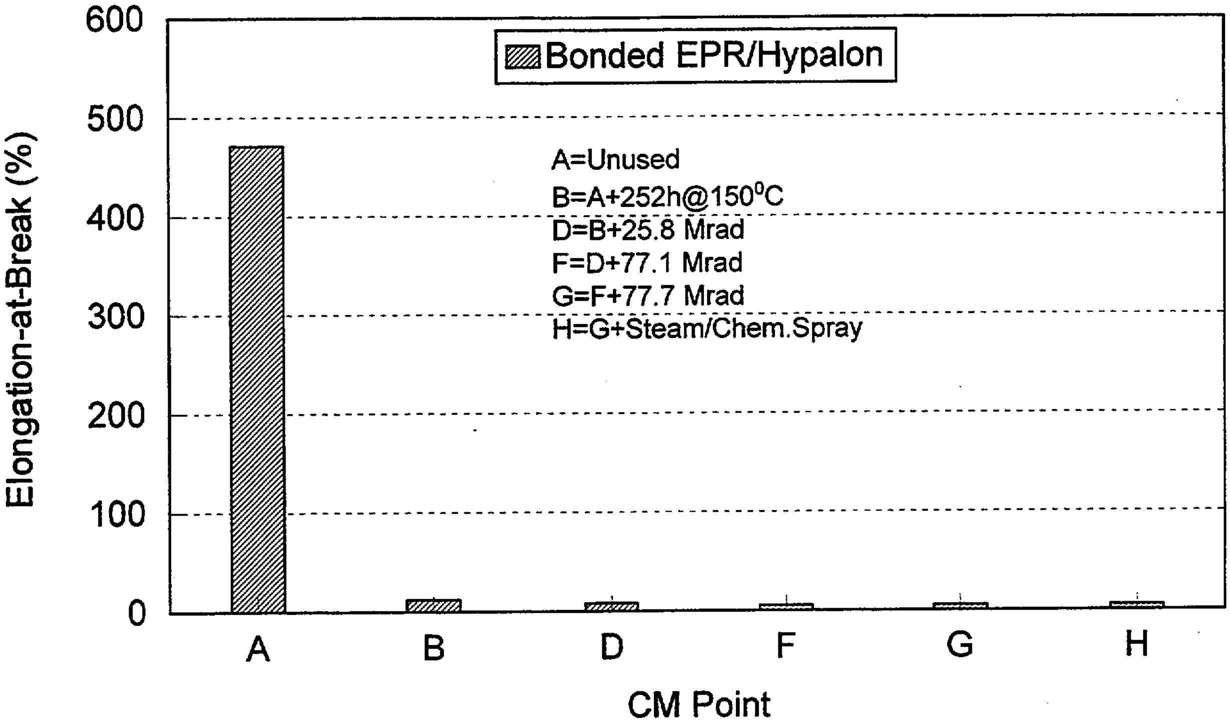


Figure 5.5 Effect of aging and LOCA testing on the EAB of Okonite EPR/Hypalon® Cable LNI81OK020 (Test 5.2, Specimen 0504)

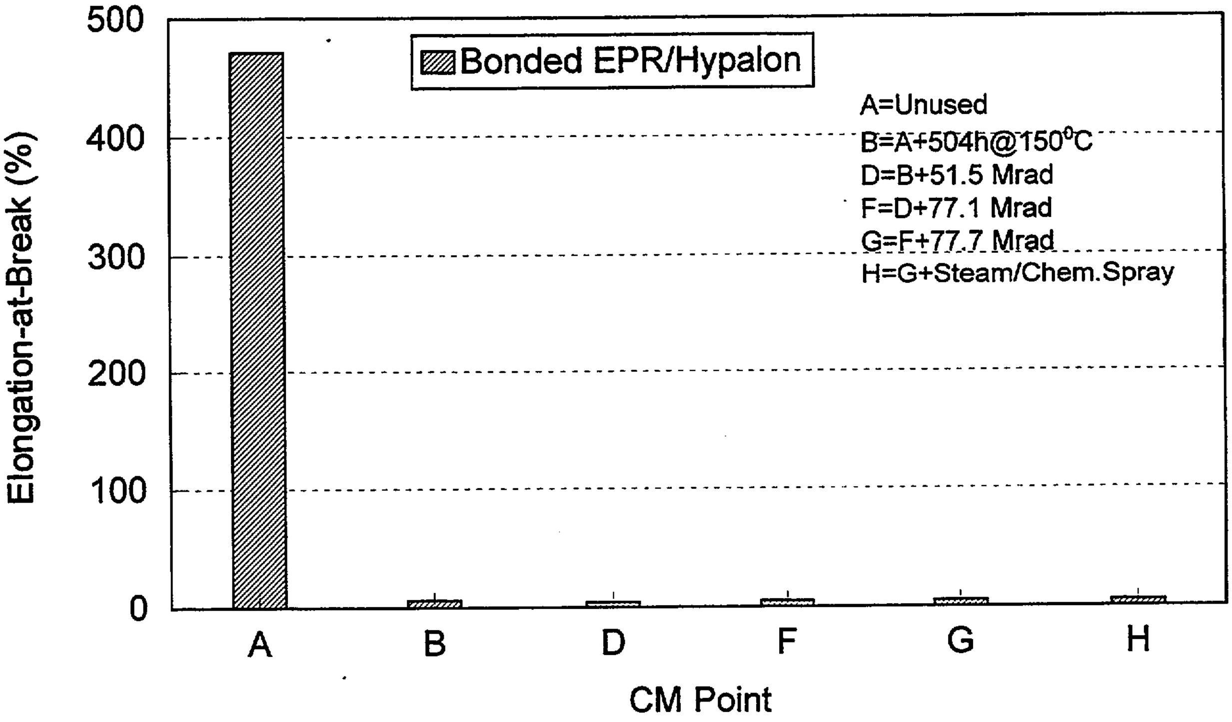


Figure 5.6 Effect of aging and LOCA testing on the EAB of Okonite EPR/Hypalon® Cable LNI81OK020 (Test 5.3, Specimen 0510)

Because of the similar behavior of the two cables, only results from test sequence 4 specimens are described here. Figures 5.7 and 5.8 show EAB data for bonded EPDM/Hypalon® composite specimens that were aged to 20 and 40 years of qualified life, respectively. As expected, the 40-year qualification protocol gave the larger losses in ductility for both the outer jacket and EPDM/Hypalon® duplex specimens. At the 40-year aging time (CM point E), the outer jacket had an EAB of about 320 percent whereas the EPDM/Hypalon® specimens had an EAB of about 170 percent. Although this is a major decrease from the ductility of unaged material, the cable specimens retained a large amount of ductility. Subsequent LOCA radiation and steam/chemical sprays again caused the EAB to fall, but the specimens were still ductile.

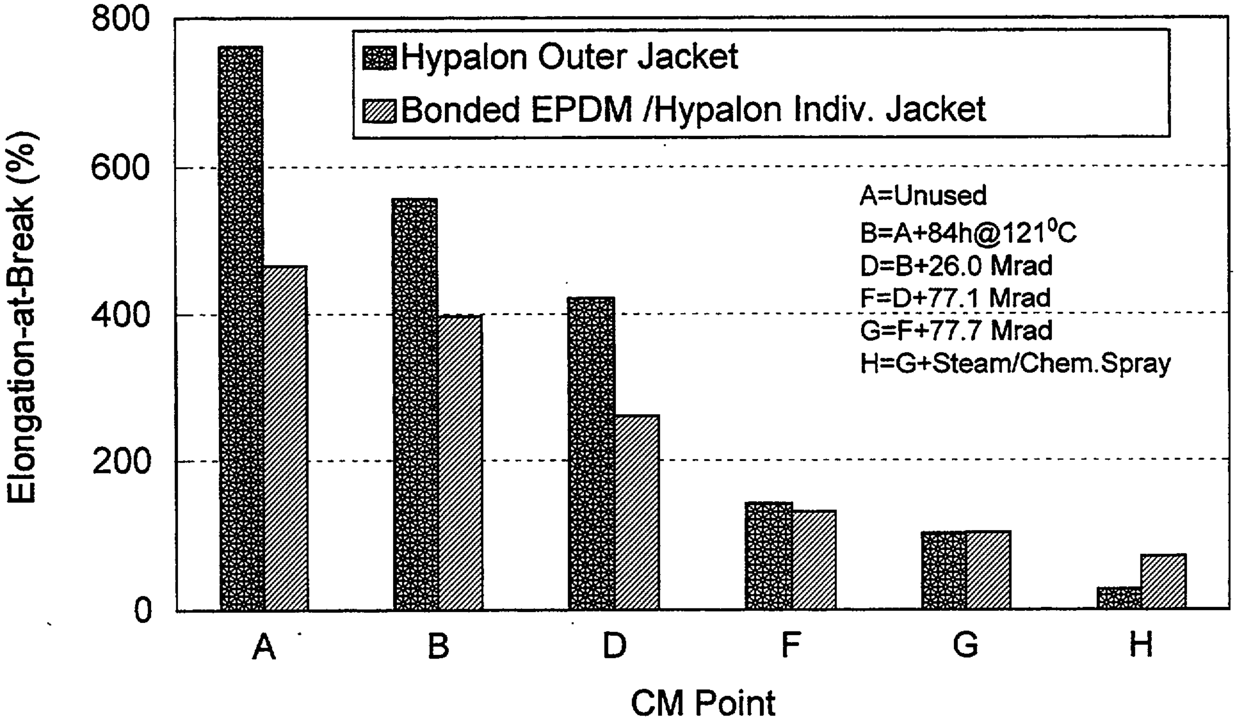


Figure 5.7 Effect of aging and LOCA testing on the EAB of Samuel Moore EPDM/Hypalon® cable PNI82SM008 (Test 4.2, Specimen 0403)

5.2.3 Normalized EAB Results

In order to more clearly illustrate the losses in EAB for the various types of cable as a function of service thermal aging and radiation, the EAB results, from specimens that had been given a range of different aging protocols, were normalized to a single assumed aging temperature of 140°F (60°C). This was achieved by using an Arrhenius analysis and an activation energy that is consistent with the pre-aging parameters used in the original qualification test. It should be remembered that, for the EAB tests, the insulation and jacket specimens were aged together according to a single preselected protocol. The activation energy used to determine the aging time was that for the insulation since it is generally accepted that the insulation is the primary component relied on for cable integrity. However, in the present analysis, to normalize aging times to a common service temperature of 140°F (60°C), the aging times for the Hypalon®

jacket material were calculated using an activation energy of 1.24 eV/molecule (Holzman, 1992), rather than assuming that the jacket had the same activation energy as the insulation. Table 5.1 shows the calculated service aging times at 140°F (60°C) for the different cable components and the associated EAB values.

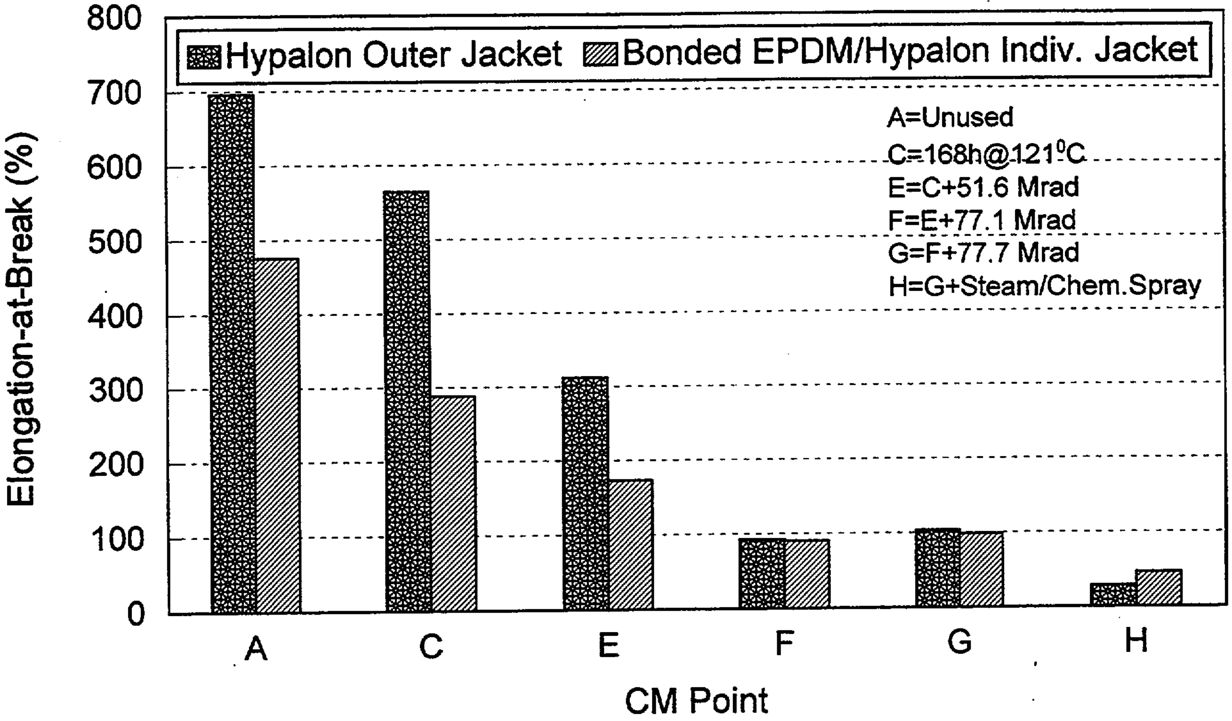


Figure 5.8 Effect of aging and LOCA testing on the EAB of Samuel Moore EPDM/Hypalon® cable PNI82SM008 (Test 4.4, Specimen 0412)

The EAB values for unbonded Hypalon® jackets are given in Figure 5.9. There is a large loss in EAB during the first 20 years of aging, after which the rate of aging degradation shows a decrease. Note that the Hypalon® outer jackets consistently have a higher EAB than the individual jackets, as is documented in the detailed data in Appendix A. It is possible that this is caused by the different shapes of the two types of jacket (the outer jacket specimens are in the form of "dogbones", whereas the individual jackets are in tubular form). Also, the outer jackets have thicker walls than the individual jackets and, therefore, will be less oxidized under the same aging conditions. The results indicate that, after about 60 years of service at 140°F (60°C), the EAB for the jackets will be about 80 to 100 percent.

Figure 5.10 shows the EAB results for EPR insulation from AIW and Anaconda. The curve drawn through the data points shows that during the early part of aging the EAB decreases to an initial plateau and this is followed at longer aging times by a second large drop in EAB. The basic shape of the curve for aging times of 0 to 60 years is similar to that reported in Figure 4.5 for XLPE. The early decreases in EAB for EPR appear to be connected with thermally-induced changes in the insulation by oxidative processes that are not known. It is assumed that the shape of the curve for aging times greater than 60 years is also similar to that reported in Figure 4.5. The second large loss in EAB is probably associated with the depletion of antioxidants, which allows the main polymer structure to be attacked by a different oxidation process. Support for this interpretation can be found in Figure 3.47 of Section 3.7, in Volume 1 of this report, which shows that, for EPR insulation aged in air at 140°F (60°C), the antioxidants are depleted after about 50 years. This is consistent with the large EAB loss at this time, as shown in Figure 5.10.

Figure 5.11shows data for EPR and EPDM-insulated cable with bonded individual Hypalon® jackets. The two Samuel Moore cables show differences in EAB with aging, although the trends are similar. There are no results for Okonite EPR between 0-100 years, but it is likely that the EAB values are similar to those for EPDM. A smooth curve was drawn through all the data points. Based on the curve through the data, it appears that after 60 years of service aging in air at 140°F (60°C) the EAB of bonded EPR and EPDM insulation will have decreased to about 40-50 percent.

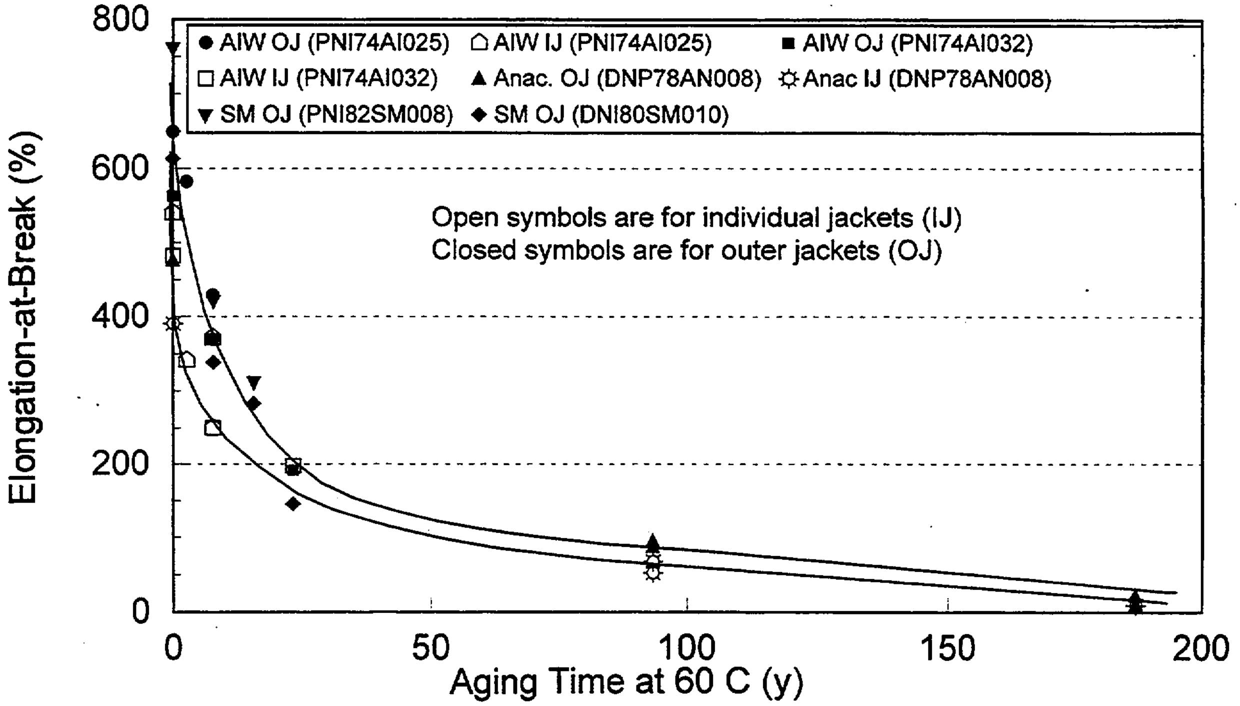


Figure 5.9 Comparison of EAB results for unbonded Hypalon® jacket material from different manufacturers

5.3 Oxidation Induction Time

The only two EPR/Hypalon® cables studied in this effort were manufactured by AIW and were included in test sequences 2 and 6. One of the samples is a 4-conductor cable that consists of black, white, red, and green individual Hypalon® jackets. The other has black, white, and red individual jackets. Both cables have EPR insulation and Hypalon® outer jackets. All OITM results are given in Appendix B of this report.

Figure 5.12 shows typical OITM thermograms for EPR from Group 2.2 that was given an accelerated aging treatment to simulate 24 years of natural aging to match that for the naturally-aged cable in Group 2.3. Note that the flat line in the figure denotes the test temperature profile with time. The thermal aging (CM point B) consisted of oven aging for 28.45 hours at 250°F (121°C). The service radiation dose was 3.25 Mrad (CM point D). There is a large decrease in OITM after thermal aging, but a small increase after radiation.

Table 5.1 EAB for cable materials normalized to a service temperature of 140°F (60°C)

Cable	Group	Material	Aging Protocol	EAB % (Equivalent Aging Time at 60°C in years)			
				Outer Jacket	Individual Jacket	Insulation	Bonded Components
AIW (PNI74AI025)	2.1 (Specimen 0201)	Unbonded EPR/White Hypalon® Individual Jacket, and Hypalon ® Outer Jacket. 4-conductor Cable	0	649 (0)	540 (0)	284 (0)	Not applicable
AIW (PNI74AI027)	2.2 (Specimen 0205)		28.5 hr.@ 121°C + 3.25 Mrad	582 (2.62)	341 (2.62)	224 (1.9)	Not applicable
AIW (PNI74AI028)	2.4 (Specimen 0213)		82.5 hr.@ 121°C + 25.8 Mrad	429 (7.57)	371 (7.57)	196 (5.48)	Not applicable
AIW (PNI74AI031)	2.1 (Specimen 0202)	Unbonded EPR/White Hypalon® Individual Jacket, and Hypalon® Outer Jacket. 3-conductor Cable	0	563 (0)	482 (0)	341 (0)	Not applicable
AIW (PNI74AI032)	2.4 (Specimen 0214)		82.5 hr.@ 121°C + 25.8 Mrad	369 (7.57)	250 (7.57)	224 (5.48)	Not applicable
AIW (PNI74AI035)	6.2 (Specimen 0611)		252 hr.@ 121°C + 38.7 Mrad	191 (23.2)	197 (23.2)	218 (16.8)	Not applicable
Anaconda (DNP78AN008)	5.1 (Specimen 0503)	Unbonded EPR/White Hypalon® Individual Jacket and Hypalon® Outer Jacket	0	476 (0)	390 (0)	356 (0)	Not applicable
	4.3 (Specimen 0407)		84 hr.@ 150°C + 25.7 Mrad	87(93.5)	52 (93.5)	138 (59.9)	Not applicable
	5.2 (Specimen 0508)		84 hr.@ 150°C + 25.7 Mrad	94 (93.5)	67 (93.5)	166 (59.9)	Not applicable
	4.3 (Specimen 0407)		168 hr.@ 150°C + 53.6 Mrad	11(187)	9(187)	13(120)	Not applicable
	5.3 (Specimen 0515)		168 hr.@ 150°C + 53.6 Mrad	22 (187)	9 (187)	22 (120)	Not applicable
Okonite (LNI81OK020)	5.2 (Specimen 0504)	Bonded EPR/Hypalon®	0	Not applicable	Not applicable	Not applicable	471 (0)
	5.2 (Specimen 0504)		252 hr.@ 150°C + 25.8 Mrad	Not applicable	Not applicable	Not applicable	8 (99.4)
	5.3 (Specimen 0510)		504 hr.@ 150°C + 51.5 Mrad	Not applicable	Not applicable	Not applicable	4 (199)
	6.2 (Specimen 0605)		756 hr.@ 150°C + 77.3 Mrad	Not applicable	Not applicable	Not applicable	≤5 (298)
Sam. Moore (PNI82SM008)	4.2 (Specimen 0403)	Bonded EPDM/Red Hypalon® Individual Jacket with Hypalon® Outer Jacket	0	762(0)	Not applicable	Not applicable	467(0)
	4.2 (Specimen 0403)		84 hr.@ 121°C + 26.0 Mrad	422 (7.74)	Not applicable	Not applicable	261(14.8)
	4.4 (Specimen 0412)		168 hr.@ 121°C +51.6 Mrad	312 (15.5)	Not applicable	Not applicable	173(29.6)
Sam. Moore (DNI80SM010)	5.2 (Specimen 0506)	Bonded EPDM/Hypalon® White Individual Jacket with Hypalon® Outer Jacket	0	613 (0)	Not applicable	Not applicable	418 (0)
	5.2 (Specimen 0506)		84 hr.@ 121°C +26.0 Mrad	338 (7.74)	Not applicable	Not applicable	147 (14.8)
	5.3 (Specimen 0513)		168 @ 121°C + 51.5 Mrad	283 (15.5)	Not applicable	Not applicable	94 (29.6)
	6.2 (Specimen 0608)		252 hr.@ 121°C + 77.3 Mrad	145 (23.2)	Not applicable	Not applicable	68 (44.4)

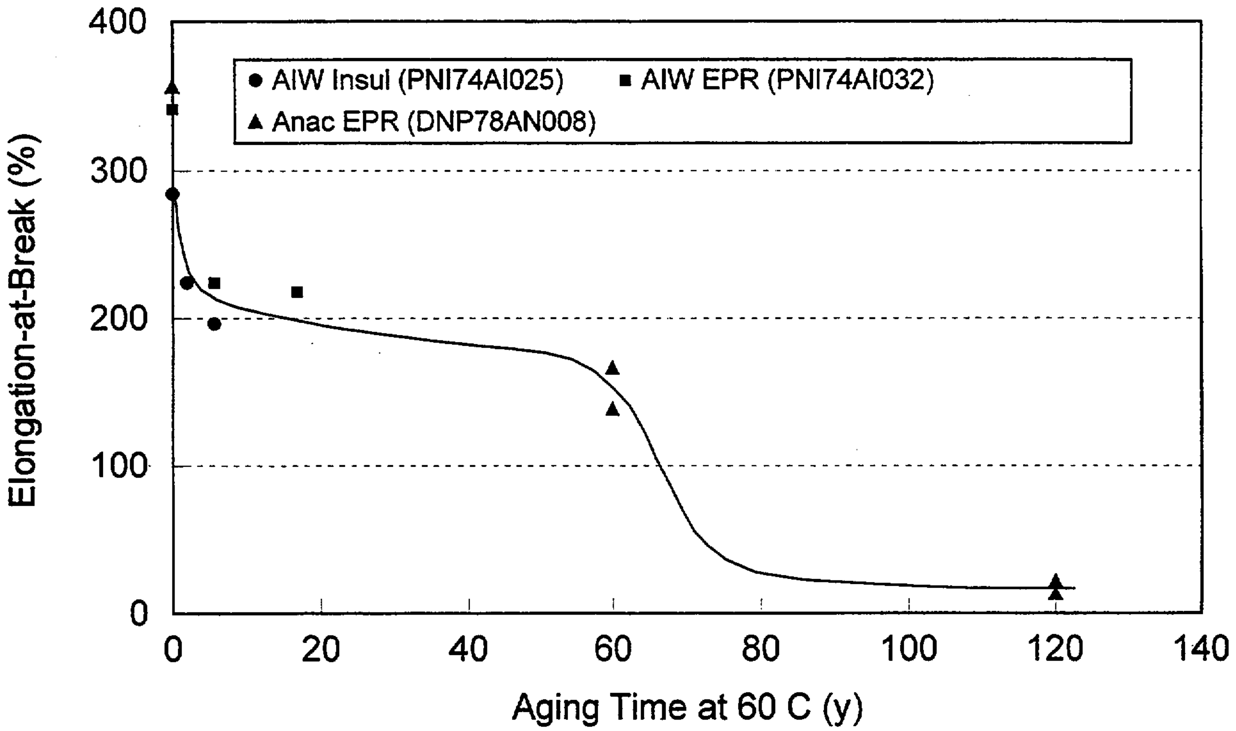


Figure 5.10 Comparison of EAB results for unbonded EPR insulation from different manufacturers

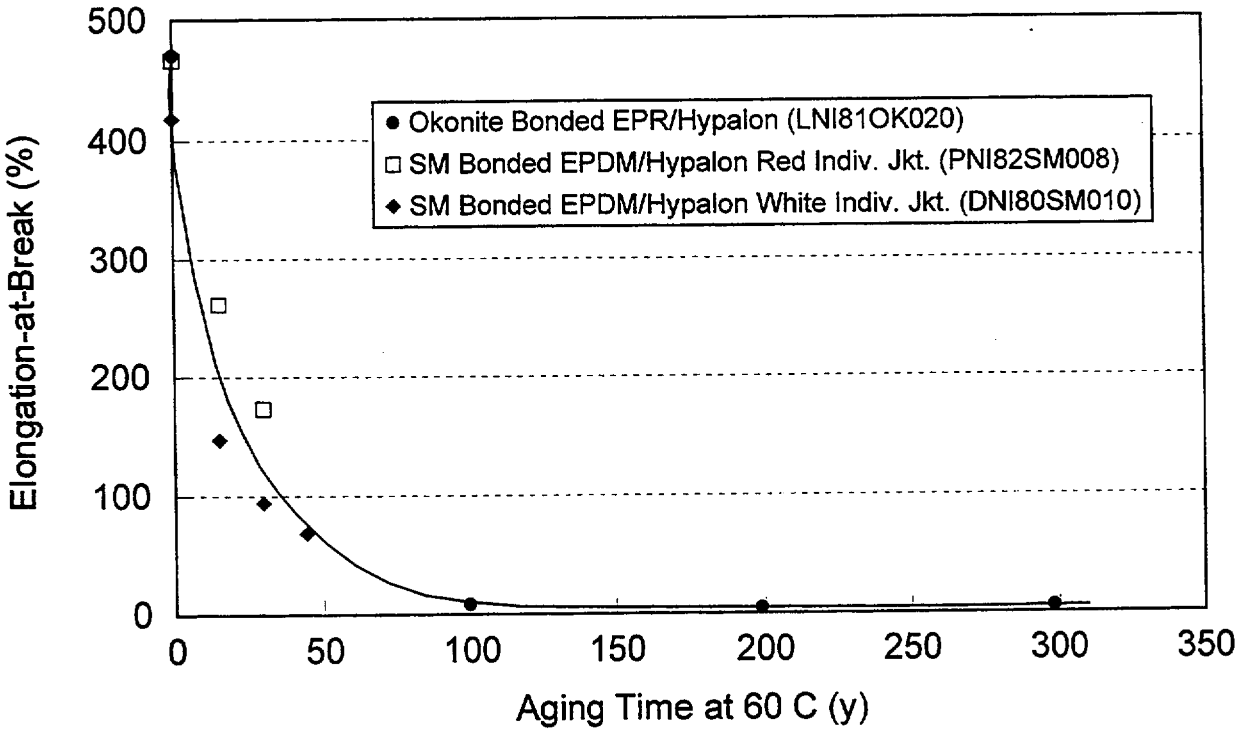


Figure 5.11 Comparison of EAB results for bonded EPR and EPDM insulation from different manufacturers.

The accelerated service aging treatment for the Group 2.4 specimens simulated one-half of the manufacturers 40-year qualification test protocol. It involved a thermal aging step of 82.45 hours at 250°F (121°C) and a radiation dose of 25.5 Mrad (CM points C and E, respectively). LOCA accident radiation doses of 78.6 and 76.8 Mrad were given at CM points F and G, respectively. For the Hypalon® outer jacket, the OITM decreases consistently for each successive treatment step (Figure 5.13). Note that the results in Figure 5.13 are for the four-conductor cable. The three-conductor cable did not display a classical OITM thermogram with the flat section that indicates protection by the antioxidants. This may be seen in Figure 5.14, which compares the thermograms for the four and three conductor cable jackets. Note the absence of the flat region in the curve for the three-conductor, which prevents the OITM from being determined.

Figure 5.15 summarizes the changes in OITM for the insulation and outer jacket materials for the four-conductor cable that had been pre-aged to one-half of the manufacturer's 40-year qualified life. The OITM shows consistent decreases for each successive service aging step (CM points C and E) and for the LOCA radiation test protocols (CM points F, and G).

Figure 5.16 compares the results for artificially-aged and naturally-aged EPR insulation that had received 24 years of aging. Comparing the baseline condition of specimen 0207 (CM point A) with the artificially aged specimen 0203 (CM point D), it is seen that there is reasonable agreement in OITM. The results indicate that OITM measurements on artificially aged EPR are reasonable approximations for those on naturally aged material.

Comparisons between the OITM for artificially- and naturally-aged Hypalon® outer jackets could not be made because the naturally-aged jackets did not display a classical thermogram with the flat oxidation-resistant region.

The relationships between the OITM for EPR/Hypalon® cable and elongation-at-break, as well as service aging time were explored using results from this study. The thermal aging treatments given to the cable specimens were normalized to a common service temperature of 140°F (60°C) using the Arrhenius equation. Table 5.2 summarizes the relevant data. As shown, a consistent decrease in OITM is observed as aging increases.

Figure 5.17 is a correlation between the OITM for EPR insulation and the elongation-at-break. Although the data are limited, because of the small number of predetermined aging protocols used in this study, both the three- and four conductor cables show that the elongation-at-break continuously decreases as the OITM decreases. There is a significant difference between the two cables with the three-conductor cable having the highest ductility for a given OITM. However, a good correlation between OITM and EAB is shown for both types of cable insulation.

Figure 5.18 shows the correlation between the OITM and the service aging time. For service aging to the equivalent of about 17 years at 140°F (60°C) the OITM decreases to about 3 min. The OITM tends to zero when the antioxidants have been depleted. Extrapolating the curve in Figure 5.18 indicates that this would occur at a service time in excess of 20 years . Unfortunately, the precise time cannot be determined since the curve is asymptotic. However, this time is consistent with the value that may be calculated using the EPR OITM equation taken from Section 3.7 of Volume 1 of this report. The equation is:

$$\ln t(\mathrm{min}) = 28.38/RT(^{\circ}K) - 26.67 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

in which t is the time at which the antioxidants have become depleted during oxidation in oxygen, and R is the gas constant.

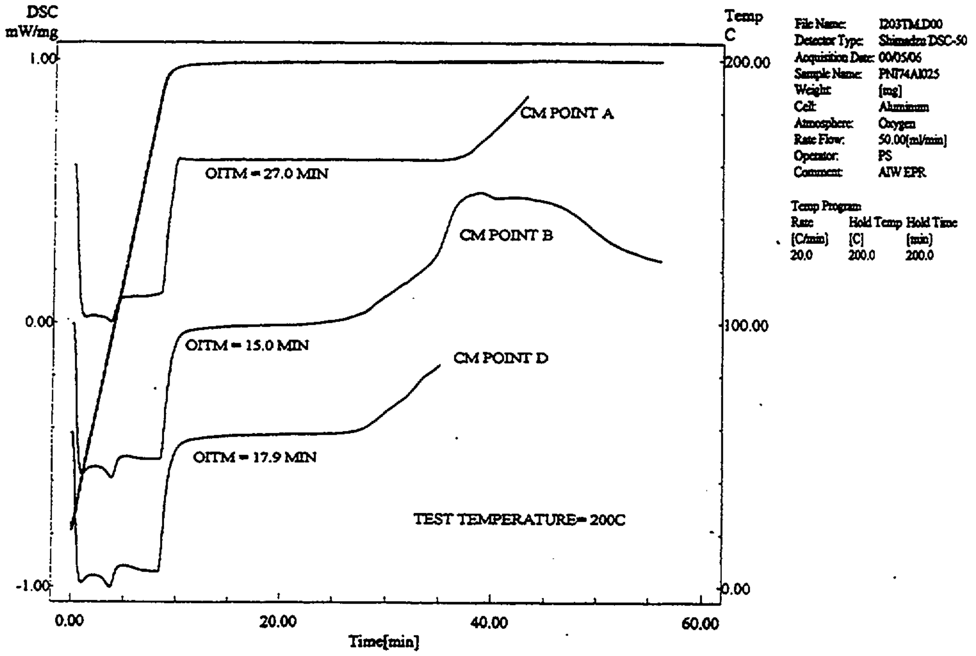


Figure 5.12 OITM Thermograms at 392°F (200°C) for AIW EPR insulation PNI74AI026 (Group 2.2, Specimen 0203)

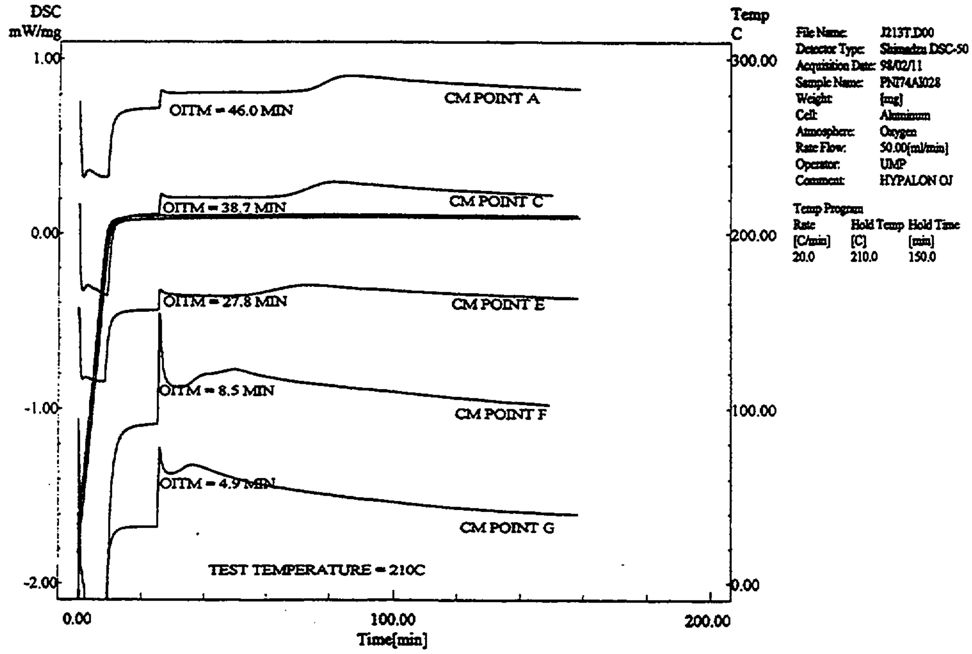


Figure 5.13 OITM Thermograms at 410°F (210°C) for AIW Hypalon® outer jackets PNI74AI028 (Group 2.4, Specimen 0213)

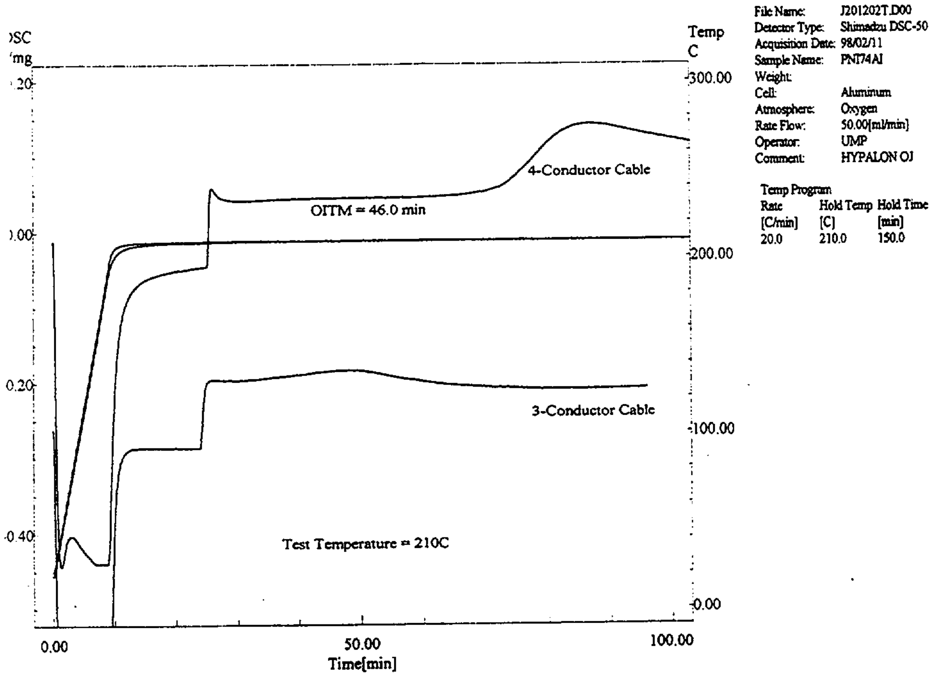


Figure 5.14 Comparison of Thermograms for Hypalon® outer jackets for unaged four- and three-conductor from AIW cable

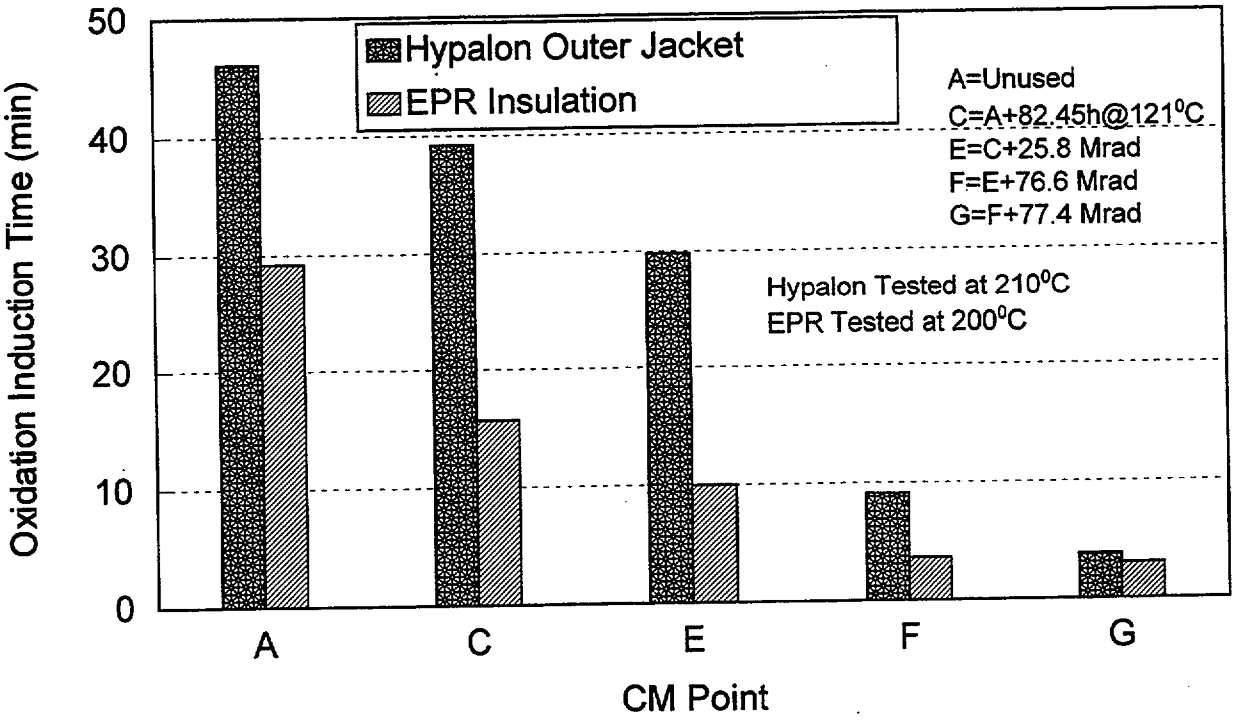


Figure 5.15 OITM for AIW four-conductor cable PNI74AI028 (Group 2.4, Specimen 0213) as a function of CM point

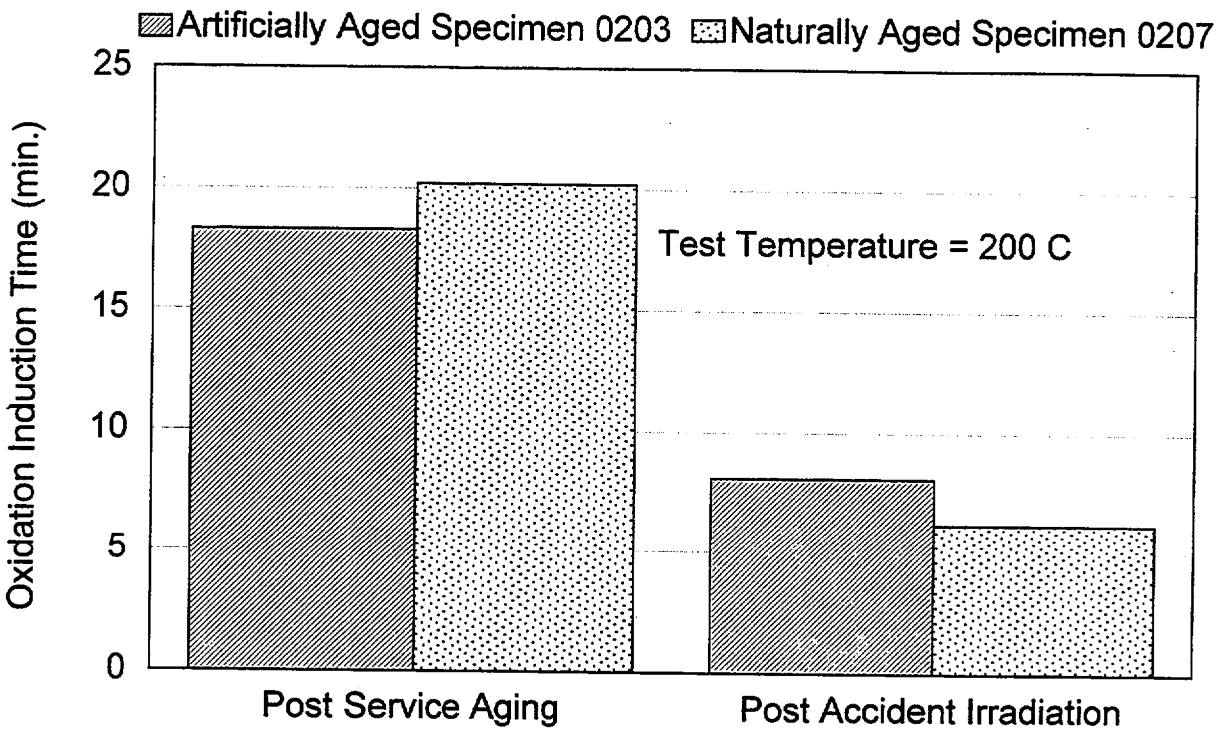


Figure 5.16 Comparison of OITM for artificially-aged and naturally-aged EPR Insulation from AIW cable after 24-Years of service aging

For a service aging temperature of 140°F (60°C), the time for the depletion of antioxidants is calculated to be 21 years. No data were obtained for oxidation times in air but, since the oxidation times in air for EPR are double those for oxygen, as was shown for XLPE (see Section 3.7, Vol. 1 of this report) then the time to deplete all of the antioxidants should be approximately 42 years. The trend of the curve in Figure 5.18 appears to be consistent with this time.

Figures 5.19 and 5.20 show correlations between OITM and EAB and service aging time for Hypalon® outer jackets. Again, the data are limited but there is a clear relationship between the variables in each figure. This indicates that the OITM is a useful parameter to predict the EAB for Hypalon®.

5.4 Oxidation Induction Temperature

OITP measurements were made on cable specimens manufactured by AIW, along with a small number of Anaconda specimens from test sequences 4 and 5 since they had been pre-aged to simulate longer aging times. Measurements were made on specimens that had received both accelerated thermal and radiation treatments.

Table 5.2 Oxidation induction time for AIW cable PNI74AI028(Group 2.4, Specimens 0213 and 0214) as a function of simulated service aging at 140°F (60°C)

Group	Cable Sample	Aging Protocol	Equivalent Aging Time at 140°F (60°C), (yrs)		Oxidation Induction Time (min)(a)	
			Hypalon® Outer Jacket	EPR Insulation	Hypalon® Outer Jacket	EPR Insulation
2.4 (Specimen 0213A)	PNI74AI028 (4 conductor)	None	0	0	46.1	29.2
2.4 (Specimen 0214A)	PNI74AI028 (3 conductor)	None	0	0	(b)	25.3
2.2 (Specimen 0203D)	PNI74AI026 (4 conductor)	28.45 hr.@121°C + 3.25 Mrad	2.62	1.9	42.2	18.3
2.4 (Specimen 0213E)	PNI74AI028 (4 conductor)	82.5 hr.@121°C +25.8 Mrad	7.57	5.48	29.8	10.0
2.4 (Specimen 0214E)	PNI74AI028 (3 conductor)	82.5 hr.@121°C +25.8 Mrad	7.57	5.48	(b)	8.2
6.2 (Specimen 0611E)	PNI74AI035 (3 conductor)	252 hr.@121°C +38.7 Mrad	23.2	16.8	(b)	2.9

(a) Hypalon® tested at 410°F (210°C) and EPR at 392°F (200°C)
(b) Non-classical thermogram, OITM not determinable

Figures 5.21 and 5.22 show thermograms for AIW EPR insulation (Group 2.4, Specimen 0214)). Note that the straight lines in the figures denote the test temperature profile with time. The OITP values for the service aging protocols (CM points C and E in Figure 5.21) are one-half of that used in the manufactures's 40-year qualification tests, viz. 82.5 hrs. at 250°F (121°C) and 25.5 Mrad of gamma radiation, respectively. A decrease in the OITP is noted after the thermal aging step, but the radiation dose did not cause any significant additional change in the OITP. Results for the LOCA tested specimens in Figure 5.22, show that the OITP decreases after CM points F and G in which the specimens received about 78 Mrad of radiation, and for the steam/chemical spray (CM point H). The Hypalon® outer jacket results, given in Figures 5.23 and 5.24, for Group 2.4, Specimen 0214, show that for each CM point the OITP decreases consistently.

Figure 5.25 summarizes all of the OITP data for Group 2.4, Specimen 0213, and includes results for the EPR insulation, Hypalon® outer jackets, and white individual jackets. Note the very close agreement in the OITP values for the black outer and black individual jackets for the service aging protocols. This indicates that the chemical composition of the two components is the same. The OITP values for the white individual jackets are very similar to those for the other colored individual jackets (see Appendix C) and are significantly higher than those for the black jackets.

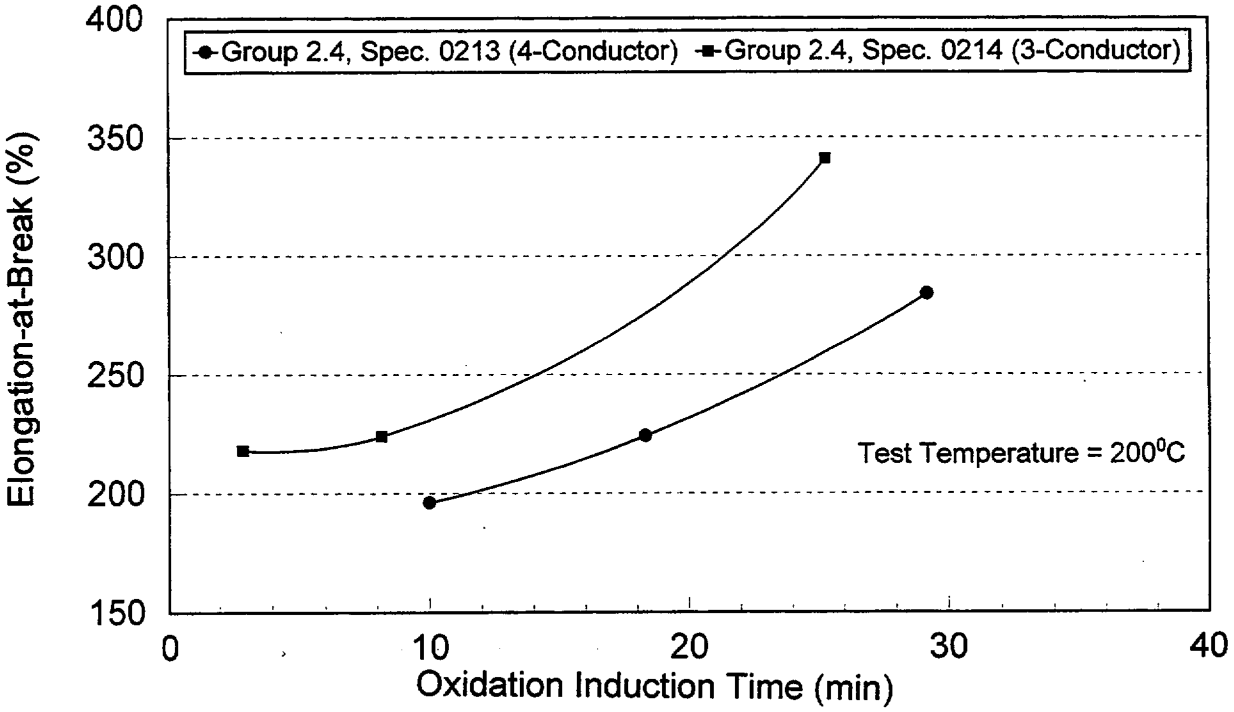


Figure 5.17 Correlation between OITM and EAB for EPR insulation from AIW cable PNI74AI028 (Group 2.4, Specimens 0213 and 0214)

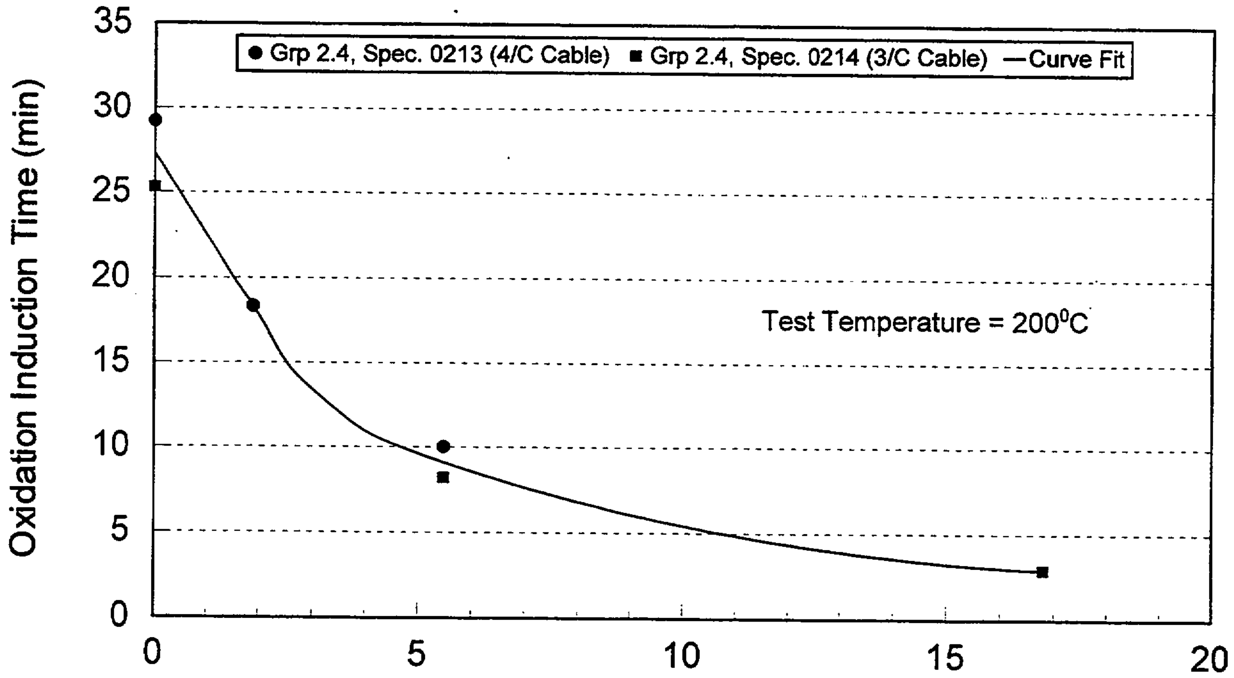


Figure 5.18 Correlation between OITM and service aging time for EPR insulation from AIW cable PNI74AI028 (Group 2.4, Specimens 0213 and 0214)

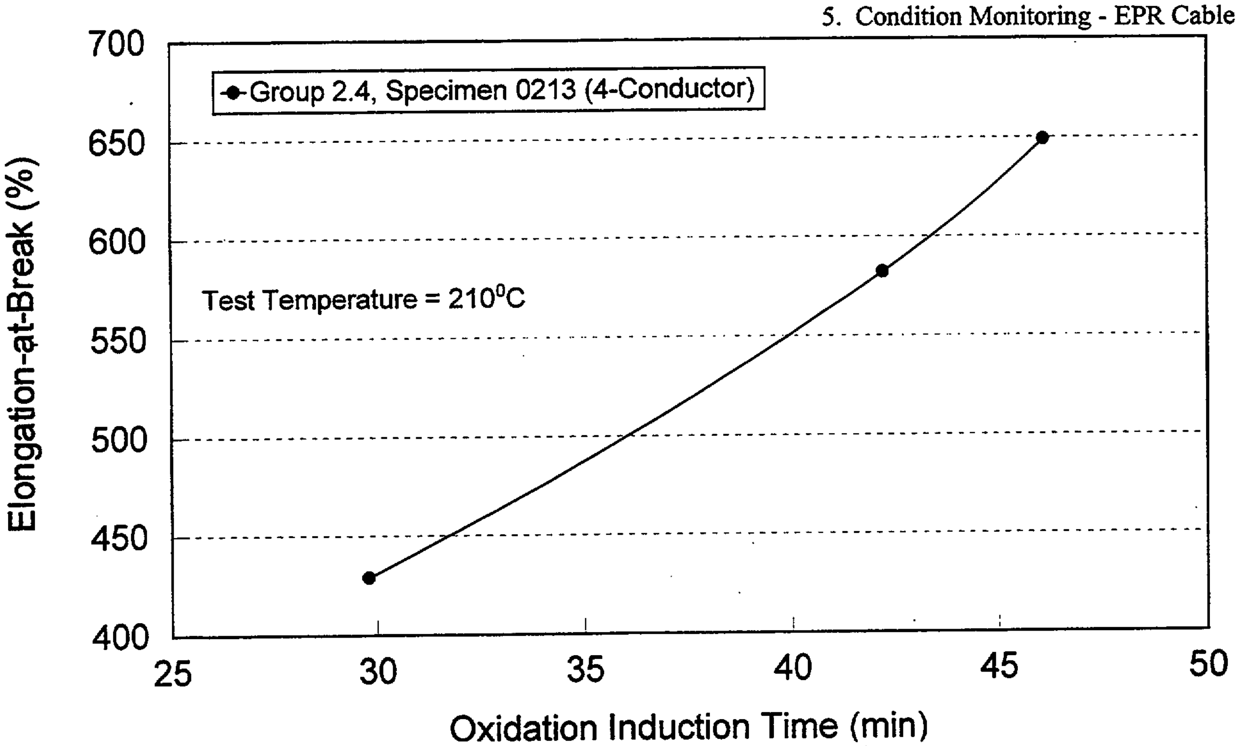


Figure 5.19 Correlation between OITM and EAB for Hypalon® outer jackets from AIW cable PNI74AI028 (Group 2.4, Specimen 0213)

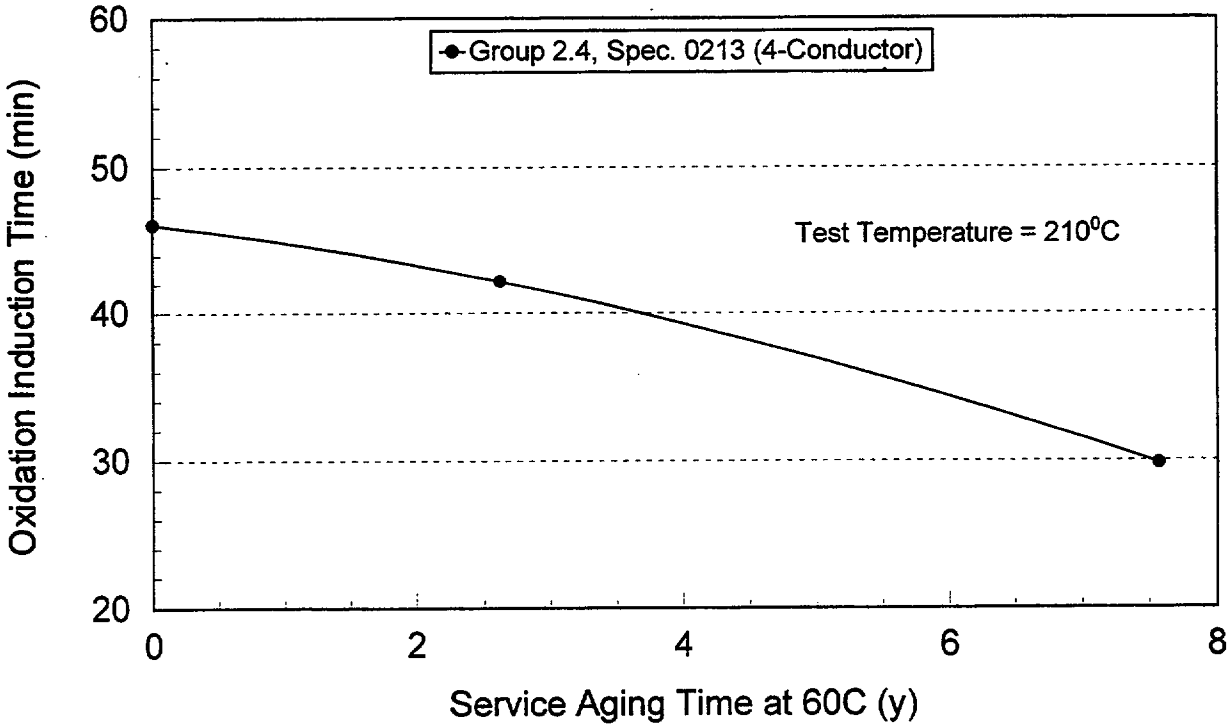


Figure 5.20 Correlation between OITM and service aging time for Hypalon® outer jackets from AIW cable PNI74AI028 (Group 2.4, Specimens 0213)

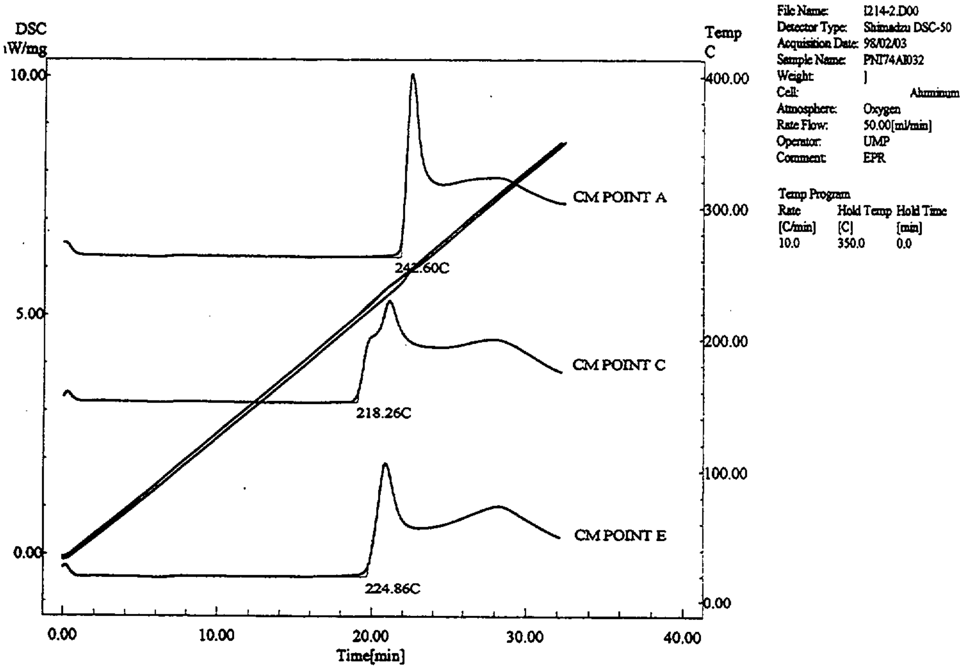


Figure 5.21 OITP for AIW EPR (PNI74AI032) as a function of service testing protocols

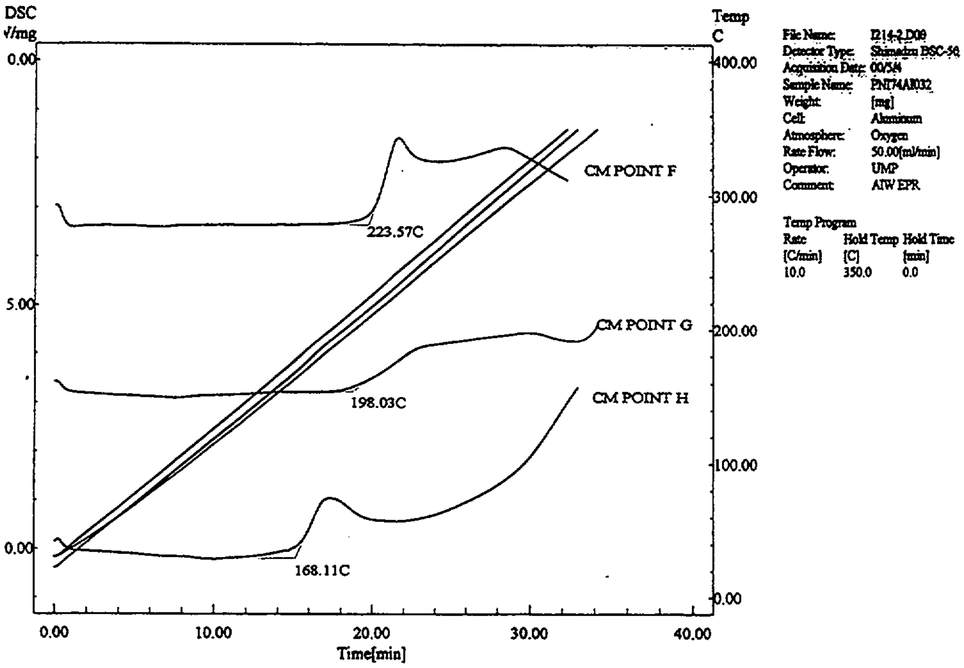
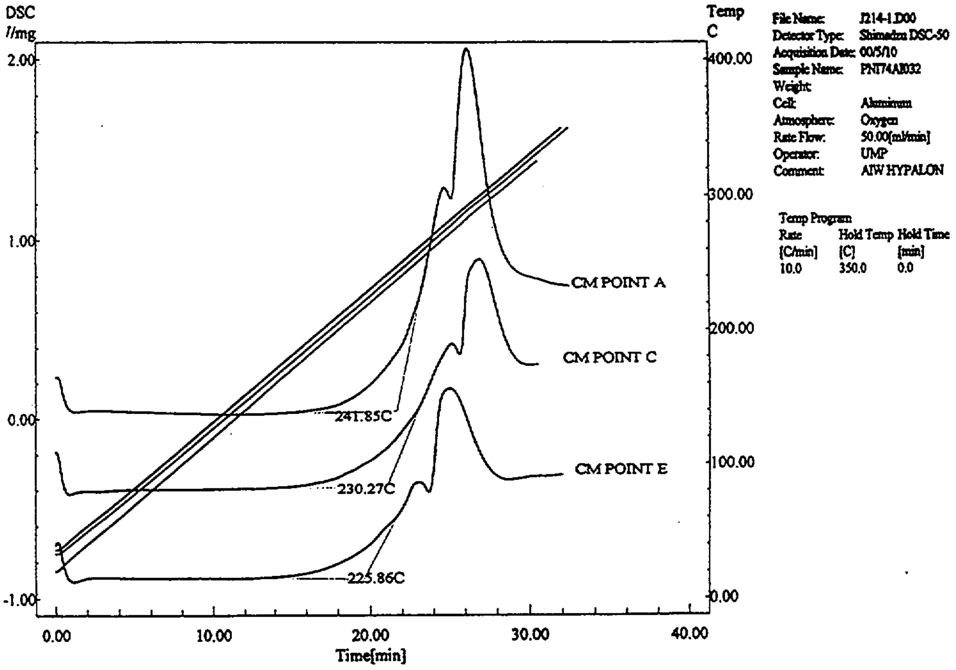


Figure 5.22 OITP for AIW EPR (PNI74AI032) as a function of LOCA testing protocols

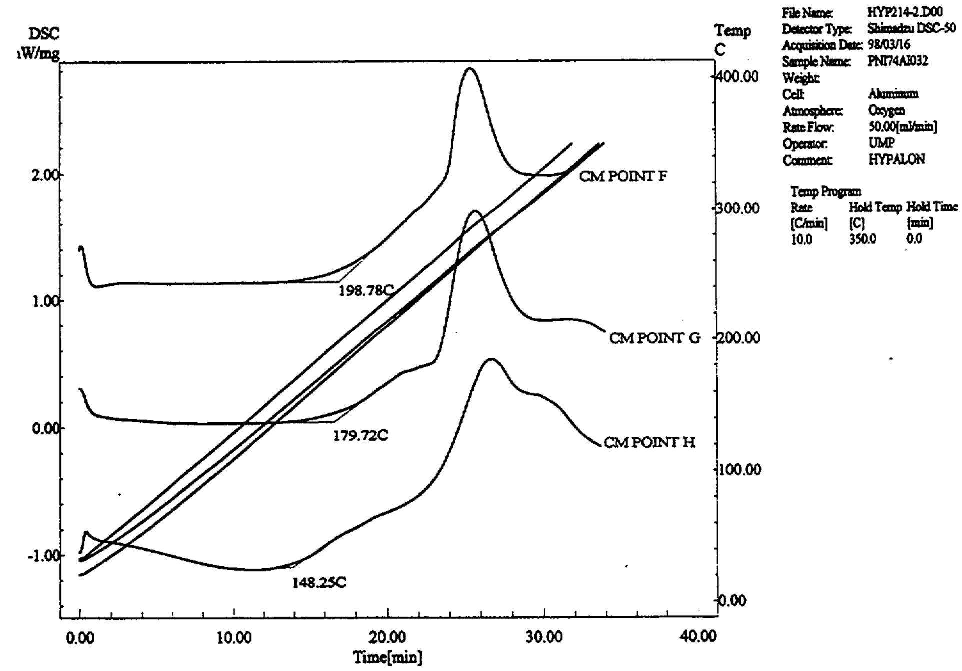


File Name: J214-1.D00
Detector Type: Shimadzu DSC-50
Acquisition Date: 00/5/10
Sample Name: PNI74AI032
Weight:
Cell: Aluminum
Atmosphere: Oxygen
Rate Flow: 50.00[ml/min]
Operator: UMP
Comment: AIW HYPALON

Temp Program

Rate [C/min]	Hold Temp [C]	Hold Time [min]
10.0	350.0	0.0

Figure 5.23 OITP for AIW Hypalon® (PNI74AI032) as a function of service testing protocols



File Name: HYP214-2.D00
Detector Type: Shimadzu DSC-50
Acquisition Date: 98/03/16
Sample Name: PNI74AI032
Weight:
Cell: Aluminum
Atmosphere: Oxygen
Rate Flow: 50.00[ml/min]
Operator: UMP
Comment: HYPALON

Temp Program

Rate [C/min]	Hold Temp [C]	Hold Time [min]
10.0	350.0	0.0

Figure 5.24 OITP for AIW Hypalon® (PNI74AI032) as a function of LOCA testing protocols

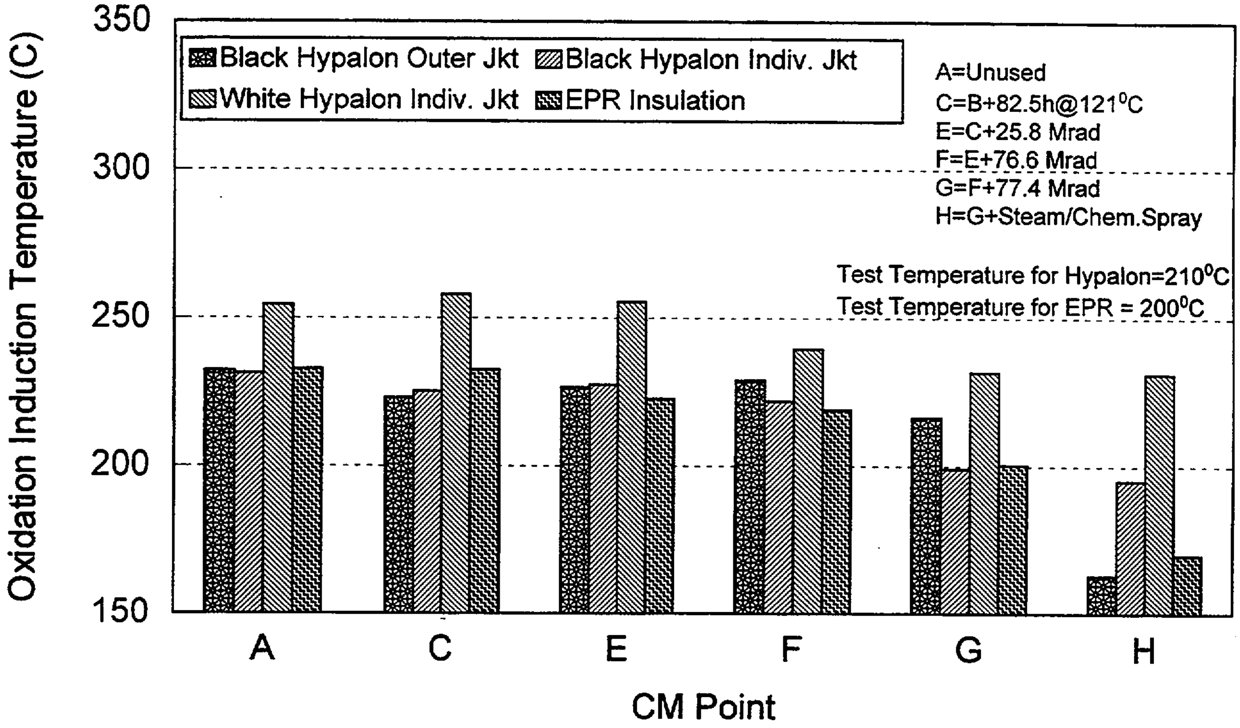


Figure 5.25 OITP for AIW EPR/Hypalon® cable (Group 2.4, Specimen 0213) as a function of CM point

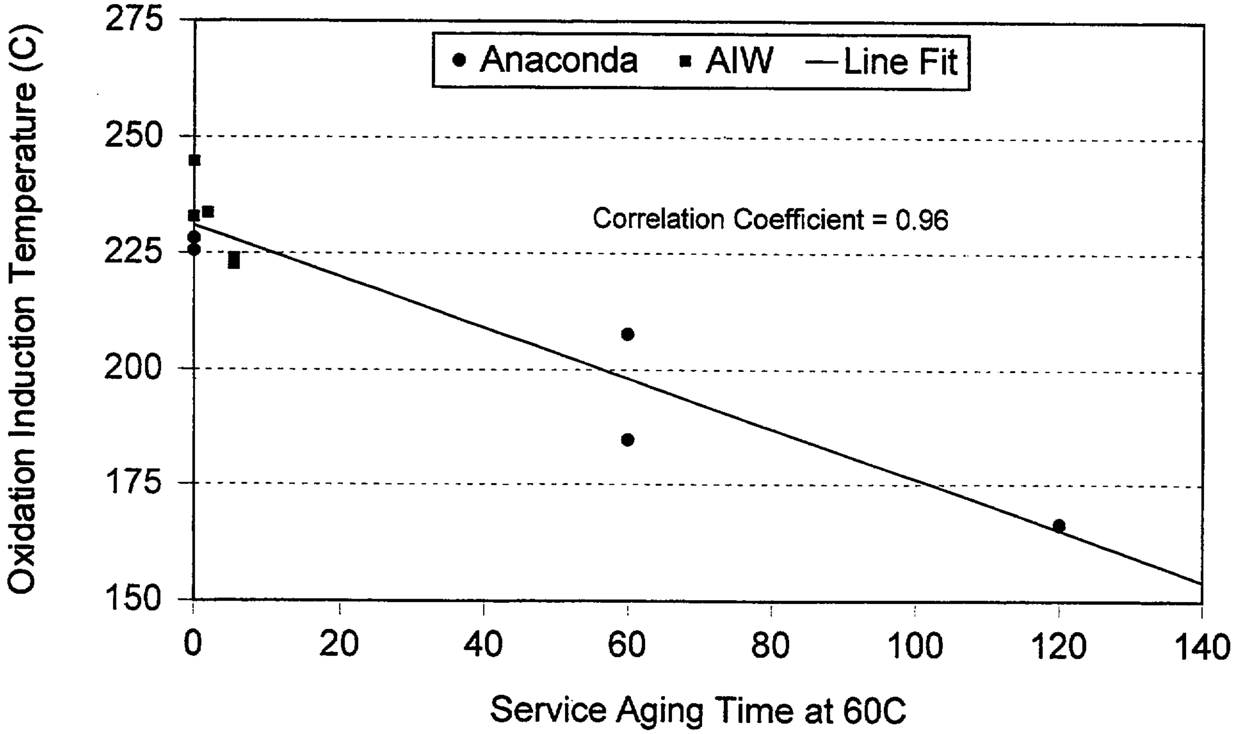


Figure 5.26 OITP for EPR insulation as a function of service aging time at 140°F (60°C)

Table 5.3 Oxidation induction temperature results for EPR insulation as a function of simulated service aging at 140°F (60°C)

Group	Manufacturer	Aging Protocol	Equivalent Aging Time at 140°F (60°C) (years)	Oxidation Induction Temperature (°C)
2.4 (Specimen 0213A)	AIW (PNI74AI028)	None	0	234.9 230.6 Avg = 232.7
2.4 (Specimen 0214A)	AIW (PNI74AI032)	None	0	242.6 246.7 Avg = 244.7
2.2 (Specimen 0205D)	AIW (PNI74AI027)	28.45 hr.@ 121°C + 3.25 Mrad	1.9	234.2 233.4 Avg = 233.6
2.4 (Specimen 0213E)	AIW (PNI74AI028)	82.5 hr.@ 121°C + 25.8 Mrad	5.5	223.9 221.2 Avg = 222.6
2.4 (Specimen 0214E)	AIW (PNI74AI032)	82.5 hr.@ 121°C + 25.8 Mrad	5.5	224.9 223.0 Avg = 223.9
4.3 (Specimen 0407A)	Anaconda (DNP78AN008)	None	0	225.0 226.0 Avg = 225.5
5.1 (Specimen 0503A)	As above	None	0	228.8 227.5 Avg = 228.1
4.3 (Specimen 0407D)	As above	84 hr.@ 150°C + 25.7 Mrad	60	186.6 183.0 Avg = 184.8
5.2 (Specimen 0508D)	As above	As above	60	208.8 206.4 Avg = 207.6
4.3 (Specimen 0407E)	As above	168 hr.@ 150°C + 53.6 Mrad	120	166.1 166.4 Avg = 166.2
5.3 (Specimen 0515E)	As above	As above	120	166.9 166.0 Avg = 166.4

Table 5.4 Oxidation Induction Temperature results for Hypalon® jackets as a function of simulated service aging at 140°F (60°C)

Group	Material	Aging Protocol	Equivalent Aging Time at 140°F (60°C) (years)	Oxidation Induction Temperature (°C)		
				Black Outer Jacket	Black Indiv. Jacket	Avg. for Colored Jackets
2.4 (Specimen 0213A)	AIW (PNI74AI028)	None	0	231.9 232.6 Avg = 232.2	231.7 230.8 Avg = 231.3	256.9
2.4 (Specimen 0214A)	AIW (PNI74AI032)	None	0	233.1 235.0 Avg = 234.0	240.8 241.9 Avg = 241.3	259.4
2.2 (Specimen 0205D)	AIW (PNI74AI027)	28.45 hr.@ 121°C + 3.25 Mrad	2.6	229.8 227.8 Avg = 228.8	228.6 227.2 Avg = 227.9	254.9
2.4 (Specimen 0213E)	AIW (PNI74AI028)	82.5 hr.@ 121°C + 25.8 Mrad	7.6	227.7 225.3 Avg = 226.5	227.3 227.5 Avg = 227.4	253.9
2.4 (Specimen 0214E)	AIW (PNI74AI032)	82.5 hr.@ 121°C + 25.8 Mrad	7.6	225.9 221.6 Avg = 223.8	228.8 228.0 Avg = 228.4	250.2

Table 5.3 is a tabulation of OITP results for AIW EPR insulation from test sequence 2 and Anaconda EPR insulation from test sequences 4 and 5. The service aging protocols are normalized to a service temperature of 140°F (60°C) using the Arrhenius equation. Figure 5.26 shows that there is a linear correlation between the OITP and service time. A linear relationship also exists between the OITP for EPR and the EAB, as shown in Figure 5.27.

The OITP values for the AIW outer and individual jackets are given in Table 5.4 and Figure 5.28 as a function of the service aging time. The black outer and individual jackets show similar behavior. The OITP values for the colored (non-black) individual jackets were averaged because of their similarity. It is noticed that the OITP values for the colored jackets are about 35°F (20°C) higher than those for black jackets. This shows that the colored jackets are more resistant to oxidation than the black jackets. Figure 5.29 shows that there is a correlation between the EAB and OITP for the black jackets. Therefore, in principle, the OITP may be used to estimate the residual EAB in aged black jackets. There also appears to be a correlation between EAB and OITP for the colored individual jackets, as shown in Figure 5.30 despite considerable scatter in the data.

In summary, a reasonable correlation was found between OITP and EAB, therefore, OITP is judged to be an acceptable method for estimating EAB for EPR/Hypalon® cable materials.

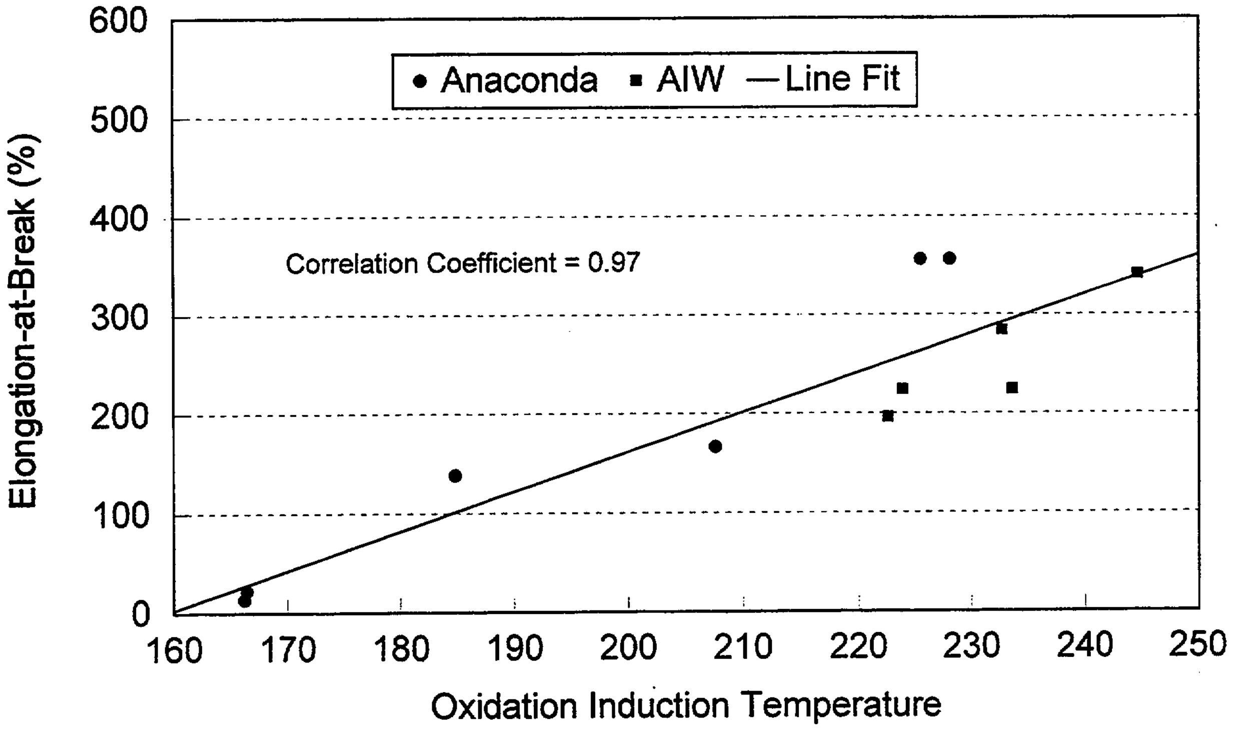


Figure 5.27 Correlation between EAB and OITP for EPR insulation from different manufacturers

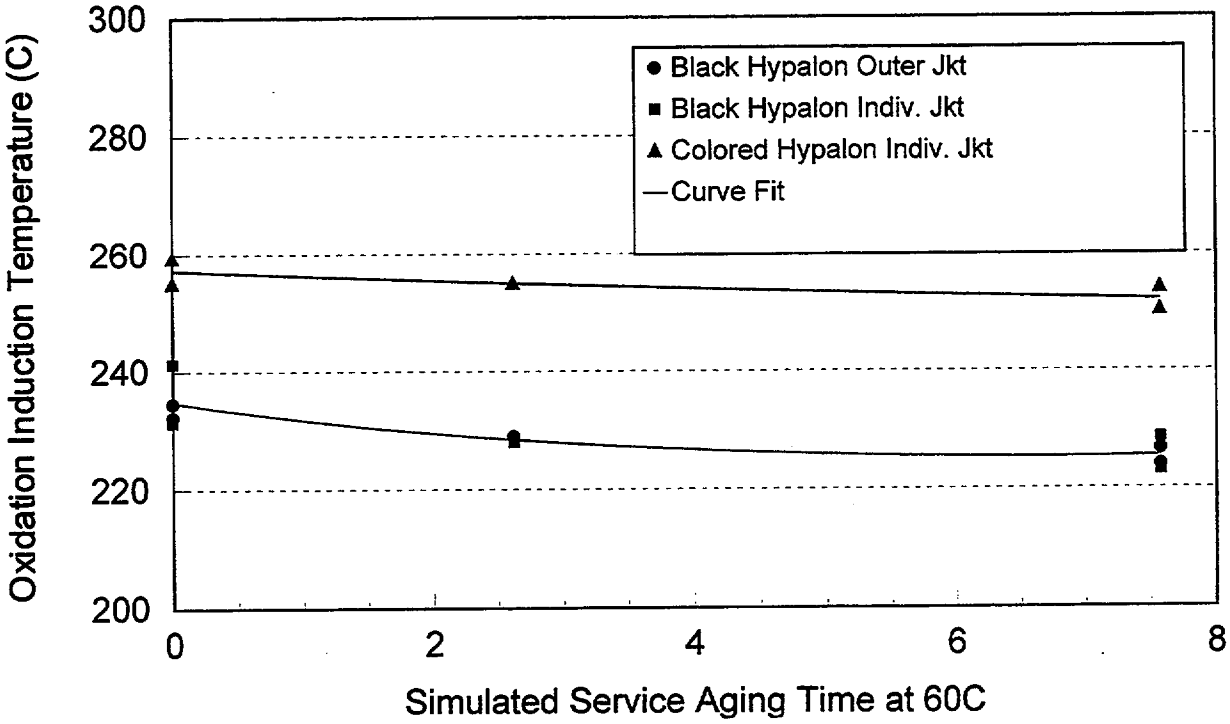


Figure 5.28 OITP for AIW Hypalon® outer and individual jackets as a function of service aging time at 140°F (60°C)

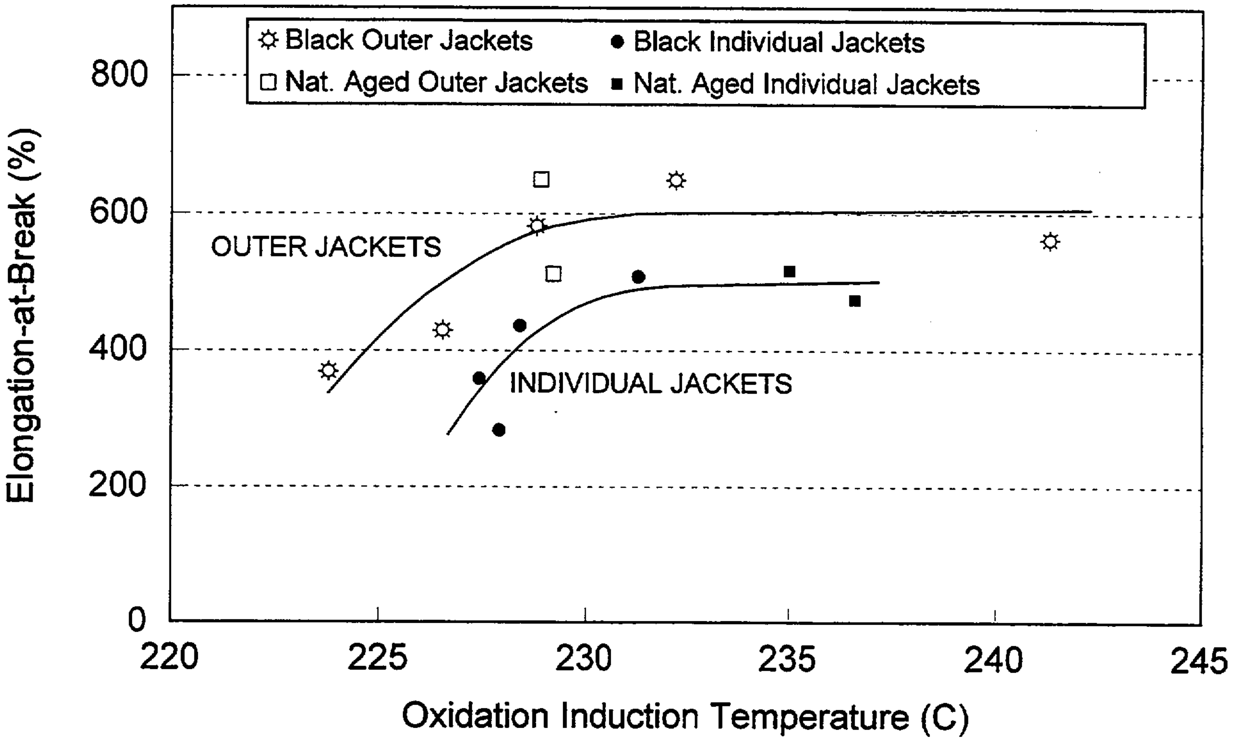


Figure 5.29 Correlation between EAB and OITP for AIW Hypalon® outer and black individual jackets as a function of OITP

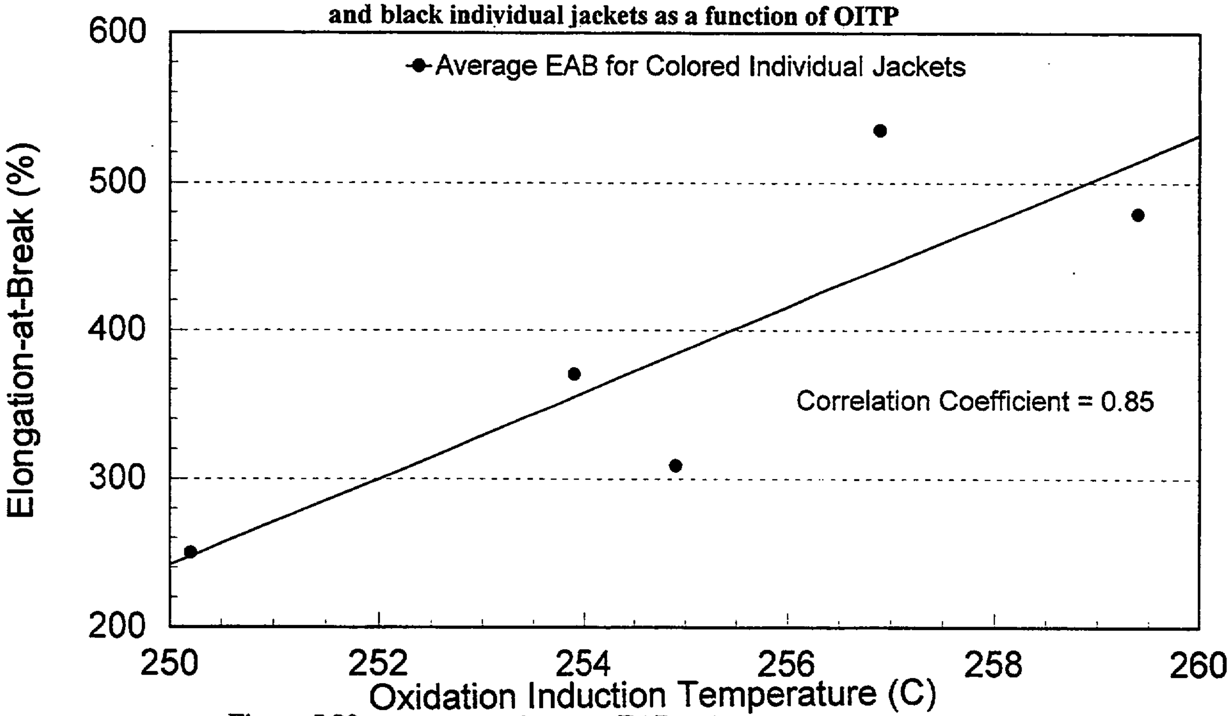


Figure 5.30 Correlation between EAB and OITP for AIW colored Hypalon® individual jackets as a function of OITP

5.5 Fourier Transform Infrared Spectroscopy

The technique used for the study of AIW EPR/Hypalon® cables is similar to that used for the XLPE/Neoprene® cables (see Sections 3.5 and 4.5 of this report). Appendix D is a tabulation of FTIR data obtained in the current program. Figure 5.31 shows FTIR spectra for EPR insulation that had received an accelerated aging protocol that simulates the aging that was received by the naturally aged cable in Group 2.3. This involved thermal aging of 28.45 hrs. at 250°F (121°C), CM point B, plus an irradiation of 3.25 Mrad, CM point D. Subsequent LOCA irradiations of 78.7 and 77.0 Mrad are given at CM points F and G, followed by steam/chemical spraying at CM point H. The EPR results, together with data for Hypalon® outer and white individual jackets, are plotted in Figure 5.32. They show that the service aging results in a small increase in transmittance for all three materials. After the second LOCA irradiation dose, the transmittance again increases slightly. When the steam/chemical spray is administered, the outer and individual jackets show a further increase in transmittance, but the EPR insulation shows a small decrease.

Figure 5.33 shows data for cable that had received one-half of the 40 year qualification test protocol used by the cable manufacturer. The protocol involved a thermal aging step of 82.5 hrs at 250°F (121°C), CM point C, and an irradiation of 25.5 Mrad (CM point E). This is followed by two LOCA radiation exposures of 78.6 and 76.8 Mrad at CM point F and G, respectively. A final steam/chemical spray is administered at CM point H. The trends in transmittance for the various CM points are similar to those for the 20-year aging protocol shown in Figure 5.32.

Results for the 24-year naturally aged cable obtained by BNL are shown in Figure 5.34. LOCA irradiation and steam/chemical spraying usually caused small increases in the transmittance for the outer and white individual jackets and the EPR insulation. In comparing the transmittance values for the 24-year naturally aged cable material (CM point A in Figure 5.34) with those for materials artificially aged to an equivalent age (CM point D in Figure 5.32) it is found that the values are noticeably lower for the naturally aged cables. It is possible that the cables had different formulations which could contribute to the differences. Another explanation is that the amount of surface oxidation is greater in the artificially aged materials because of the high aging temperature compared to the naturally aged cable. Since FTIR is a surface characterization technique, the greater amount of surface oxidation in the artificially aged materials would give a higher transmittance if -CH_2 bonds are lost during the oxidation process, as described in Section 4.5. It would be expected that the difference in behavior between the artificially and naturally aged materials would be smaller if the artificial aging temperature had been decreased (i.e., the aging time increased) since it would minimize oxidation gradients at the specimen surfaces. However, in Section 4.5, it was noted that there was little difference in FTIR transmittance for naturally and artificially aged XLPE.

Table 5.5 shows FTIR and EAB data taken from Appendices E and B, respectively. Using this information the transmittances for three and four conductor AIW cable materials are plotted, respectively, in Figures 5.35 and 5.36 as a function of service aging time at a normalized temperature of 140°F (60°C). For both cable types, the percent increases with aging time. The one exception is for the EPR insulation for the four-conductor cable (Figure 5.36) which does not show a significant change after about 5 years of aging.

Figures 5.37 and 5.38 show the FTIR transmittance as a function of the elongation-at-break for AIW three and four conductor cables, respectively. When the materials are given service aging treatments, the ductilities decrease and the transmittances increase. This is in keeping with the loss of -CH_2 bonds by oxidation.

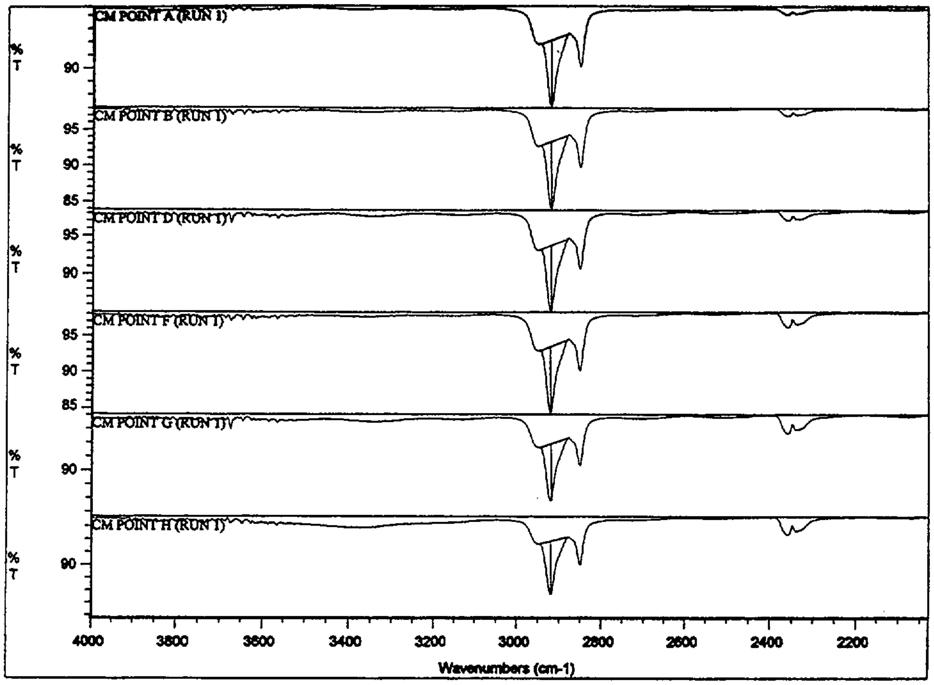


Figure 5.31 FTIR spectra for EPR insulation from AIW cable PNI74AI027 (Group 2.2, Specimen 0205) artificially aged to 20 years service

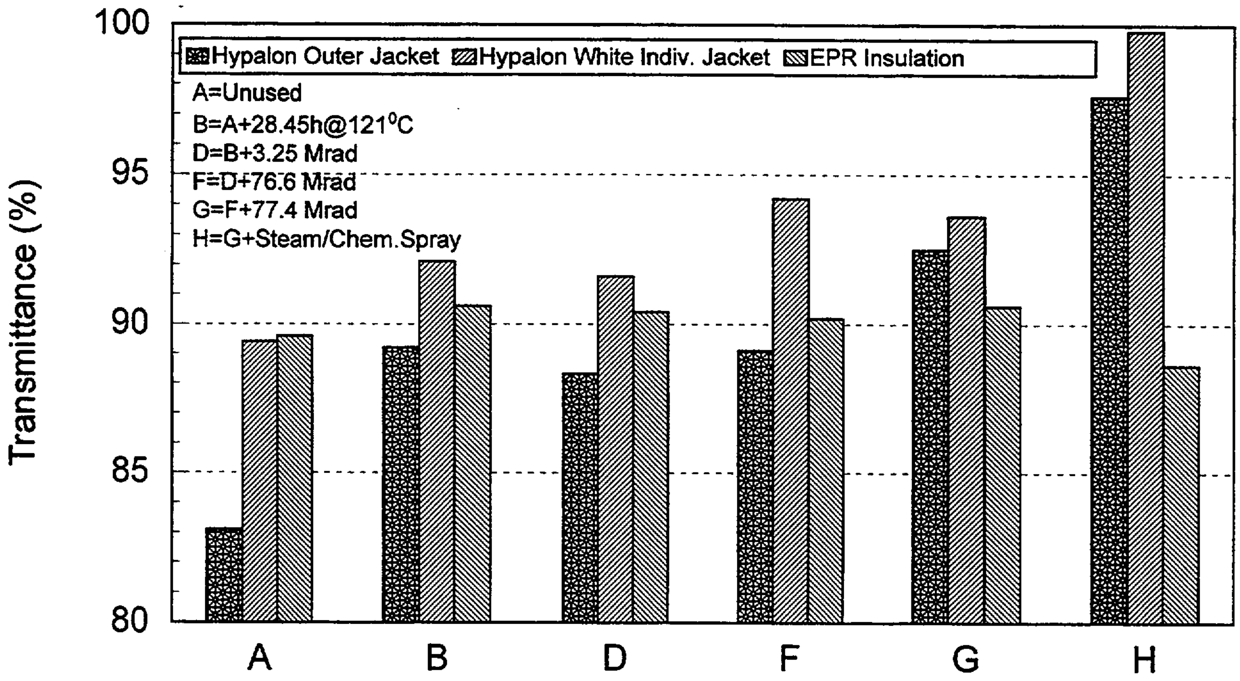


Figure 5.32 FTIR results for AIW cable PNI74AI027 (Group 2.2, Specimen 0205) artificially aged to 20 years service as a function of CM point

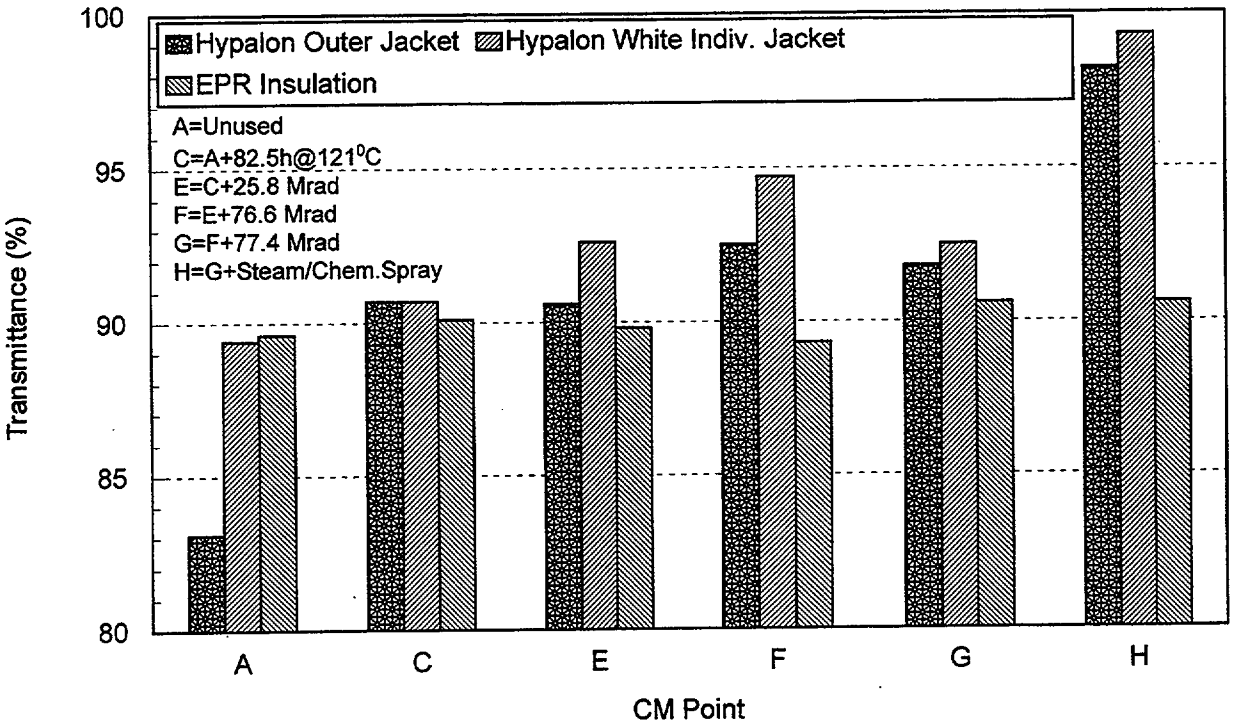


Figure 5.33 FTIR results for AIW cable PNI74AI028 (Group 2.4, Specimen 0213) artificially aged to one-half of the 40 year qualification protocol

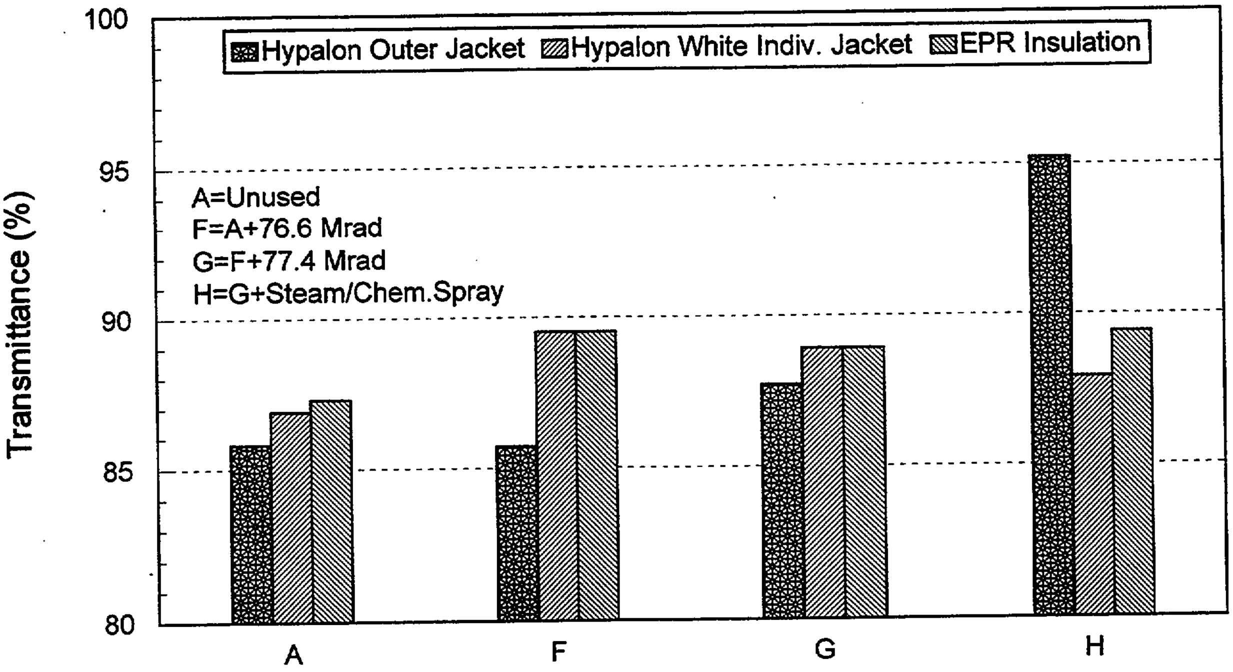


Figure 5.34 FTIR results for AIW cable PNI74AI019 (Group 2.3, Specimen 0210) naturally aged to 20 years service

Table 5.5 FTIR results for AIW EPR/Hypalon® cables as a function of aging and elongation-at-break

Group	Material	Service Aging Protocol	Equiv. Aging Time at 60°C (years)	Transmittance at Wavenumber 2916 cm^{-1} (%)(a)	EAB (%)(a)
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (Hypalon® Outer Jacket)	None	0	83.1	649
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (Hypalon® Outer Jacket)	28.45 hr.@121°C + 3.25 Mrad	2.6	88.3	582
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (Hypalon® Outer Jacket.)	82.5 hr.@121°C + 25.8 Mrad	7.6	90.6	429
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (Hypalon® White Individual Jacket)	None	0	89.4	540
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (Hypalon® White Individual Jacket)	28.45 hr.@121°C + 3.25 Mrad	2.6	91.6	341
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (Hypalon® White Individual Jacket)	82.5 hr.@121°C + 25.8 Mrad	7.6	92.6	371
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (EPR Insulation)	None	0	89.6	284
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (EPR Insulation)	28.45 hr.@121°C + 3.25 Mrad	1.9	90.4	224
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (EPR Insulation)	82.5 hr.@121°C + 25.8 Mrad	5.5	89.8	196
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (Hypalon® Outer Jacket)	None	0	78.6	563
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (Hypalon® Outer Jacket)	82.5 hr.@121°C + 25.8 Mrad	7.6	83.3	369
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (Hypalon® Outer Jacket)	252 hr.@121°C + 38.7 Mrad	23.2	89.1	191
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (Hypalon® White Individual Jacket)	None	0	90.5	482
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (Hypalon® White Individual Jacket	82.5 hr.@121°C + 25.8 Mrad	7.6	93.0	250
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (Hypalon® White Individual Jacket)	252 hr.@121°C + 38.7 Mrad	23.2	97.8	197
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (EPR Insulation)	None	0	90.6	341
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (EPR Insulation)	82.5 hr.@121°C + 25.8 Mrad	5.5	91.8	224
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (EPR Insulation)	252 hr.@121°C + 38.7 Mrad	16.8	94.7	218

(a) Average of at least 3 tests

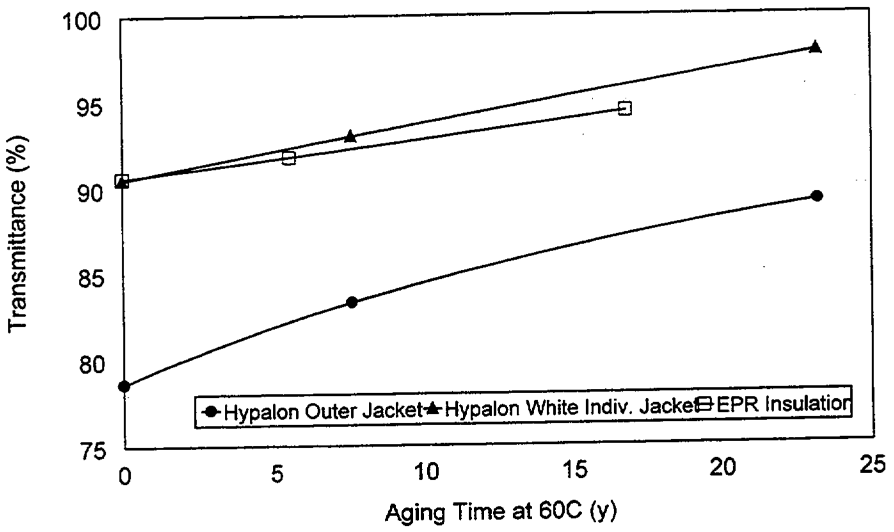


Figure 5.35 Correlation between FTIR transmittance and service aging time at 140°F (60°C) for AIW three-conductor cable

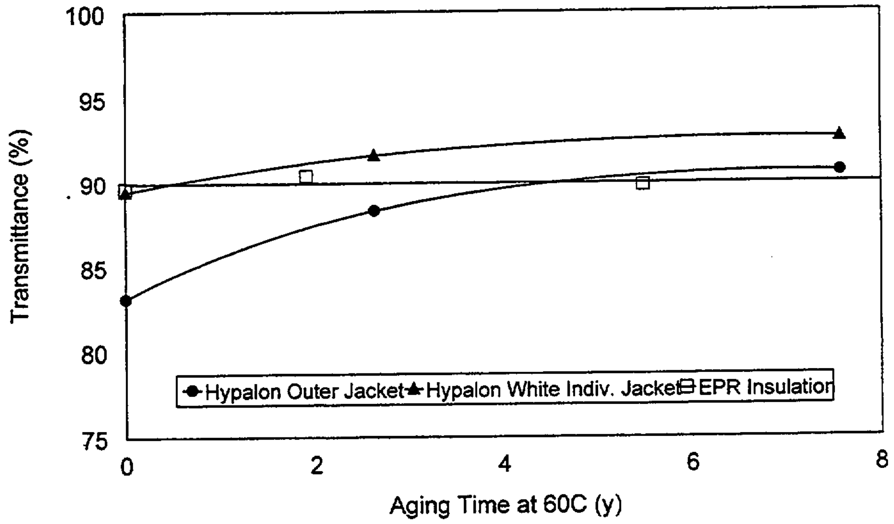


Figure 5.36 Correlation between FTIR transmittance and service aging Time at 140°F (60°C) for AIW four-conductor cable

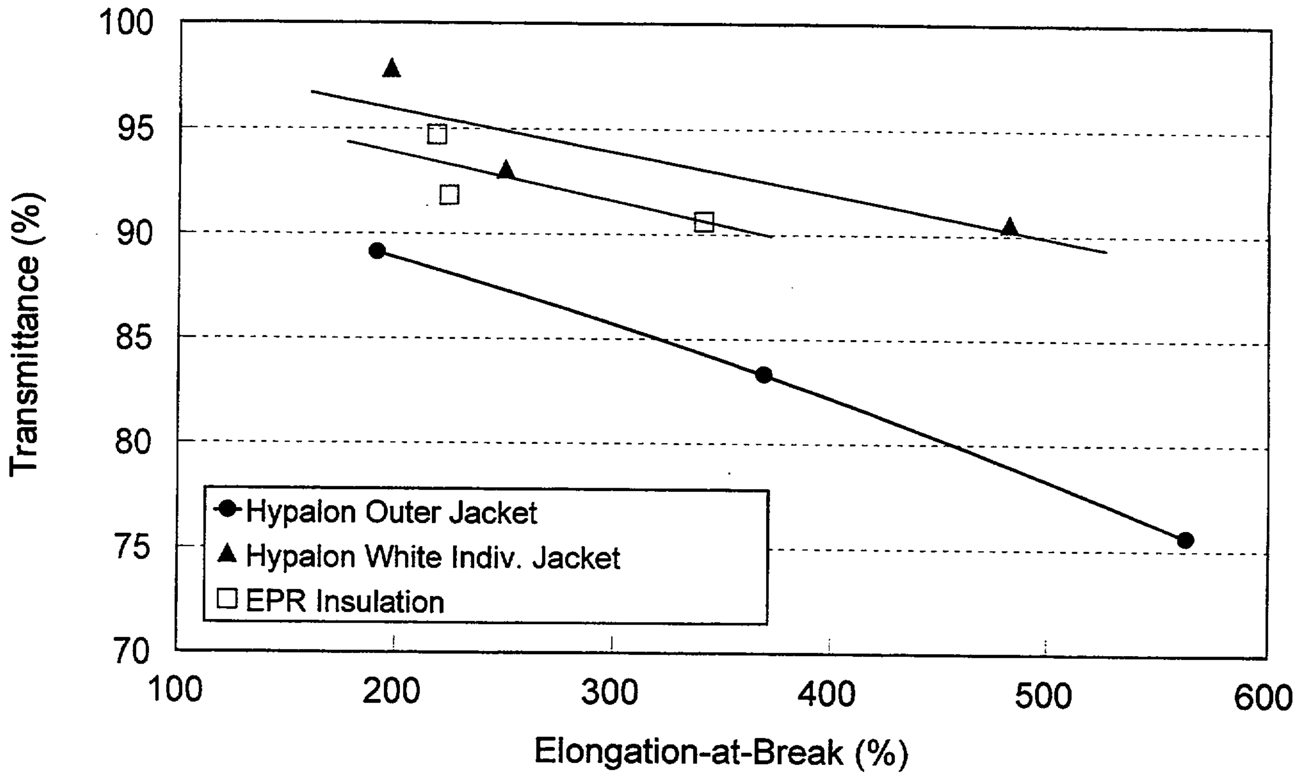


Figure 5.37 Correlation between FTIR transmittance and elongation-at-break for AIW three-conductor cable

One potential drawback to laboratory evaluation of FTIR is that accelerated aging at high temperatures may cause a large oxidation gradient to form near the surface of the specimens. Thus, FTIR surface measurements will not always be representative of bulk aging behavior. However, if the measurements are performed on naturally aged materials, the oxidation gradients will be minimized and FTIR spectroscopy may be valuable in monitoring long term degradation.

In summary, the FTIR technique that monitors aging through transmittance measurements on the -CH_2 peak at 2916 cm^{-1} appears to be capable of trending the aging degradation of EPR insulation. Although these bonds are usually very stable for the polymer backbone, there may be similar bonds present in other cable constituents. Oxidation, according to the theory described in Section 4.5, should cause a decrease in the number of -CH_2 bonds and be reflected by an increase in transmittance. Additional work should be performed to more fully establish the technique as a viable condition monitoring procedure.

5.6 Indenter

This section presents the results of the indenter tests on the EPR-insulated cable specimens. Test sequences 2, 4, 5 and 6 included cables with EPR insulation. Selected results are presented and discussed in the following paragraphs. Complete indenter results are tabulated in Appendix E.

Figure 5.39 provides the results of the indenter tests on the EPR insulation from the AIW specimens in test sequence 6, which were pre-aged to the equivalent of 60 years of qualified life. These specimens had an unbonded individual Hypalon® jacket on top of the EPR insulation, which was removed prior to indenter testing. The composite EPR/unbonded Hypalon® individual jacket insulation was tested separately. As shown, the AIW EPR insulation did

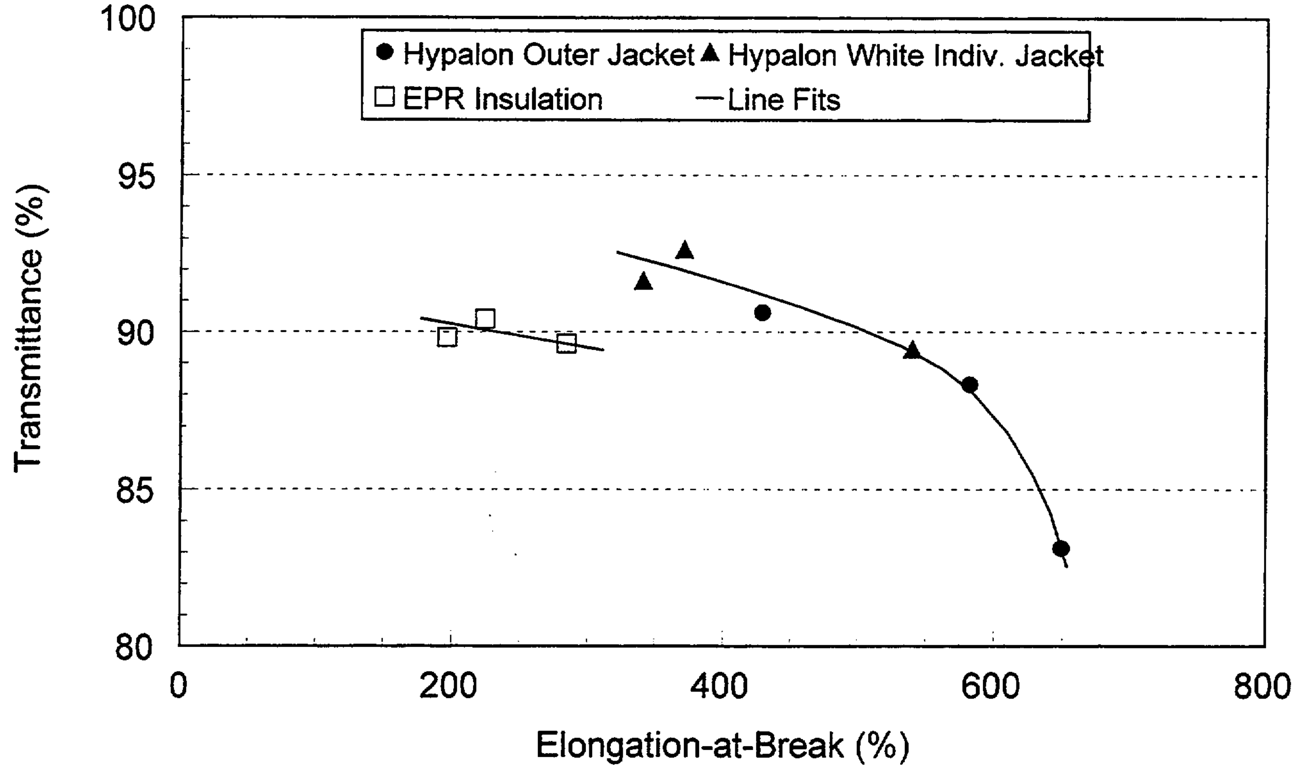


Figure 5.38 Correlation between FTIR transmittance and elongation-at-break for AIW four-conductor cable

not exhibit any significant change in compressive modulus from baseline to post-accident radiation (overall 3 percent increase). Similar results were seen for the EPR materials from the Anaconda specimens pre-aged to the equivalent of 20 and 40 years of qualified life. The data indicate that the Anaconda EPR is a relatively stable material when exposed to the thermal and radiation stressors applied in this program.

Figure 5.40 presents the compressive modulus as a function of pre-aging for the composite EPR/unbonded Hypalon® individual jacket insulation for the test sequence 6 AIW specimens. Unlike the results for EPR alone, the composite shows a definite increasing trend with increasing exposure to aging stressors. While the overall change in compressive modulus from baseline to post-accident radiation is relatively small (11 to 17 N/mm, 63 to 97 lbs./in.), it represents a 55 percent increase, which is significant. Also, the increase is continuous, except for the slight decrease in modulus after the second half of the accident radiation exposure, and it can be detected with the indenter. Comparing these results with the results for the EPR alone (Figure 5.39), the data suggest that the Hypalon individual jacket is more susceptible to aging than the EPR and, when applied to the EPR in the form of an individual jacket, the resulting composite insulation is less stable under aging stress than the EPR alone. The compressive modulus of the composite is also more responsive to aging degradation, which makes it a better candidate for monitoring with the indenter.

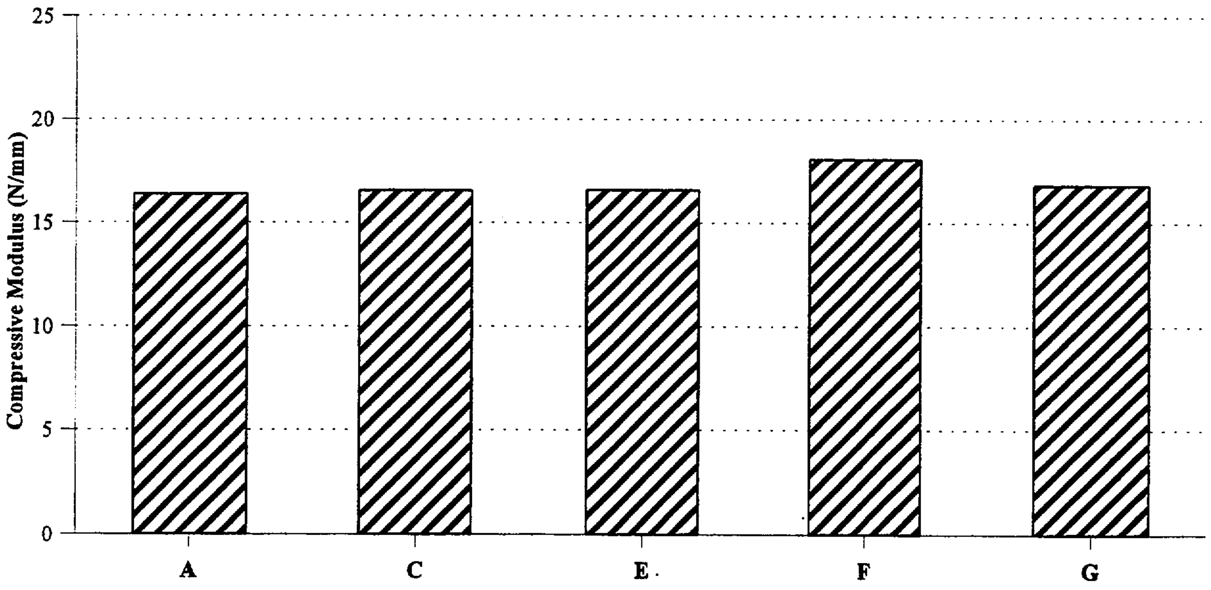


Figure 5.39 Average compressive modulus for EPR insulation from AIW specimens pre-aged to 60 yr.

A = Baseline
C = Post Thermal Pre-aging
E = Post Service Radiation
F = Post half accident radiation
G = Post full accident radiation

To examine this further, data for EPR-insulated Anaconda specimens pre-aged to 40 years of equivalent qualified life, both with and without the Hypalon® individual jacket, were compared (Figure 5.41). As shown, the specimens with EPR alone exhibited a smaller increase in compressive modulus from their baseline value to post-service aging (overall increase of 37 percent) compared to the specimens with the composite EPR/unbonded Hypalon® individual jacket (overall increase of 149 percent). These results are consistent with those from the AIW specimens and indicate that the Hypalon® individual jacket influences the change in compressive modulus of the insulation as a function of aging degradation.

In Figure 5.42 the compressive modulus values for the Samuel Moore specimens pre-aged to 60 years of equivalent qualified life are presented. These specimens included a composite EPR/bonded Hypalon® individual jacket insulation. As shown, a definite increasing trend with age was noted for these specimens with a continuous, overall increase of 277 percent (14.3 N/mm baseline to 53.9 N/mm after service aging plus accident radiation). These results are consistent with the results for the composite EPR/unbonded Hypalon® individual jacket insulation and suggest that this composite is well suited to be monitored and trended with the indenter.

The compressive modulus for the Okonite specimens pre-aged to 60 years of equivalent qualified life was also examined (Figure 5.43). These data show that the compressive modulus increased dramatically after thermal aging and subsequently remained relatively stable. This is believed to be due to the severe thermal aging received by the Okonite specimens as compared to the other specimens. After thermal aging, the Okonite specimens were essentially brittle, therefore, subsequent exposure to the radiation stressors had little effect on the material ductility; thus, no change in compressive modulus was evident. This is confirmed by the EAB data, which show the insulation had little, if any ductility remaining after thermal aging.

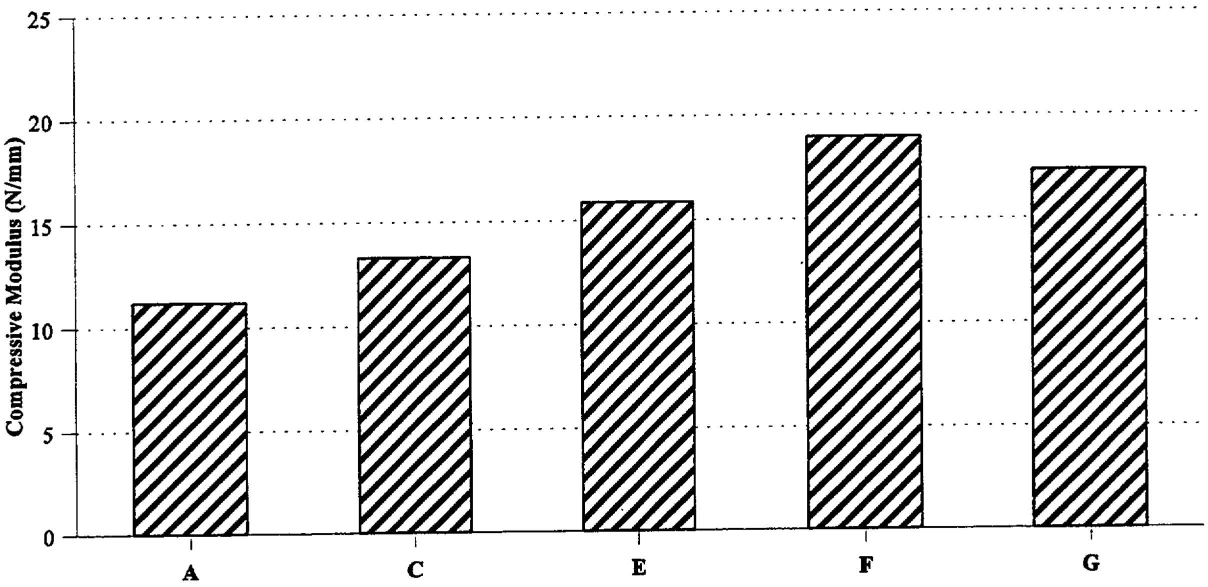


Figure 5.40 Average compressive modulus for composite EPR/unbonded Hypalon® insulation from AIW specimens in test sequence 6 pre-aged to 60 yr.

A = Baseline
E = Post Service Radiation
F = Post half accident radiation
C = Post Thermal Pre-aging
G = Post full accident radiation

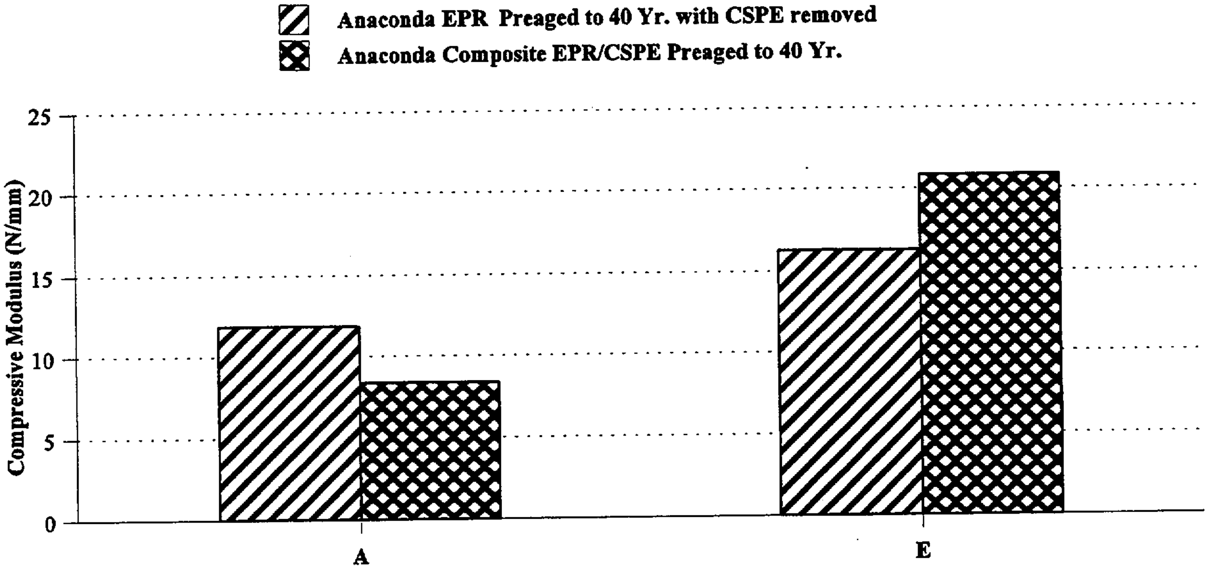


Figure 5.41 Average compressive modulus for EPR insulation from Anaconda specimens in test sequence 4 pre-aged to 40 yr. with and without Hypalon® individual jacket

A = Baseline
E = Post Thermal and Radiation Service Pre-aging

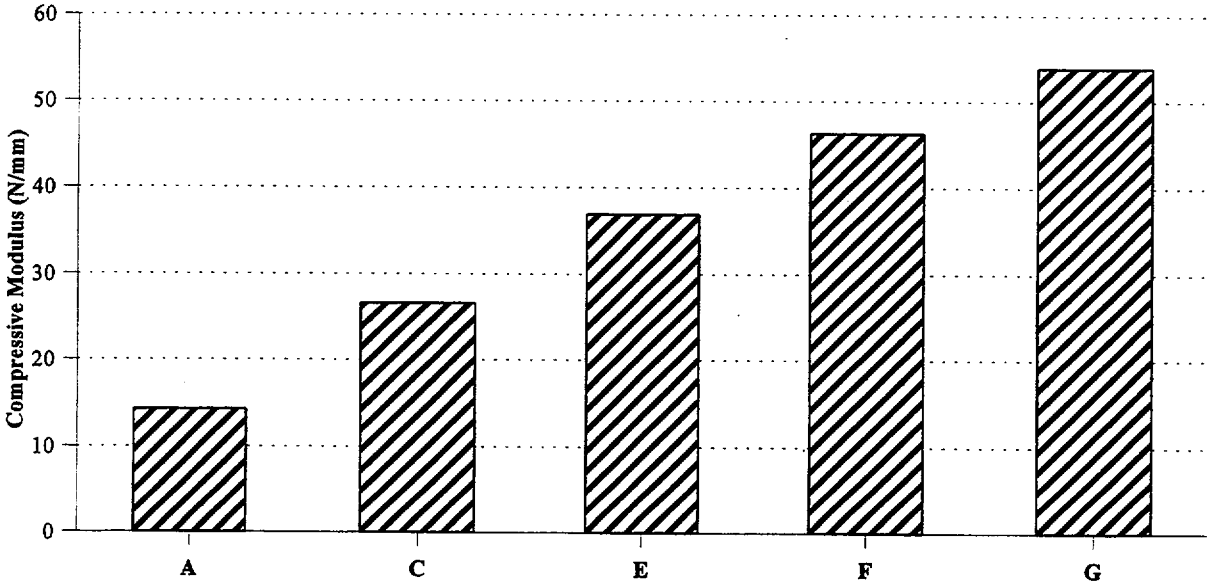


Figure 5.42 Average compressive modulus for composite EPR/bonded Hypalon® insulation from Samuel Moore specimens in test sequence 6 pre-aged to 60 yr.

A = Baseline
C = Post Thermal Pre-aging
E = Post Service Radiation
G = Post full accident radiation
F = Post half accident radiation

Compressive modulus was measured for the Hypalon® outer jackets used on the Samuel Moore, Anaconda and AIW cable specimens. Figure 5.44 presents the results for the AIW outer jacket, which show a definite, continuous increase in the compressive modulus with pre-aging. While the overall increase is small (9.5 to 14.1 N/mm, 52 to 81 lbs./in.), this represents a 48 percent increase and should be measurable with the indenter. The results for the Samuel Moore outer jacket show a more pronounced change in compressive modulus, which increases from 13.9 to 60.5 N/mm (79 to 345 lbs./in.) (Figure 5.45). Both of these results indicate that these materials are suitable candidates for monitoring with the indenter.

An observation made during the analysis of the above data is that, in all cases, effective trending of the compressive modulus results was found to depend on having a good baseline value to use as a reference. Comparison of subsequent measurements to the baseline value was found to be very helpful in determining and interpreting variations in the values obtained. Therefore, it is important to establish a baseline value for the cables to be monitored as early in life as possible to most effectively utilize the indenter measurements. Of equal or greater importance for estimating remaining life is the establishment of a well defined end condition.

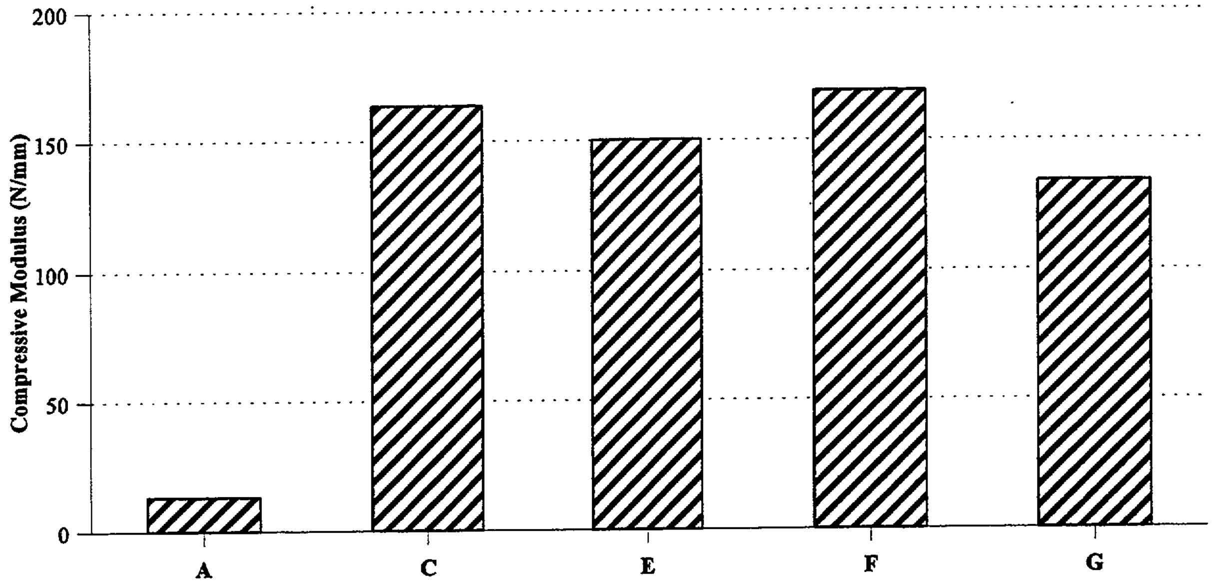


Figure 5.43 Average compressive modulus for composite EPR/bonded Hypalon® insulation from Okonite specimens in test sequence 6 pre-aged to 60 yr.

A = Baseline
E = Post Service Radiation
F = Post half accident radiation
C = Post Thermal Pre-aging
G = Post full accident radiation

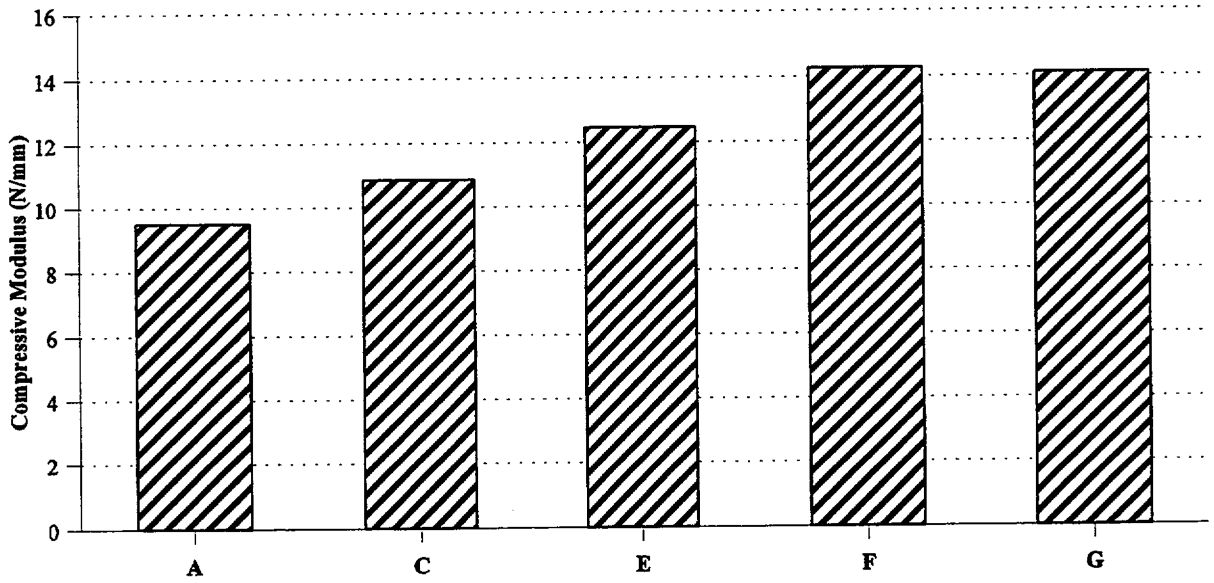


Figure 5.44 Average compressive modulus for Hypalon® outer jacket from AIW specimens in test sequence 6 pre-aged to 60 yr.

A = Baseline
E = Post Service Radiation
F = Post half accident radiation
C = Post Thermal Pre-aging
G = Post full accident radiation

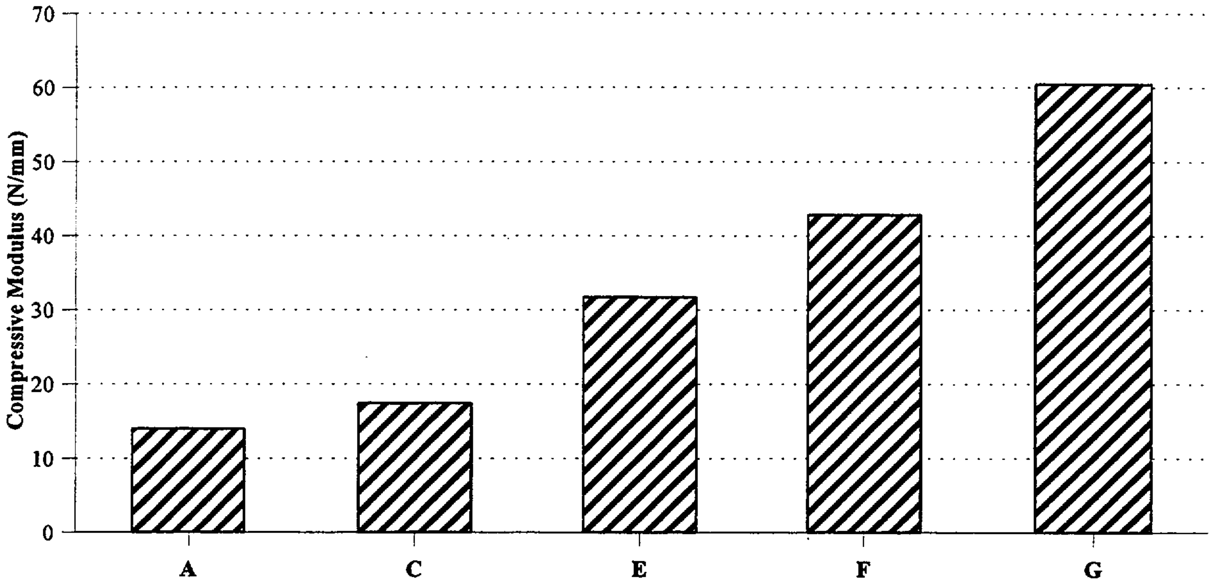


Figure 5.45 Average compressive modulus for Hypalon® outer jacket from Samuel Moore specimens in test sequence 6 pre-aged to 60 yr.

A = Baseline
C = Post Thermal Pre-aging
E = Post Service Radiation
G = Post full accident radiation
F = Post half accident radiation

Another observation made in analyzing the data is that cable construction has a definite effect on the compressive modulus. This was clearly observed with the Samuel Moore specimens tested in test sequences 4, 5, and 6. Previous research (IAEA, 2000) documented the influence of cable construction on modulus results , particularly in cables with loose construction or cables which have an inner metallic shielding. Table 5.6 provides the mean compressive modulus for the Samuel Moore specimens following accelerated aging to the equivalent of 20, 40, and 60 years of qualified life. As indicated, the specimens tested in sequence 4 exhibited markedly different results than the specimens tested in sequences 5 and 6. Each of the specimens tested had the same Hypalon® outer jackets, but were of different cable design. The specimens tested in test sequence 4 were from a two conductor thermocouple extension wire with solid conductors, while the specimens in test sequences 5 and 6 were from a two conductor instrument wire with stranded copper conductors. The cable specimens with the stranded copper conductor had higher compressive modulus values than the thermocouple wire. However, the two conductor thermocouple wire exhibited a higher percentage increase in compressive modulus after aging to the equivalent of 40 years of qualified life (72 percent vs. 56 percent) when compared to the instrumentation wire in test sequences 5 and 6. Also, a continuous increase in modulus was noted for this cable during the accident irradiation exposure.

The indenter results for the EPR-insulated cables showed modest increases in compressive modulus for the pre-aging used in this study. This is indicative of the overall resistance of this material to thermal and irradiation degradation, however, it also highlights the potential difficulty in using the indenter to monitor aging degradation in conditions where aging stressors may be less severe than simulated herein. In general, the materials studied do show a consistent trend toward increasing modulus with increasing aging degradation.

Table 5.6 Samuel Moore Hypalon® outer jacket compressive modulus values

Test Sequence	Cable Type	Compressive Modulus (N/mm)(lbs/in)			
		Baseline	Pre-aged to 20 yr.	Pre-aged to 40 yr.	Pre-aged to 60 yr.
4	Thermocouple Cable	9.13 (52.45)	12.8 (73.53)	15.7 (90.19)	NA
5 & 6	Instrumentation Cable	15.16 (87.09)	20.36 (116.96)	23.66 (135.92)	32.29 (185.50)

As discussed previously, EAB is often considered the standard against which the effectiveness of other condition monitoring techniques is measured. To determine how well the indenter data obtained in this study correlates with the EAB values for the materials tested, compressive modulus was plotted against EAB for several of the specimens. As shown in Figure 5.46, the EPR insulation alone did not have a very good correlation with EAB since the compressive modulus changed very little with increasing aging while the EAB continuously decreased. However, with a Hypalon® individual jacket applied to the EPR, the compressive modulus values correlated very well with EAB, as shown in Figures 5.47 and 5.48 for the AIW and Samuel Moore specimens, respectively. In both cases, an excellent correlation was found with compressive modulus continuously increasing corresponding to a decrease in EAB as aging degradation increased. Correlation of compressive modulus with EAB for the Hypalon® outer jacket was also found to be very good (Figure 5.49).

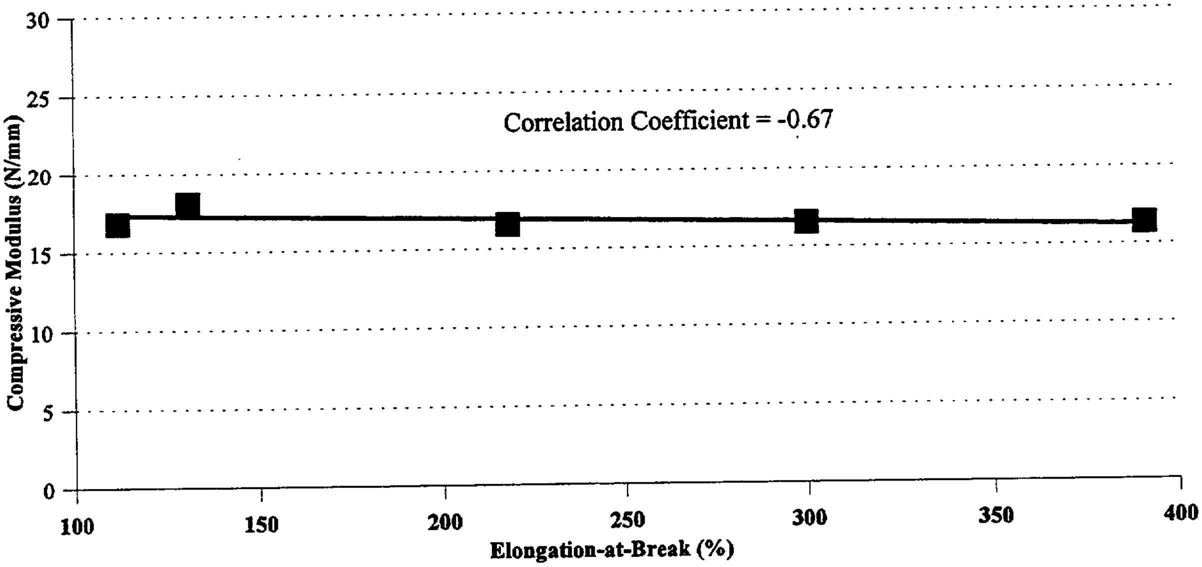


Figure 5.46 Correlation of Compressive Modulus with EAB for EPR insulation from AIW specimens in test sequence 6 pre-aged to 60 yr.

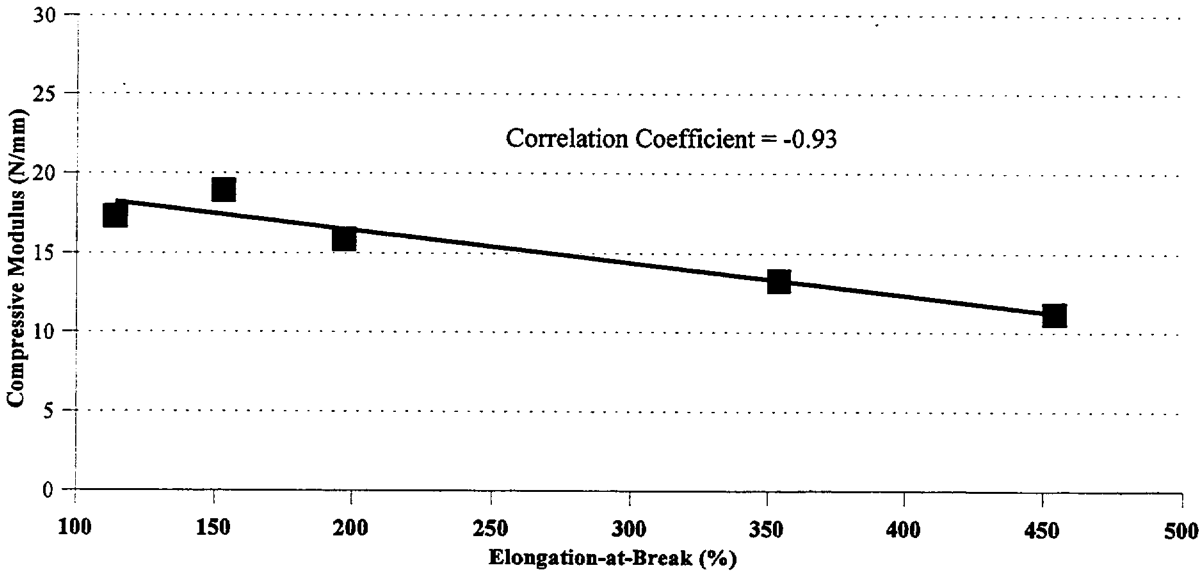


Figure 5.47 Correlation of Compressive Modulus with EAB for composite EPR/unbonded Hypalon® insulation from AIW specimens in test sequence 6 pre-aged to 60 yr.
(Note: EAB values are for Hypalon® individual jacket alone)

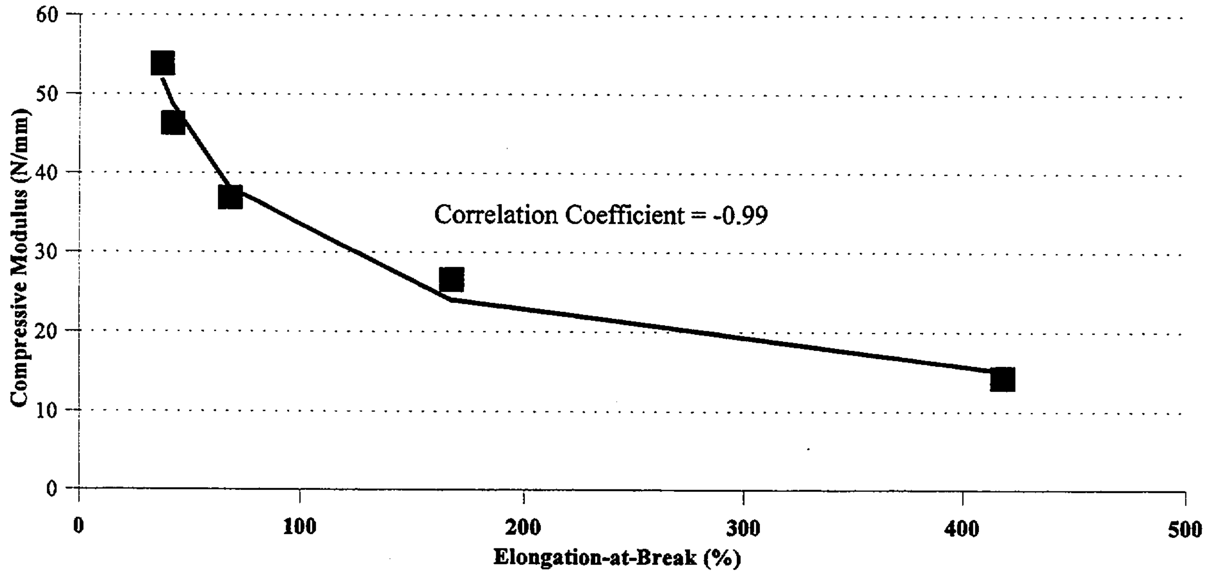


Figure 5.48 Correlation of Compressive Modulus with EAB for composite EPR/bonded Hypalon® insulation from Samuel Moore specimens in test sequence 6 pre-aged to 60 yr.

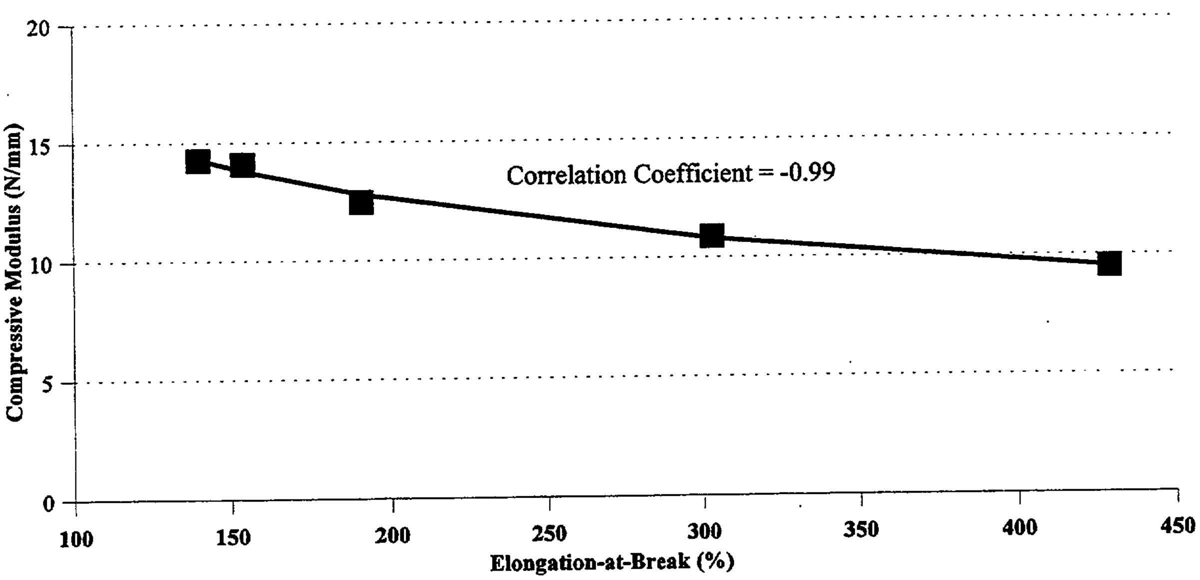


Figure 5.49 Correlation of Compressive Modulus with EAB for Hypalon® outer jacket from AIW specimens in test sequence 6 pre-aged to 60 yr.

5.7 Hardness

Hardness data were obtained for the AIW EPR-insulated cable specimens in test sequence 2. The average hardness results for the Group 2.4 specimens pre-aged to the equivalent of 20 years of qualified life show that none of the specimens tested in this sequence exhibited a dramatic increase in hardness (Figures 5.50 and 5.51). Figure 5.50 shows the EPR insulation experienced a 34 percent increase in hardness (21.7 to 29). The increase was continuous and would provide a means of trending degradation rate for this material.

By comparison, the Hypalon® individual and outer jackets experienced smaller overall increases of approximately 5 percent and 15 percent, respectively. It is noted that the Hypalon® individual and outer jackets were initially harder than the EPR insulation. Given the inherent error associated with reading the vernier scale on the durometer, the overall change in hardness for neither the individual jackets nor the outer jackets would be readily apparent during in situ use.

The hardness data were plotted against EAB to determine if a correlation exists between these two techniques. Figure 5.52 shows that, for the EPR insulation, a good correlation with EAB exists. This suggests that hardness could provide trendable data for monitoring degradation of this material. For the Hypalon® material, Figure 5.53 shows a fair correlation for the outer jacket material, however, the individual jacket had a poor correlation. This is due to the small amount of change in the hardness values as a function of aging degradation.

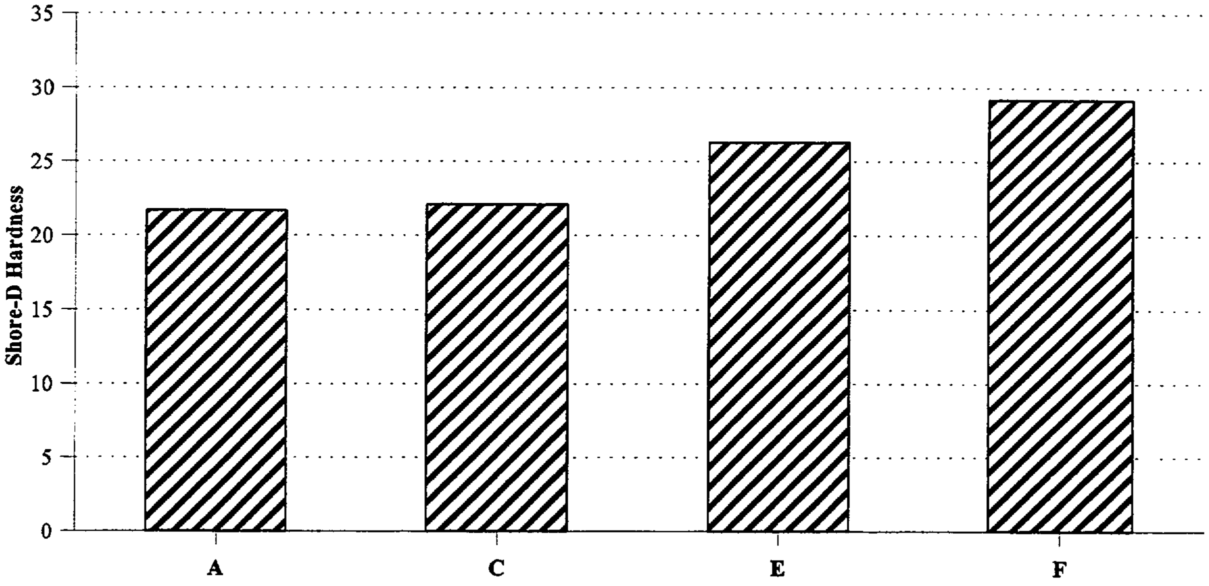


Figure 5.50 Hardness versus pre-aging for EPR material from AIW specimens in Group 2.4, test sequence 2 pre-aged to 20 yr.

A = Baseline
C = Post Thermal Pre-aging
E = Post Service Radiation
F = Post half accident radiation

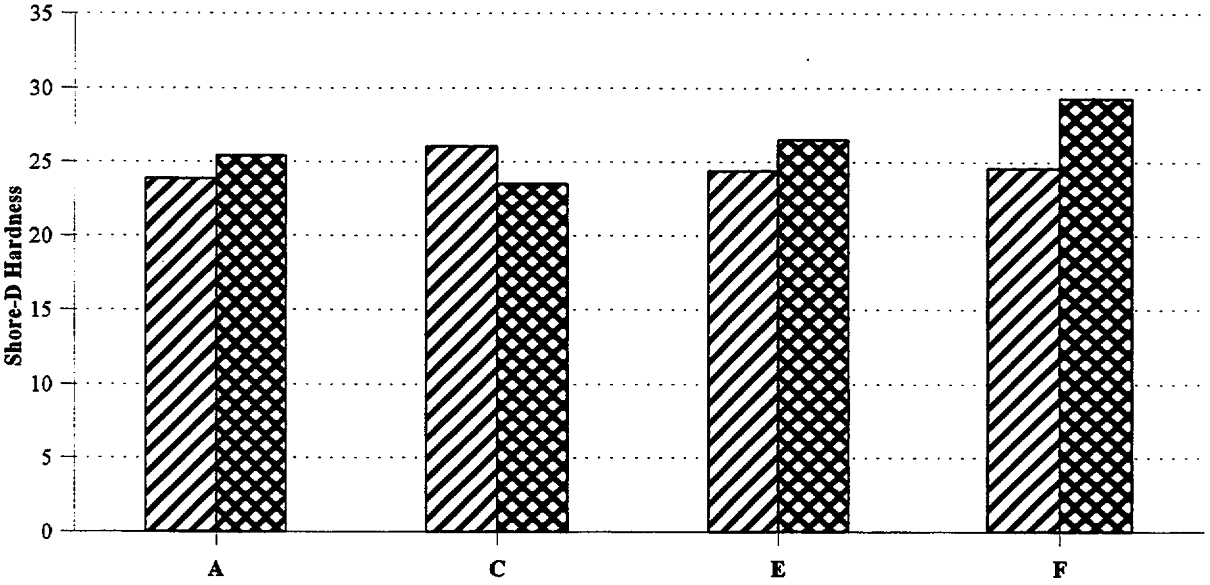


Figure 5.51 Hardness versus pre-aging for Hypalon® material from AIW specimens in Group 2.4, test sequence 2 pre-aged to 20 yr.

A = Baseline
C = Post Thermal Pre-aging
E = Post Service Radiation
F = Post half accident radiation

The good correlation observed for the EPR material indicates that hardness can be used as a reasonable indication of aging for this material. However, as discussed in Section 3.7, a specially designed hardness tester would be needed to mitigate puncture of the material being tested.

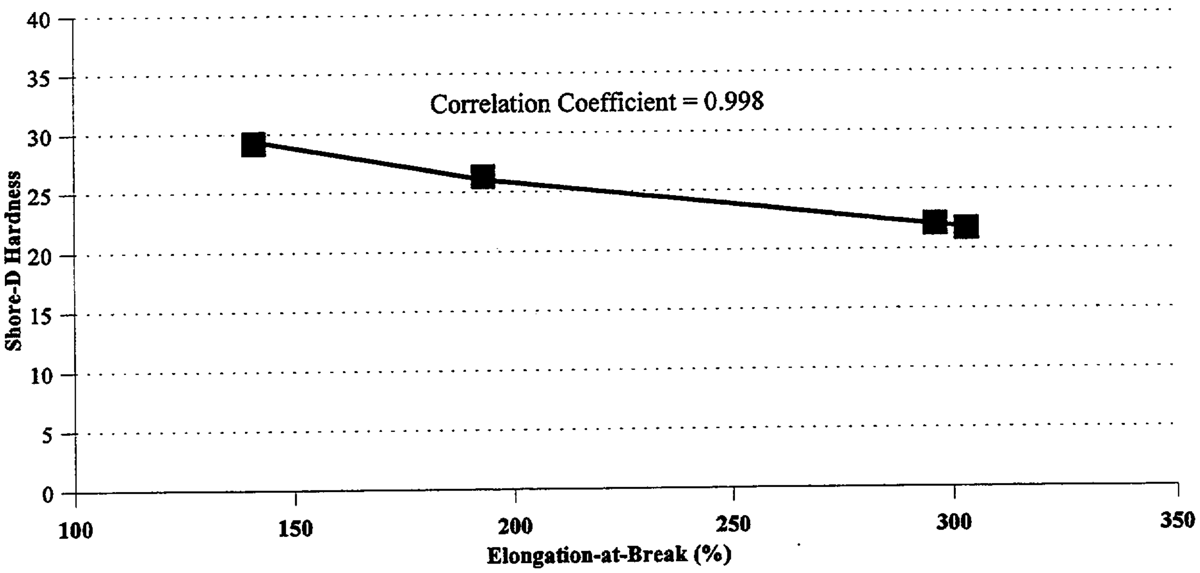


Figure 5.52 Correlation of Shore-D Hardness with EAB for EPR insulation from Group 2.4 AIW specimens pre-aged to 20 yr.

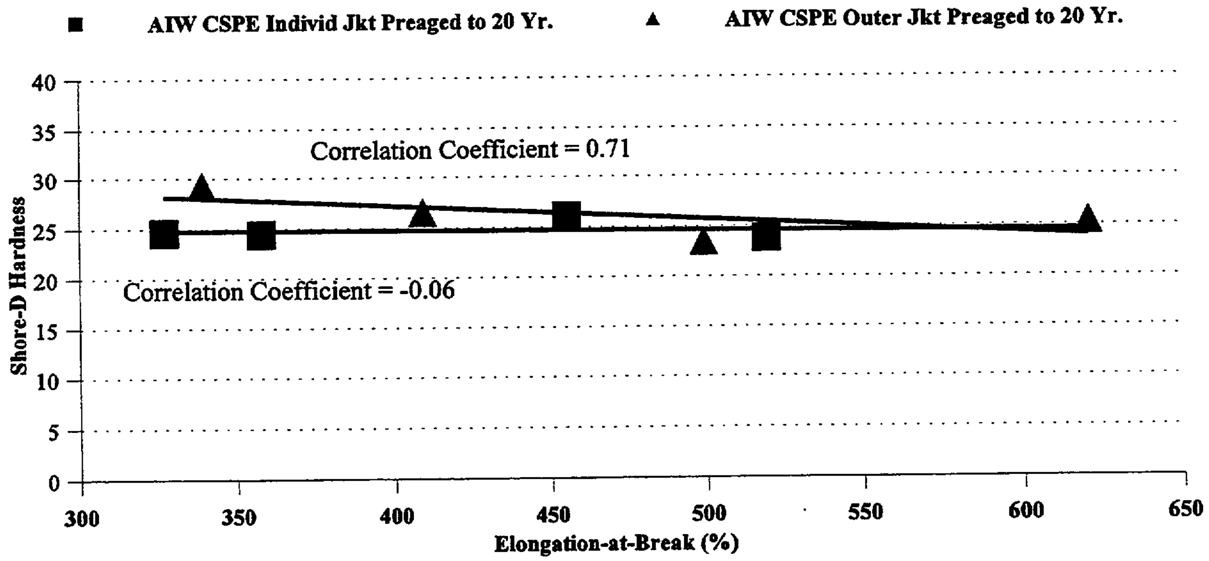


Figure 5.53 Correlation of Shore-D Hardness with EAB for Hypalon® from Group 2.4 AIW specimens pre-aged to 20 yr.

5.8 Dielectric Loss

Dielectric loss measurements were performed in accordance with a BNL approved test procedure using a two-channel Hewlett Packard HP 35670A Dynamic Signal Analyzer as described in Section 3.8. The data obtained are included in Appendix G. Selected results are discussed in the following paragraphs.

Figure 5.54 presents the data for 1/C #12 AWG Okonite EPR-insulated cables with bonded Hypalon® jackets. The average dielectric phase angle measured from conductor-to-ground as a function of the frequency of the applied ac test voltage is plotted for the baseline cables (no pre-aging) and for cables pre-aged to the equivalent of 20, 40, and 60 years of qualified life using the pre-aging parameters found in the original qualification test reports. From approximately 5 to 5000 Hz (the maximum frequency measured in this program), the plot generally moves toward the origin throughout the service pre-aging process compared to the baseline values. A large change can be seen in the cables pre-aged to 60 years; the 60 year specimens experienced 100 percent failure in the subsequent LOCA exposure test.

The results shown in Figure 5.54 indicate that, as cable insulation deteriorates over time, either as a result of natural in-service aging or by being subjected to accelerated aging, the degradation in the dielectric properties of the insulating material can be detected, monitored, and trended using this technique. Low voltage ac applied to the test specimens at frequencies between 50 and 500 Hz were found to be the most effective in showing the effects of insulation degradation on dielectric properties. Lower frequency applied test voltage also showed the dielectric changes, especially at severe levels of insulation damage and degradation. However, as was found with the XLPE-insulated cables, the very low frequency (less than 1 Hz) measurements were much more difficult to perform, very time consuming, not consistently trendable, and results were not as repeatable.

As discussed in Section 3.8, the dielectric measurements can be presented in terms of the insulation power factor, i.e., the cosine of the dielectric phase angle, cos θ. Table 5.7 summarizes the insulation power factor values for pre-aged Okonite EPR-insulated cables with bonded Hypalon® jackets compared to the baseline values measured before any pre-aging had been performed. The insulation power factors measured at 50, 100, 500 Hz are presented as an example, since the changes and trends were most consistently demonstrated within this range of frequencies.

The data in Table 5.7 show a measurable general trend of increasing insulation power factor from the unaged condition of the cable to the post-service aging condition. There is also good consistency in the relative insulation power factor as the total equivalent service aging, and corresponding level of insulation degradation, progressively increased from 20 years up to 60 years.

An EPR-insulated cable with individual Hypalon® jackets was also tested in a multiple conductor cable configuration. This was a Samuel Moore 2/C #16 AWG low voltage I&C cable with shield and bare copper drain (ground) conductor enclosed in an overall Hypalon® jacket. Insulation power factor measurements for this cable showed an increasing trend as the cable insulation degraded during pre-aging from the baseline value (no pre-aging) up to a maximum of 60 years of equivalent service.

Table 5.8 is a tabulation of the insulation power factor values, measured from the black-to-white-insulated conductors, for pre-aged Samuel Moore EPDM-insulated cables with individual bonded Hypalon® jackets compared to the baseline values measured before any pre-aging had been performed. Measurements were made with the cable intact in its original multiconductor configuration. The insulation power factors measured at 50, 100, and 500 Hz are given since the changes and trends were most consistently demonstrated within this range of frequencies.

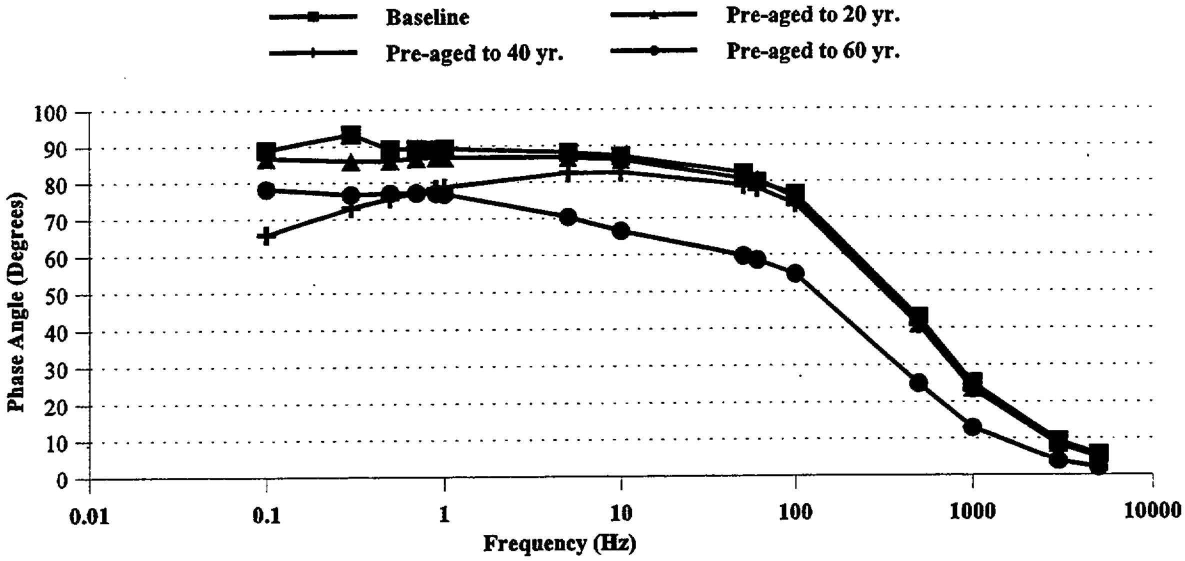


Figure 5.54 Dielectric phase angle vs test voltage frequency for aged Okonite cables

Table 5.7 Insulation power factor for Okonite EPR-insulated cables with bonded Hypalon® jacket

Insulation Power Factor Low Voltage Okonite EPR-insulated Cables with Bonded Hypalon® Jacket					
Cable Specimens	**Group**	**Aging (Years)**	**Frequency of Applied ac Test Voltage**		
			50 Hz	**100 Hz**	**500 Hz**
Baseline	All	None	0.13	0.24	0.73
20 Years	5.2 OK	None	0.13	0.23	0.73
		20	0.16	0.25	0.75
40 Years	5.3 OK	None	0.13	0.24	0.73
		40	0.19	0.28	0.76
60 Years	6.2 OK	None	0.13	0.24	0.74
		60	0.50	0.58	0.91

Table 5.8 Insulation power factor for Samuel Moore EPDM-insulated cables with bonded individual Hypalon® jackets, conductor-to-conductor

Insulation Power Factor - Conductor-to-conductor Low Voltage Samuel Moore EPR-insulated Cables with Bonded Individual Hypalon® Jacket					
Cable Specimens	**Group**	**Aging (Years)**	**Frequency of Applied ac Test Voltage**		
			50 Hz	**100 Hz**	**500 Hz**
Baseline	All	None	0.16	0.27	0.80
20 Years	5.2 SM	None	0.16	0.27	0.80
		20	0.20	0.33	0.85
40 Years	5.3 SM	None	0.16	0.28	0.81
		40	0.21	0.34	0.85
60 Years	6.2 SM	None	0.16	0.27	0.80
		60	0.21	0.35	0.86

Similarly, Table 5.9 is a tabulation of the insulation power factor values, measured from the black-insulated conductor to ground, for pre-aged Samuel Moore EPDM-insulated cables with individual bonded Hypalon® jackets compared to the baseline values measured before any pre-aging had been performed. As shown by the data, the trend toward increasing insulation power factor measurements is even more pronounced in the conductor-to-ground measurement because there is only a single thickness of insulating material between the measured conductors.

Table 5.9 Insulation power factor for Samuel Moore EPDM-insulated cables with bonded individual Hypalon® jackets, conductor-to-ground

Insulation Power Factor - Conductor-to-ground Low Voltage Samuel Moore EPR-insulated Cables with Bonded Individual Hypalon® Jacket					
Cable Specimens	**Group**	**Aging (Years)**	**Frequency of Applied ac Test Voltage**		
			50 Hz	**100 Hz**	**500 Hz**
Baseline	All	None	0.25	0.40	0.89
20 Years	5.2 SM	None	0.25	0.40	0.89
		20	0.29	0.44	0.91
40 Years	5.3 SM	None	0.25	0.40	0.89
		40	0.29	0.45	0.92
60 Years	6.2 SM	None	0.25	0.39	0.89
		60	0.42	0.58	0.94

The other multiple conductor cable configurations with EPR insulation and individual Hypalon® jackets (AIW 3/C and 4/C #16 AWG with bare copper drain (ground) and Anaconda 3/C #12 AWG) demonstrated the same trend of increasing power factor with greater insulation material degradation as for the Okonite and Samuel Moore cables. The one exception involved the AIW cables, which showed an initial improvement in dielectric properties (lower insulation power factor) after 20 years of pre-aging compared to the baseline values. The data for the AIW cables are tabulated in Table 5.10 for measurements between the black- and white-insulated conductors, and in Table 5.11 for the white-insulated conductors-to-ground.

The data in Tables 5.10 and 5.11 show the decrease in power factor after receiving the equivalent of 20 years of thermal and radiation aging. This improvement in dielectric properties is attributed to drying out the moisture that had been absorbed by the cable insulation and jacket materials, and the water vapor within the cable interior that had accumulated during the 24 calendar years since the date of manufacture. The positive effects of the drying during thermal aging offset the degradation caused by the thermal and radiation aging. This phenomenon was also detected by the insulation resistance measurements (see Section 5.9). The moisture effects observed could complicate electrical measurements made in a plant environment.

Table 5.10 Insulation power factor for aged AIW EPR-insulated cables, conductor-to-conductor

Insulation Power Factor - Conductor-to-conductor Low Voltage AIW EPR-insulated Cables with Individual Hypalon® Jacket					
Cable Specimens	**Group**	**Aging (Years)**	**Frequency of Applied ac Test Voltage**		
			50 Hz	**100 Hz**	**500 Hz**
Baseline	All	None	0.20	0.33	0.85
20 Years	2.4	None	0.21	0.33	0.85
		20	0.19	0.30	0.81
60 Years	6.2 AI	None	0.19	0.31	0.83
		60	0.24	0.36	0.86

Table 5.11 Insulation power factor for aged AIW EPR-insulated cables, conductor-to-ground

Insulation Power Factor - White-insulated Conductor-to-ground Low Voltage AIW EPR-insulated Cables with Individual Hypalon® Jacket					
Cable Specimens	**Group**	**Aging (Years)**	**Frequency of Applied ac Test Voltage**		
			50 Hz	**100 Hz**	**500 Hz**
Baseline	All	None	0.33	0.49	0.92
20 Years	2.4	None	0.35	0.51	0.93
		20	0.30	0.45	0.91
60 Years	6.2 AI	None	0.30	0.45	0.91
		60	0.37	0.54	0.94

Nevertheless, the EPR-insulated cables with bonded and unbonded Hypalon® jackets, in both single and multiple conductor configurations, all demonstrated a measurable trend toward increasing power factor (deteriorating dielectric strength) with greater insulation material degradation. This trend was most pronounced and consistent at applied ac test voltage frequencies in the range from 10 to 500 Hz. The effect was also best observed in measurements from conductor-to-ground. Based on these results, dielectric loss measurements, particularly when compared to a baseline measurement, are considered a good electrical condition monitoring technique for these materials. It is again noted that a well defined end condition would have to be established to estimate remaining life.

5.9 Insulation Resistance

Insulation resistance measurements were performed in accordance with a BNL-approved test procedure using a General Radio Model 1864 Megohmmeter, as described in Section 3.9. The data obtained are included in Appendix H. Selected results are discussed in the following paragraphs.

Insulation resistance measurements were made for EPR-insulated cables from four different manufacturers. Two of these were constructed using bonded individual Hypalon® jackets; the others had unbonded individual Hypalon® jackets. The average insulation resistance readings at 1 minute and at 10 minutes are summarized in Table 5.12 for these cables, along with the corresponding polarization indices. Polarization indices in the range of about 2 or below are indicative of weakened or deteriorated cable insulation. All values in the table are for cable specimens tested intact, on stainless steel mandrels or in steel Unistrut® channels, in their multiconductor configuration, with the exception of the single conductor Okonite cable.

Table 5.12 Insulation resistance (IR) and polarization index (PI) for aged EPR-insulated cables

Cable			IR Time And PI	Overall Average Baseline Unaged	Insulation Resistance (Teraohms, Corrected to 60°F)					
					20 Years		40 Years		60 Years	
					Unaged	Aged	Unaged	Aged	Unaged	Aged
BONDED JACKET	OK	C/E	1 min	8.57	4.49	0.07	6.83	0.07	9.25	0.22
			10 min	49.06	19.81	0.07	20.03	0.09	38.75	0.48
			PI	5.729	4.41	1.14	2.93	1.47	4.19	2.22
	SM	C/C	1 min	5.18	6.94	3.22	4.98	1.93	6.08	2.43
			10 min	55.01	33.75	11.28	80.92	5.07	103.74	10.04
			PI	10.63	4.86	3.50	16.26	2.63	17.07	4.13
		C/E	1 min	1.65	1.30	0.77	5.48	0.15	1.31	0.98
			10 min	13.87	8.96	6.27	35.40	0.34	10.11	2.98
			PI	8.41	6.91	7.96	16.54	2.21	7.74	3.05
UNBONDED JACKET	AN	C/C	1 min	3.24	4.55	3.00	2.35	0.79	-----	-----
			10 min	23.83	27.00	10.40	24.07	3.18	-----	-----
			PI	7.36	5.93	3.35	10.29	4.05	-----	-----
	AI	C/C	1 min	27.39	46.91	0.87	-----	-----	4.55	0.47
			10min	46.98	74.31	1.41	-----	-----	10.21	1.58
			PI	1.72	1.58	1.49	-----	-----	2.25	3.34
		C/E	1 min	3.34	4.11	0.32	-----	-----	1.10	0.47
			10 min	12.57	13.22	0.46	-----	-----	3.96	0.82
			PI	3.76	3.22	1.44	-----	-----	3.59	1.66

OK - Okonite 1/C #12
SM - Samuel Moore 2/C #16 with shield & ground
AN - Anaconda 3/C #12
AI - American Insulated Wire 3/C & 4/C #16 with ground
C/C - Conductor-to-Conductor
C/E - Conductor-to-Ground
PI - Polorization Index

All of the EPR-insulated cables showed a trend toward decreasing IR values after pre-aging. The Samuel Moore and Anaconda cables, which experienced relatively mild pre-aging compared to the Okonite cables, exhibited a very strong incremental trend toward decreasing IR with a corresponding increase in pre-aging/insulation degradation. This is illustrated in Figure 5.55 for the Samuel Moore cables and Figure 5.56 for the Anaconda cables in which the average conductor-to-conductor, temperature-corrected IR values are plotted as a function of the incremental level of pre-aging administered.

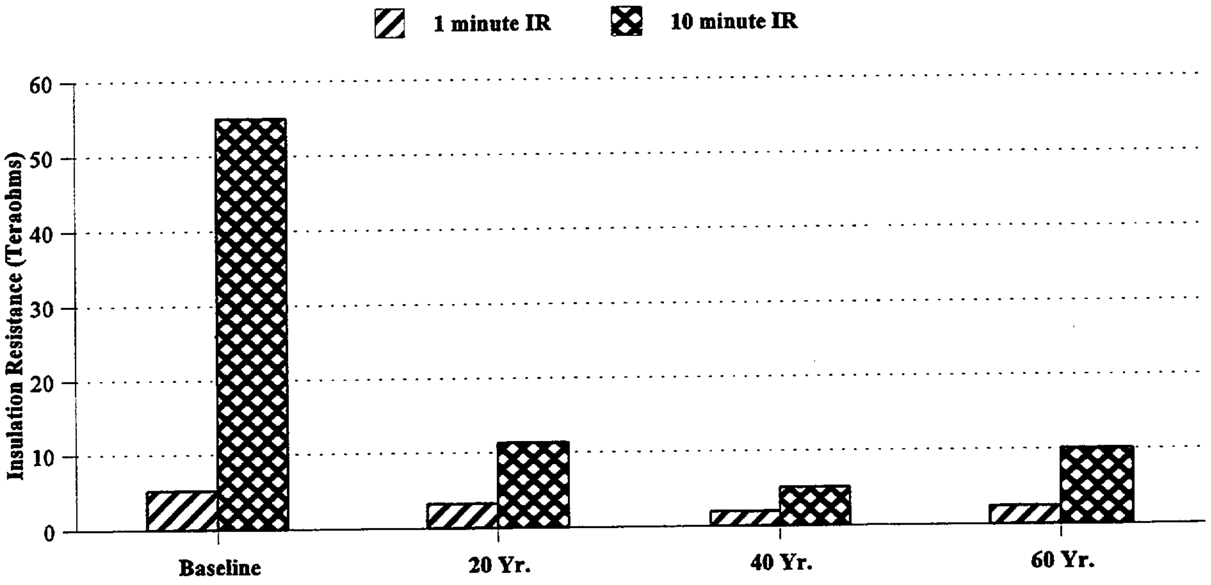


Figure 5.55 Insulation Resistance (IR) for aged EPR-insulated Samuel Moore cables

In contrast, the insulation on the Okonite cables, which experienced very harsh pre-aging conditions, was completely embrittled even after 20 years of pre-aging, as evidenced by the low EAB values in Tables 3.22 and 3.26 of Volume 1 of this report. The additional 40 and 60 year pre-aging administered to the Okonite cables did little further damage to the insulation compared to the 20 year aged insulation. This is reflected in the uniformly low average IR readings for the 20, 40, and 60 year cables and the corresponding low average PI values. Given the large drop in IR between the unaged overall baseline values and the 20 year aged cables, however, it follows that insulation resistance/polarization index could be a trendable parameter for gradual increments of degradation smaller than the severe pre-aging conditions applied in this test.

The pre-aging applied to the AIW cables was not as severe as that experienced by the Okonite cables, and the EAB measurements in Tables 3.8 and 3.26 of Volume 1 of this report show a significant amount of ductility remaining in the insulation; 196 percent and 218 percent for the 20 and 60 year cables, respectively. This indicates that the two groups were similar in their physical condition. Electrically, the two groups also exhibit similar IR readings. However, the large decrease in IR compared to the average baseline levels, together with poor PI readings, indicate that the dielectric properties of the insulation had deteriorated significantly after only 20 years of pre-aging and were electrically similar to the 60 year aged cables. A subsequent post-LOCA 6 inspection showed that the white-colored individual Hypalon® jackets had numerous small (approximately 1mm) surface cracks, which may have contributed to the observations in Table 5.12.

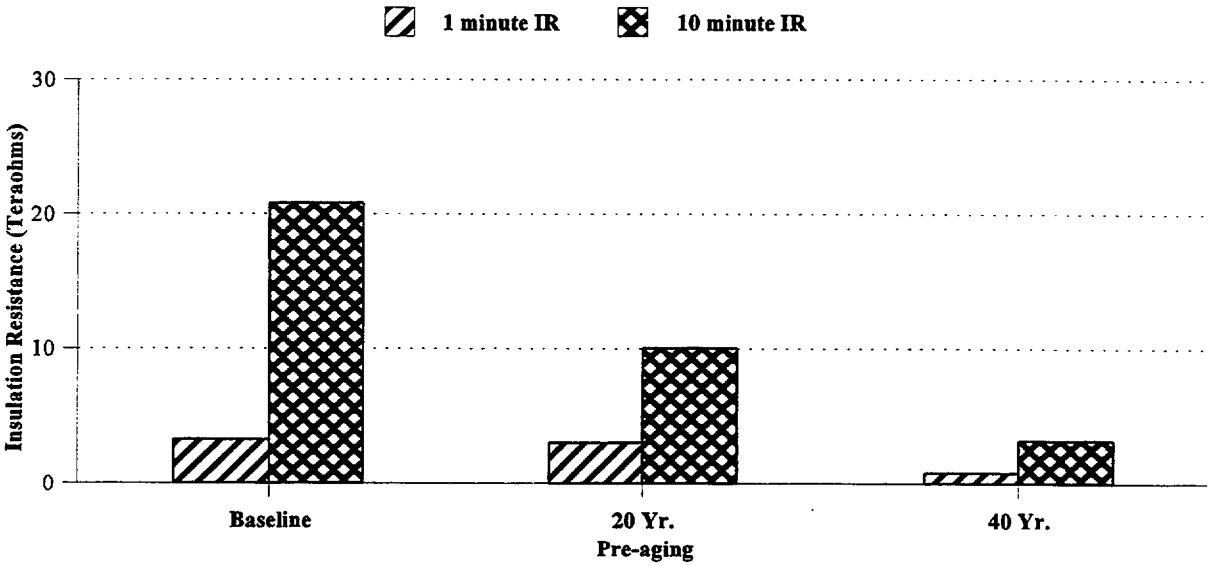


Figure 5.56 Insulation Resistance (IR) for aged EPR-insulated Anaconda cables

Nevertheless, the large change in insulation resistance from the baseline to the 20 and 60 year aged cables implies that the insulation resistance/polarization index could be a trendable parameter for gradual increments of degradation smaller than the relatively severe pre-aging applied during qualification testing. This was in fact found to be the case in test sequence 2 (Lofaro, et.al., November 1998C) where temperature-corrected insulation resistance measurements for baseline EPR-insulated AIW cables, 24-year-old naturally aged cables, cables aged to match the naturally aged cables, and incrementally aged 20 year cables corresponded to the relative level of degradation for each group.

The test data for hold points in the pre-aging process, as described in Volume 1 of this report, and observations by the BNL test engineers indicate that the insulation resistance readings are a trendable parameter for the smaller increments of insulation damage that would be encountered during normal service aging in a nuclear power plant environment. Based on these results, temperature-corrected insulation resistance or polarization index values, particularly when compared to a baseline measurement, are considered an electrical condition monitoring technique capable of observing incremental trends in degradation for these materials. If well defined end conditions can be established, this technique may be useful for estimating remaining life.

5.10 Functional Performance

EPR-insulated cables from four different manufacturers were connected into individual 4-20 mA instrumentation loop circuits in order to assess their functional performance throughout the LOCA exposures in test sequences 2, 4, 5, and 6, as discussed in Section 3.10. All of the pre-aged Samuel Moore (EPDM-insulated 2/C #16 AWG with individual bonded Hypalon® jackets and overall Hypalon® jacket), AIW (EPR-insulated 3/C & 4/C #16 AWG with individual unbonded Hypalon® jackets and overall Hypalon® jacket) and Anaconda cables (EPR-insulated 3/C #12 AWG with individual unbonded Hypalon® jackets and overall Hypalon® jacket) performed adequately on the functional performance test. Instrument loop circuit currents and voltages remained at their nominal levels and leakage currents were negligible throughout the duration of the LOCA exposures.

The pre-aged 1/C #12 AWG Okonite cables with EPR insulation and bonded Hypalon® jacket experienced problems on the functional performance test in both test sequences 5 and 6. Test sequence 5 contained unaged (Group 5.1), 20 year (Group 5.2), and 40 year (Group 5.3) pre-aged Okonite cables. Instrument loop circuit currents and voltages remained at their nominal levels and leakage currents were negligible throughout the initial preheat of the test chamber and the double peak pressure/temperature transient. During cooldown from the second transient peak, at approximately 15 hours into test, chemical spray was initiated and maintained for the next 24 hours. Immediately upon initiation of the chemical spray, leakage currents, ranging from 0.2mA to 0.6mA, were observed for the three specimens in Group 5.3. Upon completion of the chemical spray, the leakage currents returned to negligible levels.

After completion of the LOCA exposure for test sequence 5, a check of the test specimen wiring revealed that the single conductor Okonite specimens had inadvertently been connected in to the positive side of the test circuit. Since this portion of the circuit was referenced to ground, this configuration minimized the potential between the conductors and ground. This impaired the ability of the test setup to monitor the full leakage current for the Okonite specimens. This is documented in Notice of Anomaly 11 in Appendix B to Volume 1 of this report.

The Okonite cables aged to the equivalent of 60 years of service at 194°F (90°C) (Group 6.2) also experienced problems during the LOCA exposure for test sequence 6. During the 3 hour hold period at the peak conditions of the first pressure/temperature transient, a leakage current of 0.2mA was observed in Okonite Specimen 0605. This returned to 0mA during the cooldown preceding the second pressure transient. Within a minute of initiating the second transient, the 1/32 ampere protective fuses in the instrument loop circuits in all three of the Group 6.2 Okonite specimens blew. After the fuses were replaced, two of the three circuits continued to operate; 0607 blew the new fuse immediately and it could not be replaced successfully until about 15 minutes later. The protective fuses for circuits 0605 and 0606 blew for the second time during cooldown from the second transient, with circuit currents measured at between 200 and 300mA. Approximately one hour later, the protective fuse for circuit 0607 blew for the third time with a circuit current measured at about 273mA. All three of the Okonite circuits were removed from service for the remainder of the LOCA test.

The functional performances for the pre-aged EPR-insulated Anaconda, Samuel Moore, and AIW cables were adequate. Instrument loop circuit currents and voltages remained at their nominal levels, and leakage currents were negligible throughout the duration of the LOCA exposures. These results are in agreement with several of the other condition monitoring tests such as the elongation-at-break, insulation resistance/polarization index, and dielectric power factor.

Referring to the elongation-a-break (EAB) values for Okonite cables aged to 20 years of service at 194°F (90°C) in Table 3.22 of Volume 1 of this report, it can be seen that the EAB had been reduced to less than 5 percent. This means that the ductility of the EPR/Hypalon® insulation for the 20, 40, and 60 year cable groups had all been reduced to minimum, and little difference would be expected in the level of degradation among the three groups. The poor insulation resistance and insulation power factor values reinforced these EAB findings by showing that the dielectric integrity for the three groups of cables was also marginal.

Because of the severe pre-aging administered to the Okonite cables, the cable insulation was extremely degraded and the resulting leakage currents were very high. This caused the protective fuses in the instrument loop circuits to blow frequently making it impossible to make meaningful quantitative measurements of circuit error. Post-LOCA visual inspection revealed that catastrophic failure of the cable insulation/jacket material occurred at some time during the LOCA exposure for the all of the 40 year (Group 5.3) and 60 year (Group 6.2) Okonite cables. Consequently, the functional performance test for the pre-aged Okonite cables in these groups was in effect a pass/fail test because of the excessive leakage currents.

5.11 Voltage Withstand

Upon completion of the LOCA exposure test, EPR-insulated cables from four different manufacturers in test sequences 2, 4, 5, and 6 were removed from the LOCA test chamber and subjected to a post-LOCA submerged voltage withstand test. This test, described in Section 3.11, is the final step of the pre-aging/LOCA test sequence followed in the BNL test program. The data obtained are included in Appendix I. Selected results are discussed in the following paragraphs.

Each long cable specimen was connected, one conductor at a time, to a Hippotronics Model 760-2HVT high potential test set and energized at 2,400Vac (80Vac per mil of insulation thickness), 60 Hz, while submerged in tap water at room temperature (~73°F/23°C). The test voltage was applied to each conductor for a total duration of 5 minutes, and the leakage current and applied test voltage were recorded. If the leakage current exceeded the maximum level that the test set is capable of measuring, 10mA in this case, or a voltage breakdown was observed, the test specimen was considered failed.

As discussed in Section 3.11, the submerged voltage withstand test is the final step in the environmental qualification type test procedure described in IEEE Std. 383-1974 for electric cables. The BNL test sequence differs from the IEEE standard in that the cable specimen is voltage withstand tested as-is, coiled on its stainless steel test mandrel, or straight, in a steel Unistrut® support channel. In the IEEE test, the cable specimen is removed from its test mandrel following the LOCA exposure, straightened, and then coiled back onto a mandrel prior to final voltage withstand testing. This process of straightening and recoiling the test specimen was judged to be unnecessarily severe, and was, therefore, not included in the BNL test sequence.

The results of the submerged post-LOCA voltage withstand test on the EPR-insulated cables from four different manufacturers are summarized in Table 5.13. The test data from Tables 3.9, 3.19, 3.23, and 3.27 in Volume 1 of this report for test sequences 2, 4, 5, and 6, respectively, were sorted by the amount of pre-aging received by the EPR-insulated specimens prior to the LOCA exposure test, and the average leakage current measured for each pre-aging group was then calculated. The leakage currents for those specimens that successfully withstood the applied test voltage for the full 5 minute duration of the test are included in each group. The quantity of cable conductors successfully passing the test is shown for each pre-aging group.

Table 5.13 clearly shows that there is a trend toward increasing leakage current observed during the voltage withstand test for EPR-insulated cable specimens that had been subjected to a greater level of pre-aging prior to LOCA exposure, compared to those with no pre-aging prior to LOCA exposure. This trend, observed in the EPR-insulated cables from all four manufacturers, is generally what would be expected for increased amounts of insulation degradation.

As mentioned in Sections 3.5.7 and 3.6.7 in Volume 1 of this report, one of the 1/C #12 AWG Okonite cables that was pre-aged to the equivalent of 20 years of service at 194°F(90°C) displayed a 12cm-long longitudinal crack visible in the outer jacket during the LOCA exposure, and those that were pre-aged to 40 and 60 years experienced catastrophic failure of the EPR insulation/bonded Hypalon® jacket. Therefore, it was virtually impossible for these specimens to pass the submerged voltage withstand test, and testing confirmed this.The EPR-insulated cable specimens from the other three manufacturers displayed a trend of increasing leakage current during the post-LOCA voltage withstand test that corresponded to the increased levels of degradation brought about by pre-aging to 20, 40, and 60 years prior to LOCA exposure testing. This trend was supported by data from other condition monitoring methods such as elongation-at-break, insulation power factor measurements, and insulation resistance/polarization index measurements. Cables that were not pre-aged, or that experienced pre-aging degradation that resulted in an average leakage current below 1,000μA on the post-LOCA voltage withstand, test experienced no failures. For average leakage currents between 1,000 and 1,500μA, failures were approximately 7.5 percent; for average leakage currents between 1,500 and 2,000μA, failures were approximately 20 percent; and for average leakage currents between 2,000 and 3,040μA, failures were approximately 33 percent.

Table 5.13 Results of post-LOCA submerged voltage withstand test for aged EPR/Hypalon® cables

Cable		Conductor	Average Leakage Current (micro Amperes)			
			0 Years	20 Years	40 Years	60 Years
BONDED JACKET	OK	C/E	730	1000	>10000	>10000
		Qty Passing	2 of 2	1 of 2	0 of 3	0 of 3
	SM	White	767	1200	1750	3600
		Black	717	1250	1400	2667
		C/E	742	1225	1575	3040
		Qty Passing	6 of 6	8 of 8	8 of 10	5 of 6
UNBONDED JACKET	AN	White	790	785	1242	-----
		Black	760	925	1166	-----
		C/E	775	855	1204	-----
		Qty Passing	4 of 4	4 of 4	10 of 10	-----
	AI	White	920	926	-----	4200
		Black	1093	874	-----	1400
		C/E	1024	900	-----	2333
		Qty Passing	5 of 6	10 of 10	-----	3 of 6

OK - Okonite 1/C #12
AN - Anaconda 3/C #12
C/E - Avg White & Black Conductor-to-Ground
SM - Samuel Moore 2/C #16 w/ Shld & Gnd
AI - American Insulated Wire 3/C & 4/C #16 w/ Gnd

The AIW cables that received no pre-aging prior to LOCA performed slightly worse than AIW cables that had been pre-aged to the equivalent of 20 years of service prior to LOCA exposure. This apparent discrepancy was observed and discussed in the sections on ac impedance testing and insulation resistance/polarization index testing where a similar behavior was observed. This is attributed to improved dielectric strength brought about by driving entrapped and absorbed moisture out of the cable materials during the mild 20 year service pre-aging. This improved the cables' performance during the LOCA exposure, and was apparently carried over into slightly better performance on the post-LOCA submerged voltage withstand test. One white Hypalon®-jacketed, EPR insulated conductor on the unaged AIW control cable Specimen 0603 failed the voltage withstand test. Subsequent visual inspection and testing revealed that the white-colored Hypalon® jackets in all of the AIW cables in test sequence 6 had numerous longitudinal cracks, approximately 1mm in length, but occasionally as long as 10mm. The failure in cable Specimen 0603 had occurred at the site of one of the longer cracks in the white-colored Hypalon®.

5. Condition Monitoring - EPR Cables

The submerged voltage withstand test provides a measure of the electrical condition of a cable specimen's insulation following LOCA exposure testing. However, in its present protocol for this research program, it is not a true condition monitoring test. Even conducted as a dry high potential test, it would not normally be used in situ, by nuclear power plant technicians, to assess and trend the dielectric integrity of an I&C cable's insulation system. Since it is a high voltage test, it has the potential to destroy a cable if a voltage breakdown should occur. Even at lower levels of applied test voltage, within the voltage rating of the cable, the cable insulation is incrementally weakened by each high potential test. Thus, the risks of causing either catastrophic or incipient damage to cable insulation make this an unsuitable condition monitoring method.

6. CONCLUSIONS

Each of the condition monitoring techniques studied in this program was evaluated in terms of how effective it is at monitoring the in situ condition of low-voltage I&C electric cables, and whether the technique was capable of predicting accident survivability. It should be noted that all of the condition monitoring data evaluated in this study were obtained in a laboratory setting, therefore, conclusions regarding the application of the techniques in an actual plant setting cannot be directly drawn from this work. The impact of plant operating environments and logistics on the feasibility of performing these techniques in situ should be considered. The following paragraphs discuss the conclusions for each of the CM techniques resulting from this study. Advantages and limitations of each technique are discussed.

6.1 Effectiveness of CM techniques for in situ monitoring

In general, no one CM technique was identified that could be used to effectively monitor the conditions of all types and configurations of cables. Some techniques were found to be more effective than others depending upon the application and the environment under which measurements were made. Each technique has advantages and limitations that must be considered and accounted for when applying it. It is believed that a combination of techniques is the most useful approach to effectively monitor the condition of low-voltage electric cables in situ. Each of the CM techniques studied is discussed below in terms of its effectiveness, advantages and limitations.

6.1.1 Visual Inspection

Visual inspection was found to be a very effective technique for providing a qualitative assessment of a cable's condition. While no quantitative data is obtained, the results can be trended to provide an assessment of how fast a cable is degrading under the operating conditions to which it is exposed. This technique can be used to evaluate the condition of a cable and determine if more extensive testing is required to characterize its condition. In most cases in this program, cables that appeared to be in good physical condition through visual inspection showed acceptable electrical performance under accident conditions.

The major advantage of the visual inspection is that it is inexpensive to perform and it does not require any expensive equipment. A standardized procedure should be developed to ensure that a consistent inspection approach is used and that all of the important cable attributes are inspected.

The most serious limitation of this technique is that the cable to be inspected must be accessible and visible. In some cases, cables may be installed in closed conduits or buried beneath other cables in a cable tray. In these cases, visual inspection would not be directly useful. Also, even for visually accessible cables, usually only the jacket can be seen. Therefore, inspection of the insulation would probably not be possible. However, visual inspection of representative cables that are accessible could be used to provide an indirect measure of the condition of the inaccessible cables.

Based on the results of this study it is concluded that visual inspection should be considered for inclusion in any cable condition monitoring program. While it does not provide quantitative data, it does provide useful information on the condition of the cable that is easy and inexpensive to obtain, and that can be used to determine if further investigation of the cable condition is warranted. A significant limitation of this technique is that the cable must be visually accessible.

6.1.2 Elongation-at-Break

The analyses presented in Sections 4.2 and 5.2, and the data base given in Appendix A of this report, show that EAB is a very valuable parameter for monitoring aging in cable materials because of its sensitivity to microstructural changes in polymers brought about by service aging. The specimens tested in the current program were prepared from cable that had been disassembled into insulation and jacket components where possible. For bonded components, however, it was necessary to test composite specimens consisting of jacket material bonded to the insulation. Since the individual cable components were directly exposed to the service aging and LOCA test environments, it is likely that the EAB measurements are conservative when compared to data taken from cables that were aged in the as-received condition and then disassembled for EAB testing. This is because the outer jacket would be expected to provide some degree of protection to the individual jackets, if present, and the insulation during the aging process. Below are given some of the general observations for the unbonded cables types that were studied:

- For XLPE and EPR insulation, simulated reactor power plant service aging will cause gradual decreases in EAB, even when antioxidants are still present in the material. The EAB appears to decrease to a plateau value provided that the antioxidants have not become completely depleted by the oxidation process. Similar decreases in EAB occur for Neoprene® and Hypalon® jackets during simulated service aging.

- When all of the antioxidants have been depleted from the insulation, the EAB values for the insulation begin to decrease dramatically to a low value and embrittlement may result. No results are available from this effort to show whether the jacket materials behave similarly, since no estimates could be made regarding the times at which the antioxidants had become depleted.

- LOCA radiation doses of about 150 Mrad usually cause major losses in EAB for both unaged and service-aged cable components. However, in many cases, these large radiation doses, while causing major losses in EAB, do not alone cause complete embrittlement since post-radiation EAB values of 40-50 percent are commonly observed. It appears that cable materials must already have lost a large amount of ductility from service aging before the LOCA radiation can cause embrittlement.

- Of the jacket materials studied, Neoprene® is more susceptible than Hypalon® to radiation-induced losses in EAB.

- The LOCA steam/chemical spray administered after the 150 Mrad of LOCA radiation usually increases the EAB for XLPE. The EPR, Neoprene®, and Hypalon® show losses in EAB after spraying.

- Data for bonded EPR/Hypalon® and EPDM/Hypalon® cable specimens generally followed the same trends as for the unbonded materials. The simulated service aging, and the LOCA radiations and steam/chemical sprays, cause decreases in EAB, but complete embrittlement was not observed unless the service aging was extremely severe.

In general, EAB measurements provide a useful quantitative assessment of the remaining integrity of a cable. As the EAB decreases to a low value, and crack initiation and propagation become possible from in-service stresses, moisture intrusion and current leakage could become a problem. At this time there does not appear to be any commonly acceptable criterion that defines the minimum EAB for a cable material that will define the end of its useful service life. A conservative value of ≥50 percent has been used as an acceptance criterion, even though there is usually some useful service life remaining. It may be feasible to correlate with an existing electrical failure criterion so that a minimum EAB value could be specified.

The major concern with EAB testing is that it is a destructive test, and relatively large amounts of cable are required. They can only be obtained if cable is removed from service, or if surveillance-type cables are available for periodic evaluation.

In summary, elongation-at-break was found to be a reliable technique for determining the condition of the polymers studied. It provides trendable data that can be directly correlated with material condition. It is useful as a reference technique, however, its destructive nature prevents it from being used as an in situ means of monitoring electric cables unless sacrificial cable specimens are available.

6.1.3 Oxidation Induction Time

Both the OITM and EAB for XLPE decrease as service aging time increases. As shown in Section 4.2, a rapid decrease in EAB occurs when the antioxidants in the insulation are depleted. Data for EPR (Figs. 5.17 and 5.18) show similar trends in which decreases in OITM are observed when the EAB decreases and the service aging time increases. Since the OITM, which is a measure of the remaining amount of antioxidant in an aged specimen, changes sensitively with aging, it is an ideal technique for monitoring the kinetics of degradation. The ability to correlate this parameter with EAB make it possible to estimate the residual ductility of cable insulation.

The limited results for Hypalon® jacket material were mainly for specimens that were exposed to LOCA test conditions (see Appendix B). They show that LOCA radiation doses of about 150 Mrad cause a decrease in the OITM, as would be expected. This is an indication that OITM measurements would also be capable of monitoring aging and EAB changes in Hypalon® for normal service aging conditions. No results were obtained for Neoprene® because the classical thermogram curve, with a flat oxidation-induction period, was not present under the current test conditions.

In summary, OITM was found to be a promising technique for monitoring the condition of electric cables. Results show that aging degradation can be trended with this technique for both XLPE and EPR insulation. While a small sample of cable material is needed to perform this test, the relatively small amount required should be obtainable without impacting cable performance.

6.1.4 Oxidation Induction Temperature

The OITP results for XLPE given in Section 4.4 and Appendix C are not comprehensive since the materials were either aged for very short service aging periods for which little change would be expected, or for very severe qualification protocols that rendered the material brittle. The data in Appendix C show that, for mild service aging conditions, the OITP shows very little change. For a severe aging treatment that causes embrittlement of the XLPE, however, the OITP for XLPE decreased by about 60°F (33°C). For more normal service aging treatments, the relative changes in OITP are small compared to those for OITM. For LOCA radiation doses of about 150 Mrad, the OITP for XLPE does not decrease by more than several degrees. After steam/chemical spraying, the OITP for XLPE decreased again. Data for Neoprene® jackets show that service thermal aging initially increases the OITP, however, after the service radiation the OITP falls to a value close to that for the unaged material.

LOCA radiation decreases the OITP for Neoprene®, but steam/chemical spraying cause an increase. It is possible that the increase could be a result of oxidizable compounds deposited on the specimens during the spray tests. If these compounds oxidize during the tests, they would decrease the rate of attack on the cable material and increase the OITP. Currently, there are insufficient data on XLPE/Neoprene® cables to determine the usefulness of OITP measurements to estimate aging characteristics.

For EPR, the OITP shows a consistent decrease with service aging. Also, there is a good correlation between OITP and the EAB. Similar correlations were found for Hypalon® jackets, but there is more uncertainty in the data trend. At this time, therefore, it is concluded that EPR/Hypalon® cables are amenable to OITP measurements that may be used to estimate the EAB. As such, OITP measurements for this type of cable are promising as a condition monitoring technique.

Based on the relative sensitivity to aging, however, it appears that OITP measurements, while very valuable, are less sensitive than OITM in trending the aging behavior of cable polymers. This is concluded from the fact that OITP values change by only tens of degrees Celsius from starting values of about 240-250°C (a change of about 10-15 percent), whereas OITM values, depending on the test temperature and material, can change from 40-100 minutes to essentially zero.

In summary, while it is related to OITM, OITP was found to be less sensitive to the detection of aging degradation for the polymers studied. It may be useful as an in situ technique, however, OITM is preferred at this time.

6.1.5 Fourier Transform Infrared Spectroscopy

FTIR spectroscopy was evaluated as a potential condition monitoring technique for cable insulation. A selenium "Thunderdome®" attachment to the infrared spectroscope was used to obtain surface measurements on aged cable specimens. Previous researchers have measured changes in the absorbance (or transmittance) of infrared radiation by carbonyl bonds. Since these C=O bonds are formed during oxidative degradation, they are a direct indication of polymer oxidation. Unfortunately, the selenium crystal could not detect any significant peaks at the 1730 cm^{-1} wavenumber location. According to the manufacturer of the Thunderdome® attachment, this might be a result of incompatibility between the refractive indices for the selenium crystal and the cable materials. It was, therefore, decided to measure the transmittance of infrared radiation at wavenumber 2916 cm^{-1}, which represents the $-CH_2$ bond, to determine if it changed as a material was aged. It has been generally assumed that the $-CH_2$ bonds are extremely stable since they are incorporated in the polymer backbone structure, which is protected by the presence of antioxidants.

The experiments show that decreases in the $-CH_2$ bond actually do occur with aging and radiation. This is indicated for XLPE, although the data are very limited, and for EPR. It is not clear whether the loss of the bonds is from the backbone or from some other constituent in the insulation that contains the $-CH_2$ bond. The transmittance has been shown to be correlatable with the EAB. As the EAB decreases as a result of aging, the transmittance increases. This is consistent with the loss of $-CH_2$ bonds which would give increased transmittance. The technique has the advantage of examining very small areas of cable and is, therefore, non intrusive.

One of the potential problems with the FTIR spectroscopy technique is that it is a surface examination procedure in which the infrared radiation passes into the surface of the specimen and is refracted back into the crystal. By analyzing the intensity of the incident and reflected rays, the transmittance is determined. Since accelerated thermal aging at elevated temperatures will produce an oxidation gradient at the specimen surface, the spectroscope will detect a higher amount of oxidation that the average bulk value. The technique would, therefore, be expected to give a more accurate estimate of bulk aging for naturally-aged specimens, for which oxidation gradients will be minimized at the lower service aging temperatures.

Based on the current results, it is not clear if FTIR spectroscopy would be appropriate as a non-intrusive condition monitoring technique. As a surface monitoring procedure it has limitations when attempts are made to correlate data to bulk properties such as EAB.

6.1.6 Indenter

The indenter was found to be easy to operate and capable of producing repeatable results. It can be operated by one person in the laboratory, though in situ testing in a nuclear power plant would require two persons. Over the course of the six test sequences, the indenter was used to obtain over 15,000 data points on over 100 cable specimens. Over this period, only one operational problem was noted, resulting in the replacement of the electric motor. This failure was easily identified by widely-varying modulus results and did not affect any of the data used in this program.

In many instances, cables are not easily accessible in nuclear plants. Often they may be stacked in cable trays or run through conduits, which severely limits access to perform CM testing. For cables which are accessible, the indenter can be used to determine the modulus of the outer jackets. For those cables that are not accessible, it is not desirable nor possible, in some instances, to excessively handle the cables to permit indenter testing. To monitor the modulus of individual jackets or insulation, access would be needed at a termination point. This is not the optimum situation, since the termination points may be physically located in a different plant location and exposed to very different ambient conditions than the remainder of the cable. This highlights the potential benefit from the use of test coupons which could be strategically located throughout the plant and used for CM. However, in the absence of test specimens, there may be no alternative, and CM must be performed where physically accessible.

An assessment of the condition of an electrical cable must focus on the insulation. The outer jacket (for unbonded specimens) is primarily for physical protection, and not for electrical performance. This creates a unique problem, because, as seen from the results obtained from this program, an outer jacket may be severely degraded while the integrity of the insulation is still maintained.

The indenter was found to be a non-destructive test which did not affect the continued operation of the cable. The indenter software prevented the probe from penetrating the material being tested, from leaving residual marks, or from causing any other type of damage. It is suitable for use on various materials (XLPE, EPR, Hypalon® and Neoprene®). However, not every material produced significant age-induced changes that could easily be correlated with thermal or radiation exposure. For low levels of aging, relatively small modulus changes were seen, which, in the absence of baseline measurements, might be difficult to correlate with aging. Cable construction and manufacturer were also found to produce different modulus results for the same aging. The results obtained were found to be correlatable with EAB measurements, which is an indication of this technique's usefulness. It can also provide an alternative to EAB, which by its nature requires specially prepared samples and is a destructive test.

From the results of this program, it was determined that the indenter is an effective mechanical monitoring technique, which can be used in situ or in the laboratory. The changes in a polymer's compressive modulus reflect the condition of the material, and can be an important indicator of remaining life. Dramatic increases in modulus are indications of extreme exposure to temperature and radiation, which can be used to determine replacement schedules for the whole, or individual sections of the cable.

6.1.7 Hardness

As discussed in Sections 4.7 and 5.7, hardness was one of the condition monitoring methods used to assess the mechanical condition of the cable specimens in this test program. For this purpose, a Type-D Rex Durometer was chosen. This type of hand held hardness tester has a sharp pointed tip which, when pressed against the polymer using a ten pound spring force, allows the Shore-D hardness to be read on the vernier type scale. Rather than risk inducing damage on the long specimens being tested, basket specimens were used for the hardness testing. Similar to the indenter, cable location would present a potential problem for the in situ use of this method. Specimens located in conduits or buried in cable trays would be inaccessible.

The polymers tested in this program (EPR, Hypalon®, Neoprene®, and XLPE) transitioned from being very soft, to various degrees of hardness, up to totally brittle when aged. Because of this wide span of hardness, a major difficulty encountered was that the Rex durometer was found to be inadequate in effectively obtaining hardness measurements. The sharp tipped point was more suited for softer, thicker materials, while a rounded tip would have been better suited for the brittle material conditions.

As discussed, the thickness of the polymer materials tested in this program necessitated sample stacking in order to obtain hardness readings. Without doing this, the sharp pointed tip penetrated the material. While the stacking technique was found suitable for laboratory use, it is not feasible for in situ studies. One exception to this conclusion would be the use of test coupons, which could be removed and tested. Penetrating the jacket or insulation is unacceptable for several reasons, not the least of which is personnel safety. Contact of the tip of the hardness tester with a potentially energized cable could result in serious physical harm.

Discussions regarding improvements in the hardness testing technique with experts in this technique indicated that a specialized tester could be designed to accommodate various material hardness values. This tester would have the capability to change the tips and the spring force. However, the indenter is an alternative that provides similar data and has already been shown to be effective. Therefore, development of an improved hardness tester was judged not to be appropriate.

6.1.8 Dielectric Loss

Dielectric loss measurement using the two-channel Hewlett Packard HP 35670A Dynamic Signal Analyzer is a very simple and straightforward condition monitoring technique. An internal source provides the applied ac voltage signal to the test specimens, and an internal disk drive allows the data to be stored for later analysis. The instrument is programmable so the testing routine can be setup, stored on a 3.25" diskette, and reloaded whenever it is needed. For the testing performed in this program, the instrument was programmed to apply the 5 Vac (peak) test voltage at increasing increments of frequency ranging from 0.1 Hz to 5000 Hz, while measuring and recording the dielectric phase angle at each increment. This feature yields very repeatable results.

Some of the factors which affect the dielectric loss measurement technique include cable length, humidity or moisture within the cable and insulation, and electrical equipment operating in the vicinity of the test cable. Testing was performed at BNL to study and quantify these effects by testing various lengths of cable in cable tray with other cables in an industrial environment. The effect of length is very uniform and predictable, resulting in a relative increase in insulation power factor as the length of cable increases. This effect is most easily accounted for by making in situ baseline measurements for each cable to be monitored to serve as a standard for comparison with similar measurements in the future. The effect of other operating electrical equipment or energized cables in the same tray was concentrated at the frequency of the operating equipment. In most cases, this was the 60 Hz power frequency and it had a more pronounced effect on longer cables than short ones. This problem can be avoided by making measurements at an applied ac test voltage with a frequency below 50 Hz or above 70 Hz.

The effects of humidity or moisture within the cable and insulation were observed in measurements made on EPR-insulated cables. As described in Sections 5.8 and 5.9, the cable specimens exhibited improved dielectric properties after initial thermal aging had driven all moisture and humidity out of the cables. The effect on dielectric loss measurements was less severe than for the insulation resistance tests. In any event, the sudden extreme change in moisture would not normally occur in a plant environment. By making baseline measurements against which future condition monitoring results can be compared, the effects of moisture would be minimized under normal plant conditions.

The major advantage of the dielectric loss technique is that the cable being tested does not have to be completely accessible. The test equipment can be connected to the ends of the cable, and the test can be performed without physically touching the length of the cable. Also, no material samples need be taken from the cable.

A disadvantage of the dielectric loss technique is that the cable under test must be disconnected in order to attach the test instrument. However, this can be controlled by test procedures with independent verification steps, as are commonly used for surveillance and maintenance procedures in nuclear power plants.

EPR-insulated cables with bonded and unbonded Hypalon® jackets, in both single and multiple conductor configurations, all demonstrated a measurable trend toward increasing power factor (deteriorating dielectric strength) with greater insulation material degradation. Similarly, XLPE-insulated cables also exhibited the trend toward increasing power factor as the cables were subject to greater degradation during pre-aging. This trend was most pronounced and consistent at applied ac test voltage frequencies in the range from 10 to 500 Hz. The effect was also best observed in measurements from conductor-to-ground. Dielectric loss measurements, particularly when compared to a baseline measurement, are thus considered a good electrical condition monitoring technique for these materials.

6.1.9 Insulation Resistance

Insulation resistance measurement using the General Radio Model 1864 Megohmmeter is a very simple and straightforward condition monitoring technique. The megohmmeter is a familiar piece of test equipment known to all electrical maintenance personnel and it is routinely used in nuclear power plants. The main advantages of this test method are that it is relatively easy to perform and requires inexpensive test equipment. For quantitative data collection on electric cables, a megohmmeter that is capable of accurately measuring insulation resistance in the Teraohm range is required.

One disadvantage of making insulation resistance measurements is that the cable under test must be disconnected in order to attach the test instrument. However, this can be controlled by test procedures with independent verification steps, as are commonly used for surveillance and maintenance procedures in nuclear power plants.

The major factor affecting insulation resistance measurements is temperature. The effect of temperature is predictable and can be corrected by normalizing the raw insulation resistance readings to a common temperature, such as 60°F (16°C), for purposes of comparison. Using the ratio of the 10 minute insulation resistance to the 1 minute reading, the polarization index can provide a measure of dielectric condition that minimizes temperature effects. Consequently, in order to collect data that are trendable, accurate time and temperature data must accompany the raw quantitative insulation resistance measurements. For this reason, plant personnel often look upon the insulation resistance test as a simple pass/fail test for the dielectric integrity of electrical equipment and cables, but too irregular for trendable condition monitoring. The quantitative measurements in the BNL test program show that this test can be used to trend and monitor the condition of cable insulation.

Some of the other factors that can affect the insulation resistance technique include cable length, humidity or moisture within the cable and insulation, dirt, oil, and other surface contaminants, personnel in close proximity to the equipment under test, and electrical equipment operating in the vicinity of the test cable. Testing was performed at BNL to study and quantify some of these effects by testing various lengths of cable in cable tray with other cables in an industrial environment. The effect of length is very uniform and predictable, resulting in a relative decrease in insulation resistance as the length of cable increases. The effects of length and some of the other factors mentioned are most easily accounted for by making in situ baseline measurements for each cable to be monitored to serve as a standard for comparison with similar measurements in the future. The effect of other operating electrical equipment or energized cables in the same tray was found to be negligible in the BNL tests.

The effects of humidity or moisture within the cable and insulation were observed in measurements made on EPR-insulated cables. As described in Section 5.9, in comparison to baseline measurements the AIW cable specimens in test sequence 2 exhibited improved dielectric properties after initial thermal aging had driven all moisture and humidity out of the cables. In any event, the sudden extreme change in moisture would not normally occur in a plant environment. By making baseline measurements against which future condition monitoring results can be compared, the effects of moisture would be minimized under normal plant conditions. The effects of moisture and humidity on cables with XLPE insulation were found to be negligible under the humidity conditions experienced during the BNL condition monitoring tests.

EPR-insulated cables with bonded and unbonded Hypalon® jackets, in both single and multiple conductor configurations, all demonstrated a measurable trend toward decreasing insulation resistance and polarization index (deteriorating dielectric strength) with greater insulation material degradation. Similarly, XLPE-insulated cables also exhibited the trend toward decreasing insulation resistance and polarization index as the cables were subject to greater degradation during pre-aging. The trend was similar in measurements made from conductor-to-conductor and from conductor-to-ground. Insulation resistance measurements, particularly when compared to a baseline measurement, are thus considered a good electrical condition monitoring technique for these materials.

6.1.10 Functional Performance

One of the tests used to evaluate the cables in this program is the functional performance test. The ultimate objective for environmentally qualified low voltage power and instrumentation and control (I&C) cables is to be capable of successfully performing their intended function during a design basis accident occurring at the end of their service life. By including each cable specimen under test as part of a 4-20 mA instrumentation loop circuit, the performance of that cable specimen can be assessed throughout the LOCA exposure test by monitoring the performance of the instrumentation loop circuit. The accuracy and longevity required of an instrument circuit during an accident, and hence the acceptance criteria for a functional test, are application-dependent. They might be expressed, for example, as a maximum allowable percentage of error in the instrument circuit for some specified period of time following an accident.

During routine technical specification or preventive maintenance surveillance testing of instrumentation circuits in nuclear power plants, direct condition monitoring specifically for the instrumentation cable is normally limited to specialty cables for nuclear instrumentation and in-core monitoring. The majority of instrument circuit cables are only monitored indirectly as part of a surveillance test performed for an instrument loop, such as a calibration, functional test, response time test, or logic system functional test. If an instrument loop is not performing within specifications, the instrumentation cable is one potential cause, however, most problems are likely to be associated with the sensor, power supply, connectors, and actuators rather than the low voltage instrumentation cable. For this reason, BNL does not consider the functional performance test to be a good method for routine monitoring of cable condition.

For purposes of the research program, however, the functional performance test demonstrated that 4-20mA instrument loop circuits could continue to provide accurate indication even with severely degraded instrumentation cables operating in a simulated LOCA environment. Despite the presence of high leakage currents, the loop power supply typically could continue to supply current to the circuit with less than 10 percent error in the indicated pressure reading. The error in indicated pressure only became significant in the most severely degraded aged cables, such as the Okonite and Rockbestos specimens discussed in Sections 4.10 and 5.10, in which the leakage current became great enough to blow the 1/32 ampere fuse protecting the circuit power supply.

6.1.11 Voltage Withstand Test

Upon completion of the LOCA exposure test, each long cable specimen was connected, one conductor at a time, to a Hippotronics Model 760-2HVT high potential (high-pot) test set and energized at 2400Vac (80Vac per mil of insulation thickness), 60 Hz, while submerged in tap water at room temperature (~73°F/23°C). The test voltage was applied to each conductor for a total duration of five minutes, and the leakage current and applied test voltage were recorded. If the leakage current exceeded the maximum level that the test set is capable of measuring, 10mA in this case, or a voltage breakdown was observed, the test specimen was considered failed.

The post-LOCA submerged voltage withstand test was included as the final step in the test sequences for this program which were developed in accordance with the environmental qualification type test procedure described in IEEE Std. 383-1974 for electric cables. The BNL test sequence differs from the IEEE standard in that the cable specimen is voltage withstand tested as is, coiled on its stainless steel test mandrel, or straight, in a steel Unistrut® support channel. In the IEEE test, the cable specimen is removed from its test mandrel following the LOCA exposure, straightened, and then coiled back onto a mandrel prior to final voltage withstand testing. This process of straightening and recoiling the test specimen was judged to be unnecessarily severe, and was therefore not included in the BNL test sequence.

The test was also designated as the final step in the test sequence procedure because it is a high voltage test that has the potential to cause a voltage breakdown, which would permanently ruin the cable insulation. Each application of the high voltage may cause an incremental increase in the amount of degradation to the dielectric integrity of the insulation. This would alter the cable and compromise the results of other non-destructive electrical condition monitoring methods that were being evaluated under this research program. If this test is repeated a number of times, the dielectric strength may become so weakened that the cable could fail because of the testing.

The submerged voltage withstand test provides a measure of the electrical condition of a cable specimen's insulation following LOCA exposure testing. However, in its present protocol for this research program, it is not a true condition monitoring test which would be used to evaluate and trend the status of an I&C circuit's insulation system over the course of its service life. Even if it were conducted as a dry high potential test, it would not normally be used in situ, by nuclear power plant technicians, to assess and trend the dielectric integrity of an I&C cable's insulation system. Since it is a high voltage test, it has the potential to destroy a cable if a voltage breakdown should occur. Even at lower levels of applied test voltage, within the voltage rating of the cable, the cable insulation is incrementally weakened by each high potential test. Thus, the risks of causing either catastrophic or incipient damage to cable insulation make this an unsuitable condition monitoring method.

6.2 Using CM Techniques to Predict Accident Survivability

6.2.1 Visual Inspection

Visual inspection was found to be a useful technique for assessing the condition of a cable in a qualitative manner. In most cases in this study, cables that appeared to be in good physical condition showed acceptable electrical performance under accident condition. However, visual inspection alone is not considered sufficient to determine the accident survivability of a cable. For example, in this program Samuel Moore specimens that appeared to be in good physical condition failed a submerged voltage withstand test after exposure to 10 days of simulated accident conditions. Also, it was found that the condition of a cable's outer jacket was not, necessarily, indicative of the condition of the underlying insulation. Therefore, visual inspections alone should not be used to determine if a cable will perform acceptably under accident conditions. Rather, visual inspections should be used to determine if additional, more in-depth testing of a cable is warranted.

From visual examinations and electrical tests on long lengths of cable that were artificially-aged to simulate natural service aging, and then LOCA tested to determine the effects of high radiation doses and steam/chemical spraying, an approach to check cable survivability during a LOCA may be developed. The extensive visual examinations described in Volume 1, and Sections 4.1 and 5.1 in Volume 2 of this report, showed that local weaknesses or punctures in aged cables may lead to unacceptable current leakage. Subsequent submerged voltage withstand tests were also employed to detect cables that did not survive a LOCA test.

6.2.2 Elongation-at-Break

LOCA survivability was found to be related to the EAB measurements on 6-inch lengths of insulation and jacket materials that received the same aging and LOCA treatments as the long cables. Therefore, these results, reported in Appendix A, may be used to correlate with survivability. For the XLPE/Neoprene® cables, some of the severe service aging protocols resulted in EAB values for the XLPE and Neoprene® of only a few percent. Despite this, none of the cables failed in any of the BNL electrical tests after LOCA simulations. This indicates that embrittlement of

XLPE/Neoprene® cables does not provide the necessary pathways, such as deep cracks or weaknesses, to cause electrical failure. To be conservative in assuring survivability, one could show that the EAB values for the cable materials, during long term service, maintain some level of ductility. A residual EAB of 50 percent has been used by some to provide confidence that the cable will survive a LOCA.

Cables made from EPR/Hypalon® were also examined for electrical failure during LOCA testing. It was found that, unlike XLPE/Neoprene® cables, failures could occur even though the EAB for the cable components were relatively high. For example, in test sequence 4, some Samuel Moore cables failed the submerged voltage withstand test despite the fact that the EAB for the EPR insulation and Hypalon® outer jackets were 173 and 312 percent, respectively, after the 40-year qualified life aging. Therefore, the limiting EAB values for predicting accident survivability can vary based on materials of construction and cable configuration.

6.2.3 Oxidation Induction Time

Conceptually, OITM measurements can also be used as an indicator of cable survivability. Appendix B shows data for XLPE/Neoprene® and EPR/Hypalon® cables that have received accelerated service aging followed by LOCA testing. Some of the results are plotted in Sections 4.3 and 5.3 of this report. It was found that service aging followed by LOCA radiation and steam/chemical spray result in decreases in OITM. From extensive testing it should be possible to define the envelope of service aging conditions for which cables will pass a LOCA test. The associated OITM values for these limiting service conditions must be measured. If a cable material has an OITM value that is greater than these limiting values it would indicate survivability. To assure conservatism, a safety margin should be added to the limiting OITM values.

6.2.4 Oxidation Induction Temperature

The approach for using OITP measurements to check cable survivability is similar to that outlined above for OITM. Again, the envelope of service conditions that would allow a cable to pass a LOCA test would be determined, and this boundary defined in terms of the OITP values for the cable materials. By ensuring that the OITP values do not fall below the limiting values, there would be some confidence in survivability. Safety margins should be added to the limiting OITP values for conservatism.

6.2.5 Fourier Transform Infrared Spectroscopy

This condition monitoring technique evaluates the surface degradation of the cable materials. As stated in Section 6.1.5, above, there may be a problem associated with using the technique to predict bulk material behavior. Since, cable survivability is closely connected with bulk material degradation, the FTIR technique may not be appropriate for determining cable survivability.

6.2.6 Indenter

The Ogden Polymer Cable Indenter was used to monitor changes in the materials compressive modulus throughout various aging sequences. Compressive modulus results for cables aged to the equivalent of 20, 40, and 60 years of service, which did not fail,can be viewed as a representative bound for a given material. Since the cables in use have not been exposed to these levels of aging, any material approaching these upper bounds would be cause for additional evaluation (e.g., excessive temperature or radiation hot spots). This would allow plant owners who use the indenter to periodically assess the in situ condition of cables, and make a decision for continued use or replacement. The frequency of the CM can be altered by trending the modulus results and comparing it to the ranges provided. Cables which are exhibiting an increasing trend close to the upper bound reported may need to be tested more frequently, as opposed to those which remain near the lower bounds.

The compressive modulus ranges for XLPE and EPR insulation are summarized in Table 6.1. From modulus results observed in this study, EPR was found not to experience any significant change in modulus due to the pre-aging protocols used. XLPE, however, did experience some increase in the modulus, particularly following significant aging.

Table 6.1 Summary of compressive modulus values for XLPE and EPR insulation

	XLPE (Rockbestos) N/mm (lbs/in)			EPR (AIW, Anaconda) N/mm (lbs/in)		
	20 years	**40 years**	**60 years**	**20 years**	**40 years**	**60 years**
Baseline	100 (572)	104 (595)	102 (583)	13 (74)	12 (69)	16 (91)
Aged	116 (663)	152 (869)	196 (1121)	14 (80)	17 (97)	17 (97)

Tables 6.2 and 6.3 provide similar comparisons for cables which have individual unbonded and bonded jackets on the insulation, respectively. Due to the bonding, individual jacket and insulation measurements were not possible for Okonite and Samuel Moore bonded jacket specimens. Significant variations in modulus results were found between these two cable specimen types. Other than the comparatively higher modulus values noted for the bonded Okonite cables, the indenter did not provide any specific indications of the deleterious performance of this cable in the LOCA test. The range of modulus values does provide an indication of the material's condition prior to the LOCA exposure, and any in situ specimens in this range should be closely evaluated for acceptability for continued use.

The condition of the insulation is of paramount importance in the ability of the cable to survive a LOCA exposure. However, as discussed, access to the insulation for indenter testing is often not possible. This means that the insulation needs to tested at termination points which may be exposed to different ambient conditions than the rest of the cable, and may not be representative of the cable. Provided the cable is not buried in a cable tray, or installed in conduits, access to the outer jacket may be obtained for indenter testing. Unfortunately, the condition of the outer jacket may not be representative of the condition of the insulation. As shown in Table 6.4, Neoprene® outer jackets may be degraded due to aging making it brittle and cracked. While it is anticipated that, if this condition was found in situ, the cable would be replaced, the XLPE insulation under the jacket was still in good condition and able to function properly.

Table 6.2 Summary of compressive modulus values for Hypalon® individual jackets

	AIW N/mm (lbs/in)			Anaconda N/mm (lbs/in)		
	20 years	**40 years**	**60 years**	**20 years**	**40 years**	**60 years**
Baseline	11 (63)	NA	11(63)	8 (51)	8 (51)	NA
Aged	13 (74)	NA	16 (91)	21 (120)	29 (166)	NA

NA=Data not available from this test program

Table 6.3 Summary of compressive modulus values for bonded jacket cables

	Samuel Moore N/mm (lbs/in)			Okonite N/mm (lbs/in)		
	20 years	**40 years**	**60 years**	**20 years**	**40 years**	**60 years**
Baseline	14 (80)	14 (80)	14 (80)	13 (74)	13 (74)	13 (74)
Aged	22 (126)	27 (154)	36 (206)	141 (806)	190 (1087)	160 (915)

Table 6.4 Summary of compressive modulus values for outer jackets

	Neoprene (Rockbestos) N/mm (lbs/in)			Hypalon® (AIW, Samuel Moore, Anaconda) N/mm (lbs/in)		
	20 years	**40 years**	**60 years**	**20 years**	**40 years**	**60 years**
Baseline	10 (57)	10 (57)	10 (57)	9 (34)	9 (34)	9 (34)
Aged	190 (1087)	Brittle	Brittle	20 (114)	43 (246)	60 (343)

In summary, the indenter can be a valuable asset in predicting a cable's accident survivability when used to supplement other CM techniques. Comparing in situ modulus values to values obtained from aged specimens will provide an indication as to the degree of aging and an estimate of remaining life. As discussed, accessability to cables in situ may be severely limited. To rectify this difficulty, consideration may be given to strategically locating test coupons in the plant. These would allow for baseline measurements (which have been found to vary) and periodic monitoring throughout life.

6.2.7 Hardness

The results from this program show that no single CM technique is capable of assessing the cables ability to survive an accident. However, when the results of various CM techniques are evaluated, certain insights are obtained which can assist in assessing accident survivability. Hardness, when used in conjunction with EAB and the indenter provided such mechanical insights.

As discussed in Section 6.1.7, difficulties with the specific hardness tester initially chosen for use prevented it from being used beyond the first three test sequences. However, valuable insights were still obtained. Accident tests on the Rockbestos Firewall® III specimens, after being accelerated aged to the equivalent of 20 and 40 years of service, resulted in no failures. When hardness tests were performed on the Neoprene® outer jackets of these specimens, it was found that the aged condition was inconsequential to the condition of the XLPE insulation and its ability to function under accident conditions. The Neoprene® jackets on the Rockbestos Firewall® III specimens were found to be totally brittle and cracked, yet the XLPE insulation performed satisfactorily. This leads to the conclusion that hardness measurements should be made directly on the insulation, which is often difficult.

Hardness measurements obtained for the XLPE insulation (using basket specimens) showed no significant increase for samples aged to the equivalent of either 20 or 40 years of service. Both exhibited a baseline value of 40 (Shore-D hardness), which increased to 50 following the 40 years of aging. No XLPE sample in either test sequence exhibited severe stiffness or embrittlement. This would indicate that any in situ measurements performed on this material should fall within this range. Measurements exceeding this range would highlight the need for additional evaluation and may be indicative of severe aging or hot spots.

In test sequence 2, EPR insulation and Hypalon® jackets (outer and individual) were tested for specimens which were accelerated aged to the equivalent of 20 years. No anomalies were noted for these specimens during simulated accident conditions. For this relatively small amount of aging, no significant changes were seen in any of the hardness values. For the EPR insulation, baseline values of 21 increased to 26, while no significant detectable change from a baseline of 25 was seen for the Hypalon® jackets. Again these values provide a range where in situ measurements would be expected to lie. Higher values may be indicative of more severe aging, and would be the cause of additional engineering evaluation, however it would not necessarily be indicative of unacceptable behavior.

As previously discussed, the limitations found for the use of the hand held Rex D Durometer prevented it from extensive use in this program. A specially designed tester was discussed which would be capable of predicting more accurate hardness results in situ without requiring the use of test coupons.

6.2.8 Dielectric Loss

The evaluation of this condition monitoring method in Section 6.1.8 indicated that measurements on XLPE- and EPR-insulated cables all demonstrated a measurable trend toward increasing power factor (deteriorating dielectric strength) with greater insulation material degradation. This trend was most pronounced and consistent at applied ac test voltage frequencies in the range from 10 Hz to 500 Hz. The effect was also best observed in measurements from conductor-to-ground. Therefore, dielectric loss measurements, particularly when compared to a baseline measurement, are considered a good electrical condition monitoring technique for these materials.

Since the method demonstrated a measurable trend, its usefulness for predicting the LOCA survivability of an I&C cable was examined. Sample insulation power factor data for XLPE-insulated cables are presented in Table 6.5 together with the corresponding post-LOCA submerged voltage withstand test data. The trend toward increasing insulation power factor can be seen for all the pre-aging groups. The failure of Specimen 0313 in the 40 year group during the post-LOCA submerged voltage withstand test was attributed to handling damaged, so it was not included as a test-induced failure. The power factor measured for the individual Specimen 0310, however, was greater than the average for the 60 year pre-aging group.

Table 6.5 Insulation power factor and LOCA performance of pre-aged XLPE-insulated cables

Group	Aging (Years)	Insulation Power Factor (Applied AC Test Voltage @ 100Hz)		Post-LOCA Voltage Withstand Test		
				Leakage Current (µA)	Conductors Passing	
		Baseline Avg	After Pre-aging		Quantity	Percent
1.1 3.1 6.1	0	0.24	-----	648	14 of 14 (a)	100
1.4	20	0.26	0.29	712	10 of 10	100
3.4	40	0.23	0.33	1,178	8 of 8 (b)	100
6.2	60	0.23	0.33	2,517	5 of 6	83.3

(a) Group 1.1 cables passed after faulty splices had been removed

(b) Specimen 0313 not included; failure attributed to handling damage

From the data in Table 6.5, and the measurement for Specimen 0313, it appears that the XLPE-insulated cables in this research program with an insulation power factor greater than approximately 0.3 are at potential risk for failure when exposed to LOCA conditions. In a plant setting, they would be candidates for more careful and frequent inspection and surveillance, or, depending on the importance of the application, replacement. Recalling from the discussions in Section 6.1.8 that many factors, such as temperature, humidity, length, and adjacent operating equipment and cables can affect these measurements, it is difficult to specify an acceptance criterion for insulation power factor that would apply to all circumstances. Rather, it is recommended that dielectric parameters, such as insulation power factor, be referenced and trended against a baseline value and a well defined end point in order to assess cable condition and make decisions regarding LOCA survivability.

Table 6.6 provides a similar presentation of insulation power factor data and post-LOCA voltage withstand data for EPR-insulated cables. For these cables it appears that an insulation power factor of about 0.4 would be a conservative point at which further investigation should be considered to verify LOCA survivability. Note that the Okonite cables were subjected to severe pre-aging parameters, causing extensive insulation degradation and embrittlement (EAB < 5%) after only 20 years of pre-aging. Even though the insulation power factor data for Okonite cables continued to trend above 20 years of pre-aging, differential swelling between the jacket and insulation material played the major role in the outcome of cable performance after extensive pre-aging and subsequent LOCA testing. This further highlights the need to rely on information from multiple sources of condition monitoring in order to make a complete, well-informed assessment of cable condition and LOCA survivability.

One of the AIW cables with no pre-aging failed its post-LOCA voltage withstand test. The unaged cables demonstrated weaker dielectric properties in several electrical condition monitoring tests than the group of cables receiving 20 years of mild pre-aging. This was attributed to the thermal aging process driving out moisture and humidity trapped within the cable and its materials over the 24 years since it had been manufactured. Note that the average power factor of 0.49 measured for this group of unaged cables is above the 0.4 acceptance criterion suggested by the data in Table 6.5. If this guideline for LOCA survivability is applied in this case, the possibility of the cable failing during LOCA or post-LOCA testing is significant, even though the cable had never been pre-aged.

As mentioned above, many factors can affect the dielectric measurements of cables. This makes it difficult to select a universal acceptance criterion for a given parameter, such as insulation power factor, that could be applied to all cable installation circumstances for predicting LOCA survivability. A prudent approach is to take baseline measurements of the selected dielectric parameters, and to reference future periodic measurements to the baseline values. Trends will then reveal themselves over time. Combining dielectric measurements with data from other condition monitoring methods will provide an integrated picture of the status of a cable. This information then becomes a meaningful tool for experienced maintenance personnel to assess cable condition and to make engineering judgments regarding the LOCA survivability of electric cables.

6.2.9 Insulation Resistance

The evaluation of this electrical condition monitoring method in Section 6.1.9 indicated that measurements on XLPE- and EPR-insulated cables all demonstrated a measurable trend toward decreasing insulation resistance, indicating deteriorating dielectric strength, with greater insulation material degradation. The effect was best observed in measurements from conductor-to-ground since the insulation resistance readings for a single thickness of insulation tend to be about one order of magnitude lower than conductor-to-conductor readings. Insulation resistance readings, normalized for temperature effects, provide a trendable electrical parameter, particularly when compared to a baseline measurement. For this reason, insulation resistance measurement are considered a good electrical condition monitoring technique for these materials. If a well defined end point can be established, this technique may be useful for estimating remaining life.

Table 6.6 Insulation power factor and LOCA performance of pre-aged EPR-insulated cables

Cable		Group	Aging (Years)	Insulation Power Factor (Applied AC Test Voltage@100Hz)		Post-LOCA Voltage Withstand Test		
						Leakage Current (µA)	Conductors Passing	
				Baseline Avg	After Pre-aging		Quantity	Percent
BONDED JACKET	**OK** B/E	5.1 6.1	0	0.24	——	730	2 of 2	100
		5.2	20	0.23	0.25	1,000	1 of 2	50
		5.3	40	0.24	0.28	>10,000 (@200Vac)	0 of 3	0
		6.2	60	0.24	0.58	>10,000 (@50Vac)	0 of 3	0
	SM B/E	4.1 5.1 6.1	0	0.40	——	742	6 of 6	100
		4.2 5.2	20	0.40	0.44	1,225	8 of 8	100
		4.3 5.3	40	0.40	0.45	1,575	8 of 10	80
		6.2	60	0.39	0.58	3,040	5 of 6	83.3
UNBONDED JACKET	**AN** B/W	4.1 5.1	0	0.24	——	775	4 of 4	100
		5.2	20	0.24	0.29	855	4 of 4	100
		4.3 5.3	40	0.34	0.38	1,204	10 of 10	100
		None	60	——	——	——	——	—
	AI W/E	2.1	0	0.49	——	1,024	5 of 6	83.3
		2.4	20	0.51	0.45	900	10 of 10	100
		None	40	——	——	——	——	—
		6.2	60	0.45	0.54	2,333	3 of 6	50

OK - Okonite 1/C #12
AN - Anaconda 3/C #12
B/E - Black-Insulated Conductor-to-Ground
W/E - White-Insulated Conductor-to-Ground

SM - Samuel Moore 2/C #16 w/ Shld & Gnd
AI - American Insulated Wire 3/C & 4/C #16 w/ Gnd
B/W - Conductor-to-Conductor

Since this method demonstrated a measurable trend, its usefulness for predicting the LOCA survivability of an I&C cable was examined. Sample insulation resistance measurements for XLPE-insulated cables, taken from conductor-to-conductor after 10 minutes, are presented in Table 6.7 together with the corresponding post-LOCA submerged voltage withstand test data. The trend toward decreasing insulation resistance can be seen for both the 40 and 60 year pre-aging groups. The failure of Specimen 0313 in the 40 year group during the post-LOCA submerged voltage withstand test was attributed to handling damaged, so it was not included as a test-induced failure. The temperature-corrected insulation resistance measured for Specimen 0313 after the equivalent of 40 years of service aging, was 0.29TΩ from conductor-to-conductor after 10 minutes, however, the polarization index was only 1.4. This is lower than the average polarization index for both 40 and 60 year pre-aging groups, indicating that this specimen was at risk for failure during LOCA in spite of the handling damage problem.

Table 6.7 Insulation resistance/polarization index and LOCA performance of XLPE-insulated cables

Group	Aging (Years)	Insulation Resistance (Corrected to 60°F) (@ 10 min in Tera Ohms)		Polarization Index		Post-LOCA Voltage Withstand Test		
		Baseline Avg	After Pre-aging	Baseline Avg	After Pre aging	Leakage Current (µA)	Conductors Passing	
							Quantity	Percent
3.1 6.1	0	64.3	——	7.2	——	648	14 of 14 (a)	100
3.4	40	185.5	1.2	11.4	1.9	1,178	8 of 8 (b)	100
6.2	60	177.5	6.5	117.2	3.4	2,517	5 of 6	83.3

(a) Group 1.1 cables passed after faulty splices had been removed
(b) Specimen 0313 not included; failure attributed to handling damage

From the data in Table 6.7, and the measurements for Specimen 0313, it appears that XLPE-insulated cables in this research program show a clear trend of decreasing insulation resistance with age compared to baseline values. However, the variations from specimen to specimen make it difficult to specify a general acceptance criterion for insulation resistance. Part of the difficulty is attributable to the severe pre-aging conditions that produced extremely degraded and embrittled insulation (EAB < 5%) after the equivalent of only 20 years of service aging. The cable insulation in the 20 year pre-aging group was so degraded that additional pre-aging beyond that level produced very little additional decrease in insulation resistance.

A general guideline for polarization index is that readings lower than approximately 2 indicate weakened dielectric strength. As would be expected, the variations affecting insulation resistance readings are carried over into the polarization index calculation. In this program it was found that, because of the variations among specimens, the most prudent approach is to trend insulation resistance/polarization index in comparison to individual baseline measurements, and then to take into consideration data from other condition monitoring methods when making an overall assessment of the condition of a cable and its ability to survive a LOCA exposure.

Table 6.8 provides a similar presentation of insulation resistance/polarization index data and post-LOCA voltage withstand data for EPR-insulated cables. Note that the Okonite cables were subjected to severe pre-aging parameters, similar to the case for the XLPE cables discussed in the previous paragraphs, causing extensive insulation degradation and embrittlement (EAB < 5%) after only 20 years of pre-aging.

One of the AIW cables with no pre-aging failed its post-LOCA voltage withstand test. The unaged cables demonstrated weaker dielectric properties in other electrical condition monitoring tests than the group of cables receiving 20 years of mild pre-aging. This was attributed to the thermal aging process driving out moisture and humidity trapped within the cable and its materials. Note that the average insulation resistance of the unaged cables appears to be adequate, and the polarization index is well above 3.0 indicating good insulation. The individual readings for cable Specimen 0603 are 2.7TΩ for insulation resistance from the white conductor-to-ground after 10 minutes and the polarization index is 2.0. These are below the average for the unaged AIW cables, however, they do not stand out as being in a problem range, nor would they, taken alone, indicate that there would be a problem under LOCA conditions.

The EPR-insulated cables from the other manufacturers were subjected to much less severe pre-aging conditions than the Rockbestos and Okonite cables, and this is reflected in the adequate average insulation resistance/polarization index values. There is a great deal of variation in the insulation resistance/polarization index measurements from specimen to specimen, as was noted above for the XLPE-insulated cables. The individual values measured for a cable are, therefore, a better measure of the cable's condition, and potential LOCA survivability than a generic acceptance criterion derived from the group averages.

As mentioned above, many factors can affect the insulation resistance measurements for electric cables. This makes it difficult to select a universal acceptance criterion for a given parameter, such as insulation resistance, that could be applied to all cable installation circumstances for predicting LOCA survivability. Specimen-to-specimen variations among cables in similar condition further complicate attempts to set an acceptance criterion for insulation resistance/polarization index. The most prudent approach is to take baseline measurements of the selected insulation resistance/polarization index parameters for each individual cable, and then reference future periodic measurements to the baseline values. Trends will then reveal themselves over time. Combining insulation resistance/polarization index measurements with data from other condition monitoring methods will provide an integrated picture of the status of a cable. This would then be a meaningful tool for experienced maintenance personnel to assess cable condition and to make predictions regarding LOCA survivability.

6.2.10 Functional Performance

The ultimate objective for environmentally qualified low voltage power and instrumentation and control (I&C) cables is to be capable of successfully performing their intended function during a design basis accident occurring at the end of their service life. As discussed in Section 6.1.10, the functional performance test was used in this research program to assess the effects of cable degradation on the overall accuracy of an instrumentation circuit into which a cable test specimen had been wired. The performance of that cable specimen could then be assessed throughout the LOCA exposure test by monitoring the performance, i.e., accuracy and longevity, of the instrumentation loop circuit.

The functional performance test was not intended to be an acceptance criterion for success or failure for the LOCA exposure portion of the research test sequence. Rather, the performance test was designed to demonstrate the level of accuracy that could be expected from each type of cable in a typical nuclear power plant instrumentation application, after having been pre-aged to a specified equivalent service age. Cable that was to be environmentally qualified for a particular nuclear power plant I&C application would have to satisfy the specified accuracy, longevity, or other parameters required for the intended application. There were no generic acceptance criteria set for the functional performance of electric cable specimens during the LOCA exposure.

Table 6.8 Insulation resistance/polarization index and LOCA performance of pre-aged EPR-insulated cables

Cable		Group	Aging (Years)	Insulation Resistance (Corrected to 60°F) (@ 10 min - Tera Ohms)		Polarization Index		Post-LOCA Voltage Withstand Test		
								Leakage Current (µA)	Conductors Passing	
				Baseline Avg	After Pre-aging	Baseline Avg	After Pre-aging		Quantity	Percent
BONDED JACKET	OK B/E	5.1 6.1	0	49.1	——	5.7	——	730	2 of 2	100
		5.2	20	19.8	0.1	4.4	1.1	1,000	1 of 2	50
		5.3	40	20.0	0.1	2.9	1.4	>10,000 (200Vac)	0 of 3	0
		6.2	60	38.7	0.5	4.2	2.2	>10,000 (50Vac)	0 of 3	0
	SM B/E	4.1 5.1 6.1	0	13.9	——	8.4	——	742	6 of 6	100
		4.2 5.2	20	9.0	6.3	6.9	8.0	1,225	8 of 8	100
		4.3 5.3	40	35.4	0.3	16.5	2.2	1,575	8 of 10	80
		6.2	60	10.1	3.0	7.7	3.1	3,040	5 of 6	83.3
UNBONDED JACKET	AN B/W	4.1 5.1	0	20.8	——	6.4	——	775	4 of 4	100
		5.2	20	27.0	10.4	5.9	3.4	855	4 of 4	100
		4.3 5.3	40	24.1	3.2	10.3	4.0	1,204	10 of 10	100
		None	60	——	——	——	——	——	——	—
	AI W/E	2.1	0	12.6	——	3.8	——	1,024	5 of 6	83.3
		2.4	20	13.2	0.5	3.2	1.4	900	10 of 10	100
		None	40	——	——	——	——	——	——	—
		6.2	60	4.0	0.8	3.6	1.7	2,333	3 of 6	50

OK - Okonite 1/C #12
AN - Anaconda 3/C #12
B/E - Black-Insulated Conductor-to-Ground
W/E - White-Insulated Conductor-to-Ground
SM - Samuel Moore 2/C #16 w/ Shld & Gnd
AI - American Insulated Wire 3/C & 4/C #16 w/ Gnd
B/W - Conductor-to-Conductor

Instrument circuit calibrations, functional tests, and logic system functional tests are commonly performed in nuclear power plants during preventive maintenance and technical specification surveillance testing. However, while these tests may indirectly monitor the functional performance of low-voltage I&C cables, they provide no specific data for assessing the condition of the cables, and they are of little or no help in trying to predict the LOCA survivability of a cable.

Routine surveillance testing under normal plant conditions will produce very different results than the same tests performed under the conditions of a LOCA exposure. A low-voltage cable with dry, cracked, and damaged insulation can perform adequately under normal plant conditions, as long as it has not contacted an electrical ground. The same cable might not function under saturated steam conditions. For the reasons cited above, functional performance testing is not considered an effective method for determining, in situ, the LOCA survivability for a particular cable.

6.2.11 Voltage Withstand

As discussed in Section 6.1.11, the submerged voltage withstand test, as used in this program, as well as in IEEE Std. 383-1974, is intended to be a post-LOCA test to assess the remaining dielectric integrity of a cable specimen's insulation. It served as a success criterion for cables in a qualification type test.

In the setting of a research program, correlating the level of pre-aging administered to a cable's insulation with the leakage current measured during a successful performance of a post-LOCA submerged voltage withstand test, such as the data presented in Table 5.13, could provide some measure of the probability of survival during a LOCA exposure. More importantly, further correlation of data from a non-destructive condition monitoring technique, gathered after pre-aging, with subsequent performance during LOCA exposure testing (as measured by the leakage current observed during post-LOCA submerged voltage withstand testing), would provide a quantitative means for using the data from that condition monitoring technique to predict a probability for LOCA survival.

The post-LOCA submerged voltage withstand test, however, is a high voltage test that has the potential to cause a voltage breakdown, which would permanently ruin the cable insulation. Each application of the high voltage may further cause an incremental increase in the amount of degradation to the dielectric integrity of the insulation. For this reason, it is not a true condition monitoring test that could be used in situ, by nuclear power plant technicians, to predict the LOCA survivability of an I&C circuit's insulation system over the course of its service life. Even at lower levels of applied test voltage, within the voltage rating of the cable, the cable insulation is incrementally weakened by each high potential test. Thus, the risks of causing either catastrophic or incipient damage to cable insulation make this an unsuitable method for assessing the LOCA survivability of low voltage electric cable in situ.

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Appendix A

Elongation-at-Break Data

Tables

Table A-1 Elongation-at-Break for Rockbestos Cable PNI79RB188 (Group 1.1, Specimen 0101)

CM Point	Elongation at Break (%)		
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation
A [Unused]	589 556 530 549 492 534 523 527 521 Avg = 535±27	595 638 644 Avg = 626±27	613 640 657 654 629 585 579 Avg = 622±31
B,C,D,E	No change - no additional preaging after last CM Point		
F [A + 78.3 Mrad]	226 248 232 224 286 Avg = 243±26	279 307 304 312 304 Avg = 301±13	308 314 300 260 286 Avg = 294±22
G [F + 78.3 Mrad]	125 106 62 57 Avg = 88±33	130 155 125 147 153 Avg = 142±14	128 103 113 90 120 Avg = 111±15
H [G + Steam/Chem. Spray]	30 33 31 32 31 Avg = 31±1	140 139 124 109 149 Avg = 132±16	141 86 131 93 147 Avg = 120±28

Table A-2 Elongation-at-Break for Rockbestos Cable PNI85RB191 (Group 1.2, Specimen 0106)

CM Point	Elongation at Break (%)			
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation	Red XLPE Insulation
A [Unused]	429	372	367	369
	455	371	379	352
	453	416	384	373
	493	298	387	285
	438	385	378	
	Avg = 454±25	Avg = 368±43	Avg = 379±8	Avg = 345±41
B [A + 2.86 hrs @ 120°C]	404	407	413	429
	467	336	443	424
	444	418	421	408
	440	310	432	424
	383	445	426	
	Avg = 428±34	Avg = 383±57	Avg = 427±11	Avg = 421±9
C	No change - no additional preaging after last CM Point			
D [B + 0.63 Mrad]	410	355	399	355
	410	349	387	358
	434	353	345	352
	432	402	381	368
	418	351	374	347
	Avg = 421±12	Avg = 362±22	Avg = 377±20	Avg = 356±8
E	No Change - no additional preaging after last CM Point			
F [D + 78.3 Mrad]	110	157	257	219
	71	203	203	242
	84	233	263	231
	120	214	237	238
	101	258	245	224
	Avg = 97±20	Avg = 213±38	Avg = 241±24	Avg = 231±10
G [F + 78.3 Mrad]	56	63	136	98
	57	66	105	96
	47	95	113	118
	49	101	146	114
	49	37	99	112
	Avg = 52±5	Avg = 72±26	Avg = 120±20	Avg = 108±11
H [G + Steam/Chem. Spray}	33	134	178	134
	38	110	184	145
	28	125	134	175
		108	134	184
		121	171	115
	Avg = 33±5	Avg = 120±11	Avg = 160±24	Avg = 151±29

Table A-3 Elongation-at-Break for Rockbestos Cable PAP86RB267 (Group 1.3, Specimen 0111)

CM Point	Elongation at Break (%)			
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation	Red XLPE Insulation
A [Naturally Aged 10 yrs]	519 508 519 546 516 Avg = 521±14	400 408 366 369 Avg = 386±21	400 421 390 425 423 Avg = 412±16	363 338 355 340 Avg = 349±12
B,C,D,E	No change - no additional preaging after last CM Point			
F [A + +78.3 Mrad]	70 78 67 80 71 Avg = 73±6	92 143 197 112 99 Avg = 129±43	178 183 200 184 Avg = 186±10	143 143 175 119 200 Avg = 156±32
G [F + 78.3 Mrad]	33 46 48 39 56 Avg = 44±9	30 26 21 18 64 77 Avg = 39±25	55 105 71 98 43 Avg = 74±27	69 76 85 57 Avg = 72±12
H [G + Steam/Chem. Spray]	45 35 40 45 Avg = 41±5	142 127 126 127 149 Avg = 134±11	169 194 145 192 128 Avg = 166±30	175 157 132 182 88 Avg = 147±38

Table A-4 Elongation-at-Break for Rockbestos Cable PNI79RB188 (Group 1.4, Specimen 0112)

CM Point	Elongation at Break (%)		
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation
A [Unused]	589 556 530 549 492 492 534 523 527 521 Avg = 531±29	595 638 644 Avg = 626±27	613 640 657 654 629 585 579 Avg = 622±31
B	No change - no additional preaging after last CM Point		
C [A + 648.5 hrs @150°C]	Specimens brittle; not tested		
D	No change - no additional preaging after last CM Point		
E [C + 26.1 Mrad]	2.0 (Est.)	4.7 4.2 3.9 3.8 5.9 Avg = 4.5±0.9	2.4 2.9 3.1 2.5 Avg = 2.7±0.3
F [E + 78.3 Mrad]	2.0 (Est)	2.8 3.4 1.4 3.1 2.1 Avg = 2.6±0.8	2.1 1.9 Avg = 2.0±0.1
G [F + 78.3 Mrad	2.0 (Est)	1.8 1.8 1.7 Avg = 1.8±0.1	1.9 1.7 1.5 Avg = 1.7±0.2
H [G + Steam/Chem. Spray]	2.0 (Est)	4.7 4.2 3.9 3.8 5.9 Avg = 4.5±0.9	2.8 2.0 2.7 2.6 Avg = 2.5±0.4

Table A-5 Elongation-at-Break for AIW Cable PNI74AI025 (Group 2.1, Specimen 0201)

CM Point	Elongation at Break (%)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul
A [Unused]	663 699 636 645 603 Avg = 649±35	587 371 479 615 487 Avg = 508±97	542 566 553 560 481 Avg = 540±34	525 513 526 493 518 Avg = 515±13	545 476 596 588 550 Avg = 551±46	367 278 279 225 273 Avg = 284±51
B	No change - no additional preaging after last CM Point					
C	No change - no additional preaging after last CM Point					
D	No change - no additional preaging after last CM Point					
E	No change - no additional preaging after last CM Point					
F [A + 76.6 Mrad]	609 558 564 557 665 Avg = 591±47	446 449 521 493 415 Avg = 465±42	482 289 354 271 Avg = 349±96	471 467 473 481 331 Avg = 445±64	344 223 443 369 Avg = 345±91	214 227 205 Avg = 215±11
G [F + 77.5 Mrad]	496 550 493 472 396 Avg = 481±56	372 333 346 383 Avg = 359±23	362 367 374 347 Avg = 363±11	366 361 342 352 Avg = 355±11	319 351 367 345 Avg = 345±20	201 189 209 149 Avg = 187±27
H [G + Steam/Chem. Spray]	155 126 146 188 196 Avg = 162±29	65 80 92 64 93 Avg = 79±14	63 59 53 59 62 Avg = 59±4	41 56 50 52 48 Avg = 49±6	37 30 43 52 39 Avg = 40±8	48 42 27 25 34 35 42 28 Avg = 35±8

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

Table A-6 Elongation-at-Break for AIW Cable PNI74AI031 (Group 2.1, Specimen 0202)

CM Point	Elongation at Break (%)				
	OJ[a]	IJB	IJW	IJR	Insul
A [Unused]	578 610 552 547 527 Avg = 563±32	550 554 530 542 Avg = 544±11	462 544 408 514 Avg = 482±60	464 505 456 489 462 Avg = 475±21	348 324 328 329 377 Avg = 341±22
B	No change - no additional preaging after last CM Point				
C	No change - no additional preaging after last CM Point				
D	No change - no additional preaging after last CM Point				
E	No change - no additional preaging after last CM Point				
F [A + 76.6 Mrad]	488 514 449 423 448 Avg = 464±36	484 418 465 442 451 Avg = 452±25	375 375 374 423 312 Avg = 372±39	Not tested	224 186 209 213 225 Avg = 211±16
G [F + 77.5 Mrad]	349 368 345 381 351 Avg = 359±15	267 300 271 285 Avg = 281±15	235 205 254 265 Avg = 240±26	Not tested	166 152 112 144 118 Avg = 138±23
H [G + Steam/Chem. Spray]	80 86 94 94 75 Avg = 86±8	30 72 55 24 35 Avg = 43±20	25 32 37 38 24 Avg = 31±7	Not tested	32 43 25 35 35 50 13 28 Avg = 33±11

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

Table A-7 Elongation-at-Break for AIW Cable PNI74AI026 (Group 2.2, Specimen 0203)

CM Point	Elongation at Break (%)					
	OJ[a]	IJB	IJW	IJR	IJG	Insul
A[b] [Unused]	663 699 636 645 603 Avg = 649±35	587 371 479 615 487 Avg = 508±97	542 566 553 560 481 Avg = 540±34	525 513 526 493 518 Avg = 515±13	545 476 596 588 550 Avg = 551±46	367 278 279 225 273 Avg = 284±51
B [A + 28.45 hrs @ 121°C]	597 668 649 680 575 Avg = 634±46	584 551 417 536 Avg = 522±73	424 460 440 456 457 Avg = 447±15	365 427 522 501 519 Avg = 467±69	500 434 498 505 510 Avg = 489±31	365 326 379 282 328 Avg = 336±38
C	No change - no additional preaging after last CM Point					
D [B + 3.25 Mrad]	601 632 552 518 607 Avg = 582±46	360 289 234 248 Avg = 283±57	271 411 Avg = 341±99	384 267 340 Avg = 330±59	294 235 270 269 217 Avg = 257±31	256 248 204 189 Avg = 224±33
E	No change - no additional preaging after last CM Point					
F [D + 76.6 Mrad]	516 521 540 607 Avg = 546±42	332 458 328 366 343 Avg = 365±54	450 396 445 Avg = 430±30	304 432 385 419 Avg = 385±58	441 379 394 430 Avg = 411±29	111 170 143 179 Avg = 151±31
G	No change - no additional preaging after last CM Point					
H [F + Steam/Chem. Spray]	235 214 265 218 200 Avg = 226±25	161 195 103 130 Avg = 147±40	71 64 79 94 94 Avg = 80±13	38 57 86 74 114 Avg = 74±29	98 95 64 63 66 Avg = 77±18	62 112 144 73 72 143 165 77 Avg = 106±40

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

(b) Baseline values of EAB listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

Table A-8 Elongation-at-Break for AIW Cable PNI74AI027 (Group 2.2, Specimen 0205)

CM Point	Elongation at Break (%)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul
A(b) [Unused]	663 699 636 645 603 Avg = 649±35	587 371 479 615 487 Avg = 508±97	542 566 553 560 481 Avg = 540±34	525 513 526 493 518 Avg = 515±13	545 476 596 588 550 Avg = 551±46	367 278 279 225 273 Avg = 284±51
B(c) [A + 28.45 hrs @ 121°C]	597 668 649 680 575 Avg = 633±46	584 551 417 536 Avg = 522±73	424 460 440 456 457 Avg = 447±15	365 427 522 501 519 Avg = 467±69	500 434 498 505 510 Avg = 489±31	365 326 379 282 328 Avg = 336±38
C	No change - no additional preaging after last CM Point					
D(c) [B + 3.25 Mrad]	601 632 552 518 607 Avg = 582±46	360 289 234 248 Avg = 283±57	271 411 Avg = 341±99	384 267 340 Avg = 330±59	294 235 270 269 217 Avg = 257±31	256 248 204 189 Avg = 224±33
E	No change - no additional preaging after last CM Point					
F(c) [D + 76.6 Mrad]	516 521 540 607 Avg = 546±42	332 458 328 366 343 Avg = 365±54	450 396 445 Avg = 430±30	304 432 385 419 Avg = 385±58	441 379 394 430 Avg = 411±29	111 170 143 179 Avg = 151±31
G [F + 77.5 Mrad]	305 310 323 309 343 Avg = 318±16	213 166 260 164 Avg = 201±46	285 277 302 205 Avg = 267±43	292 279 207 297 287 Avg = 273±37	264 209 270 277 268 Avg = 258±28	117 129 121 130 135 Avg = 126±7
H [G + Steam/Chem. Spray]	204 159 152 150 163 Avg = 166±22	58 102 63 75 33 Avg = 66±25	28 69 32 60 48 Avg = 47±18	45 35 40 27 58 Avg = 41±12	30 39 48 48 41 Avg = 41±7	42 73 53 52 35 38 42 30 Avg = 46±14

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

(b) Baseline values of EAB listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

(c) CM point B, D and F values of EAB listed are for identical specimen PNI74AI026 (Group 2.2, Specimen 0203)

Table A-9 Elongation-at-Break for AIW Cable PNI74AI015 (Group 2.3, Specimen 0207)

CM Point	Elongation at Break (%)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul
A [Naturally Aged 24 yrs]	700 691 627 582 Avg = 650±56	517 Avg = 517	461 459 483 Avg = 468±13	370 341 479 462 439 Avg = 418±60	494 437 355 535 Avg = 455±78	336 364 329 342 Avg = 343±15
B	No change - no additional preaging after last CM Point					
C	No change - no additional preaging after last CM Point					
D	No change - no additional preaging after last CM Point					
E	No change - no additional preaging after last CM Point					
F [A + 76.6 Mrad]	457 443 376 Avg = 425±43	217 351 264 Avg = 277±68	361 312 357 360 345 Avg = 347±21	344 346 Avg = 345±1	270 273 344 268 382 Avg = 307±50	226 151 128 155 149 Avg = 162±37
G [F + 77.5 Mrad]	336 292 350 363 405 Avg = 349±41	209 192 190 190 140 Avg = 184±26	285 279 298 220 Avg = 270±35	208 302 302 267 259 Avg = 268±39	207 310 292 282 Avg = 273±45	112 146 134 136 154 Avg = 136±16
H [G + Steam/Chem. Spray]	181 189 173 152 197 Avg = 178±17	97 73 88 95 80 Avg = 87±10	52 54 102 61 44 Avg = 62±23	53 52 78 79 38 Avg = 60±18	65 88 72 Avg = 75±12	32 67 117 78 60 116 108 110 Avg = 86±31

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

Table A-10 Elongation-at-Break for AIW Cable PNI74AI019 (Group 2.3, Specimen 0210)

CM Point	Elongation at Break (%)					
	OJ[(a)]	IJB	IJW	IJR	IJG	Insul
A [Naturally Aged 24 yrs]	427 517 519 546 552 Avg = 512±50	412 526 462 534 443 Avg = 475±53	510 534 499 514 Avg = 514±15	499 445 367 Avg = 437±66	436 522 532 411 343 Avg = 449±79	329 356 308 349 352 Avg = 339±20
B	No change - no additional preaging after last CM Point					
C	No change - no additional preaging after last CM Point					
D	No change - no additional preaging after last CM Point					
E	No change - no additional preaging after last CM Point					
F [A + 76.6 Mrad]	540 382 463 346 Avg = 433±87	198 190 259 Avg = 216±38	387 248 436 381 Avg = 363±81	412 378 373 239 Avg = 351±76	362 263 230 347 Avg = 301±64	132 187 138 192 144 Avg = 159±29
G [F + 77.5 Mrad]	311 381 325 382 Avg = 350±37	212 194 205 193 Avg = 201±9	278 277 272 267 285 Avg = 276±7	284 268 220 254 253 Avg = 256±24	282 268 280 289 Avg = 280±9	119 117 152 157 Avg = 136±21
H [G + Steam/Chem. Spray]	168 151 159 143 172 Avg = 159±12	83 120 80 111 73 Avg = 93±21	85 99 75 79 74 Avg = 82±10	97 73 93 70 Avg = 83±14	110 77 83 72 77 Avg = 84±15	76 80 80 79 95 60 72 110 Avg = 82±15

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

Table A-11 Elongation-at-Break for AIW Cable PNI74AI028 (Group 2.4, Specimen 0212)

CM Point	Elongation at Break (%)					
	OJ[a]	IJB	IJW	IJR	IJG	Insul
A[b] [Unused]	663 699 636 645 603 Avg = 649±35	587 371 479 615 487 Avg = 508±97	542 566 553 560 481 Avg = 540±34	525 513 526 493 518 Avg = 515±13	545 476 596 588 550 Avg = 551±46	367 278 279 225 273 Avg = 284±5
B	No change - no additional preaging after last CM Point					
C [A + 82.5 hrs @ 121°C]	480 591 523 625 548 Avg = 553±57	450 508 546 535 Avg = 510±43	431 472 499 504 500 Avg = 481±31	502 417 484 333 Avg = 434±77	454 373 389 505 Avg = 430±61	329 342 229 287 229 Avg = 283±53
D	No change - no additional preaging after last CM Point					
E [C + 25.8 Mrad]	346 468 488 407 436 Avg = 429±56	343 394 339 Avg = 359±31	441 301 Avg = 371±99	309 397 305 Avg = 337±52	419 532 379 280 Avg = 402±104	223 160 153 246 Avg = 196±46
F [E + 76.6 Mrad]	368 285 394 342 371 Avg = 352±42	287 292 201 282 Avg = 266±43	357 377 272 219 342 Avg = 313±66	355 221 339 370 Avg = 321±68	302 353 361 290 Avg = 326±36	143 161 115 147 138 Avg = 141±17
G	No change - no additional preaging after last CM Point					
H [F + Steam/Chem. Spray]	162 187 155 165 222 Avg = 178±27	113 109 134 102 93 Avg = 110±15	79 59 Avg = 69±14	91 93 45 82 56 Avg = 73±22	73 77 40 60 45 Avg = 59±16	80 92 101 78 42 53 72 73 Avg = 74±19

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

(b) Baseline values of EAB listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

Table A-12 Elongation-at-Break for AIW Cable PNI74AI028 (Group 2.4, Specimen 0213)

CM Point	Elongation at Break (%)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul
A(b) [Unused]	663 699 636 645 603 Avg = 649±35	587 371 479 615 487 Avg = 508±97	542 566 553 560 481 Avg = 540±34	525 513 526 493 518 Avg = 515±13	545 476 596 588 550 Avg = 551±46	367 278 279 225 273 Avg = 284±51
B	No change - no additional preaging after last CM Point					
C(c) [A + 82.5 hrs @ 121°C]	480 591 523 625 548 Avg = 553±57	450 508 546 535 Avg = 510±43	431 472 499 504 500 Avg = 481±31	502 417 484 333 Avg = 434±77	454 373 389 505 Avg = 430±61	329 342 229 287 229 Avg = 283±53
D	No change - no additional preaging after last CM Point					
E(c) [C + 25.8 Mrad]	346 468 488 407 436 Avg = 429±56	343 394 339 Avg = 359±31	441 301 Avg = 371±99	309 397 305 Avg = 337±52	419 532 379 280 Avg = 402±104	223 160 153 246 Avg = 196±46
F(c) [E + 76.6 Mrad]	368 285 394 342 371 Avg = 352±42	287 292 201 282 Avg = 266±43	357 377 272 219 342 Avg = 313±66	355 221 339 370 Avg = 321±68	302 353 361 290 Avg = 326±36	143 161 115 147 138 Avg = 141±17
G [F + 77.5 Mrad]	247 244 255 277 Avg = 256±15	212 184 178 115 144 Avg = 167±38	210 252 248 253 250 Avg = 243±18	260 268 248 240 235 Avg = 250±14	245 200 240 Avg = 228±25	111 112 147 113 118 Avg = 120±15
H [G + Steam/Chem. Spray]	136 112 128 150 134 Avg = 132±14	45 62 79 60 115 Avg = 72±27	32 22 38 25 42 Avg = 32±8	39 50 35 49 52 Avg = 45±8	Not tested	22 30 32 55 52 Avg = 38±15

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

(b) Baseline values of EAB listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

(c) CM point C, E and F values of EAB listed are for identical specimen PNI74AI028 (Group 2.4, Specimen 0212)

Table A-13 Elongation-at-Break for AIW Cable PNI74AI032 (Group 2.4, Specimen 0214)

CM Point	Elongation at Break (%)				
	OJ(a)	IJB	IJW	IJR	Insul
A(b) [Unused]	578 610 552 547 527 Avg = 563±32	550 554 530 542 Avg = 544±11	462 544 408 514 Avg = 482±60	464 505 456 489 462 Avg = 475±21	348 324 328 329 377 Avg = 341±22
B	No change - no additional preaging after last CM Point				
C [A + 82.5 hrs @ 121°C]	411 405 384 415 333 Avg = 390±34	455 468 443 438 Avg = 451±13	416 434 417 432 400 Avg = 420±14	Not tested	390 246 364 230 360 Avg = 318±74
D	No change - no additional preaging after last CM Point				
E [C + 25.8 Mrad]	423 340 304 403 377 Avg =369±48	449 426 440 430 Avg = 436±10	276 214 268 244 Avg = 250±28	Not tested	256 248 204 189 Avg = 224±33
F [E + 76.6 Mrad]	349 315 226 362 312 Avg = 313±53	267 370 240 307 282 Avg = 293±49	278 355 325 314 345 Avg = 323±30	Not tested	142 158 148 112 Avg = 140±20
G [F + 77.5 Mrad]	243 178 261 212 223 Avg = 223±32	236 236 263 170 Avg = 226±40	207 170 202 217 158 Avg = 191±25	Not tested	136 133 127 128 135 Avg = 132±4
H [G + Steam/Chem. Spray]	86 115 59 64 83 Avg = 81±22	54 33 58 78 66 Avg = 58±17	20 42 39 37 35 Avg = 35±9	Not tested	25 27 16 22 39 37 20 Avg = 27±9

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, IJG = Hypalon® green individual jacket, and Insul = EPR insulation

(b) Baseline values of EAB listed are for identical specimen PNI74AI031 (Group 2.1, Specimen 0202)

Table A-14 Elongation-at-Break for Rockbestos Cable PNI79RB188 (Group 3.1, Specimen 0301)

CM Point	Elongation at Break (%)	
	Neoprene® Jacket	White XLPE Insulation
A [Unused]	516 570 518 Avg = 535±31	619 630 611 Avg = 620±10
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.65 Mrad]	197 195 160 Avg = 184±21	277 244 256 Avg = 259±17
G [F + 76.75 Mrad]	44 46 43 Avg = 44±2	61 58 51 80 73 Avg = 65±12
H [G + Steam/Chem. Spray]	15 10 11 Avg = 12±3	100 112 119 Avg = 111±10

Table A-15 Elongation-at-Break for Rockbestos Cable PNI85RB191 (Group 3.1, Specimen 0302)

CM Point	Elongation at Break (%)	
	Neoprene® Jacket	White XLPE Insulation
A [Unused]	422 468 439 Avg = 443±23	444 420 448 Avg = 437±15
B	No chance - no additional preaging after last CM Point	
C	No chance - no additional preaging after last CM Point	
D	No chance - no additional preaging after last CM Point	
E	No chance - no additional preaging after last CM Point	
F [A + 76.65 Mrad]	107 120 86 Avg = 104±17	210 206 Avg = 208±3
G [F + 76.75 Mrad]	36 52 50 46 Avg = 46±7	31 41 31 38 Avg = 35±5
H [G + Steam/Chem. Spray]	13 19 17 12 18 Avg = 16±3	145 139 Avg = 142±4

Table A-16 Elongation-at-Break for Rockbestos Cable PNI85RB191 (Group 3.2, Specimen 0303)

CM Point	Elongation at Break (%)	
	Neoprene® Jacket	White XLPE Insulation
A [Unused]	404 462 429 414 Avg = 427±25	429 425 424 Avg = 426±3
B [A + 9.93 hrs @ 120°C]	394 353 339 Avg = 362±29	375 384 414 Avg = 391±20
C	No change - no additional preaging after last CM Point	
D [B + 2.27 Mrad]	376 400 443 Avg = 406±34	390 407 411 Avg = 403±11
E	No change - no additional preaging after last CM Point	
F [D + 76.65 Mrad]	52 69 57 53 Avg = 58±8	176 148 176 Avg = 167±16
G [F + 76.75 Mrad]	34 33 43 Avg = 37±6	57 70 51 Avg = 59±10
H [G + Steam/Chem. Spray]	13 14 18 11 15 Avg = 14±3	112 128 134 Avg = 125±11

Table A-17 Elongation-at-Break for Rockbestos Cable PAP86RB229 (Group 3.3, Specimen 0307)

CM Point	Elongation at Break (%)	
	Neoprene® Jacket	White XLPE Insulation
A [Naturally aged 10 yrs]	632 610 553 Avg = 598±41	470 457 468 Avg = 465±7
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.65 Mrad]	245 278 219 239 Avg = 245±25	210 238 194 Avg = 214±22
G [F + 76.75 Mrad]	99 78 102 Avg = 93±13	104 86 65 Avg = 85±20
H [G + Steam/Chem. Spray]	18 14 12 12 Avg = 14±3	127 127 105 Avg = 120±13

Table A-18 Elongation-at-Break for Rockbestos Cable PAP86RB267 (Group 3.3, Specimen 0311)

CM Point	Elongation at Break (%)	
	Neoprene® Jacket	White XLPE Insulation
A [Naturally aged 10 yrs]	571 592 581 Avg = 581±11	422 452 439 Avg = 438±15
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F(a) [A + 76.65 Mrad]	245 278 219 239 Avg = 245±25	210 238 194 Avg = 214±22
G [F + 76.75 Mrad]	43 40 45 Avg = 43±3	24 29 15 18 19 Avg = 21±6
H [G + Steam/Chem. Spray]	17 22 19 Avg = 19±3	155 169 152 Avg = 159±9

(a) Since there was insufficient naturally-aged 0311 material available to complete this test, the 0311F data were assumed to be the same as those obtained for 0307 cable

Table A-19 Elongation-at-Break for Rockbestos Cable PNI79RB188 (Group 3.4, Specimen 0312)

CM Point	Elongation at Break (%)	
	Neoprene® Jacket	White XLPE Insulation[b]
A [Unused]	535 567 503 524 Avg = 532±27	619 630 611 Avg = 620±10
B	No change - no additional preaging after last CM Point	
C [A + 1301 hrs @ 150°C]	(a)	(a)
D	No change - no additional preaging after last CM Point	
E [C + 51.5 Mrad]	(a)	(a)
F [E + 76.65 Mrad]	(a)	(a)
G [F + 76.75Mrad]	(a)	(a)
H [G + Steam/Chem. Spray]	(a)	(a)

(a) Specimens very brittle; not tested
(b) Baseline values of EAB listed are for identical specimen PNI79RB188 (Group 3.1, Specimen 0301)

Table A-20 Elongation-at-Break for Anaconda Cable DNP78AN008 (Group 4.1, Specimen 0401)

CM Point	Elongation-at-Break (%)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a)
A	454 483 490 Avg = 476±19	(b)	390 397 384 Avg = 390±7	(b)	418 293 360 352 Avg = 356±51
B	No change - no additional preaging after last CM Point				
C	No change - no additional preaging after last CM Point				
D	No change - no additional preaging after last CM Point				
E	No change - no additional preaging after last CM Point				
F [77.1 Mrad]	95 87 91 Avg = 91±4	(b)	118 91 116 Avg = 108±15	(b)	188 185 189 Avg = 187±2
G [F+77.7 Mrad]	161 144 144 Avg = 150±10	(b)	97 113 150 132 Avg = 123±23	(b)	144 140 109 159 Avg = 138±21
H [G+Steam/ Chem.Spray]	73 77 93 Avg = 81±11	(b)	147 149 137 Avg = 144±6	(b)	125 144 164 126 Avg = 140±18

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation

(b) Not tested

Table A-21 Elongation-at-Break for Samuel Moore Cable PNI82M008, (Group 4.1, Specimen 0402)

CM Point	Elongation-at-Break (%)		
	Hypalon® Outer Jacket	Bonded Hypalon® Red Individual Jacket/EPDM Insulation	Bonded Hypalon® Purple Individual Jacket/EPDM Insulation
A	696 709 682 Avg = 696±14	480 487 458 Avg = 475±15	(a)
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [77.1 Mrad]	215 265 214 Avg = 231±29	147 163 143 Avg = 151±11	(a)
G [F+77.7 Mrad]	222 234 213 Avg = 223±11	153 167 89 112 Avg = 130±36	(a)
H [G+Steam/Chem.Spray]	70 34 38 93 Avg = 59±28	95 103 88 104 Avg = 98±8	(a)

(a) Not tested

Table A-22 Elongation-at-Break for Samuel Moore Cable PNI82SM008 (Group 4.2, Specimen 0403)

CM Point	Elongation-at-Break (%)		
	Hypalon® Outer Jacket	Bonded Hypalon® Red Individual Jacket/EPDM Insulation	Bonded Hypalon® Purple Individual Jacket/EPDM Insulation
A	755 736 796 Avg = 762±31	451 499 452 Avg = 467±27	(a)
B [A+84h@121°C]	615 533 524 Avg = 557±50	415 389 388 Avg = 397±15	(a)
C	No change - no preaging after last CM Point		
D [B+26.0 Mrad]	476 396 394 Avg = 422±47	256 258 270 Avg = 261±8	(a)
E	No change - no preaging after last CM Point		
F [D+77.1 Mrad]	122 136 168 Avg = 142±24	133 123 138 Avg = 131±8	(a)
G [F+77.7 Mrad]	91 97 119 Avg = 102±15	96 103 110 Avg = 103±7	(a)
H [G+Steam/Chem.Spray]	39 18 24 25 Avg = 27±9	65 76 71 Avg = 71±6	(a)

(a) Not tested

Table A-23 Elongation-at-Break for Anaconda Cable DNP78AN008 (Group 4.3,Specimen 0407) Aged to 20 yrs Service

CM Point	Elongation-at-Break (%)				
	OJ[a]	IJB[a]	IJW[a]	IJR[a]	Insul[a]
A[d]	454 483 490 Avg = 476±19	(c)	390 397 384 Avg = 390±7	(c)	418 293 360 352 Avg = 356±51
B[b] [A+84h@150°C]	133 153 121 Avg = 136±16	(c)	70 100 85 Avg = 85±15	(c)	225 226 211 Avg = 221±8
C	No change - no additional preaging after last CM Point				
D[b] [B+25.7 Mrad]	96 76 89 Avg = 87±10	(c)	58 46 60 42 Avg = 52±9	(c)	155 127 134 Avg = 138±15
E	No change - no additional preaging after last CM Point				
F					
G					
H					

(a) OJ = Hypalon® outer jacket, IJB = Hypalon ®black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation
(b) Aged to 20 yrs. service
(c) Not tested
(d) Baseline values of EAB listed are for identical specimen DNP78AN008 (Group 4.1, Specimen 0401)

Table A-24 Elongation-at-Break for Anaconda Cable DNP78AN008 (Group 4.3, Specimen 0407) Aged to 40 yrs Service

CM Point	Elongation-at-Break (%)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a)
A(d)	454 483 490 Avg = 476±19	(c)	390 397 384 Avg = 390±7	(c)	418 293 360 352 Avg = 356±51
B	No change - no additional preaging since last CM Point				
C(b) [168h@150°C]	22 21 29 Avg = 24±4	(c)	20 17 14 Avg = 17±3	(c)	27 10 29 10 30 Avg = 21±10
D	No change - no additional preaging since last CM Point				
E(b) [C+53.6 Mrad]	14 11 9 Avg = 11±3	(c)	10 9 7 Avg = 9±2	(c)	20 11 9 10 Avg = 13±5
F [E+77.1 Mrad]	10 8 10 Avg = 10±1	(c)	≤5	(c)	12 11 20 10 Avg = 13±4
G [F+77.7 Mrad]	8 10 9 Avg = 9±1	(c)	≤5	(c)	18 15 11 21 Avg = 16±4
H [G+Steam/ChemSpray]	12 11 12 Avg = 11±1	(c)	6	(c)	Not tested. Specimens badly distorted

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation
(b) Aged to 40 yrs. service
(c) Not tested
(d) Baseline values of EAB listed are for identical specimen DNP78AN008 (Group 4.1, Specimen 0401)

Table A-25 Elongation-at-Break for Samuel Moore Cable PNI82SM008 (Group 4.4, Specimen 0412)

CM Point	Elongation-at-Break (%)		
	Hypalon® Outer Jacket	Bonded Hypalon® Red Individual Jacket/EPDM Insulation	Bonded Hypalon® Purple Individual Jacket/EPDM Insulation
A[b]	696 709 682 Avg = 696±14	480 487 458 Avg = 475±15	(a)
B	No change - no additional preaging after last CM Point		
C [168h@121°C]	579 525 589 Avg = 564±34	304 290 270 Avg = 288±17	(a)
D	No change - no additional preaging after last CM Point		
E [C+51.6 Mrad]	291 358 288 Avg = 312±40	174 186 158 Avg = 173±14	(a)
F [E+77.1 Mrad]	100 88 88 Avg = 92±7	96 94 80 Avg = 90±9	(a)
G [F+77.7 Mrad]	95 101 114 Avg = 103±10	96 99 97 Avg = 98±2	(a)
H [G+Steam/Chem. Spray]	36 20 28 Avg = 28±8	44 46 46 Avg = 46±1	(a)

(a) Not tested

(b) Baseline values of EAB listed are for identical specimen PNI82SM008 (Group 4.1, Specimen 0402)

Table A-26 Elongation-at-Break for Okonite Cable LNI81OK020 (Group 5.1, Specimen 0501)

CM Point	Elongation-at-Break (%)
	Bonded Hypalon® Jacket/EPR Insulation
A	490 471 450 Avg = 471±20
B	No change - no additional preaging after last CM Point
C	No change - no additional preaging after last CM Point
D	No change - no additional preaging after last CM Point
E	No change - no additional preaging after last CM Point
F [A+77.1 Mrad]	157 178 183 Avg = 172±14
G [F+77.7 Mrad]	213 232 251 Avg = 232±19
H [G+Steam/Chem.Spray]	130 131 140 Avg = 134±6

Table A-27 Elongation-at-Break for Samuel Moore Cable DNI80SM010 (Group 5.1, Specimen 0502)

CM Point	Elongation-at-Break (%)		
	OJ[a]	IJB/Insul[a]	IJW/Insul[a]
A	619 639 581 Avg = 613±29	(b)	408 432 414 Avg = 418±12
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A+77.1 Mrad]	157 134 172 Avg = 154±19	(b)	123 107 128 Avg = 119±11
G [F+77.7 Mrad]	237 240 238 Avg = 239±2	(b)	155 164 171 Avg = 163±8
H [G+Steam/Chem.Spray]	62 70 72 Avg = 68±5	(b)	70 86 65 Avg = 74±11

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black bonded individual jacket, IJW = Hypalon® white bonded individual jacket, Insul = EPDM bonded insulation

(b) Not tested

Table A-28 Elongation-at-Break for Anaconda Cable DNP78AN008 (Group 5.1, Specimen 0503)

CM Point	Elongation-at-Break (%)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a)
A	454 483 490 Avg = 476±19	(b)	390 397 384 Avg = 390±7	(b)	418 293 360 352 Avg = 356±5
B	No change - no additional preaging after last CM Point				
C	No change - no additional preaging after last CM Point				
D	No change - no additional preaging after last CM Point				
E	No change - no additional preaging after last CM Point				
F [A+77.1 Mrad]	166 153 142 Avg = 154±12	(b)	117 115 110 Avg = 114±4	(b)	123 139 148 Avg = 137±13
G [F+77.7 Mrad]	169 156 135 Avg = 153±17	(b)	128 132 122 Avg = 128±5	(b)	150 142 129 Avg = 140±11
H [G+Steam/Chem.Spray]	118 150 112 161 134 Avg = 135±21	(b)	70 73 83 Avg = 76±7	(b)	Not tested. Specimens badly distorted

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation

(b) Not tested

(c) Baseline values of EAB listed are for identical specimen DNP78AN008 (Group 4.1, Specimen 0401)

Table A-29 Elongation-at-Break for Okonite Cable LNI81OK020 (Group 5.2, Specimen 0504)

CM Point	Elongation-at-Break (%)
	Bonded Hypalon® Jacket/EPR Insulation
A[a]	490 471 450 Avg = 471±20
B [A+252h@121°C]	10 14 10 Avg = 12±2
C	No change - no additional preaging after last CM Point
D [B+25.8 Mrad]	8 6 9 Avg = 8±2
E	No change - no additional preaging after last CM Point
F [D+77.1 Mrad]	≤5
G [F+77.7 Mrad]	≤5
H [G+Steam/Chem.Spray]	≤5

(a) Baseline values of EAB listed are for identical specimen LNI81OK020 (Group 5.1, Specimen 0501)

Table A-30 Elongation-at-Break for Samuel Moore Cable DNI80SM010 (Group 5.2, Specimen 0506)

CM Point	Elongation-at-Break (%)		
	OJ(a)	IJB/Insul(a)	IJW/Insul(a)
A(c)	619 639 581 Avg = 613±29	(b)	408 432 414 Avg = 418±12
B [A+84h@121°C]	484 401 474 Avg = 453±45	(b)	255 214 228 Avg = 233±21
C	No change - no additional preaging after last CM Point		
D [B+26.0 Mrad]	336 357 322 Avg = 338±18	(b)	144 146 150 Avg = 147±3
E	No change - no additional preaging after last CM Point		
F [D+77.1 Mrad]	86 90 90 Avg = 89±2	(b)	74 75 74 Avg = 75±1
G [F+77.7 Mrad]	109 92 84 Avg = 95±13	(b)	81 67 75 Avg = 74±7
H [G+Steam/Chem.Spray]	46 64 49 Avg = 53±10	(b)	63 63 52 Avg = 59±6

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black bonded individual jacket, IJW = Hypalon® white bonded individual jacket, Insul = EPDM bonded insulation

(b) Not tested

(c) Baseline values of EAB listed are for identical specimen DNI80SM010 (Group 5.1, Specimen 0502)

Table A-31 Elongation-at-Break for Anaconda Cable DNP78AN008 (Group 5.2, Specimen 0508)

CM Point	Elongation-at-Break (%)				
	OJ[a]	IJB[a]	IJW[a]	IJR[a]	Insul[a]
A[c]	454 483 490 Avg = 476±19	(b)	390 397 384 Avg = 390±7	(b)	418 293 360 351 Avg = 356±5
B [A+84h@121°C]	162 147 154 Avg = 155±8	(b)	107 110 104 Avg = 107±3	(b)	296 272 292 Avg = 287±13
C	No change - no additional preaging after last CM Point				
D [B+25.7 Mrad]	97 89 97 Avg = 94±5	(b)	67 71 64 Avg = 67±4	(b)	184 152 162 Avg = 166±16
E	No change - no additional preaging after last CM Point				
F [D+77.1 Mrad]	42 38 37 Avg = 39±3	(b)	21 14 31 Avg = 22±9	(b)	84 99 102 Avg = 95±10
G [F+77.7 Mrad]	29 28 31 Avg = 29±2	(b)	20 19 29 Avg = 23±6	(b)	88 78 86 Avg = 84±5
H [G+Steam/Chem.Spray]	37 43 38 Avg = 40±3	(b)	30 32 33 Avg = 32±2	(b)	Not tested. Specimens badly distorted.

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation

(b) Not tested

(c) Baseline values of EAB listed are for identical specimen DNP78AN008 (Group 4.1, Specimen 0401)

Table A-32 Elongation-at-Break for Okonite Cable LNI81OK020 (Group 5.3, Specimen 0510)

CM Point	Elongation-at-Break (%)
	Bonded Hypalon® Jacket/EPR Insulation
A(a)	490 471 450 Avg = 471±20
B	No change - no additional preaging after last CM Point
C [A+504h@121°C]	6 6 5 Avg =6±1
D	No change - no additional preaging after last CM Point
E [C+51.5 Mrad]	4 4 Avg = 4
F [E+77.1 Mrad]	≤5
G [F+77.7 Mrad]	≤5
H [G+Steam/Chem.Spray]	≤5

(a) Baseline values of EAB listed are for identical specimen LN181OK020 (Group 5.1, Specimen 0501)

Table A-33 Elongation-at-Break for Samuel Moore Cable DNI80SM010 (Group 5.3, Specimen 0513)

CM Point	Elongation-at-Break (%)		
	OJ[a]	IJB/Insul[a]	IJW/Insul[a]
A[c]	619 639 581 Avg = 613±29	(b)	408 432 414 Avg = 418±12
B	No change - no additional preaging after last CM Point		
C [A+168h@121°C]	436 387 394 Avg = 406±27	(b)	203 177 178 Avg = 186±15
D	No change - no additional preaging after last CM Point		
E [C+51.5 Mrad]	291 271 288 Avg = 283±11	(b)	101 89 93 Avg = 94±6
F [G+77.1 Mrad]	77 79 82 Avg = 79±3	(b)	57 54 49 Avg = 53±4
G [F+77.7 Mrad]	61 74 83 Avg = 73±11	(b)	60 55 60 Avg = 58±3
H [G+Steam/Chem.Spray]	30 36 33 Avg = 33±3	(b)	38 34 36 Avg = 36±2

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black bonded individual jacket, IJW = Hypalon® white bonded individual jacket, Insul = EPDM bonded insulation

(b) Not tested

(c) Baseline values of EAB listed are for identical specimen DNI80SM010 (Group 5.1, Specimen 0502)

Table A-34 Elongation-at-Break for Anaconda Cable DNP78AN008 (Group 5.3, Specimen 0515)

CM Point	Elongation-at-Break (%)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a)
A(c)	454 483 490 Avg = 476±19	(b)	390 397 384 Avg = 390±7	(b)	418 293 360 352 Avg = 356±51
B	No change - no additional preaging after last CM Point				
C [A+168h@150°C]	25 36 31 Avg = 31±6	(b)	17 14 17 Avg = 16±2	(b)	13 36 21 12 Avg = 20±11
D	No change - no additional preaging after last CM Point				
E [C+53.6 Mrad]	17 26 21 Avg = 22±5	(b)	10 9 10 Avg = 9±1	(b)	13 31 23 Avg = 22±9
F [E+77.1 Mrad]	9 7 6 4 Avg = 6±2	(b)	≤5	(b)	10 Avg = 10
G [F+77.7 Mrad]	9 8 7 Avg = 8±2	(b)	≤5	(b)	12 7 7 11 33 Avg = 14 ±11
H [G+Steam/Chem.Spray]	12 7 11 Avg = 10±3	(b)	≤5	(b)	Not tested. Specimens badly distorted

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation

(b) Not tested

(c) Baseline values of EAB listed are for identical specimen DNP78AN008 (Group 4.1, Specimen 0401)

Table A-35 Elongation-at-Break for Okonite Cable LNI81OK020 (Group 6.1, Specimen 0601)

CM Point	Elongation-at-Break (%)
	Hypalon® Bonded Outer Jacket /EPR Insulation
A[a]	490 471 450 Avg = 471±20
B	No change - no additional preaging after last CM Point
C	No change - no additional preaging after last CM Point
D	No change - no additional preaging after last CM Point
E	No change - no additional preaging after last CM Point
F [A+79.0 Mrad]	371 369 339 Avg = 360±18
G [F+77.6 Mrad]	226 237 241 Avg = 234±8
H [G+Steam/Chem.Spray]	Not tested

(a) Baseline values of EAB listed are for identical specimen LNI81OK020 (Group 5.1, Specimen 0501)

Table A-36 Elongation-at-Break for Samuel Moore Cable DNI80SM010 (Group 6.1, Specimen 0602)

CM Point	Elongation-at-Break (%)		
	OJ[a]	IJB/Insul[a]	IJW/Insul[a]
A	619 637 581 Avg = 613±29	(b)	408 432 414 Avg = 418±12
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A+79.0 Mrad]	338 380 364 Avg = 361±21	(b)	288 324 288 Avg = 300±21
G [F+77.6 Mrad]	240 249 230 Avg = 240±10	(b)	177 179 156 Avg = 171±13
H [G+Steam/Chem.Spray]	(b)	(b)	(b)

(a) OJ = Hypalon ®outer jacket, IJB = Hypalon® black bonded individual jacket, IJW = Hypalon® white bonded individual jacket, Insul = EPDM bonded insulation

(b) Not tested

(c) Baseline values of EAB listed are for identical specimen DNI80SM010 (Group 5.1, Specimen 0502)

Table A-37 Elongation-at-Break for AIW Cable PNI74AI035, (Group 6.1, Specimen 0603)

CM Point	Elongation-at-Break (%)				
	OJ[a]	IJB[a]	IJW[a]	IJR[a]	Insul[a]
A	444 475 367 Avg = 429±56	(b)	462 395 477 482 Avg = 454±40	(b)	401 400 373 Avg = 391±16
B	No change - no additional preaging after last CM Point				
C	No change - no additional preaging after last CM Point				
D	No change - no additional preaging after last CM Point				
E	No change - no additional preaging after last CM Point				
F [A+79.0 Mrad]	355 361 401 Avg = 373±25	(b)	447 414 321 Avg = 394±65	(b)	431 500 468 Avg = 466±35
G [F+77.6 Mrad]	281 295 233 Avg = 270±33	(b)	317 324 338 Avg = 326±11	(b)	160 155 168 Avg = 161±7
H [G+Steam/Chem.Spray]	(b)	(b)	(b)	(b)	(b)

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation

(b) Not tested

Table A-38 Elongation-at-Break for Rockbestos Cable PNI79RB188 (Group 6.1, Specimen 0604)

CM Point	Elongation-at-Break (%)		
	Neoprene® Outer Jacket	Black XLPE Insulation	White XLPE Insulation
A	592 515 565 Avg = 557±39	(a)	560 595 568 Avg = 574±18
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A+79.0 Mrad]	171 188 162 Avg = 174±13	(a)	311 353 355 Avg = 340±25
G [F+77.6 Mrad]	115 148 153 154 Avg = 143±19	(a)	155 143 159 Avg = 152±8
H [G+Steam/Chem.Spray}	(a)	(a)	(a)

(a) Not tested

Table A-39 Elongation-at-Break for Okonite Cable LNI81OK020 (Group 6.2, Specimen 0605)

CM Point	Elongation-at-Break (%)
	Hypalon® Bonded Outer Jacket/ EPR Insulation
A[(a)]	490 471 450 Avg = 471±20
B	No change - no additional preaging after last CM Point
C [A+756h@302°F]	Brittle ≤ 5%
D	No change - no additional preaging after last CM Point
E [C+77.3 Mrad]	Brittle ≤ 5%
F [E+79.0 Mrad]	Brittle ≤ 5%
G [F+77.6 Mrad]	Brittle ≤ 5%
H [G+Steam/Chem.Spray]	Brittle ≤ 5%

(a) Baseline values of EAB listed are for identical specimen LNI81OK020 (Group 5.1, Specimen 0501)

Table A-40 Elongation-at-Break for Samuel Moore Cable DNI80SM010 (Group 6.2, Specimen 0608)

CM Point	Elongation-at-Break (%)		
	OJ[a]	IJB/Insul[a]	IJW/Insul[a]
A[c]	619 639 581 Avg = 613±29	(b)	408 432 414 Avg = 418±12
B	No change - no additional preaging after last CM Point		
C [A+252h@250°F]	436 376 349 Avg = 387±45	(b)	176 174 154 Avg = 168±12
D	No change - no additional preaging after last CM Point		
E [C+77.3 Mrad]	139 151 146 Avg =145±6	(b)	65 68 70 Avg = 68±3
F [E+79.0 Mrad]	75 67 68 Avg = 70±4	(b)	45 41 44 38 43 Avg = 42±3
G [F+77.6 Mrad]	59 49 53 Avg = 54±5	(b)	37 38 36 Avg = 37±1
H [G+Steam/Chem.Spray]	(b)	(b)	(b)

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black bonded individual jacket, IJW = Hypalon® white bonded individual jacket, Insul = EPDM bonded insulation

(b) Not tested

(c) Baseline values of EAB listed are for identical specimen DNI80SM010 (Group 5.1, Specimen 0502)

Table A-41 Elongation-at-Break for AIW Cable PNI74AI035 (Group 6.2, Specimen 0611)

CM Point	Elongation-at-Break (%)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a)
A	444 475 367 Avg = 429±56	(b)	462 395 477 482 Avg = 454±40	(b)	401 400 373 Avg = 391±16
B	No change - no additional preaging after last CM Point				
C [A+252h@250°F]	390 306 266 249 Avg = 303±63	(b)	334 374 Avg = 354±28	(b)	340 304 255 Avg = 300±43
D	No change - no additional preaging after last CM Point				
E [C+38.65 Mrad]	177 207 191 Avg = 191±15	(b)	203 219 170 Avg = 197±25	(b)	238 160 273 202 Avg = 218±48
F [E+79.0 Mrad]	139 177 104 Avg = 140±37	(b)	148 146 167 Avg = 153±12	(b)	134 126 133 Avg = 131±4
G [F+77.6 Mrad]	140 152 171 Avg = 154±16	(b)	93 130 118 Avg = 114±19	(b)	126 131 123 Avg = 127±4
H [G+Steam/Chem.Spray]	(b)	(b)	(b)	(b)	(b)

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul = EPR insulation

(b) Not tested

Table A-42 Elongation-at-Break for Rockbestos Cable PNI79RB188 (Group 6.2, Specimen 0621) Aged to 40 yrs Service

CM Point	Elongation-at-Break (%)		
	Neoprene® Outer Jacket	Black XLPE Insulation	White XLPE Insulation
A(c)	592 515 565 Avg = 557±39	(a)	560 595 568 Avg = 574±18
B(b) [A+909.5h@302°F]	Brittle ≤ 5	(a)	Brittle ≤5
C	No change - no additional preaging after last CM Point		
D(b) [B+51.4 Mrad]	Brittle ≤ 5	(a)	Brittle ≤5
E	No change - no additional preaging after last CM Point		
F			
G			
H			

(a) Not tested
(b) Aged to 40 yrs service
(c) Baseline values of EAB listed are for identical specimen PNI79RB188 (Group 6.1, Specimen 0604)

Table A-43 Elongation-at-Break for Rockbestos Cable PNI79RB188 (Group 6.2, Specimen 0621) Aged to 60 yrs Service

CM Point	Elongation-at-Break (%)		
	Neoprene® Outer Jacket	Black XLPE Insulation	White XLPE Insulation
A[(c)]	592 515 565 Avg = 557±39	(a)	560 595 568 Avg = 574±18
B	No change - no additional preaging after last CM Point		
C[(b)] [A+1364h@302°F]	Brittle ≤5%	(a)	Brittle ≤ 5%
D	No change - no additional preaging after last CM Point		
E[(b)] [C+77.0 Mrad]	Brittle ≤5%	(a)	Brittle ≤ 5%
F [E+79.0 Mrad]	Brittle ≤5%	(a)	Brittle ≤ 5%
G [F+77.6 Mrad]	Brittle ≤5%	(a)	Brittle ≤ 5%
H [G+Steam/Chem.Spray]	Brittle ≤5%	(a)	Brittle ≤ 5%

(a) Not tested
(b) Aged to 60 yrs service
(c) Baseline values of EAB listed are for identical specimen PNI79RB188 (Group 6.1, Specimen 0604)

Table A-44 Correlation Between Aging Time and Elongation-at-Break for White XLPE from Rockbestos Cable PNI85RB191

Specimen	Aging Time at 350°F (177°C) (hrs.)	Elongation-at-Break (%)
1	0	444 426 433 Avg = 434±9
2	6	440 475 498 Avg = 471±29
3	18	447 339 Avg = 393±76
4	24	346 393 408 Avg = 382±32
5	48	357 318 362 Avg = 346±24
6	72	368 358 Avg = 363±7
7	96	213 153 157 Avg = 174±34
8	120	65 102 79 Avg = 82±19
9	144	81 84 64 Avg = 76±11
10	168	75 86 95 Avg = 86±10

Appendix B

Oxidation Induction Time Data

Tables

Table B-1 Oxidation Induction Time for Rockbestos Cable PNI79RB188 (Group 1.1, Specimen 0101)

CM Point	Oxidation Induction Time (min) at 200°C		
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation
A [Unused]	(a)	45.8 46.0 Avg = 45.9±0.1	91.7 84.7 Avg = 88.2±5.0
B,C,D,E	No change - no additional preaging after last CM Point		
F [A + 78.3 Mrad]	(a)	28.6 29.3 Avg = 29.0±0.5	18.7 21.23 Avg = 20.0±1.8
G [F + 78.3 Mrad]	(a)	36.6 38.9 Avg = 37.8±1.6	29.6 28.7 Avg = 29.1±0.6
H [G + Steam/Chem. Spray]	(a)	25.8	24.6

(a) Non-classical thermogram; unable to determine oxidation induction times.

Table B-2 Oxidation Induction Time for Rockbestos Cable PNI85RB191 (Group 1.2, Specimen 0106)

CM Point	Oxidation Induction Time (min) at 220°C			
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation	Red XLPE Insulation
A [Unused]	(a)	103.0	111.2	111.0
B [A + 2.86 hrs @ 120°C]	(a)	102.2	111.8	111.6
C	No change - no additional preaging after last CM Point			
D [B + 0.63 Mrad]	(a)	104.4	114.1	109.6
E	No change - no additional preaging after last CM Point			
F [D + 78.3 Mrad	(a)	48.2	53.7	41.9
G [F + 78.3 Mrad]	(a)	31.0	53.5	52.5
H [G + Steam/Chem. Spray]	(a)	30.6	20.9	12.3

(a) Non classical thermogram; unable to determine oxidation induction times.

Table B-3 Oxidation Induction Time for Rockbestos Cable PAP86RB267 (Group 1.3, Specimen 0111)

CM Point	Oxidation Induction Time (min) at 220°C			
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation	Red XLPE Insulation
A [Naturally Aged 10 yrs]	(a)	109.3	112.8	(b)
B,C,D,E	No change - no additional preaging after last CM Point			
F [A + 78.3 Mrad]	(a)	60.5	54.8	(b)
G [F + 78.3 Mrad]	(a)	61.9	59.1	(b)
H [G + Steam/Chem. Spray]	(a)	32.0	29.2	(b)

(a) Non classical thermogram; unable to determine oxidation induction times
(b) Not tested

Table B-4 Oxidation Induction Time for Rockbestos Cable PNI79RB188 (Group 1.4, Specimen 0112)

CM Point	Oxidation Induction Time (min)		
	Neoprene® Jacket	Black XLPE Insulation	White XLPE Insulation
A Unused	(a)	45.9 (@ 200°C 8.0 (@220°C	(c)
B	No change - no additional preaging after last CM Point		
C 648.5 hrs @ 150°C	(a)	Instantaneous oxidation at 200°C	(c)
D	No change - No additional preaging after last CM Point		
E [C + 26.1 Mrad]	(a)	(b)	(c)
F [E + 78.3 Mrad]	(a)	(b)	(c)
G [F + 78.3 Mrad]	(a)	(b)	(c)
H [G + Steam/Chem. Spray]	(a)	(b)	(c)

(a) Non classical thermogram; unable to determine oxidation induction times
(b) Instantaneous oxidation upon introduction of oxygen
(c) Not tested

Table B-5 Oxidation Induction Time for AIW Cable PNI74AI025 (Group 2.1, Specimen 0201)

CM Point	Oxidation Induction Time (min)	
	Hypalon® Outer Jacket[a]	**EPR Insulation[b]**
A [Unused]	46.1 46.0 Avg = 46.1±0.1	27.0 29.5 31.0 Avg = 29.2±2.0
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.6 Mrad]	22.3 21.3 Avg = 21.8±0.7	15.0 14.1 Avg = 14.5±0.6
G [F + 77.5 Mrad]	6.6 5.9 Avg = 6.2±0.5	8.2 8.6 Avg = 8.4±0.3

(a) Test temperature is 210° C
(b) Test temperature is 200° C

Table B-6 Oxidation Induction Time for AIW Cable PNI74AI026 (Group 2.2, Specimen 0203)

CM Point	Oxidation Induction Time (min)	
	Hypalon® Outer Jacket(a)	EPR Insulation(b)
A(c) [Unused]	46.1 46.0 Avg = 46.1±0.1	27.0 29.5 31.0 Avg = 29.2±2.0
B [A + 28.45 hrs @ 121°C]	41.4 42.1 Avg = 41.8±0.5	15.6 16.2 17.8 15.0 Avg = 16.1±1.2
C	No change - no additional preaging after last CM Point	
D [B + 3.25 Mrad]	42.4 42.0 Avg = 42.2±0.3	17.9 18.7 Avg = 18.3±0.6
E	No change - no additional preaging after last CM Point	
F [D + 76.6 Mrad]	13.6 12.2 Avg = 12.9±1.0	8.0 8.2 Avg = 8.1±0.1
G	No change - no additional preaging after last CM Point	

(a) Test temperature is 210°C
(b) Test temperature is 200°C
(c) Baseline values of OIT listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

Table B-7 Oxidation Induction Time for AIW Cable PAI74AI015 & 019 (Group 2.3, Specimens 0207 and 0210)

CM Point	Oxidation Induction Time (min)			
	Group 0207		Group 0210	
	Hypalon® Outer Jacket(a)	EPR Insulation(b)	Hypalon® Outer Jacket(a)	EPR Insulation(b)
A Naturally aged 24 yrs	(c)	20.1 20.2 Avg = 20.2±0.1	(c)	21.8 18.2 Avg = 20.0±2.6
B	No change - no additional preaging after last CM Point			
C	No change - no additional preaging after last CM Point			
D	No change - no additional preaging after last CM Point			
E	No change - no additional preaging after last CM Point			
F 76.6 Mrad	(c)	6.3 6.0 Avg = 6.2±0.2	(c)	4.5 3.9 Avg = 4.2±0.4
G 154.1 Mrad	(c)	3.1 3.2 Avg = 3.2±0.1	(c)	(c)

(a) Test temperature is 210°C
(b) Test temperature is 200°C
(c) Thermogram non classical in shape; unable to determine the oxidation induction time

Table B-8 Oxidation Induction Time for AIW Cable PNI74AI028 & 032 (Group 2.4, Specimens 0213 and 0214)

CM Point	Oxidation Induction Time (hrs)			
	Group 0213 (4-conductor)		Group 0214 (3-conductor)	
	Hypalon® Outer Jacket(a)(e)	EPR Insulation(b)(e)	Hypalon® Outer Jacket(a)	EPR Insulation(b)
A Unused	46.1 46.0 Avg = 46.1±0.1	27.0 29.5 31.0 Avg = 29.2±2.0	(c)	24.7 26.0 Avg = 25.3±0.9
B	No change - no additional preaging after last CM Point			
C [A + 82.45 hrs @ 121°C]	39.7 38.7 Avg = 39.2±0.7	15.5 15.8 Avg = 15.7±0.2	(c)	6.1 6.8 7.4 8.4 Avg = 7.2±1.0
D	No change - no additional preaging after last CM Point			
E [C + 25.8 Mrad]	27.8 31.8 Avg = 29.8±2.8	9.2 10.8 Avg = 10.0±1.1	(c)	8.4 8.0 Avg = 8.2±0.3
F [E + 76.6 Mrad]	8.5 9.7 Avg = 9.1±0.9	3.2 4.1 Avg = 3.6±0.6	(c)	5.4 4.0 Avg = 4.7±1.0
G [F + 77.5 Mrad]	4.9 2.7 Avg = 3.8±1.6	3.0 3.0 Avg = 3.0	(c)	(d)

(a) Test temperature is 210°C
(b) Test temperature is 200°C
(c) Thermogram non classical in shape; unable to determine the oxidation induction time
(d) Not tested
(e) Baseline values of OIT listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

Table B-9 Oxidation Induction Time for White XLPE Insulation from Rockbestos Cable PNI79RB188 (Group 3.1, Specimen 0301)

CM Point	Oxidation Induction Time (min) at 220°C	
	First Peak	Second Peak
A [Unused]	(a)	10.0 8.1 Avg = 9.1±1.3
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.5 Mrad]	(a)	7.7 8.0 Avg = 7.9±0.2
G [F + 76.5 Mrad]	(a)	7.5 7.1 Avg = 7.3±0.3
H [G + Steam/Chem. Spray]	(a)	2.5 2.5 Avg = 2.5

(a) First peak not observed or poorly defined

Table B-10 Oxidation Induction Time for White XLPE Insulation from Rockbestos Cable PNI85RB191 (Group 3.1, Specimen 0302)

CM Point	Oxidation Induction Time (min) at 220°C	
	First Peak	**Second Peak**
A [Unused]	98 105 Avg = 101±5	101 107 Avg = 104±4
B	No chance - no additional preaging after last CM Point	
C	No chance - no additional preaging after last CM Point	
D	No chance - no additional preaging after last CM Point	
E	No chance - no additional preaging after last CM Point	
F [A + 76.5 Mrad]	45 41 Avg = 43±3	56 60 Avg = 58±3
G [F + 76.5 Mrad]	31 35 Avg = 33±3	60 66 Avg = 63±4
H [G + Steam/Chem. Spray]	42 42 Avg = 42	46 44 Avg = 45±1

Table B-11 Oxidation Induction Time for White XLPE Insulation from Rockbestos Cable PNI85RB191 (Group 3.2, Specimen 0303)

CM Point	Oxidation Induction Time (min) at 220°C	
	First Peak	Second Peak
A[(a)] [Unused]	98 105 Avg =101±5	101 107 Avg = 104±4
B [A + 9.93 hrs@ 120°C]	91 97 Avg = 94±4	97 103 Avg = 100±4
C	No change - no additional preaging after last CM Point	
D [B + 2.27 Mrad]	94 90 Avg = 92±3	107 104 Avg = 106±2
E	No change - no additional preaging after last CM Point	
F [D + 76.5 Mrad]	38 38 Avg = 38	50 52 Avg = 51±1
G [F + 76.5 Mrad]	34 36 Avg = 35±1	60 61 Avg = 60±1
H [G + Steam/Chem. Spray]	24 26 Avg = 25±1	44 42 Avg = 43±1

(a) Baseline values of OIT listed for identical specimen PNI79RB191 (Group 3.1, Specimen 0302)

Table B-12 Oxidation Induction Time for White XLPE Insulation from Rockbestos Cable PAP86RB229 (Group 3.3, Specimen 0307)

CM Point	Oxidation Induction Time (min) at 220°C	
	First Peak	Second Peak
A [Naturally aged 10 yrs]	101 104 Avg = 102±2	102 105 Avg = 103±2
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.5 Mrad]	52 53 Avg = 52±1	69 69 Avg = 69
G [F + 76.5 Mrad]	33 35 Avg = 34±1	59 60 Avg = 60±1
H [G + Steam/Chem. Spray]	30 23 Avg = 27±5	67 65 Avg = 66±1

Table B-13 Oxidation Induction Time for White XLPE Insulation from Rockbestos Cable PNI79RB188 (Group 3.4, Specimen 0312)

CM Point	Oxidation Induction Time (min) at 220°C	
	First Peak	Second Peak[c]
A [Unused]	(a)	10.0 8.1 Avg = 9.1±1.0
B	No change - no additional preaging after last CM Point	
C [A +1301 hrs @ 150°C]	(a)	0[b]
D	No change - no additional preaging after last CM Point	
E [C + 51.5 Mrad]	(a)	0
F [E + 76.5 Mrad]	(a)	0
G [F + 76.5 Mrad]	(a)	0
H [G + Steam/Chem. Spray]	(a0	0

(a) Peak not observed or poorly defined
(b) After artificial thermal aging, material oxidized immediately upon introduction of oxygen
(c) Baseline values of OIT listed are for identical specimen PNI79RB188 (Group 3.1, Specimen 0301)

Table B-14 Oxidation Induction Time for AIW Cable PNI74AI035 (Group 6.2, Specimen 0611)

CM Point	Oxidation Induction Time (min)	
	Hypalon® Outer Jacket[a]	EPR Insulation[b]
A [Unused]	(c)	24.7 26.0 Avg = 25.3±1
B	No change - no additional preaging after last CM Point	
C [A + 252h@250°F]	(c)	(d)
D	No change - no additional preaging after last CM Point	
E [C + 38.65 Mrad]	(c)	2.6 3.2 Avg = 2.9±0.4
F [E + 79.0 Mrad]	(c)	5.4 4.0 Avg = 4.7±1.0
G [F + 77.6 Mrad]	(c)	(d)

(a) Test temperature is 210°C
(b) Test temperature is 200°C
(c) None classical thermogram, OITM not measurable
(d) Not tested

Table B-15 Oxidation Induction Time for AIW Cable PNI74AI028 (Group 2.4, Specimens 0213 and 0214) as a Function of Simulated Service Aging at 140°F (60°C)

Group	Material	Aging Protocol	Equivalent Aging Time at 140°F (60°C), (yrs)		Oxidation Induction Time (min)[a]	
			Hypalon® Outer Jacket	EPR Insulation	Hypalon® Outer Jacket	EPR Insulation
2.4 (Specimen 0213A)	PNI74AI028	None	0	0	46.1	29.2
2.2 (Specimen 0203D)	PNI74AI026	28.45h@121°C + 3.25 Mrad	2.6	1.9	42.2	18.3
2.4 (Specimen 0213E)	PNI74AI028	82.5h@121°C + 25.8 Mrad	7.6	5.5	29.8	10.0
2.4 (Specimen 0214E)	PNI74AI028	82.5h@121°C + 25.8 Mrad	7.6	5.5	(b)	8.2
6.2 (Specimen 0611E)	PNI74AI035	252h@121°C + 38.65 Mrad	23.2	16.8	(b)	2.9

(a) Hypalon® tested at 210°C and EPR at 200°C
(b) Non-classical thermogram, OITM not determinable

Appendix C

Oxidation Induction Temperature Data

Tables

Table C-1 Oxidation Induction Temperature for Rockbestos Cable PNI79RB188 (Group 1.1, Specimen 0101)

CM Point	Oxidation Induction Temperature (°C)			
	Neoprene® Jacket		Black XLPE Insulation	White XLPE Insulation
	Peak 1	Peak 2		
A [Unused]	210.2 210.3 Avg = 210.2±0.1	292.9 292.6 Avg = 292.8±0.2	247.2 250.5 Avg = 248.9±2.3	239.1 241.7 Avg = 240.4±1.8
B,C,D,E	No change - no additional preaging after last CM Point			
F [A + 78.3 Mrad]	203.8 204.1 Avg = 204.0±0.2	294.2 297.4 Avg = 295.8±2.3	242.9 243.5 Avg = 243.2±0.4	242.7 240.0 Avg = 241.3±1.9
G [F + 78.3 Mrad]	200.3 200.1 Avg = 200.2±0.1	291.1 289.1 Avg = 290.1±1.4	246.6 246.1 Avg = 246.3±0.3	241.9 241.6 Avg = 241.7±0.2
H [G + Steam/Chem. Spray]	214.3 214.1 Avg = 214.2±0.1	292.4 294.0 Avg = 293.2±1.1	214.0 214.8 Avg = 214.4±0.6	207.6 205.3 Avg = 206.4±1.6

Table C-2 Oxidation Induction Temperature for Rockbestos Cable PNI85RB191 (Group 1.2, Specimen 0106)

CM Point	Oxidation Induction Temperature (°C)				
	Neoprene® Jacket		Black XLPE Insulation	White XLPE Insulation	Red XLPE Insulation
	Peak 1	Peak 2			
A [Unused]	209.9 208.5 Avg = 209.2±1.0	299.5 301.3 Avg = 300.4±1.3	272.9 273.0 Avg=273.0±0.1	272.8 271.4 Avg=272.1±1.0	271.1 270.1 Avg=270.6±0.7
B [A + 2.86 hrs @ 120°C]	212.9 212.1 209.5 Avg=211.5±1.8	292.8 294.4 297.6 Avg=294.9±2.4	267.4 267.7 Avg=267.5±0.2	268.9 270.9 269.0 269.3 Avg=269.5±0.9	268.6 270.8 269.8 268.6 Avg=269.4±1.1
C	No change - no additional preaging after last CM Point				
D [B + 0.63 Mrad]	212.1 211.3 Avg=211.7±0.6	298.2 298.8 Avg=298.5±0.4	268.5 268.5 Avg=268.5	269.5 269.2 Avg=269.3±0.2	268.6 268.5 Avg=268.5±0.1
E	No change - no additional preaging after last CM Point				
F [D + 78.3 Mrad]	203.3 203.8 Avg=203.6±0.3	295.0 295.8 Avg=295.4±0.6	267.9 268.0 Avg=268.0±0.1	263.2 264.0 266.4 Avg=264.5±1.7	264.3 267.1 267.2 Avg=266.2±1.7
G [F + 78.3 Mrad]	203.7 204.9 Avg=204.3±0.9	291.8 290.1 Avg=291.0±1.2	262.9 263.1 Avg=263.0±0.1	265.8 264.8 Avg=265.3±0.7	262.8 263.8 Avg=263.3±0.7
H [G + Steam/Chem. Spray]	211.8 217.2 Avg=214.5±3.8	291.7 295.1 Avg=293.4±2.4	260.1 264.8 Avg=262.4±3.3	259.7 260.1 Avg=259.9±0.3	261.0 259.5 Avg=260.2±1.1

Table C-3 Oxidation Induction Temperature for Rockbestos Cable PAP86RB267 (Group 1.3, Specimen 0111)

CM Point	Oxidation Induction Temperature (°C)				
	Neoprene® Jacket		Black XLPE Insulation	White XLPE Insulation	Red XLPE Insulation
	Peak 1	Peak 2			
A [Naturally Aged 10 yrs]	207.1 212.0 207.6 206.3 Avg=208.2±2.6	296.4 290.6 292.9 299.9 Avg=295.0±4.1	270.1 270.7 269.0 268.4 Avg=269.6±1.0	274.0 272.3 Avg=273.1±1.2	271.5 270.6 Avg=271.0±0.6
B,C,D,E	No change - no additional preaging after last CM Point				
F [A + 78.3 Mrad]	200.8 200.4 Avg=200.6±0.3	295.7 290.8 Avg=293.2±3.5	263.2 262.2 Avg=262.7±0.6	261.4 261.9 Avg=261.7±0.3	263.8 263.4 Avg=263.6±0.3
G [F + 78.3 Mrad]	200.7 201.4 Avg=201.0±0.5	286.1 288.8 Avg=287.4±1.9	265.9 265.5 Avg=265.7±0.3	264.5 264.4 Avg=264.4±0.1	264.5 264.0 Avg=264.2±0.3
H [G + Steam/Chem. Spray]	193.1 187.4 Avg=190.2±4.0	295.6 294.3 Avg=295.0±0.9	259.5 263.4 Avg=261.4±2.8	264.0 260.2 Avg=262.1±2.7	257.6 262.0 Avg=259.8±3.1

Table C-4 Oxidation Induction Temperature for Rockbestos Cable PNI79RB188 (Group 1.4, Specimen 0112)

CM Point	Oxidation Induction Temperature (°C)			
	Neoprene® Jacket		Black XLPE Insulation	White XLPE Insulation
	Peak 1	Peak 2		
A [Unused]	210.2 210.3 Avg = 210.2±0.1	292.9 292.6 Avg = 292.8±0.2	247.2 250.5 Avg = 248.9±2.3	239.1 241.7 Avg = 240.4±1.8
B	No Change - no additional preaging after last CM Point			
C [A + 648.5 hrs @ 150°C]	233.9 240.3 244.4 241.0 Avg = 239.9±4.4	(a)(1)	209.9 210.5 209.8 209.6 Avg = 210.0±0.4	206.1 207.0 206.1 205.4 Avg = 206.1±0.7
D	No Change - no additional aging since last CM Point			
E [C + 26.1 Mrad]	209.4 211.3 Avg = 210.3±1.3	(a)	208.8 208.7 Avg = 208.8±0.1	207.3 207.3 Avg = 207.3
F [E + 78.3 Mrad]	206.3 209.6 Avg = 208.0±2.3	(a)	207.4 213.4 Avg = 210.4±4.2	207.0 210.2 Avg = 208.6±2.3
G [F + 78.3 Mrad]	206.5 207.0 Avg = 206.8±0.3	(a)	207.8 207.2 Avg = 207.5±0.4	203.1 203.2 Avg = 203.1±0.1
H [G + Steam/Chem. Spray]	228.5 227.8 Avg = 228.1±0.5	(a)	214.1 213.1 Avg = 213.6±0.7	216.3 211.1 Avg = 213.7±3.7

(a) No second peak

Table C-5 Oxidation Induction Temperature for AIW Cable PNI74AI025 (Group 2.1, Specimen 0201)

CM Point	Oxidation Induction Temperature (°C)					
	OJ[a]	IJB	IJW	IJR	IJG	Insul.
A [Unused]	231.9 232.6 Avg = 232.2±0.5	231.7 230.8 Avg = 231.3±0.6	256.5	256.7 258.8 Avg = 257.8±1.5	256.5	234.9 230.6 Avg = 232.7±3.0
B	No change - no additional preaging after last CM Point					
C	No change - no additional preaging after last CM Point					
D	No change - no additional preaging after last CM Point					
E	No change - no additional preaging after last CM Point					
F [A + 76.6 Mrad]	226.9 227.0 Avg = 226.9±0.1	226.1 226.0 Avg = 226.0±0.1	247.4 246.8 Avg = 247.1±0.4	245.0 246.4 Avg = 245.7±1.0	246.9 243.9 Avg = 245.4±2.1	232.2 232.2 Avg = 232.2
G [F + 77.5 Mrad]	221.8 220.9 Avg = 221.3±0.6	220.4 223.4 Avg = 221.9±2.1	241.5 238.3 Avg = 239.9±2.3	240.1 240.0 Avg = 240.1±0.1	242.6 242.5 Avg = 242.5±0.1	221.7 218.8 Avg = 220.3±2.0
H [G + Steam/Chem. Spray]	219.5 217.2 Avg = 218.4±1.6	209.8 210.2 Avg = 210.0±0.3	225.3 226.4 Avg = 225.9±0.8	226.9 224.7 Avg = 225.8±1.6	221.1 221.4 Avg = 221.3±0.2	155.3 169.5 179.0 Avg = 167.9±11.9

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

Table C-6 Oxidation Induction Temperature for AIW Cable PNI74AI031 (Group 2.1, Specimen 0202)

CM Point	Oxidation Induction Temperature (⁰C)				
	OJ[a]	IJB	IJW	IJR	Insul.
A [Unused]	240.8 241.9 Avg = 241.3±0.87	(b)	258.5	260.9 259.4 260.9 Avg. = 260.4±0.9	242.6 246.7 Avg = 244.7±2.9
B	No change - no additional preaging after last CM Point				
C	No change - no additional preaging after last CM Point				
D	No change - no additional preaging after last CM Point				
E	No change - no additional preaging after last CM Point				
F [76.6 Mrad]	215.5 216.8 Avg = 216.2±0.9	205.3 204.0 Avg = 204.7±0.9	247.4 245.6 Avg = 246.5±1.3	(b)	229.2 227.2 Avg = 228.2±1.4
G [F + 77.5 Mrad]	200.2 198.2 Avg = 199.2±1.4	186.3 187.3 Avg = 186.8±0.7	228.1 229.7 Avg = 228.9±1.1	(b)	211.7 209.5 Avg = 210.6±1.6
H [G + Steam/Chem. Spray]	228.2 227.4 Avg = 227.8±0.6	224.6 221.2 Avg = 222.9±2.4	226.1 220.1 Avg = 223.1±4.2	(b)	165.5 166.8 Avg = 166.2±0.9

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Not tested

Table C-7 Oxidation Induction Temperature for AIW Cable PNI74AI026 (Group 2.2, Specimen 0203)

CM Point	Oxidation Induction Temperature (°C)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul.
A(b) [Unused]	231.9 232.6 Avg = 232.2±0.5	231.7 230.8 Avg = 231.3±0.6	256.5	256.7 258.8 Avg =257.8±1.5	256.5	234.9 230.6 Avg = 232.7±3.0
B [A + 28.45 hrs @ 121°C]	224.9 222.0 Avg = 223.5±2.1	233.0 231.7 Avg = 232.4±0.9	258.6 259.8 Avg = 259.2±0.9	257.3 257.6 Avg = 257.5±0.2	255.1	229.5 228.8 Avg = 229.2±0.5
C	No change - no additional preaging after last CM Point					
D [B + 3.25 Mrad]	229.8 227.8 Avg = 228.8±1.4	228.6 227.2 Avg = 227.9±1.0	255.5	254.0 253.0 Avg = 253.5±0.7	256.2 255.5 Avg = 255.8±0.5	234.2 233.4 Avg = 233.8±0.6
E	No change - no additional preaging after last CM Point					
F [D + 76.6 Mrad]	236.4 236.3 Avg =236.4±0.1	226.3 228.5 Avg = 227.4±1.6	244.9 245.1 Avg = 245.0±0.1	243.8 241.1 Avg = 242.5±1.9	248.6 247.7 Avg = 248.1±0.6	224.3 225.0 Avg = 224.7±0.5
G	No change - no additional preaging after last CM Point					
H [F + Steam/Chem. Spray]	228.9 227.9 Avg = 228.4±0.7	223.6 226.0 Avg =224.8±1.7	223.1 223.3 Avg = 223.2±0.1	220.9 218.5 Avg = 219.7±1.7	223.4 223.5 Avg = 223.5±0.1	195.7 190.0 Avg = 192.9±4.0

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Baseline values of OI Temperature listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

Table C-8 Oxidation Induction Temperature for AIW Cable PNI74AI027 (Group 2.2, Specimen 0205)

CM Point	Oxidation Induction Temperature (°C)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul.
A(b) [Unused]	231.9 232.6 Avg = 232.2±0.5	231.7 230.8 Avg = 231.3±0.6	256.5	256.7 258.8 Avg =257.8±1.5	256.5	234.9 230.6 Avg =232.7±3.0
B(c) [A + 28.45 hrs @ 121°C]	224.9 222.0 Avg = 223.5±2.0	233.0 231.7 Avg = 232.4±0.9	258.6 259.8 Avg = 259.2±0.9	257.3 257.6 Avg = 257.5±0.2	255.1	229.5 228.8 Avg = 229.2±0.5
C	No change - no additional preaging after last CM Point					
D(c) [B + 3.25 Mrad]	229.8 227.8 Avg = 228.8±1.4	228.6 227.2 Avg = 227.9±1.0	255.5	254.0 253.0 Avg = 253.5±0.7	256.2 255.5 Avg = 255.8±0.5	234.2 233.4 Avg =233.8±0.6
E	No change - no additional preaging after last CM Point					
F [D + 76.6 Mrad]	236.4 236.3 Avg = 236.4±0.1	226.3 228.5 Avg = 227.4±1.6	244.9 245.1 Avg = 245.0±0.1	243.8 241.1 Avg = 242.5±1.9	248.6 247.7 Avg = 248.1±0.6	224.3 225.0 Avg = 224.7±0.5
G [F + 77.5 Mrad]	214.7 214.1 Avg = 214.4±0.4	196.0	236.0 232.5 Avg = 234.3±2.5	225.0 221.1 Avg = 223.0±2.8	230.3 228.8 Avg = 229.6±1.1	210.0 211.2 Avg = 210.6±0.9
H [G + Steam/Chem. Spray]	213.6 213.9 Avg = 213.7±0.2	206.9 206.0 Avg = 206.5±0.6	226.6 227.5 Avg = 227.1±0.6	226.1 224.8 Avg = 225.5±0.9	222.6 224.7 Avg = 223.7±1.5	169.5 173.8 Avg = 171.7±3.0

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Baseline values of OI Temperature listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

(c) Values of OI Temperature listed are for identical specimen PNI74AI026 (Group 2.2, Specimen 0203)

Table C-9 Oxidation Induction Temperature for AIW Cable PNI74AI015
(Group 2.3, Specimen 0207)

CM Point	Oxidation Induction Temperature (^{0}C)					
	OJ[a]	IJB	IJW	IJR	IJG	Insul.
A [Nat. Aged 24 yrs]	228.2 229.7 Avg = 228.9±1.1	234.4 235.6 Avg = 235.0±0.9	251.6	250.6 252.7 Avg = 251.6±1.5	254.0	229.0 232.6 Avg = 230.8±2.6
B	No change - no additional preaging after last CM Point					
C	No change - no additional preaging after last CM Point					
D	No change - no additional preaging after last CM Point					
E	No change - no additional preaging after last CM Point					
F [A + 76.6 Mrad]	227.4 229.7 Avg = 228.6±1.6	224.5 225.6 Avg = 225.0±0.8	238.2 238.7 Avg = 238.4±0.3	239.3 238.5 Avg = 238.9±0.6	245.2 245.7 Avg = 245.5±0.3	217.7 217.5 Avg = 217.6±0.1
G [F + 77.5 Mrad]	216.3 217.1 Avg = 216.7±0.6	201.4 205.4 Avg = 203.4±2.8	221.1 219.5 Avg = 220.3±1.1	222.0 221.6 Avg = 221.8±0.3	227.6 230.0 Avg = 228.8±1.7	203.3 202.4 Avg = 202.9±0.6
H [G + Steam/Chem. Spray]	220.3 219.2 Avg = 219.8±0.8	235.2 237.8 Avg = 236.5±1.8	222.6 222.1 Avg = 222.4±0.3	221.3 219.0 Avg = 220.2±1.6	219.5 218.4 Avg = 219.0±0.8	186.8 183.7 Avg = 185.3±2.2

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

Table C-10 Oxidation Induction Temperature for AIW Cable PNI74AI019 (Group 2.3, Specimen 0210)

CM Point	Oxidation Induction Temperature (°C)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul.
A [Nat. Aged 24 yrs]	228.4 231.5 227.9 Avg = 229.2±2.0	236.6 236.5 Avg = 236.6±0.1	252.6	251.2 251.5 Avg = 251.4±0.2	253.4	228.3 234.3 Avg = 231.3±4.2
B	No change - no additional preaging after last CM Point					
C	No change - no additional preaging after last CM Point					
D	No change - no additional preaging after last CM Point					
E	No change - no additional preaging after last CM Point					
F [A + 76.6 Mrad]	228.0 229.2 229.2 Avg = 228.8±0.7	207.2 208.0 Avg = 207.6±0.6	240.4 238.7 Avg = 239.5±1.2	237.4 237.4 Avg = 237.4	243.0 241.9 Avg = 242.5±0.8	209.7 210.1 Avg = 209.9±0.3
G [F = 77.5 Mrad]	214.6 216.3 Avg = 215.4±1.2	197.0	233.7 233.0 Avg = 233.4±0.5	229.2 226.9 Avg =228.0±1.6	234.3 236.7 Avg =235.5±1.7	197.0 199.1 Avg = 198.1±1.5
H [G + Steam/Chem. Spray]	204.2 204.6 Avg = 204.4±0.3	200.4 201.4 Avg = 200.9±0.7	220.8 221.6 Avg =221.2±0.6	217.2 218.5 Avg = 217.9±0.9	224.2 220.6 Avg = 222.4±2.6	179.8 174.5 Avg = 177.2±3.8

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

Table C-11 Oxidation Induction Temperature for AIW Cable PNI74AI028 (Group 2.4, Specimen 0212)

CM Point	Oxidation Induction Temperature (°C)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul.
A(b) [Unused]	231.9 232.6 Avg =232.2±0.5	231.7 230.8 Avg = 231.3±0.6	256.5	256.7 258.8 Avg =257.8±1.5	256.5	234.9 230.6 Avg = 232.7±3.0
B	No change - no additional preaging after last CM Point					
C [A +82.5 hrs @ 121°C]	221.7 224.1 Avg = 222.9±1.7	224..8 225.4 Avg = 225.1±0.4	257.9 258.0 Avg = 257.9±0.1	255.9 257.0 Avg = 256.5±0.8	257.4 257.4 Avg = 257.4	232.6 232.2 Avg = 232.4±0.3
D	No change - no additional preaging after last CM Point					
E [C + 25.8 Mrad]	227.7 225.3 Avg = 226.5±1.7	227.3 227.5 Avg = 227.4±0.1	255.4	252.2 252.5 Avg = 252.3±0.2	254.1	223.9 221.2 Avg = 222.6±1.9
F [E + 76.6 Mrad]	229.3 228.7 Avg = 229.0±0.4	222.0 221.6 Avg = 221.8±0.3	239.7 239.3 Avg = 239.5±0.3	237.6 237.6 Avg = 237.6	247.2 247.6 Avg = 247.4±0.3	218.0 219.9 Avg = 219.0±1.3
G	No change - no additional preaging after last CM Point					
H [F + Steam/Chem. Spray]	218.2 218.3 Avg = 218.2±0.1	208.6 207.7 Avg = 208.2±0.6	222.9 223.3 Avg = 223.1±0.3	226.4 228.0 Avg = 227.2±1.1	225.0 223.2 Avg = 224.1±1.3	168.6 167.9 Avg = 168.2±0.5

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Baseline values of OI Temperature listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

Table C-12 Oxidation Induction Temperature for AIW Cable PNI74AI028 (Group 2.4, Specimen 0213)

CM Point	Oxidation Induction Temperature (°C)					
	OJ(a)	IJB	IJW	IJR	IJG	Insul.
A(c) [Unused]	231.9 232.6 Avg = 232.2±0.5	231.7 230.8 Avg = 231.3±0.6	256.5	256.7 258.8 Avg = 257.8±1.5	256.5	234.9 230.6 Avg = 232.7±3.0
B	No change - no additional preaging after last CM Point					
C(d) [A +82.5 hrs @ 121°C]	221.7 224.1 Avg = 222.9±1.7	224..8 225.4 Avg = 225.1±0.4	257.9 258.0 Avg = 257.9±0.1	255.9 257.0 Avg = 256.5±0.8	257.4 257.4 Avg = 257.4	232.6 232.2 Avg = 232.4±0.3
D	No change - no additional preaging after last CM Point					
E(d) [C + 25.8 Mrad]	227.7 225.3 Avg = 226.5±1.7	227.3 227.5 Avg = 227.4±0.1	255.4	252.2 252.5 Avg = 252.3±0.2	254.1	223.9 221.2 Avg = 222.6±1.9
F(d) [E + 76.6 Mrad]	229.3 229.0 Avg = 229.0±0.4	222.0 221.6 Avg = 221.8±0.3	239.7 239.3 Avg = 239.5±0.3	237.6 237.6 Avg = 237.6	247.2 247.6 Avg = 247.4±0.3	218.0 219.9 Avg = 219.0±1.3
G [F + 77.5 Mrad]	216.9 215.9 Avg = 216.4±0.7	199.1	231.7	228.5 230.3 Avg = 229.4±1.3	226.1	200.1 200.7 Avg = 200.4±0.4
H [G + Steam/Chem. Spray]	161.1 164.9 Avg =163.0±2.7	192.4 197.6 Avg = 195.0±3.7	232.2 230.0 Avg = 231.1±1.6	222.8 224.4 Avg = 223.6±1.1	(b)	170.2 169.6 Avg = 169.9±0.4

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Not tested

(c) Baseline values of OI Temperature listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

(d) Values of OI Temperature listed are for identical specimen PNI74AI028 (Group 2.4, Specimen 0212)

Table C-13 Oxidation Induction Temperature for AIW Cable PNI74AI032 (Group 2.4, Specimen 0214)

CM Point	Oxidation Induction Temperature (°C)				
	OJ[a]	IJB	IJW	IJR	Insul.
A[c] [Unused]	240.8 241.9 Avg = 241.3±0.8	(b)	258.5	260.9 259.4 260.9 Avg = 260.4±0.9	242.6 246.7 Avg = 244.7±2.9
B	No change - no additional preaging after last CM Point				
C [A +82.5 hrs @ 121°C]	231.8 230.3 Avg = 231.0±1.1	223.0 219.2 Avg = 221.1±2.7	262.0 262.1 Avg = 262.0±0.1	(b)	218.6 223.0 Avg = 220.8±3.1
D	No change - no additional preaging after last CM Point				
E [C + 25.8 Mrad]	225.9 221.6 Avg = 223.8±3.0	228.8 228.0 Avg = 228.4±0.6	250.6 249.8 Avg = 250.2±0.6	(b)	224.9 223.0 Avg = 223.9±1.3
F [E + 76.6 Mrad]	198.8 198.3 Avg = 198.6±0.4	186.4 188.6 Avg = 187.5±1.6	246.3 249.5 Avg = 247.9±2.3	(b)	223.6 222.2 Avg = 222.9±1.0
G [F + 77.5 Mrad]	179.7 171.5 Avg = 175.6±5.8	177.0 174.7 Avg = 175.9±1.6	238.8 238.6 Avg = 238.7±0.1	(b)	198.0 197.4 Avg = 197.7±0.4
H [G + Steam/Chem. Spray]	148.2 149.5 Avg = 148.9±0.9	233.6 232.5 Avg = 233.1±0.8	231.3 230.2 Avg = 230.8±0.8	(b)	168.1 171.5 Avg = 169.8±0.4

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Not tested

(c) Baseline values of OI Temperature listed are for identical specimen PNI74AI031 (Group 2.1, Specimen 0202)

Table C-14 Oxidation Induction Temperature for Rockbestos Cable PNI79RB188 (Group 3.1, Specimen 0301)

CM Point	Oxidation Induction Temperature (°C)		
	Neoprene® Jacket		White XLPE
	First Peak	Second Peak	
A [Unused]	209.5 210.1 Avg = 209.8±0.4	301.3 298.2 Avg = 299.8±2.2	245.1 246.0 Avg = 245.6±0.6
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A + 76.65 Mrad]	205.1 206.1 Avg = 205.6±0.7	296.6 297.1 Avg = 296.9±0.3	243.3 241.9 Avg = 242.6±1.0
G [F + 76.75 Mrad]	207.9 209.4 Avg = 208.7±1.1	285.2 285.4 Avg = 285.3±0.1	238.3 238.2 Avg = 238.3±0.1
H [G + Steam/Chem. Spray]	202.3 203.6 Avg = 202.9±0.9	286.9 289.6 Avg = 288.3±1.9	213.3 213.0 Avg = 213.1±0.2

Table C-15 Oxidation Induction Temperature for Rockbestos Cable PNI85RB191 (Group 3.1, Specimen 0302)

CM Point	Oxidation Induction Temperature (°C)		
	Neoprene® Jacket		White XLPE
	First Peak	Second Peak.	
A [Unused]	209.9 208.5 Avg = 209.2±1.0	299.5 301.3 Avg = 300.4±1.3	270.0 268.9 Avg = 269.5±0.8
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A +76.65 Mrad]	209.0 208.2 Avg = 208.6±0.6	295.8 297.4 Avg = 296.6±1.1	268.2 269.7 Avg = 269.0±1.1
G [F + 76.75 Mrad]	194.3 192.9 Avg = 193.6±1.0	285.3 288.4 Avg = 286.9±2.2	264.6 267.3 Avg = 266.0±1.9
H [G + Steam/Chem. Spray]	213.6 213.9 Avg = 213.7±0.2	289.4 291.2 Avg = 290.3±1.3	272.9 272.4 Avg = 272.6±0.3

Table C-16 Oxidation Induction Temperature for Rockbestos Cable PNI85RB191 (Group 3.2 Specimen 0303)

CM Point	Oxidation Induction Temperature (°C)		
	Neoprene® Jacket		White XLPE
	First Peak	Second Peak.	
A [Unused]	209.9 208.5 Avg = 209.2±1.0	299.5 301.3 Avg = 300.4±1.3	270.0 268.9 Avg = 269.5±0.8
B [A + 9.93 hrs @ 120°C]	209.9 209.0 Avg = 209.5±0.6	298.8 300.6 Avg = 299.7±1.3	269.2 269.2 Avg = 269.2
C	No change - no additional preaging after last CM Point		
D [B + 2.27 Mrad]	208.9 212.2 Avg = 210.6±2.3	296.0 293.4 Avg = 294.7±1.8	271.0 270.4 Avg = 270.7±0.4
E	No change - no additional preaging after last CM Point		
F [D + 76.65 Mrad]	189.8 199.9 Avg = 194.9±7.1	294.7 296.3 Avg = 295.5±1.1	266.3 266.7 Avg = 266.5±0.3
G [F + 76.75 Mrad]	202.6 198.7 Avg = 200.6±2.8	282.5 286.6 Avg = 284.5±2.9	269.8 270.3 Avg = 270.0±0.3
H [G + Steam/Chem. Spray]	210.6 211.7 Avg = 211.2±0.8	290.2 292.6 Avg = 291.4±1.7	272.5 274.2 Avg = 273.3±1.2

Table C-17 Oxidation Induction Temperature for Rockbestos Cable PAP86RB229 (Group 3.3, Specimen 0307)

CM Point	Oxidation Induction Temperature (°C)		
	Neoprene® Jacket		White XLPE
	First Peak	Second Peak.	
A [Naturally aged 10 yrs]	208.9 209.9 Avg = 209.4±0.7	304.3 301.8 Avg = 303.1±1.8	269.7 269.7 Avg = 269.7
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A + 76.65 Mrad]	203.6 199.9 Avg = 201.7±2.6	297.3 299.3 Avg = 298.4±1.4	268.9 269.5 Avg = 269.2±0.4
G [F + 76.75 Mrad]	207.6 211.5 Avg = 209.6±2.8	297.6 299.0 Avg = 298.3±1.0	268.8 269.2 Avg =269.0±0.3
H [G + Steam/Chem. Spray]	205.7 207.4 Avg = 206.6±1.2	289.6 288.9 Avg = 289.2±0.5	271.9 271.2 Avg = 271.6±0.5

Table C-18 Oxidation Induction Temperature for Rockbestos Cable PNI79RB188 (Group 3.4, Specimen 0312)

CM Point	Oxidation Induction Temperature (°C)		
	Neoprene® Jacket		White XLPE
	First Peak	Second peak.	
A [Unused]	209.5 210.1 Avg = 209.8±0.4	301.3 298.2 Avg = 299.8±2.2	245.1 246.6 Avg = 245.8±1.1
B	No change - no additional preaging after last CM Point		
C [A + 1301 hrs @ 150°C]	212.5 211.1 Avg = 211.8±1.0	(a)	213.7 212.1 Avg = 212.9±1.1
D	No change - no additional preaging after last CM Point		
E [C + 51.5 Mrad]	207.4 208.2 Avg = 207.8±0.6	(a)	211.9 213.2 Avg = 212.5±0.9
F [E = 76.65 Mrad]	201.4 206.0 Avg = 203.7±3.3	(a)	218.2 218.7 Avg = 218.5±0.3
G [F + 76.75 Mrad]	210.9 209.2 Avg = 210.0±1.2	(a)	221.8 223.4 Avg = 222.6±1.1
H [G + Steam/Chem. Spray]	192.8 189.6 Avg = 191.2±2.3	(a)	194.6 192.2 Avg = 193.4±1.7

(a) Peak not observed for current test conditions

Table C-19 Oxidation Induction Temperature for Anaconda Cable DNP78AN008 (Group 4.3, Specimen 0407) Aged to 20 Years

CM Point	Oxidation Induction Temperature (°C)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a).
A(d) [Unused]	247.6 246.5 247.1 247.0 Avg = 247.0±0.4	235.2 234.8 Avg = 235.0±0.3	233.6 232.0 Avg = 232.8±1.1	(c)	225.0 226.0 Avg = 225.5±0.7
B(b) [A +84 hrs @ 150°C]	(c)	(c)	(c)	(c)	(c)
C)	No change - no additional preaging after last CM Point				
D(b) [C + 25.7 Mrad]	(c)	(c)	(c)	(c)	186.6 183.0 Avg = 184.8±2.6
E	No change - no additional preaging after last CM Point				
F [E + 77.1 Mrad]					
G [F + 77.7 Mrad]					
H [G + Steam/Chem. Spray]					

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation
(b) Aged to 20 years
(c) Not tested
(d) Baseline values of OI Temperature listed are for identical specimen DNP78AN008 (Group 4.1, Specimen 0401)

Table C-20 Oxidation Induction Temperature for Anaconda Cable DNP78AN008 (Group 4.3, Specimen 0407) Aged to 40 Years

CM Point	Oxidation Induction Temperature (°C)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a).
A(d) [Unused]	247.6 246.5 247.1 247.0 Avg = 247.0±0.4	235.2 234.8 Avg = 235.0±0.3	233.6 232.0 Avg = 232.8±1.1	(c)	225.0 226.0 Avg = 225.5±0.7
B	No change - no additional preaging after last CM Point				
C(b) [A +168 hrs @ 150°C]	(c)	(c)	(c)	(c)	(c)
D	No change - no additional preaging after last CM Point				
E(b) [C + 53.6 Mrad]	(c)	(c)	(c)	(c)	166.1 166.4 Avg = 166.2±0.2
F [E + 77.1 Mrad]	(c)	(c)	(c)	(c)	(c)
G [F + 77.7 Mrad]	(c)	(c)	(c)	(c)	(c)
H [G + Steam/Chem. Spray]	(c)	(c)	(c)	(c)	(c)

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation
(b) Aged to 40 years service
(c) Not tested
(d) Baseline values of OI Temperature listed are for identical specimen DNP78AN008 (Group 4.1, Specimen 0401)

Table C-21 Oxidation Induction Temperature for Anaconda Cable DNP78AN008 (Group 5.1, Specimen 0503)

CM Point	Oxidation Induction Temperature (°C)				
	OJ(a)	IJB(a)	IJW(a)	IJR(a)	Insul(a).
A [Unused]	(b)	(b)	(b)	(b)	228.8 227.5 Avg = 228.1±0.9
B	No change - no additional preaging after last CM Point				
	No change - no additional preaging after last CM Point				
D	No change - no additional preaging after last CM Point				
E	No change - no additional preaging after last CM Point				
F [E + 77.1 Mrad]	(b)	(b)	(b)	(b)	(b)
G [F + 77.7 Mrad]	(b)	(b)	(b)	(c)	(b)
H [G + Steam/Chem. Spray]	(b)	(b)	(b)	(b)	(b)

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Not tested

Table C-22 Oxidation Induction Temperature for Anaconda Cable DNP78AN008 (Group 5.2, Specimen 0508)

CM Point	Oxidation Induction Temperature (°C)				
	OJ[(a)]	IJB[(a)]	IJW[(a)]	IJR[(a)]	Insul[(a)].
A[(c)] [Unused]	(b)	(b)	(b)	(b)	228.8 227.5 Avg = 228.1±0.9
B[(b)] [A +84 hrs @ 121°C]	(b)	(b)	(b)	(b)	(b)
C)	No change - no additional preaging after last CM Point				
D[(b)] [B + 25.7 Mrad]	(b)	(b)	(b)	(b)	208.8 206.4 Avg = 207.6±1.7
E	No change - no additional preaging after last CM Point				
F [E + 77.1 Mrad]	(b)	(b)	(b)	(b)	(b)
G [F + 77.7 Mrad]	(b)	(b)	(b)	(b)	(b)
H [G + Steam/Chem. Spray]	(b)	(b)	(b)	(b)	(b)

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Not tested

(c) Baseline values of OI Temperature listed are for identical specimen DNP78AN008 (Group 5.1, Specimen 0503)

Table C-23 Oxidation Induction Temperature for Anaconda Cable DNP78AN008 (Group 5.3, Specimen 0515)

CM Point	Oxidation Induction Temperature (°C)				
	OJ[a]	IJB[a]	IJW[a]	IJR[a]	Insul[a].
A[C] [Unused]	(b)	(b)	(b)	(b)	228.8 227.5 Avg = 228.1±0.9
B	No change - no additional preaging after last CM Point				
C [168h@150°C]	(b)	(b)	(b)	(b)	(b)
D	No change - no additional preaging after last CM Point				
E [C+53.6 Mrad]	(b)	(b)	(b)	(b)	166.9 166.0 Avg = 166.4±0.6
F [E + 77.1 Mrad]	(b)	(b)	(b)	(b)	(b)
G [F + 77.7 Mrad]	(b)	(b)	(b)	(c)	(b)
H [G + Steam/Chem. Spray]	(b)	(b)	(b)	(b)	(b)

(a) OJ = Hypalon® outer jacket, IJB = Hypalon® black individual jacket, IJW = Hypalon® white individual jacket, IJR = Hypalon® red individual jacket, Insul. = EPR insulation

(b) Not tested

(c) Baseline values of OI Temperature listed are for identical specimen DNP78AN008 (Group 5.1, Specimen 0503)

Table C-24 Oxidation Induction Temperature Results for EPR Insulation as a Function of Simulated Service Aging at 140°F (60°C)

Group	Material	Aging Protocol	Equivalent Aging Time at 140°F (60°C), (y)	Oxidation Induction Temperature (°C)
2.4 (Specimen 0213A)	AIW (PNI74AI028)	None	0	234.9 230.6 Avg = 232.7±3.0
2.4 (Specimen 0214A)	AIW (PNI74AI032)	None	0	242.6 246.7 Avg = 244.7±2.9
2.2 (Specimen 0205D)	AIW (PNI74AI027)	28.45h@ 121°C + 3.25 Mrad	1.9	234.2 233.4 Avg = 233.8±0.6
2.4 (Specimen 0213E)	AIW (PNI74AI028)	82.5h@ 121°C + 25.8 Mrad	5.48	223.9 221.2 Avg = 222.6±1.9
2.4 (Specimen 0214E)	AIW (PNI74AI032)	82.5h@ 121°C + 25.8 Mrad	5.48	224.9 223.0 Avg = 223.9±1.3
4.3 (Specimen 0407A)	Anaconda (DNP78AN008)	None	0	225.0 226.0 Avg = 225.5±0.7
5.1 (Specimen 0503A)	As above	None	0	228.8 227.5 Avg = 228.1±0.9
4.3 (Specimen 0407D)	As above	84h@ 150°C + 25.7 Mrad	59.9	186.6 183.0 Avg = 184.8±2.6
5.2 (Specimen 0508D)	As above	As above	59.9	208.8 206.4 Avg = 207.6±1.7
4.3 (Specimen 0407E)	As above	168h@ 150°C + 53.6 Mrad	120	166.1 166.4 Avg = 166.2±0.2
5.3 (Specimen 0515E)	As above	As above	120	166.9 166.0 Avg = 166.4±0.6

Table C-25 Oxidation Induction Temperature Results for Hypalon® Jackets as a Function of Simulated Service Aging at 140°F (60°C)

Group	Material	Aging Protocol	Equiv. Aging Time at 140°F (60°C) (yr)	Oxidation Induction Temperature (°C)		
				Black Outer Jacket.	Black Indiv. Jacket	Avg. for Colored Jackets
2.4 (Specimen 0213A)	AIW (PNI74AI028)	None	0	231.9 232.6 Avg = 232.2±0.5	231.7 230.8 Avg = 231.3±0.6	Avg = 256.9±0.8
2.4 (Specimen 0214A)	AIW (PNI74AI032)	None	0	233.1 235.0 Avg = 234.0±1.3	240.8 241.9 Avg = 241.3±0.8	Avg = 259.4±1.3
2.2 (Specimen 0205D)	AIW (PNI74AI027)	28.45h@ 121°C + 3.25 Mrad	2.6	229.8 227.8 Avg = 228.8±1.4	228.6 227.2 Avg = 227.9±1.0	Avg = 254.9±1.2
2.4 (Specimen 0213E)	AIW (PNI74AI028)	82.5h@ 121°C + 25.8 Mrad	7.6	227.7 225.3 Avg = 226.5±1.7	227.3 227.5 Avg = 227.4±0.1	Avg = 253.9±1.6
2.4 (Specimen 0214E)	AIW (PNI74AI032)	82.5h@ 121°C + 25.8 Mrad	7.6	225.9 221.6 Avg = 223.8±3.0	228.8 228.0 Avg = 228.4±0.6	Avg = 250.2±0

Appendix D

Fourier Transform Infrared Spectroscopy Data

Tables

Table D-1 FTIR Results for AIW Cable PNI74AI025 (Group 2.1, Series 0201)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}		
	Hypalon® Outer Jacket	Hypalon®White Individual Jacket	EPR Insulation
A [Unused]	21.3 17.2 12.1 Avg = 16.9±4.6	9.6 10.4 11.9 Avg = 10.6±1.2	10.1 11.1 9.9 Avg = 10.4±0.6
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A + 76.6 Mrad]	15.5 22.8 15.6 Avg = 18.0±4.1	10.9 10.4 11.3 Avg = 10.8±0.4	8.0 10.8 9.8 Avg = 9.5±1.4
G [F + 77.5 Mrad]	11.9 10.1 11.0 Avg = 11.0±0.9	8.5 8.4 13.4 Avg = 10.1±2.9	9.9 9.6 10.5 Avg = 10.0±0.5
H [G + Steam/Chem. Spray]	2.6 5.6 3.9 Avg = 4.0±1.5	1.5 2.2 2.0 Avg = 1.9±0.4	10.8 12.5 12.3 Avg = 11.9±0.9

Table D-2 FTIR Results for AIW Cable PNI74AI027 (Group 2.2, Series 0205)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}		
	Hypalon®Outer Jacket	Hypalon®White Individual Jacket	EPR Insulation.
A[a] [Unused]	21.3 17.2 12.1 Avg = 16.9±4.6	9.6 10.4 11.9 Avg = 10.6±1.2	10.1 11.1 9.9 Avg = 10.4±0.6
B[b] [A + 28.45 hrs @ 121°C]	10.4 10.0 12.1 Avg = 10.8±1.1	7.3 9.0 7.3 Avg = 7.9±1.0	9.4 9.2 9.7 Avg = 9.4±0.2
C	No change - no additional preaging after last CM Point		
D[b] [B + 3.25 Mrad]	15.0 12.0 8.1 Avg = 11.7±3.5	10.1 5.5 9.5 Avg = 8.4±2.5	8.7 10.1 10.0 Avg = 9.6±0.8
E	No change - no additional preaging after last CM Point		
F[b] [D + 76.6 Mrad]	10.1 10.0 10.7 Avg = 10.3±0.4	3.4 6.6 7.3 Avg = 5.8±2.1	9.2 9.2 11.0 Avg = 9.8±1.0
G [F + 77.5 Mrad]	5.8 8.6 8.1 Avg = 7.5±1.5	6.6 4.5 8.0 Avg = 6.4±1.8	9.9 8.5 9.7 Avg = 9.4±0.8
H [G + Steam/Chem. Spray]	1.2 3.6 2.3 Avg = 2.4±1.2	0.6 0 0 Avg = 0.2±0.3	9.8 10.0 14.4 Avg = 11.4±2.6

(a) Baseline values listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)
(b) Values listed are for identical specimen PNI74AI026 (Group 2.2, Specimen 0203)

Table D-3 FTIR Results for AIW Cable PAI74AI019 (Group 2.3, Series 0210)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}		
	Hypalon®Outer Jacket	Hypalon®White Individual Jacket	EPR Insulation.
A [Nat. Aged 24 yrs]	11.2 16.9 14.5 Avg = 14.2±2.9	9.6 16.9 12.7 Avg = 13.1±3.7	16.9 11.5 9.6 Avg = 12.7±3.8
B	No change - no additional preaging after last CM Point		
C	No change - no additional preaging after last CM Point		
D	No change - no additional preaging after last CM Point		
E	No change - no additional preaging after last CM Point		
F [A + 76.65 Mrad]	12.7 12.9 17.4 Avg = 14.3±2.7	7.6 15.0 8.9 Avg = 10.5±4.0	10.1 9.7 11.6 Avg = 10.5 ±1.0
G [F + 77.75 Mrad]	12.6 11.7 12.5 Avg = 12.3±0.5	10.4 11.7 11.1 Avg = 11.1±0.7	10.7 10.9 11.7 Avg = 11.1±0.5
H [G + Steam/Chem. Spray]	5.8 3.8 4.8 Avg = 4.8±1.0	1.6 2.7 2.1 Avg = 2.1±0.6	9.3 11.7 10.7 Avg = 10.6±1.2

Table D-4 FTIR Results for AIW Cable PNI74AI028 (Group 2.4, Series 0213)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}		
	Hypalon®Outer Jacket	Hypalon®White Individual Jacket	EPR Insulation
A(a) [Unused]	21.3 17.2 12.1 Avg = 16.9±4.6	9.6 10.4 11.9 Avg = 10.6±1.2	10.1 11.1 9.9 Avg = 10.4±0.6
B	No change - no additional preaging after last CM Point		
C(b) [A + 82.5 hrs @ 121°C]	7.0 11.5 9.5 Avg = 9.3±2.3	9.3 9.0 9.6 Avg = 9.3±0.3	8.9 10.7 10.0 Avg = 9.9±0.9
D	No change - no additional preaging after last CM Point		
E(b) [C + 25.8 Mrad]	7.2 9.6 11.3 Avg = 9.4±2.1	4.9 8.9 8.3 Avg = 7.4±2.2	9.7 9.5 11.5 Avg = 10.2±1.1
F(b) [E + 76.65 Mrad]	5.0 8.4 9.2 Avg = 7.5±2.2	9.4 2.5 3.9 Avg = 5.3 ±3.7	11.6 9.5 10.9 Avg = 10.7 ±1.1
G [F + 77.75 Mrad]	7.2 8.1 9.2 Avg = 8.2±1.0	7.5 5.9 9.2 Avg = 7.5±1.7	9.4 9.0 9.8 Avg = 9.4±0.4
H [G + Steam/Chem. Spray]	0.5 2.8 2.0 Avg = 1.8±1.2	1.0 1.0 0.1 Avg = 0.7±0.5	9.8 7.0 11.5 Avg = 9.4±2.3

(a) Baseline values listed are for identical specimen PNI74AI025 (Group 2.1, Specimen 0201)

(b) Baseline values listed are for identical specimen PNI74AI028 (Group 2.4, Specimen 0212)

Table D-5 FTIR Results for Rockbestos Cable PNI79RB188 (Group 3.1, Series 301)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}	
	Neoprene® Jacket	White XLPE Insulation
A [Unused]	(a)	9.8 11.5 8.2 10.1 Avg = 9.9±1.4
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.65 Mrad]	(a)	7.6 6.8 6.7 5.7 Avg = 6.7±0.8
G [F + 76.75 Mrad]	(a)	5.7 5.5 5.4 6.0 Avg = 5.7±0.3
H [G + Steam/Chem. Spray]	(a)	4.2 6.7 5.9 9.1 6.8 Avg = 6.5±1.8

(a) Not tested

Table D-6 FTIR Results for Rockbestos Cable PNI85 RB191 (Group 3.1 Series 0302)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}	
	Neoprene® Jacket	White XLPE Insulation
A [Unused]	(a)	10.6 11.1 12.5 14.7 Avg = 12.2±1.8
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.65 Mrad]	(a)	12.9 13.8 15.2 11.5 Avg = 13.4±1.6
G [F + 76.75 Mrad]	(a)	14.6 14.6 13.2 13.4 Avg = 14.0±0.8
H [G + Steam/Chem. Spray]	(a)	11.6 11.1 15.6 10.7 14.9 Avg = 12.8±2.3

(a) Not tested

Table D-7 FTIR Results for Rockbestos Cable PNI85RB191 (Group 3.2, Series 0303)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}	
	Neoprene®Jacket	White XLPE Insulation
A [Unused]	(a)	12.3 12.5 13.1 12.4 Avg = 12.6±0.4
B [A + 9.93 hrs @ 120°C]	(a)	11.3 11.6 11.0 11.6 Avg = 11.4±0.3
C	No change - no additional preaging after last CM Point	
D [B + 2.27 Mrad]	(a)	10.1 9.1 9.9 11.9 Avg = 10.2±1.2
E	No change - no additional preaging after last CM Point	
F [D + 76.65 Mrad]	(a)	10.3 9.5 10.9 10.5 Avg = 10.3±0.6
G [F + 76.75 Mrad]	(a)	10.2 10.5 9.6 9.5 Avg = 9.9±0.5
H [G + Steam/Chem. Spray]	(a)	10.8 10.1 11.1 12.8 Avg = 11.2±1.1

(a) Not tested

Table D-8 FTIR Results for Rockbestos Cable PAP86RB229 (Group 3.3, Series 0307)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}	
	Neoprene® Jacket	White XLPE Insulation
A [Naturally aged 10 yrs]	(a)	10.5 12.3 9.3 11.0 Avg = 10.8±1.2
B	No change - no additional preaging after last CM Point	
C	No change - no additional preaging after last CM Point	
D	No change - no additional preaging after last CM Point	
E	No change - no additional preaging after last CM Point	
F [A + 76.65 Mrad]	(a)	9.5 9.2 9.7 12.9 11.6 Avg = 10.5±1.6
G [F + 76.75 Mrad]	(a)	11.8 8.0 9.6 9.6 Avg = 9.8±1.5
H [G + Steam/Chem. Spray]	(a)	13.1 13.1 12.4 13.7 Avg = 13.1±0.5

(a) Not tested

Table D-9 FTIR Results for Rockbestos Cable PNI79RB188 (Group 3.4, Series 0312)

CM Point	Peak Heights at Wavenumber 2916 cm^{-1}	
	Neoprene® Jacket	White XLPE Insulation
A [Unused]	(a)	9.8 11.5 8.2 10.2 Avg = 9.9±1.4
B	No change - no additional preaging after last CM Point	
C [A + 1301 hrs @ 150°C]	(a)	(b)
D	No change - no additional preaging after last CM Point	
E [C + 51.5 Mrad]	(a)	(b)
F [E + 76.65 Mrad]	(a)	(b)
G [F + 76.75 Mrad]	(a)	(b)
H [G + Steam/Chem. Spray]	(a)	(b)

(a) Not tested
(b) Specimens very stiff; no readings possible because of poor optical contact between specimen and crystal

Table D-10 FTIR Results for Irradiated Black XLPE Insulation From Rockbestos Cable PNI79RB188

Dose (Mrad)(a)	Peak Height at Wavenumber 2916 cm^{-1}
0	8.4 9.5 10.0 8.9 Avg = 9.2±0.7
21.1	6.9 7.4 7.4 8.1 Avg = 7.4±0.5
41.8	8.2 7.5 8.4 7.9 Avg = 8.0±0.4
60.5	5.4 7.6 6.8 6.7 Avg = 6.6±0.9
78.6	4.8 4.3 3.5 3.7 Avg = 4.1±0.6
95.8	3.5 4.1 2.9 4.0 Avg = 3.6±0.6
113.0	3.8 2.2 3.6 2.1 Avg = 2.9±0.9

(a) Average dose rate is 1.4x10^4 rad/hr

Table D-11 FTIR Results for AIW EPR/Hypalon Cables as a Function of Service Aging

Group	Material	Aging Protocol	Percent Transmittance at Wavenumber 2916 cm^{-1}
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (Hypalon® Outer Jacket)	None	78.7; 82.8; 87.9 Avg = 83.1±4.6
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (Hypalon® Outer Jacket)	28.45h@121°C + 3.25 Mrad	85.0; 88.0; 91.9 Avg = 88.3±3.5
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (Hypalon® Outer Jacket.)	82.5h@121°C + 25.8 Mrad	92.8; 88.5; 90.5 Avg = 90.6±2.2
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (Hypalon® White Individual Jacket)	None	90.4; 89.6; 88.1 Avg = 89.4±1.2
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (Hypalon® White Individual Jacket.)	28.45h@121°C + 3.25 Mrad	89.9; 94.5; 90.5 Avg = 91.6±2.5
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (Hypalon® White Individual Jacket)	82.5h@121°C + 25.8 Mrad	95.1; 91.9; 91.7 Avg = 92.6±1.9
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (EPR Insulation)	None	89.9; 88.9; 90.1 Avg = 89.6±0.6
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (EPR Insulation)	28.45h@121°C + 3.25 Mrad	91.3; 89.9; 90.0 Avg = 90.4±0.8
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (EPR Insulation)	82.5h@121°C + 25.8 Mrad	90.3; 90.5; 88.5 Avg = 89.8±1.1
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (Hypalon® Outer Jacket)	None	79.2; 77.6; 78.9 Avg = 78.6±0.9
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (Hypalon® Outer Jacket)	82.5h@121°C + 25.8 Mrad	84.6; 84.2; 81.7; 82.7 Avg = 83.3±1.3
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (Hypalon® Outer Jacket)	252h@121°C + 38.65 Mrad	89.5; 88.6; 89.3 Avg = 89.1±0.5
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (Hypalon® White Individual Jacket)	None	91.2; 89.9; 91.0; 90.0 Avg = 90.5±0.7
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (Hypalon® White Individual Jacket	82.5h@121°C + 25.8 Mrad	91.6; 94.5; 93.9; 92.0 Avg = 93.0±1.4
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (Hypalon® White Individual Jacket)	252h@121°C + 38.65 Mrad	97.3; 98.1; 97.9 Avg = 97.8±0.4
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (EPR Insulation)	None	91.1; 90.7; 90.0 Avg = 90.6±0.6
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (EPR Insulation)	82.5h@121°C + 25.8 Mrad	91.9; 91.1; 92.5 Avg = 91.8±0.7
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (EPR Insulation)	252h@121°C + 38.65 Mrad	94.2; 95.5; 94.4 Avg = 94.7±0.7

Table D-12 FTIR Results for AIW EPR/Hypalon Cables as a Function of Service Aging and Elongation-at-Break

Group	Material	Aging Protocol	Equiv. Aging Time at 60°C (y)	Transmittance at Wavenumber 2916 cm^{-1} (%)(a)	EAB (%)(a)
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (Hypalon® Outer Jacket)	None	0	83.1±4.6	649
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (Hypalon® Outer Jacket)	28.45h@121°C + 3.25 Mrad	2.6	88.3±3.5	582
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (Hypalon® Outer Jacket.)	82.5h@121°C + 25.8 Mrad	7.6	90.6±2.2	429
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (Hypalon® White Individual Jacket)	None	0	89.4±1.2	540
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (Hypalon® White Individual Jacket.)	28.45h@121°C + 3.25 Mrad	2.6	91.6±2.5	341
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (Hypalon® White Individual Jacket)	82.5h@121°C + 25.8 Mrad	7.6	92.6±1.9	371
2.2 (Spec. 0205A)	PNI74AI027 (4-conductor) (EPR Insulation)	None	0	89.6±0.6	284
2.2 (Spec. 0205D)	PNI74AI027 (4-conductor) (EPR Insulation)	28.45h@121°C + 3.25 Mrad	1.9	90.4±0.8	224
2.4 (Spec. 0213E)	PNI74AI028 (4-conductor) (EPR Insulation)	82.5h@121°C + 25.8 Mrad	5.5	89.8±1.1	196
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (Hypalon® Outer Jacket)	None	0	78.6±0.9	563
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (Hypalon® Outer Jacket)	82.5h@121°C + 25.8 Mrad	7.6	83.3±1.3	369
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (Hypalon® Outer Jacket)	252h@121°C + 38.65 Mrad	23.2	89.1±0.5	191
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (Hypalon® White Individual Jacket)	None	0	90.5±0.7	482
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (Hypalon® White Individual Jacket	82.5h@121°C + 25.8 Mrad	7.6	93.0±1.4	250
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (Hypalon® White Individual Jacket)	252h@121°C + 38.65 Mrad	23.2	97.8±0.4	197
2.1 (Spec. 0202A)	PNI74AI031 (3-conductor) (EPR Insulation)	None	0	90.6±0.6	341
2.4 (Spec. 0214E)	PNI74AI032 (3-conductor) (EPR Insulation)	82.5h@121°C + 25.8 Mrad	5.5	91.8±0.7	224
6.2 (Spec. 0611E)	PNI74AI035 (3-conductor) (EPR Insulation)	252h@121°C + 38.65 Mrad	16.8	94.7±0.7	218

(a) Average of at least 3 tests

Appendix E

Indenter Data

Tables

Table E.1 Test Sequence 1 - Compressive Modulus

Specimen Group	Specimen ID	Outer Jacket (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0101	8.49 (1.02)					8.81 (1.37)	10.84 (1.36)
	0102	8.58 (1.06)					9.65 (1.25)	11.85 (1.39)
	0118	8.19 (0.78)					9.34 (1.08)	12.83 (1.35)
	0104	9.14 (0.82)					10.33 (1.42)	12.33 (1.15)
	0105	9.14 (0.89)					10.18 (2.84)	13.26 (1.31)
2	0106	10.12 (0.69)	9.66 (0.75)		9.10 (1.46)		12.17 (1.08)	15.89 (1.55)
	0107	10.06 (1.03)	9.80 (0.87)		8.61 (0.84)		11.81 (3.17)	15.92 (1.46)
	0108	10.17 (0.82)	9.53 (0.77)		8.67 (1.26)		12.12 (1.54)	15.79 (1.64)
	0109	9.87 (0.83)	10.04 (0.65)		8.96 (1.48)		12.39 (0.78)	15.69 (0.97)
	0110	9.84 (0.83)	9.68 (0.69)		8.93 (0.79)		11.84 (0.72)	14.94 (0.92)
3	0111	10.68 (0.82)					11.11 (0.85)	13.49 (1.41)
4	0112	8.95 (0.98)		190.89 (38.70)		207.71 (38.78)	187.58 (39.49)	190.53 (60.45)
	0113	8.82 (0.92)		202.02 (71.50)		202.92 (61.52)	209.63 (55.32)	178.64 (56.33)
	0114	8.82 (0.89)		180.27 (37.39)		193.30 (66.64)	168.84 (71.49)	218.91 (61.08)
	0115	8.92 (0.87)		190.39 (26.54)		168.58 (53.80)	214.34 (67.92)	184.52 (34.73)
	0116	8.80 (0.74)		211.58 (27.68)		191.88 (67.40)	194.19 (88.51)	175.66 (53.44)
	0117	8.97 (0.90)		213.41 (45.38)		185.22 (48.47)	184.16 (50.50)	NA

Table E.1 Test Sequence 1 - Compressive Modulus

Specimen Group	Specimen ID	Insulation White (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0101	106.40 (3.38)					70.87 (14.86)	105.19 (6.35)
	0102	85.65 (11.09)					88.31 (7.34)	108.08 (6.35)
	0118	105.30 (6.40)					98.14 (7.64)	109.45 (6.81)
	0104	98.10 (6.43)					98.70 (10.36)	106.58 (7.57)
	0105	107.32 (7.99)					94.98 (7.42)	105.66 (9.58)
2	0106	166.91 (20.03)	160.04 (13.10)		149.11 (12.49)		174.18 (16.91)	186.37 (14.58)
	0107	186.80 (16.72)	168.96 (7.68)		158.67 (11.74)		173.01 (11.50)	180.78 (9.18)
	0108	173.97 (10.40)	176.11 (7.44)		141.61 (24.73)		166.43 (19.01)	189.85 (6.72)
	0109	170.89 (13.12)	167.21 (11.06)		148.10 (11.50)		186.19 (14.80)	187.06 (9.26)
	0110	182.87 (15.74)	178.28 (18.52)		150.09 (11.50)		179.82 (12.14)	191.25 (18.73)
3	0111	179.02 (11.69)					184.75 (9.55)	204.50 (8.06)
4	0112	87.97 (12.66)		153.19 (4.83)		133.39 (11.23)	137.25 (9.41)	149.20 (5.23)
	0113	102.69 (5.77)		149.11 (9.04)		117.93 (18.77)	139.29 (7.95)	134.21 (15.40)
	0114	88.24 (11.95)		157.87 (15.02)		120.27 (15.04)	149.91 (7.92)	141.12 (5.64)
	0115	103.55 (6.97)		156.02 (12.31)		108.19 (18.78)	150.40 (11.42)	145.63 (11.60)
	0116	101.26 (10.81)		142.23 (14.02)		134.46 (9.36)	135.38 (11.47)	130.33 (10.21)
	0117	100.62 (5.83)		144.29 (17.82)		130.97 (13.54)	155.99 (5.25)	NA

Table E.1 Test Sequence 1 - Compressive Modulus

Specimen Group	Specimen ID	Insulation Black (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0101	98.12 (5.93)					76.22 (6.21)	104.96 (7.66)
	0102	93.21 (7.27)					73.72 (8.19)	105.39 (11.25)
	0118	108.42 (12.70)					90.67 (12.47)	99.69 (5.77)
	0104	102.15 (6.18)					96.68 (7.87)	108.88 (8.18)
	0105	99.3 (7.68)					97.91 (6.05)	99.87 (8.37)
2	0106	177.03 (15.30)	150.08 (11.87)		113.78 (8.95)		162.32 (20.47)	178.16 (18.54)
	0107	172.16 (18.63)	166.41 (10.66)		152.36 (17.55)		168.29 (37.41)	183.85 (16.79)
	0108	165.85 (17.64)	169.71 (19.46)		150.48 (20.34)		163.66 (19.92)	183.18 (24.22)
	0109	173.74 (30.03)	169.39 (8.38)		141.35 (16.93)		187.47 (38.34)	175.33 (20.93)
	0110	181.97 (14.67)	178.28 (17.55)		149.59 (11.61)		164.38 (21.72)	173.51 (11.59)
3	0111	180.36 (7.59)					187.83 (16.95)	201.30 (19.19)
4	0112	87.98 (4.05)		160.85 (19.34)		120.73 (16.73)	137.91 (10.74)	140.92 (14.28)
	0113	103.88 (1.71)		141.04 (21.98)		121.01 (14.69)	141.98 (13.22)	140.36 (9.35)
	0114	91.10 (8.84)		145.55 (13.35)		111.55 (9.90)	138.24 (11.88)	152.98 (9.56)
	0115	102.20 (2.26)		153.26 (12.35)		100.25 (13.51)	130.16 (14.07)	139.13 (16.02)
	0116	103.96 (8.80)		140.38 (9.65)		96.18 (12.47)	137.85 (4.78)	137.78 (10.94)
	0117	102.64 (2.81)		138.21 (10.53)		105.29 (11.07)	153.75 (9.91)	NA

Notes:
1. Standard deviations provided in parenthesis
2. All measurements made at room temperature
3. Probe speed: for modulus less than 100 N/mm: 12.7 mm/min.
   for modulus greater than 100 N/mm: 5.1 mm/min.

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Outer Jacket (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	9.76 (1.48)					9.70 (1.40)	9.79 (1.21)
	0202	8.83 (0.50)					9.40 (0.60)	10.45 (0.77)
2	0203	10.16 (1.87)	10.51 (2.11)		9.47 (1.58)		11.17 (1.36)	
	0204	9.69 (1.78)	10.97 (1.59)		10.56 (1.74)		11.18 (1.62)	
	0205	9.34 (1.42)	9.95 (1.47)		10.45 (1.97)		10.65 (1.99)	13.98 (2.32)
	0206	10.41 (1.84)	9.95 (1.84)		9.78 (1.30)		10.69 (1.21)	13.40 (1.66)
3	0207	10.30 (1.41)					10.24 (1.62)	
	0208	9.88 (0.93)					9.56 (1.12)	
	0209	9.82 (1.23)					10.21 (1.90)	
	0210	9.87 (1.00)					10.11 (1.03)	
4	0212	9.19 (1.24)		10.76 (1.73)		10.95 (1.76)	11.41 (1.46)	
	0213	8.71 (1.49)		11.20 (1.18)		10.66 (1.48)	13.10 (1.70)	14.98 (1.87)
	0214	8.18 (0.48)		8.79 (0.86)		9.00 (0.60)	11.00 (0.76)	13.29 (1.23)
	0215	8.92 (0.95)		10.72 (1.78)		11.85 (1.41)	11.85 (1.68)	17.60 (3.03)
	0216	8.09 (0.30)		9.75 (1.14)		9.96 (0.80)	11.91 (0.93)	17.16 (1.02)

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Individual Jacket White (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0101	11.80 (0.61)					13.00 (0.51)	12.67 (0.53)
	0202	10.19 (0.70)					11.66 (0.39)	11.85 (0.58)
2	0203	11.53 (0.45)	13.63 (0.20)		12.09 (0.33)		13.26 (0.29)	
	0204	11.99 (0.50)	13.66 (0.54)		12.11 (0.61)		13.48 (0.37)	
	0205	11.30 (0.69)	13.19 (0.52)		12.04 (0.39)		13.39 (0.39)	13.00 (0.46)
	0206	11.25 (0.58)	13.39 (0.53)		11.93 (0.35)		13.52 (0.50)	13.34 (0.54)
3	0207	11.37 (0.82)					11.89 (0.66)	
	0208	11.61 (0.78)					12.19 (0.46)	
	0209	11.77 (1.05)					13.62 (0.85)	
	0210	11.44 (0.44)					12.41 (0.23)	
4	0212	11.54 (0.64)		14.25 (0.40)		12.97 (0.32)	13.53 (0.36)	
	0213	12.00 (0.95)		14.12 (0.30)		13.47 (0.45)	14.38 (0.56)	13.69 (4.05)
	0214	11.15 (0.90)		14.53 (0.60)		12.76 (0.44)	13.90 (1.37)	14.79 (2.85)
	0215	12.46 (0.44)		14.35 (0.36)		14.06 (0.43)	15.02 (0.28)	16.03 (1.30)
	0216	11.46 (0.62)		13.99 (0.69)		14.18 (0.90)	13.21 (0.90)	16.26 (0.87)

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Individual Jacket Black (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	10.70 (0.70)					11.03 (0.55)	11.30 (0.63)
	0202	11.40 (0.59)					12.13 (0.85)	13.07 (0.87)
2	0203	10.70 (0.41)	10.89 (1.52)		10.39 (0.31)		11.76 (1.35)	
	0204	10.75 (0.52)	10.79 (0.28)		10.76 (0.26)		11.64 (0.22)	
	0205	11.51 (1.14)	10.93 (0.20)		10.70 (0.25)		11.61 (0.17)	12.74 (0.39)
	0206	11.68 (0.87)	10.99 (0.65)		10.65 (0.49)		11.21 (0.33)	12.64 (0.58)
3	0207	11.98 (0.45)					12.47 (0.81)	
	0208	11.95 (0.67)					13.24 (0.51)	
	0209	11.87 (0.60)					13.18 (0.33)	
	0210	12.74 (0.46)					13.25 (0.95)	
4	0212	11.15 (0.41)		10.95 (0.55)		10.83 (0.26)	11.38 (0.16)	
	0213	11.29 (0.80)		10.72 (0.48)		11.02 (0.35)	12.55 (0.38)	14.59 (3.04)
	0214	11.16 (0.61)		11.03 (0.44)		11.33 (0.16)	12.43 (0.57)	12.59 (1.98)
	0215	11.01 (0.70)		10.62 (0.41)		10.85 (0.35)	11.96 (0.41)	15.50 (1.32)
	0216	11.63 (0.70)		11.36 (0.73)		11.71 (0.62)	12.11 (0.61)	15.35 (1.38)

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Individual Jacket Red (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	11.83 (0.99)					11.87 (0.48)	12.92 (0.65)
	0202	10.19 (0.23)					11.52 (0.60)	12.48 (0.45)
2	0203	12.28 (067)	14.44 (0.71)		12.59 (0.61)		13.33 (0.35)	
	0204	12.50 (0.76)	13.82 (0.69)		12.55 (0.75)		13.36 (0.74)	
	0205	11.73 (0.30)	13.36 (1.10)		12.16 (0.39)		13.49 (0.91)	13.44 (0.92)
	0206	11.85 (0.48)	14.21 (0.74)		12.42 (1.11)		13.43 (0.80)	13.58 (0.86)
3	0207	11.48 (0.98)					12.71 (0.76)	
	0208	11.55 (0.49)					12.84 (1.06)	
	0209	11.79 (0.59)					13.17 (0.64)	
	0210	10.84 (0.69)					12.09 (0.53)	
4	0212	11.85 (0.64)		14.15 (0.87)		13.06 (0.51)	13.60 (0.74)	
	0213	11.70 (0.51)		14.13 (0.59)		13.35 (0.71)	14.40 (0.66)	16.36 (0.74)
	0214	10.35 (0.56)		13.29 (0.30)		12.74 (0.42)	14.23 (0.50)	14.44 (0.81)
	0215	11.89 (0.60)		14.17 (0.70)		13.79 (0.53)	N/A	17.38 (0.95)
	0216	10.49 (0.73)		13.59 (0.41)		13.32 (0.67)	N/A	15.83 (0.80)

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Individual Jacket Green (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	10.78 (0.57)					10.81 (0.84)	11.54 (0.54)
	0202	-					-	-
2	0203	10.86 (0.70)	12.45 (0.66)		10.70 (0.39)		11.30 (0.50)	
	0204	10.43 (1.20)	12.31 (0.59)		10.90 (0.39)		11.64 (0.34)	
	0205	9.84 (0.50)	11.45 (0.52)		10.59 (0.49)		11.08 (0.19)	11.78 (0.46)
	0206	10.55 (0.33)	12.07 (0.27)		10.65 (0.50)		11.54 (0.60)	12.53 (0.58)
3	0207	12.01 (0.80)					12.27 (0.72)	
	0208	11.52 (0.58)					11.86 (0.98)	
	0209	11.29 (0.51)					12.35 (0.76)	
	0210	10.92 (0.48)					11.86 (0.63)	
4	0212	10.19 (1.18)		13.05 (0.40)		11.52 (0.53)	12.31 (0.49)	
	0213	10.54 (0.85)		12.95 (0.43)		12.05 (1.01)	12.27 (0.29)	16.40 (0.94)
	0214	-		-		-	-	-
	0215	10.80 (0.53)		12.49 (0.30)		12.10 (0.45)	N/A	17.03 (0.64)
	0216	-		-		-	-	-

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Insulation White (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	12.86 (2.30)					14.69 (2.43)	13.10 (2.86)
	0202	15.81 (2.06)					14.06 (3.49)	15.57 (3.37)
2	0203	13.07 (3.38)	16.08 (1.32)		15.08 (2.70)		13.18 (2.95)	
	0204	14.75 (1.53)	14.06 (3.05)		13.78 (2.80)		14.06 (2.76)	
	0205	13.95 (2.74)	15.98 (1.98)		16.11 (2.88)		14.40 (2.54)	13.40 (3.00)
	0206	14.67 (2.18)	14.64 (1.31)		12.12 (2.66)		13.08 (3.59)	13.64 (3.66)
3	0207	16.65 (2.53)					11.50 (2.40)	
	0208	13.74 (2.27)					13.10 (3.59)	
	0209	12.14 (2.66)					14.67 (3.04)	
	0210	13.87 (3.12)					13.89 (2.83)	
4	0212	13.33 (1.62)		14.35 (1.88)		15.14 (2.10)	15.14 (3.47)	
	0213	13.56 (2.71)		16.35 (2.00)		12.65 (2.72)	15.60 (4.32)	15.03 (5.10)
	0214	14.11 (2.36)		16.63 (2.74)		15.63 (2.48)	16.62 (3.05)	17.15 (6.06)
	0215	14.27 (1.96)		14.58 (2.83)		13.98 (1.10)	16.48 (3.32)	15.05 (2.36)
	0216	15.00 (2.78)		17.57 (1.66)		15.87 (2.84)	18.78 (6.27)	17.08 (1.69)

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Insulation Black (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	12.88 (1.30)					13.16 (3.06)	14.03 (1.25)
	0202	14.90 (3.01)					14.33 (2.54)	14.84 (2.52)
2	0203	12.63 (1.92)	13.32 (2.10)		13.74 (2.58)		14.27 (2.36)	
	0204	14.59 (3.78)	14.83 (1.55)		14.77 (2.11)		14.69 (2.65)	
	0205	11.96 (3.46)	16.41 (2.35)		14.60 (2.17)		14.17 (2.25)	12.92 (2.69)
	0206	11.38 (2.08)	15.75 (2.35)		14.59 (2.06)		15.18 (3.27)	15.97 (4.61)
3	0207	15.01 (0.71)					17.46 (3.14)	
	0208	13.90 (2.14)					15.36 (1.93)	
	0209	13.44 (2.97)					15.35 (2.92)	
	0210	14.76 (1.50)					16.52 (2.28)	
4	0212	14.22 (2.09)		14.67 (2.45)		14.28 (1.67)	13.82 (3.08)	
	0213	13.17 (1.50)		13.66 (1.29)		14.00 (1.70)	14.88 (2.45)	16.35 (3.10)
	0214	12.17 (2.48)		14.00 (2.39)		13.57 (3.42)	15.32 (2.84)	16.63 (3.08)
	0215	12.49 (3.07)		12.62 (2.87)		13.62 (3.58)	13.36 (2.23)	12.37 (1.36)
	0216	12.28 (3.29)		14.44 (3.66)		13.71 (2.97)	20.18 (4.45)	17.31 (3.90)

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Insulation Red (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	14.44 (3.69)					13.45 (2.74)	13.41 (3.06)
	0202	14.49(2.90)					17.29 (2.25)	14.39 (2.86)
2	0203	13.82 (3.27)	15.32 (3.01)		14.58 (1.71)		15.31 (3.53)	
	0204	15.01 (1.98)	15.86 (2.78)		15.23 (1.91)		14.43 (2.13)	
	0205	13.11 (2.16)	15.94 (1.56)		15.52 (1.82)		15.85 (3.92)	14.51 (3.22)
	0206	10.54 (1.54)	14.25 (2.52)		13.42 (1.56)		15.72 (3.11)	12.44 (1.17)
3	0207	15.58 (2.72)					14.72 (1.59)	
	0208	14.47 (1.83)					14.90 (2.75)	
	0209	13.39 (2.24)					13.69 (4.40)	
	0210	15.04 (2.25)					16.28 (2.84)	
4	0212	17.19 (3.01)		14.59 (3.31)		14.56 (2.54)	14.61 (2.52)	
	0213	16.11 (2.63)		15.95 (3.56)		16.46 (3.09)	16.29 (5.61)	15.27 (3.17)
	0214	14.77 (1.22)		15.11 (2.12)		14.51 (2.77)	16.09 (3.83)	14.53 (2.36)
	0215	14.25 (2.63)		14.44 (1.87)		16.65 (1.83)	N/A	16.73 (3.97)
	0216	14.37 (1.65)		15.11 (0.86)		16.20 (2.83)	N/A	16.03 (1.97)

Table E.2 Test Sequence 2 - Compressive Modulus

Specimen Group	Specimen ID	Insulation Green (Newtons/mm)						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0201	13.51 (2.81)					12.85 (2.56)	13.39 (2.41)
	0202	-					-	-
2	0203	14.01 (1.85)	15.42 (1.95)		12.90 (1.71)		14.87 (2.22)	
	0204	13.98 (1.87)	15.12 (2.24)		14.23 (1.91)		13.26 (2.61)	
	0205	13.50 (0.89)	13.68 (2.91)		14.27 (1.45)		13.94 (2.44)	13.31 (2.66)
	0206	14.53 (1.74)	13.66 (1.56)		14.57 (1.90)		14.21 (2.18)	13.97 (1.52)
3	0207	14.93 (2.41)					14.28 (2.97)	
	0208	15.68 (2.66)					15.10 (2.88)	
	0209	15.25 (2.60)					15.19 (2.63)	
	0210	15.16 (2.47)					14.10 (3.22)	
4	0212	14.68 (1.59)		14.1 (1.39)		14.57 (2.33)	15.07 (2.70)	
	0213	13.65 (1.87)		14.33 (2.86)		14.01 (1.04)	14.85 (2.94)	15.05 (2.65)
	0214	-		-		-	-	-
	0215	12.46 (1.64)		12.72 (2.60)		14.94 (1.98)	N/A	14.05 (3.15)
	0216	-		-		-	-	-

Notes:
1. Standard deviations provided in parenthesis
2. All measurements made at room temperature
3. Probe speed: for modulus less than 100 N/mm: 12.7 mm/min.
   for modulus greater than 100 N/mm: 5.1 mm/min.

Table E.3 Test Sequence 3 - Compressive Modulus

Specimen Group	Specimen ID	Outer Jacket						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0301	9.66 (0.77)					10.14 (1.08)	12.96 (1.24)
	0302	10.99 (1.19)					13.16 (1.52)	17.81 (1.71)
2	0303	10.99 (0.93)	10.43 (0.95)		9.98 (0.80)		16.18 (1.41)	21.36 (2.60)
	0304	11.03 (1.08)	10.11 (1.47)		9.78 (1.13)		15.64 (1.04)	28.12 (2.01)
	0305	11.25 (0.77)	10.32 (1.30)		10.01 (0.95)		17.20 (1.67)	24.30 (3.54)
	0306	10.81 (0.61)	10.12 (0.84)		10.37 (1.32)		15.07 (1.22)	22.58 (2.43)
3	0307	10.08 (0.73)					12.50 (0.75)	17.80 (1.65)
	0308	10.45 (0.88)					15.04 (2.18)	21.67 (2.99)
	0309	10.83 (0.70)					12.19 (1.34)	17.28 (1.69)
	0310	11.06 (0.95)					12.46 (1.22)	16.39 (1.91)
	0311	9.64 (1.20)					11.69 (1.11)	16.70 (1.61)
4	0312	9.58 (0.56)		483.34 (105.34)		578.94 (345.52)	349.13 (35.67)	NA
	0313	9.15 (0.60)		475.93 (193.68)		558.46 (261.05)	372.26 (0.00)	NA
	0314	9.22 (0.85)		358.32 (118.83)		434.00 (108.46)	NA	NA
	0315	9.07 (1.07)		506.08 (124.57)		318.50 (185.09)	NA	NA
	0316	9.35 (1.01)		593.23 (112.17)		433.28 (58.80)	NA	NA
	0317	8.90 (0.89)		501.24 (122.26)		469.89 (202.65)	NA	NA

Table E.3 Test Sequence 3 - Compressive Modulus

Specimen Group	Specimen ID	Insulation White						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0301	108.36 (4.69)					110.09 (6.20)	114.87 (8.28)
	0302	194.84 (15.56)					188.61 (28.07)	210.56 (15.40)
2	0303	199.94 (9.25)	159.74 (14.02)		160.87 (6.46)		200.86 (8.58)	200.49 (9.76)
	0304	197.49 (15.48)	165.53 (12.31)		161.70 (9.21)		195.30 (6.30)	199.15 (12.46)
	0305	210.97 (18.81)	168.31 (8.70)		174.31 (7.06)		198.41 (10.20)	207.63 (14.41)
	0306	204.42 (14.70)	168.57 (10.09)		177.91 (9.37)		197.42 (9.30)	212.51 (10.48)
3	0307	203.35 (13.68)					199.16 (20.43)	230.98 (15.16)
	0308	206.90 (22.12)					215.48 (21.26)	234.88 (24.39)
	0309	208.04 (13.84)					201.57 (16.65)	223.63 (16.69)
	0310	213.11 (17.17)					200.28 (20.68)	216.50 (15.79)
	0311	213.34 (13.34)					201.36 (18.38)	237.09 (19.21)
4	0312	106.68 (6.74)		152.17 (11.84)		160.54 (11.94)	178.61 (11.29)	173.26 (10.13)
	0313	105.98 (5.98)		151.34 (11.57)		168.71 (11.00)	179.03 (18.30)	176.70 (17.79)
	0314	105.10 (7.18)		152.41 (20.87)		154.85 (17.29)	159.21 (24.98)	169.80 (15.61)
	0315	103.23 (5.76)		162.76 (16.37)		162.35 (9.34)	NA	177.85 (13.83)
	0316	104.22 (5.74)		152.06 (11.76)		162.78 (8.93)	NA	187.94 (24.42)
	0317	101.40 (8.17)		146.84 (17.17)		160.96 (12.40)	181.25 (24.90)	180.45 (18.42)

Table E.3 Test Sequence 3 - Compressive Modulus

Specimen Group	Specimen ID	Insulation Red						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0301							
	0302	181.22 (11.89)					205.36 (38.00)	196.10 (19.19)
2	0303	204.68 (26.45)	171.07 (8.52)		164.52 (4.96)		186.45 (27.75)	201.69 (12.23)
	0304	190.11 (19.80)	157.07 (13.67)		157.00 (12.59)		194.23 (10.56)	201.64 (12.55)
	0305	193.16 (22.08)	166.37 (6.50)		167.44 (7.56)		203.62 (25.26)	203.09 (8.09)
	0306	199.79 (21.07)	170.54 (15.91)		172.48 (5.96)		179.72 (16.63)	221.87 (18.14)
3	0307	196.87 (15.16)					186.00 (36.00)	229.19 (23.28)
	0308	197.54 (8.25)					183.99 (22.07)	222.42 (13.79)
	0309	195.93 (30.85)					189.06 (46.71)	210.35 (16.23)
	0310	203.97 (19.99)					199.50 (20.43)	216.12 (23.86)
	0311	189.92 (27.13)					197.37 (27.11)	214.00 (17.46)
4	0312							
	0313							
	0314							
	0315							
	0316							
	0317							

Table E.3 Test Sequence 3 - Compressive Modulus

Specimen Group	Specimen ID	Insulation Black						
		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
1	0301	98.83 (5.20)					108.73 (8.84)	122.75 (10.07)
	0302	197.24 (24.10)					249.61 (22.01)	198.17 (13.67)
2	0303	196.41 (27.55)	153.97 (14.62)		149.12 (17.40)		217.44 (30.44)	202.24 (10.09)
	0304	190.60 (9.97)	158.23 (12.46)		154.40 (9.80)		184.42 (14.30)	197.24 (10.25)
	0305	196.11 (25.45)	180.83 (13.64)		168.50 (5.51)		186.05 (21.27)	212.72 (18.27)
	0306	196.88 (21.76)	152.40 (22.20)		165.61 (13.53)		194.84 (24.83)	206.17 (19.45)
3	0307	206.36 (14.55)					200.28 (20.65)	231.13 (29.91)
	0308	198.55 (18.35)					204.17 (24.74)	240.38 (23.43)
	0309	195.76 (23.60)					206.21 (21.09)	231.61 (23.76)
	0310	215.84 (23.16)					218.81 (23.17)	217.21 (35.69)
	0311	203.56 (14.88)					215.20 (24.21)	221.20 (24.30)
4	0312	103.03 (4.39)		127.76 (11.17)		144.51 (16.70)	164.47 (15.67)	163.54 (5.86)
	0313	103.20 (4.16)		137.91 (13.22)		146.70 (12.24)	148.64 (17.76)	154.36 (18.79)
	0314	103.83 (8.85)		129.80 (12.50)		147.84 (14.24)	143.17 (17.89)	156.69 (17.46)
	0315	101.49 (4.75)		134.65 (13.16)		139.17 (15.33)	NA	166.25 (17.76)
	0316	102.76 (6.08)		130.91 (15.99)		141.89 (17.22)	NA	166.50 (20.09)
	0317	98.75 (4.13)		138.88 (15.39)		139.51 (14.32)	158.74 (28.98)	166.25 (19.27)

Notes:
1. Standard deviations provided in parenthesis
2. All measurements made at room temperature
3. Probe speed: for modulus less than 100 N/mm: 12.7 mm/min.
   for modulus greater than 100 N/mm: 5.1 mm/min.

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Outer Jacket						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401	9.45 (0.27)						
0402	8.89 (1.69)						
0403							
0404	9.10 (1.93)			11.8 (2.25)			
0405							
0406	9.59 (1.18)			13.8 (3.14)			
0407							
0408	9.38 (0.49)				43.4 (5.17)		
0409							
0410	9.56 (0.59)				44.28 (4.51)		
0411	9.67 (0.79)				41.5 (4.40)		
0412							
0413	9.04 (2.99)				15.2 (2.86)		
0414							
0415	9.43 (1.85)				17.9 (3.54)		
0416	9.20 (2.48)				12.4 (2.68)		
0417	9.51 (0.45)						
0418	8.67 (1.99)						

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Individual Jacket White						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401	7.63 (0.71)						
0402							
0403							
0404							
0404							
0406							
0407							
0408	7.52 (0.47)				20.2 (0.89)		
0409							
0410	7.77 (0.72)				19.6 (0.47)		
0411	7.36 (0.40)				20.8 (1.14)		
0412							
0413							
0414							
0415							
0416							
0417	7.81 (0.46)						
0418							

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Individual Jacket Black						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401	9.25 (0.68)						
0402							
0403							
0404							
0404							
0406							
0407							
0408	9.03 (0.37)				21.5 (0.57)		
0409							
0410	9.74 (0.85)				21.3 (0.94)		
0411	9.09 (0.63)				21.8 (0.85)		
0412							
0413							
0414							
0415							
0416							
0417	9.27 (0.50)						
0418							

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Individual Jacket Purple						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401							
0402	15.02 (2.19)						
0403	16.02 (2.30)			17.8 (1.47)			
0404	13.59 (2.39)			22.6 (3.73)			
0405							
0406	13.41 (1.38)			20.6 (3.88)			
0407							
0408							
0409							
0410							
0411							
0412							
0413	14.55 (2.15)				24.5 (4.37)		
0414	14.57 (2.72)				27.5 (1.13)		
0415	14.47 (1.43)				23.9 (2.35)		
0416	13.84 (1.46)				26.5 (3.74)		
0417							
0418	16.68 (2.66)						

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Individual Jacket Red						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401	8.38 (0.89)						
0402	14.03 (1.20)						
0403							
0404	15.19 (0.97)			23.0 (1.99)			
0405	15.78 (2.63)			24.0 (1.77)			
0406	13.76 (2.16)			22.7 (1.86)			
0407							
0408	8.24 (0.49)						
0409							
0410	7.89 (0.16)						
0411	7.98 (0.73)						
0412	14.80 (1.11)				26.6 (1.16)		
0413	13.68 (1.40)				26.8 (1.00)		
0414							
0415	15.27 (2.12)				27.8 (1.15)		
0416	13.90 (2.04)				24.4 (1.53)		
0417	8.51 (0.52)						
0418	13.81 (1.85)						

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Insulation White						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401	10.31 (1.24)						
0402							
0403							
0404							
0405							
0406							
0407	9.96 (1.48)				16.0 (1.05)		
0408	10.19 (1.21)				15.8 (0.62)		
0409	9.82 (1.01)				16.0 (1.61)		
0410	10.37 (1.35)				14.6 (0.37)		
0411	10.15 (0.93)				14.7 (1.57)		
0412							
0413							
0414							
0415							
0416							
0417	10.32 (1.27)						
0418							

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Insulation Black						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401	13.16 (1.00)						
0402							
0403							
0404							
0405							
0406							
0407							
0408	12.79 (1.65)				18.4 (0.90)		
0409							
0410	13.37 (1.56)				17.4 (2.69)		
0411	12.83 (1.02)				17.1 (2.15)		
0412							
0413							
0414							
0415							
0416							
0417	13.82 (1.05)						
0418							

Table E.4 Test Sequence 4 - Compressive Modulus

Specimen ID	Insulation Red						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0401	12.21 (2.00)						
0402							
0403							
0404							
0405							
0406							
0407							
0408	12.81 (1.03)						
0409							
0410	12.28 (1.30)						
0411	13.31 (1.62)						
0412							
0413							
0414							
0415							
0416							
0417	14.07 (2.84)						
0418							

Notes:
1. Standard deviations provided in parenthesis
2. All measurements made at room temperature
3. Probe speed: for modulus less than 100 N/mm: 12.7 mm/min.
   for modulus greater than 100 N/mm: 5.1 mm/min.

Table E.5 Test Sequence 5 - Compressive Modulus

Specimen ID	Outer Jacket						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0501							
0502	14.91 (1.62)						
0503	9.55 (1.23)						
0504							
0505							
0506	15.51 (2.85)			20.89 (3.26)			
0507	16.53 (3.59)			19.83 (3.10)			
0508	9.16 (1.92)			18.41 (2.08)			
0509	7.36 (2.16)			18.44 (1.38)			
0510							
0511							
0512							
0513	14.25 (1.70)				22.89 (2.99)		
0514	15.06 (2.56)				24.43 (4.28)		
0515	9.53 (0.58)				42.48 (5.61)		
0516	9.41 (0.34)				39.84 (4.78)		
0517	13.15 (0.82)						
0518	14.69 (2.58)						
0519	9.82 (1.08)						

Table E.5 Test Sequence 5 - Compressive Modulus

Specimen ID	Individual Jacket White						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0501							
0502	14.45 (0.65)						
0503	7.90 (0.59)						
0504							
0505							
0506	15.35 (1.01)			20.91 (0.92)			
0507	13.90 (1.28)			22.53 (2.29)			
0508	7.75 (0.40)			12.84 (0.56)			
0509	7.53 (0.64)			13.26 (0.52)			
0510							
0511							
0512							
0513	15.44 (0.90)				25.82 (1.33)		
0514	14.38 (1.12)				28.79 (1.94)		
0515	7.81 (0.35)				25.32 (1.01)		
0516	7.67 (0.78)				24.99 (1.50)		
0517							
0518	14.57 (1.56)						
0519	7.92 (0.67)						

Table E.5 Test Sequence 5 - Compressive Modulus

Specimen ID	Individual Jacket Black						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0501	13.24 (0.46)						
0502	14.38 (0.96)						
0503	8.97 (0.48)						
0504	13.01 (0.90)			135.63 (29.88)			
0505	14.05 (0.49)			145.71 (29.09)			
0506	14.63 (1.37)			22.57 (1.53)			
0507	14.18 (1.00)			21.37 (0.42)			
0508	9.19 (0.46)			13.68 (0.32)			
0509	9.10 (0.46)			14.35 (0.49)			
0510	12.86 (1.57)				183.38 (9.77)		
0511	14.18 (0.74)				190.24 (16.28)		
0512	13.24 (0.94)				195.03 (22.13)		
0513	13.99 (0.95)				27.48 (0.67)		
0514	14.23 (1.14)				27.65 (1.10)		
0515	9.44 (0.28)				29.64 (0.50)		
0516	9.29 (0.34)				27.78 (1.22)		
0517	NA				NA		
0518	14.77 (1.10)						
0519	9.21 (0.62)						

Table E.5 Test Sequence 5 - Compressive Modulus

Specimen ID	Individual Jacket Red						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0501							
0502							
0503	8.10 (0.49)						
0504							
0505							
0506							
0507							
0508	8.93 (1.09)						
0509	7.77 (0.58)						
0510							
0511							
0512							
0513							
0514							
0515	8.33 (0.38)						
0516	8.49 (0.66)						
0517							
0518							
0519	8.30 (0.42)						

Table E.5 Test Sequence 5 - Compressive Modulus

Specimen ID	Insulation White						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0501							
0502							
0503	9.98 (1.15)						
0504							
0505							
0506							
0507							
0508	11.37 (2.02)			12.80 (0.58)			
0509	9.76 (1.13)			12.37 (1.04)			
0510							
0511							
0512							
0513							
0514							
0515	10.96 (1.46)				17.44 (1.57)		
0516	10.63 (1.42)				16.32 (1.74)		
0517							
0518							
0519	9.68 (0.40)						

Table E.5 Test Sequence 5 - Compressive Modulus

Specimen ID	Insulation Black						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0501							
0502							
0503	12.99 (1.20)						
0504							
0505							
0506							
0507							
0508	12.40 (1.31)			15.09 (0.88)			
0509	12.28 (1.06)			14.40 (1.04)			
0510							
0511							
0512							
0513							
0514							
0515	10.64 (1.87)				18.96 (2.15)		
0516	11.45 (1.21)				18.06 (2.21)		
0517							
0518							
0519	13.98 (1.48)						

Table E.5 Test Sequence 5 - Compressive Modulus

Specimen ID	Insulation Red						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0501							
0502							
0503	12.18 (1.66)						
0504							
0505							
0506							
0507							
0508	13.61 (0.54)						
0509	13.80 (0.79)						
0510							
0511							
0512							
0513							
0514							
0515	12.66 (1.76)						
0516	13.96 (1.39)						
0517							
0518							
0519	13.52 (2.50)						

Notes: 1. Standard deviations provided in parenthesis
2. All measurements made at room temperature
3. Probe speed: for modulus less than 100 N/mm: 12.7 mm/min.
for modulus greater than 100 N/mm: 5.1 mm/min.

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Outer Jacket						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602	13.05 (2.10)					20.73 (3.93)	28.43 (5.14)
0603	10.32 (1.21)					10.48 (0.71)	10.90 (1.58)
0604	9.07 (1.31)					14.40 (2.23)	19.45 (1.69)
0605							
0606							
0607							
0608	13.69 (1.95)		17.40 (3.28)		34.22 (5.76)	43.09 (7.52)	56.60 (8.82)
0609	14.22 (2.20)		16.90 (3.66)		30.85 (5.19)	45.39 (9.63)	64.92 (9.92)
0610	13.89 (2.99)		17.87 (2.53)		31.80 (5.13)	39.98 (8.56)	59.83 (9.36)
0611	10.11 (0.87)		11.99 (1.18)		16.27 (5.85)	15.18 (1.31)	15.36 (1.55)
0612	8.39 (0.42)		9.61 (0.81)		10.87 (0.78)	13.65 (1.03)	14.10 (1.25)
0613	10.23 (1.78)		12.16 (1.97)		12.42 (1.36)	15.68 (1.98)	14.49 (1.84)
0614	9.30 (0.85)						
0615	8.96 (0.96)						
0616	9.13 (0.66)						
0617							
0618	13.29 (2.53)		18.96 (3.57)		33.49 (5.19)	39.80 (7.08)	59.62 (10.41)
0619	8.44 (0.60)		9.72 (0.96)		10.29 (0.41)	12.53 (1.13)	12.43 (0.89)
0621	8.93 (0.53)		524.64 (155.86)		321.63 (69.02)	503.33 (78.39)	443.37 (68.25)
0622	8.91 (0.69)		454.67 (87.50)		NA	453.43 (114.29)	NA
0623	9.04 (0.78)		440.92 (79.79)		NA	490.21 (136.25)	NA
0624	9.62 (1.22)		514.27 (144.51)		NA	446.82 (81.08)	NA

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	White Individual Jacket						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602	14.39 (1.27)					22.85 (2.03)	25.42 (3.37)
0603	10.69 (0.43)					13.77 (0.89)	12.17 (0.47)
0604							
0605							
0606							
0607							
0608	14.88 (0.98)		27.14 (2.06)		37.43 (1.67)	46.43 (2.66)	49.87 (2.41)
0609	14.56 (1.25)		26.16 (1.50)		38.93 (1.14)	47.24 (2.49)	55.46 (1.82)
0610	14.63 (0.89)		26.70 (1.87)		34.67 (1.50)	44.48 (4.30)	51.74 (3.73)
0611	11.30 (0.40)		14.70 (0.41)		17.42 (0.77)	21.62 (0.73)	18.99 (1.38)
0612	10.63 (0.86)		13.35 (0.65)		17.72 (1.00)	20.24 (1.18)	17.99 (0.35)
0613	11.75 (0.42)		14.22 (0.38)		17.01 (0.36)	19.93 (0.80)	17.84 (0.67)
0614							
0615							
0616							
0617							
0618	14.77 (1.06)		26.46 (1.82)		37.36 (0.92)	47.29 (2.50)	55.99 (4.63)
0619	10.50 (0.32)		13.31 (0.91)		15.94 (0.72)	19.09 (1.70)	16.90 (1.00)
0621							
0622							
0623							
0624							

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Black Individual Jacket						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601	13.32 (0.72)					14.66 (0.72)	15.30 (0.68)
0602	13.65 (1.73)					22.67 (1.87)	22.79 (2.78)
0603	11.34 (0.63)					12.84 (0.69)	12.47 (0.75)
0604							
0605	13.30 (0.44)		163.60 (27.65)		152.02 (39.56)	169.88 (41.40)	120.28 (25.14)
0606	12.85 (0.52)		160.76 (34.42)		140.85 (23.44)	168.12 (31.95)	138.66 (29.12)
0607	13.09 (0.59)		174.11 (15.59)		199.79 (30.45)	163.31 (44.18)	157.91 (53.15)
0608	12.32 (3.63)		25.07 (0.98)		36.53 (1.61)	45.75 (2.50)	54.92 (2.18)
0609	14.78 (0.64)		26.47 (1.77)		38.04 (1.70)	47.37 (2.52)	52.40 (2.12)
0610	14.33 (1.44)		27.43 (0.52)		35.07 (1.23)	45.14 (3.84)	54.38 (3.52)
0611	11.83 (0.85)		12.52 (0.73)		14.31 (0.91)	18.26 (0.76)	17.30 (0.92)
0612	11.18 (0.40)		12.20 (0.28)		14.54 (0.52)	18.17 (0.74)	17.81 (0.59)
0613	10.65 (0.96)		11.39 (0.31)		12.42 (0.63)	15.52 (0.53)	14.91 (0.31)
0614							
0615							
0616							
0617	13.53 (0.46)		155.49 (24.08)		144.29 (57.47)	173.46 (47.93)	118.76 (25.75)
0618	14.55 (1.38)		27.23 (1.04)		37.01 (2.03)	46.48 (2.09)	56.05 (3.65)
0619	11.69 (0.43)		11.82 (0.29)		13.47 (0.46)	16.74 (0.25)	15.82 (0.25)
0621							
0622							
0623							
0624							

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Red Individual Jacket						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602							
0603	12.18 (0.75)					14.23 (1.02)	13.15 (0.98)
0604							
0605							
0606							
0607							
0608							
0609							
0610							
0611	11.39 (0.85)		13.90 (0.42)		17.50 (0.87)	19.77 (0.87)	18.10 (0.86)
0612	10.92 (0.80)		14.32 (0.37)		18.05 (0.63)	20.73 (1.71)	19.10 (1.96)
0613	12.15 (0.70)		14.58 (0.48)		15.88 (0.86)	18.66 (0.63)	16.79 (1.01)
0614							
0615							
0616							
0617							
0618							
0619	10.66 (0.74)		13.18 (0.33)		16.69 (0.84)	19.18 (0.97)	17.59 (1.05)
0621							
0622							
0623							
0624							

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Green Individual Jacket						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602							
0603							
0604							
0605							
0606							
0607							
0608							
0609							
0610							
0611							
0612							
0613	10.30 (0.92)		13.30 (0.40)		15.35 (0.26)	18.14 (0.99)	15.82 (0.68)
0614							
0615							
0616							
0617							
0618							
0619							
0621							
0622							
0623							
0624							

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Insulation White						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602							
0603	15.14 (3.89)					16.12 (1.66)	15.38 (3.42)
0604	101.43 (7.25)					125.81 (12.25)	117.62 (25.32)
0605							
0606							
0607							
0608							
0609							
0610							
0611	16.87 (3.19)		17.31 (2.97)		17.62 (2.39)	19.28 (3.96)	19.39 (2.03)
0612	18.31 (3.96)		15.44 (2.58)		15.10 (2.79)	18.63 (4.55)	14.47 (2.32)
0613	15.17 (2.63)		18.28 (2.71)		18.03 (2.45)	18.08 (3.86)	19.13 (1.86)
0614	106.21 (10.33)						
0615	103.43 (8.19)						
0616	100.43 (7.83)						
0617							
0618							
0619	19.40 (4.02)		15.41 (2.65)		18.18 (6.43)	18.45 (4.82)	18.33 (5.26)
0621	101.37 (5.10)		169.04 (22.86)		208.54 (15.03)	207.56 (18.95)	200.74 (24.16)
0622	105.44 (3.59)		172.64 (19.07)		213.83 (30.60)	207.55 (20.22)	202.73 (17.28)
0623	100.93 (3.90)		179.47 (16.25)		188.97 (18.07)	199.85 (13.06)	199.07 (19.20)
0624	103.17 (4.48)		187.40 (42.08)		200.52 (19.67)	208.67 (37.03)	221.20 (28.76)

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Insulation Black						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602							
0603	15.66 (3.57)					14.96 (1.81)	15.89 (3.69)
0604	103.60 (4.49)					120.07 (3.80)	130.03 (9.97)
0605							
0606							
0607							
0608							
0609							
0610							
0611	17.59 (2.81)		16.59 (3.85)		17.43 (2.91)	19.37 (3.38)	13.78 (2.76)
0612	16.33 (3.55)		17.84 (1.46)		14.88 (3.62)	17.53 (3.25)	16.84 (3.65)
0613	14.77 (4.66)		15.07 (1.94)		15.38 (4.32)	16.18 (2.70)	14.82 (2.18)
0614	101.65 (8.06)						
0615	100.20 (8.48)						
0616	100.83 (7.30)						
0617							
0618							
0619	15.53 (3.27)		17.50 (2.13)		17.51 (1.41)	18.27 (2.88)	20.02 (3.27)
0621	102.95 (3.61)		136.27 (9.73)		184.50 (15.44)	208.25 (23.63)	200.09 (22.98)
0622	102.53 (6.39)		159.73 (18.13)		183.85 (14.25)	199.12 (27.96)	198.18 (24.93)
0623	100.80 (6.55)		158.27 (21.75)		192.62 (20.01)	205.86 (21.17)	192.49 (13.26)
0624	99.78 (5.99)		161.37 (22.81)		199.96 (38.20)	195.95 (22.19)	201.87 (41.26)

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Insulation Red						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602							
0603	19.58 (5.19)					17.26 (1.69)	17.12 (3.56)
0604							
0605							
0606							
0607							
0608							
0609							
0610							
0611	15.76 (2.18)		15.54 (1.78)		17.14 (2.87)	17.16 (2.92)	17.55 (2.78)
0612	16.18 (2.72)		17.25 (2.21)		16.25 (2.53)	16.71 (3.23)	16.42 (3.20)
0613	13.53 (2.56)		19.26 (4.42)		15.20 (2.16)	17.89 (3.14)	14.59 (2.91)
0614							
0615							
0616							
0617							
0618							
0619	17.60 (3.38)		14.48 (5.31)		17.61 (4.05)	19.17 (3.21)	18.65 (5.43)
0621							
0622							
0623							
0624							

Table E.6 Test Sequence 6 - Compressive Modulus

Specimen ID	Insulation Green						
	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
0601							
0602							
0603							
0604							
0605							
0606							
0607							
0608							
0609							
0610							
0611							
0612							
0613	14.10 (2.53)		15.01 (3.47)		15.02 (2.82)	18.08 (1.49)	14.66 (3.41)
0614							
0615							
0616							
0617							
0618							
0619							
0621							
0622							
0623							
0624							

Notes:
1. Standard deviations provided in parenthesis
2. All measurements made at room temperature
3. Probe speed: for modulus less than 100 N/mm: 12.7 mm/min.
   for modulus greater than 100 N/mm: 5.1 mm/min.

Appendix F

Hardness Data

Tables

Title **Page**

Table F.1 Average hardness for Groups 1 and 2 specimens - Test Sequence 1

	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
Group 1							
Outer Jacket	31.8					36.3	38.5
XLPE Insulation							
Black	40.0					41.6	47.8
White	39.5					40.2	42.2
Red	NA					NA	NA
Group 2							
Outer Jacket	34.3	30.3		29.7		35.0	40.3
XLPE Insulation							
Black	50.3	49.5		48.2		50.7	51.5
White	50.2	50.0		47.4		51.3	52.2
Red	49.2	49.3		49.3		51.0	53.8

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Table F.2 Average hardness for Groups 3 and 4 specimens - Test Sequence 1

	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
Group 3							
Outer Jacket	26.8					39.6	39.8
XLPE Insulation							
Black	46.3					51.8	52.2
White	47.5					51.7	50.8
Red	50.1					49.4	52.3
Group 4							
Outer Jacket	31.8		Brittle			Brittle	Brittle
XLPE Insulation							
Black	40.0		40.9		44.6	50.3	50.3
White	39.5		40.7		40.0	44.8	45.5
Red	NA		NA		NA	NA	NA

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Table F.3 Average hardness for Group 1 specimens - Test Sequence 2

Specimen ID		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
0201	Outer Jacket	25.4					25.4	28.8
	Individual Jacket							
	White	23.8					23.3	24.6
	Red	25.8					24.2	21.7
	Black	22.1					25.0	25.4
	Green	23.8					25.8	25.7
	EPR Insulation	21.7					16.3	18.3
0202	Outer Jacket	25.4					26.3	29.0
	Individual Jacket							
	White	25.0					25.4	25.4
	Red	25.4					NA	NA
	Black	25.7					26.0	26.3
	Green	NA					NA	NA
	EPR Insulation	20.8					20.8	14.5

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Table F.4 Average hardness for Group 2 specimens - Test Sequence 2

Specimen ID		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
0203	Outer Jacket	25.4	25.0		25.4		25.6	
	Individual Jacket							
	White	23.8	24.6		24.6		24.3	
	Red	25.8	26.7		25.8		25.2	
	Black	22.1	24.6		25.0		26.3	
	Green	23.8	25.4		25.4		26.7	
	EPR Insulation	21.7	17.5		14.8		14.5	
0205	Outer Jacket	25.4	25.0		25.4		25.6	30.8
	Individual Jacket							
	White	23.8	24.6		24.6		24.3	24.2
	Red	25.8	26.7		25.8		25.2	22.9
	Black	22.1	24.6		25.0		26.3	26.3
	Green	23.8	25.4		25.4		26.7	24.7
	EPR Insulation	21.7	17.5		14.8		14.5	15.4

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Table F.5 Average hardness for Group 3 specimens - Test Sequence 2

Specimen ID		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
0207	Outer Jacket	23.8					27.9	
	Individual Jacket							
	White	26.3					27.9	
	Red	25.8					24.2	
	Black	22.9					24.6	
	Green	26.3					21.3	
	EPR Insulation	19.5					18.8	
0210	Outer Jacket	23.2					28.8	
	Individual Jacket							
	White	22.5					26.7	
	Red	25.0					21.7	
	Black	23.3					25.8	
	Green	23.8					22.1	
	EPR Insulation	18.8					16.7	

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Table F.6 Average hardness for Group 4 specimens - Test Sequence 2

Specimen ID		Baseline	Thermal Aging		Service Radiation		Accident Radiation	
		A	B	C	D	E	F	G
0212	Outer Jacket	25.4		25.0		26.7	29.6	
	Individual Jacket							
	White	23.8		26.7		26.3	24.6	
	Red	25.8		25.0		20.8	24.6	
	Black	22.1		26.3		25.4	20.8	
	Green	23.8		26.3		25.0	28.3	
	EPR Insulation	21.7		18.3		16.3	15.0	
0214	Outer Jacket	25.4		22.1		26.3	29.2	
	Individual Jacket							
	White	23.8		25.8		26.3	29.2	
	Red	25.8		NA		NA	NA	
	Black	22.1		26.7		24.6	28.8	
	Green	23.8		NA		NA	NA	
	EPR Insulation	21.7		21.3		16.7	20.8	

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Table F.7 Average hardness for Groups 1 and 2 specimens - Test Sequence 3

	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
Group 1							
Outer Jacket	28.0					35.2	45.0
XLPE Insulation							
Black	48.5					50.2	49.8
White	46.3					49.5	49.5
Red	54.0					55.0	56.0
Group 2							
Outer Jacket	31.0	30.0		29.0		36.0	50.5
XLPE Insulation							
Black	53.0	54.5		54.0		56.5	58.5
White	48.5	54.5		50.5		55.0	52.0
Red	51.0	51.0		54.0		55.5	58.5

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Table F.8 Average hardness for Groups 3 and 4 specimens - Test Sequence 3

	Baseline	Thermal Aging		Service Radiation		Accident Radiation	
	A	B	C	D	E	F	G
Group 3							
Outer Jacket	29.0					38.8	37.5
XLPE Insulation							
Black	50.1					54.8	57.5
White	52.0					55.0	57.8
Red	51.4					54.9	55.5
Group 4							
Outer Jacket	28.0		85.5		79.5	Brittle	Brittle
XLPE Insulation							
Black	42.5		46.5		48.5	56.0	59.0
White	40.0		45.5		51.5	54.5	56.0
Red	NA		NA		NA	NA	NA

Note: No data signifies that specimens were not exposed to additional aging since last CM point.

Appendix G

Dielectric Loss Data

Tables

Table G.1 AC impedance measurements for specimens in test sequence 1
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
101	BW	A	83.8514	87.0933	87.5671	87.8632	88.5563	88.5013	89.1368	88.5724	82.2765	80.5829	75.032	36.8384	20.4533	7.2356	4.3268
102	BW	A	88.6872	86.9572	87.3754	87.719	88.3645	88.4095	88.885	88.1959	82.0524	80.4334	74.7361	36.7104	20.3692	7.2021	4.3021
118	BW	A	89.9548	86.9804	88.014	88.2664	88.2943	88.4278	88.7989	88.2135	81.9696	80.9932	74.9683	36.8079	20.4402	7.2261	4.3291
104	BW	A	84.2325	88.0607	88.0706	88.1257	88.1816	88.3077	88.6336	88.161	82.1859	80.3526	74.9459	36.9095	20.5305	7.2774	4.362
105	BW	A	89.9336	87.0703	88.1157	88.4531	88.4597	88.5505	88.9944	88.3127	82.1	80.6586	74.8874	36.8042	20.4605	7.2433	4.3536
106	BW	A	91.4432	92.2662	92.212	91.9462	91.5427	91.4841	90.3084	89.5106	82.8336	81.5879	75.23	35.8256	19.8757	7.2542	4.5125
106	BR	A	97.1844	92.3465	92.1419	91.5112	91.5306	91.4947	90.3594	89.3932	82.4238	80.4331	74.2794	34.3488	18.9742	6.9449	4.3342
106	WR	A	97.0721	92.7595	92.4315	91.7734	91.7013	91.4731	90.4407	89.6126	82.859	81.6985	75.2383	35.9417	19.984	7.3057	4.5391
107	BW	A	95.5366	91.951	91.9241	91.2595	91.377	91.1625	90.1755	89.3318	82.596	81.0479	75.0686	35.7156	19.7929	7.1866	4.4411
107	BR	A	95.2152	91.8608	91.8351	91.6944	91.3773	91.4531	90.1548	89.2821	82.3624	80.4255	74.1809	34.2885	18.8914	6.8825	4.2738
107	WR	A	90.5628	91.3197	91.1069	91.3396	91.1573	91.2023	90.2901	89.319	82.5809	81.8244	75.2028	35.9635	19.9766	7.2605	4.4969
108	BW	A	88.8745	91.3189	91.9352	91.484	91.3698	91.2291	90.5531	89.5343	82.455	80.8204	74.7072	34.8959	19.3527	7.0596	4.3882
108	BR	A	90.2547	92.1641	91.4588	91.4054	91.2381	91.1338	90.3633	89.4952	82.5259	80.7112	74.3663	34.5157	19.0631	6.9564	4.3249
108	WR	A	90.5252	91.9885	92.1461	92.0129	90.9997	91.0889	90.3376	89.6779	82.5487	81.7656	74.9693	35.4533	19.6511	7.1917	4.4626
109	BW	A	92.088	91.6301	91.2318	91.4644	91.1008	91.2159	90.3392	89.5512	82.6514	81.2219	75.088	35.7831	19.8115	7.157	4.4102
109	BR	A	95.4266	92.0304	91.5361	91.2574	91.3905	91.2537	90.2597	89.5757	82.5173	80.0472	74.3581	34.4807	19.0197	6.9158	4.286
109	WR	A	90.5891	91.7379	92.8137	91.9114	92.0018	91.6688	90.7122	89.6853	82.8493	81.6788	75.4093	36.1502	20.0672	7.2871	4.5039
110	BW	A	90.2519	91.7253	92.2302	91.0115	91.0561	91.1323	90.4866	89.5815	82.7955	81.0591	75.1459	35.8433	19.8415	7.1969	4.4346
110	BR	A	89.9209	91.6731	91.4703	91.4205	91.1547	91.1397	90.1694	89.3898	82.1474	80.0566	74.2203	34.2919	18.8092	6.8274	4.2212
110	WR	A	91.0424	91.627	91.9219	91.4137	91.2463	91.2931	90.557	89.6312	82.6621	81.7075	75.2544	36.0121	19.9375	7.2499	4.4738
110	RE	A	87.7943	89.5502	89.1882	89.2096	89.5182	89.1583	88.1463	86.5176	74.2239	71.0635	61.5896	21.2904	11.3445	4.2299	2.6701
111	BW	A	95.5923	92.094	91.6359	91.7932	91.562	91.3346	90.5592	89.7575	82.972	81.2364	75.257	35.9626	19.9334	7.2193	4.469
111	BR	A	91.5069	92.0974	91.3375	91.4688	91.4541	91.4198	90.6383	89.6836	82.503	81.2092	74.4731	34.7151	19.1261	6.9666	4.3195
111	WR	A	95.5178	92.1597	92.1998	91.8602	91.541	91.6534	90.6851	89.7848	83.1195	81.2989	75.4279	36.211	20.1008	7.3171	4.5229
111	RE	A	90.3073	89.6099	90.0085	89.7016	89.5113	89.4909	88.1797	86.6071	74.5144	71.4803	61.9207	21.8071	11.6836	4.3941	2.7911
112	BW	A	86.0632	87.1356	88.1886	88.5365	88.3949	88.5034	88.8123	88.2379	82.2063	80.627	74.9042	36.915	20.4931	7.2626	4.3563
113	BW	A	89.4548	87.2148	87.4889	88.0221	88.4229	88.4016	88.9557	88.3137	82.156	81.0375	74.9186	36.8725	20.4963	7.2678	4.367
114	BW	A	85.1759	87.064	87.5895	88.3227	88.2938	88.5872	88.9143	88.2516	82.1567	80.5341	74.8135	36.6612	20.3524	7.2061	4.3294
115	BW	A	86.4452	87.5118	87.5418	88.0249	88.3366	88.5845	89.0008	88.4034	82.1672	81.4913	74.8556	36.63	20.3554	7.2422	4.3683
116	BW	A	89.4178	87.3411	88.1111	88.5118	88.0005	88.6249	88.9532	88.4705	82.16	81.2418	74.8784	36.6507	20.3623	7.2469	4.3612
106	BW	B	83.2571	87.6607	88.7934	89.5343	89.8369	89.8003	90.2996	89.2767	82.7957	81.4737	76.4807	40.221	22.9369	8.4164	5.22048
106	BE	B	91.9292	89.5905	89.4378	89.1347	89.3694	89.4158	87.5882	85.81	76.3353	74.163	67.7787	27.9982	15.0107	5.3625	3.3132
107	BW	B	91.0975	90.1925	90.015	90.3797	90.0796	90.0637	89.3914	88.3866	82.3407	81.1541	76.2587	40.0273	22.7527	8.2697	5.0795
107	BE	B	85.8246	89.6943	90.2676	89.6067	89.5011	89.2276	87.5939	85.7279	76.3971	74.8456	67.6985	27.9922	14.9483	5.3587	3.3155
108	BW	B	89.5549	90.064	90.1865	90.4751	90.0583	90.1936	89.3965	88.4716	82.2749	81.3246	76.2241	40.1084	22.8646	8.3138	5.1145
108	BE	B	88.1778	89.3045	89.4781	89.4608	89.2725	89.2768	87.4936	85.651	76.1572	67.5389	27.7442	14.8769	5.3607	3.3123	
109	BW	B	89.5294	90.0373	90.3942	90.0865	90.2211	90.2752	89.451	88.4063	82.3574	80.7923	76.3032	40.1622	22.8369	8.3058	5.0888

Table G.1 AC impedance measurements for specimens in test sequence 1
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
109	BE	B	92.3234	89.5302	89.5581	89.4202	89.3192	89.4671	87.5419	85.8249	76.1974	74.5408	67.4529	27.7398	14.8604	5.351	3.3173
110	BW	B	90.4546	90.2074	90.1177	90.1208	90.3419	90.2069	89.4983	88.8322	82.2098	81.5961	76.2544	40.0341	22.7835	8.3157	5.1237
110	BE	B	86.5267	89.6172	89.419	89.4222	89.365	89.3738	87.4949	85.725	76.3409	74.0635	67.4745	27.6245	14.8662	5.3459	3.3444
112	BW	C	84.0814	88.8038	89.3634	89.7171	89.8541	89.9842	89.4574	88.0972	80.7747	79.6593	73.9475	35.9865	19.9921	7.1477	4.366
113	BW	C	62.7284	82.1162	85.011	86.698	87.6782	88.1845	89.4689	88.2258	80.8197	73.7964	73.7964	35.6665	19.8931	7.1421	4.4213
114	BW	C	76.5576	83.8092	86.4287	87.1458	87.6301	87.9495	88.4182	87.3337	80.3448	79.3954	73.6795	35.9218	19.9437	7.0753	4.2911
115	BW	C	92.3962	90.0814	90.0185	90.128	90.2747	90.1415	88.9204	87.5862	80.5951	79.3031	74.0766	36.7187	20.3896	7.1791	4.3133
116	BW	C	95.9494	90.1282	90.3636	89.879	90.0217	89.8395	88.8986	87.5709	80.6192	79.2645	74.1112	36.785	20.3918	7.1794	4.3065
106	BW	D	87.2652	89.8196	90.1482	90.2019	90.53	89.652	88.0316	87.9556	81.9723	81.5836	75.6169	39.6823	22.7877	8.9397	5.8997
106	BE	D	86.1946	89.3815	89.1793	89.5399	89.1467	88.4759	87.295	84.7698	73.8847	80.5597	63.807	24.4583	13.5962	5.5975	3.891
107	BW	D	90.8048	89.6227	89.887	90.1914	90.3213	90.1749	88.8879	87.8352	82.5501	79.7056	75.2383	39.4845	22.7213	8.795	5.786
107	BE	D	84.5442	89.1806	89.0777	89.4361	90.1763	91.7309	86.6994	84.7413	74.7821	82.4756	63.6299	24.4316	13.5823	5.4434	3.8509
108	BW	D	94.4771	89.9924	89.7202	89.9225	90.3224	90.2858	89.1458	87.9703	81.7757	83.1131	75.5935	39.4128	22.6257	8.7812	5.6338
108	BE	D	83.4366	88.6139	89.2929	89.1269	89.04	88.2521	87.8646	84.7263	73.7785	75.3921	64.4756	25.1582	13.0322	5.2544	3.7512
109	BW	D	92.7285	90.7144	90.8734	90.3232	90.4378	89.28	89.4805	87.7336	81.5626	80.4965	75.2747	39.3581	22.5666	8.9182	5.9698
109	BE	D	81.6465	85.9303	87.8314	88.6288	88.7623	88.1183	86.7322	84.5497	71.3085	67.4858	62.2958	23.6393	13.1226	5.54985	4.0111
109	WE	D	85.0561	89.4111	89.1553	88.6605	89.9896	89.1105	87.0353	84.9544	76.0063	70.3584	65.3197	25.5746	14.1737	6.1672	4.5799
110	BW	D	88.805	90.0835	90.0823	89.9814	90.7945	89.8965	88.7715	87.9146	81.0717	81.4038	75.3014	39.2937	22.6597	8.7376	5.68169
110	BE	D	85.5773	88.5571	88.8672	89.3904	89.4192	88.906	87.3144	84.8522	74.1303	66.912	64.7646	24.009	13.4515	5.4381	3.6651
110	WE	D	91.2462	89.583	89.2859	89.0004	89.2068	89.1007	88.1496	85.4094	75.7	60.1843	66.2108	27.2464	14.656	5.8847	4.1541
112	BW	E	91.9753	92.7208	93.1405	93.3121	92.4452	92.0562	89.2432	87.3125	79.858	82.5183	71.7276	33.6351	19.4904	9.0216	6.9367
113	BW	E	87.6492	90.8946	91.3895	92.4285	92.1747	91.9298	92.2796	89.6295	78.7931	73.7353	72.9912	34.8105	19.5468	7.9677	5.4305
114	BW	E	86.0158	90.8713	89.8623	90.5051	89.8799	89.1021	88.2801	87.3812	79.9163	78.6921	72.9794	35.3851	19.9516	7.6696	5.0095
115	BW	E	87.7252	89.2527	89.1249	89.3179	89.1767	89.2205	88.2446	86.8032	80.0004	79.6735	73.5439	36.3216	20.4015	7.6662	4.9561
116	BW	E	92.6319	88.9812	89.0718	88.8299	89.1323	89.166	87.9265	86.7107	79.7468	78.0222	73.4176	36.1681	20.2683	7.5677	4.8117
101	BW	F	82.6881	89.5011	87.4899	87.7265	86.9956	87.1876	84.035	83.3738	78.507	78.5234	74.4164	39.7614	22.9958	8.8484	5.9064
102	BW	F	81.9794	87.5729	87.0367	87.4124	87.1	87.7429	84.0162	83.0567	79.4087	75.1607	74.303	39.6456	22.9271	8.8177	5.8125
118	BW	F	83.5441	87.1184	87.9494	89.1883	87.2572	87.8051	84.9646	83.2188	78.412	79.3037	73.3539	39.7424	22.8005	8.3871	5.3339
104	BW	F	84.8408	87.6584	87.3766	87.6311	86.8302	86.9214	84.6727	83.1693	79.7624	67.7782	74.0375	40.0793	22.9252	8.6167	5.5412
105	BW	F	89.0468	87.95	87.629	86.0977	86.9176	86.6426	84.1388	83.5686	79.1807	80.0544	74.5969	39.7948	23.0286	8.7982	5.6771
106	BW	F	96.226	87.6593	88.5748	90.512	86.357	90.4753	88.7302	87.8654	80.8871	82.7902	75.5882	39.2925	22.5205	8.7176	5.7747
106	BE	F	92.6513	91.7668	88.1811	89.1308	91.223	89.5523	89.1402	85.2197	74.0844	70.1973	63.3996	24.8624	12.8657	5.4875	3.9603
106	WE	F	88.404	88.4171	88.0731	89.2758	88.6148	89.1776	85.2878	85.3608	76.3067	100.142	65.1583	26.0067	14.1911	6.1992	4.3617
107	BW	F	85.3542	89.7541	90.0834	90.3896	90.1718	90.1492	89.9307	88.1222	82.5953	81.244	75.6401	39.6353	22.4162	8.8319	5.8673
107	BE	F	92.5558	89.2962	89.8664	89.0695	88.1918	89.1466	87.0175	84.2872	71.7991	57.0295	63.8995	24.4394	13.2534	5.5515	4.1709
107	WE	F	91.3882	89.7015	88.3684	90.1273	87.9975	91.2971	87.2391	84.9342	75.211	97.7225	65.1128	26.305	14.3545	6.3595	4.3749
108	BW	F	92.7219	89.8944	90.2983	89.7097	88.6634	90.2198	88.8009	88.0922	81.0365	80.8803	75.8298	39.5742	22.6538	8.6657	5.5992

Table G.1 AC impedance measurements for specimens in test sequence 1
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
108	BE	F	92.9973	89.5236	88.9387	89.4504	89.5214	88.3629	87.3771	84.6639	74.3006	71.9017	63.6791	24.3417	13.2346	5.5276	3.8028
108	WE	F	85.6847	89.347	89.3788	89.5688	88.9513	90.1535	87.5371	85.4571	73.4129	79.4857	66.3134	26.5802	14.4957	5.982	4.3251
109	BW	F	85.0828	89.9056	90.2866	89.7481	89.9407	89.3822	89.8803	88.5294	83.2432	77.2055	75.2729	39.782	22.7534	8.9973	6.0853
109	BE	F	89.0258	89.3196	89.206	89.0549	88.2185	90.3617	86.3103	84.2801	73.1478	68.3861	63.0356	23.7668	13.172	5.6522	4.2065
109	WE	F	90.6937	89.8445	100.064	89.2535	86.2631	87.3974	86.0285	84.6611	76.849	75.0331	64.8646	25.5657	15.1912	6.4009	4.7882
110	BW	F	86.7992	89.476	89.4895	89.6852	89.5699	89.4225	90.3472	87.9902	81.7662	77.5208	75.735	39.4045	22.5763	8.6924	5.6554
110	BE	F	93.1096	89.4621	88.833	89.6513	88.7187	88.0888	88.2524	85.1789	76.1258	71.7428	65.2642	25.4297	13.2618	5.2772	3.7109
110	WE	F	85.817	89.4021	89.7386	89.2063	88.9569	88.1343	87.6223	85.7484	76.3346	67.2627	66.3448	27.4525	14.6671	5.9615	4.2213
111	BW	F	84.1806	89.9603	90.0987	90.3517	90.3392	90.3351	89.7016	88.4174	82.2599	79.6635	75.3086	39.8028	22.9034	8.9528	5.98
111	BE	F	110.697	90.8422	86.9988	88.4985	89.6626	88.1374	87.4237	84.6553	74.1751	63.574	63.4074	24.5611	13.2385	5.5737	3.9617
111	WE	F	85.365	90.736	88.7789	89.588	89.2996	87.2832	84.9959	72.5565	83.5706	65.2031	26.0732	14.4575	5.9095	4.3404	
112	BW	F	83.4615	88.034	88.5379	88.5258	87.0917	87.3745	87.2244	86.328	79.0256	67.4046	71.4652	34.8683	21.8388	11.466	9.1765
113	BW	F	91.4918	88.9799	90.1011	90.1797	89.8356	90.2893	88.0621	86.9685	79.7749	83.5521	72.2004	33.9431	18.9114	7.3023	4.8567
114	BW	F	90.0658	88.5695	88.4206	88.3901	87.9644	88.6317	87.3426	85.9689	78.5922	69.812	72.2537	34.1524	18.9723	6.9937	4.4943
115	BW	F	84.3038	87.0956	87.635	87.2267	86.7256	87.3895	86.8824	85.6306	78.9259	78.4593	72.6603	35.4921	19.5433	6.798	3.9996
116	BW	F	94.5441	89.1131	87.3284	86.982	86.4492	87.3061	85.9527	85.797	75.4216	107.963	71.0126	33.9243	20.1106	10.2544	8.41047
101	BW	G	76.5408	87.1438	86.9173	87.0638	87.3136	86.5618	84.25	83.3852	79.1508	76.4601	73.1194	38.849	22.2634	8.5081	5.5774
102	BW	G	77.4561	84.5656	86.3095	86.2917	86.1015	86.3403	83.7471	82.9306	79.4185	74.9622	73.0686	38.5659	21.974	8.0755	5.0746
118	BW	G	84.5965	86.8323	86.8285	86.8123	87.4601	86.5754	84.8887	83.0798	78.9978	72.0283	73.2558	38.772	21.885	7.9131	4.9433
104	BW	G	87.2529	83.8456	85.827	87.1733	86.0142	85.8891	84.6573	83.1495	78.7654	76.683	73.238	38.9269	22.094	8.1146	5.103
105	BW	G	74.0763	84.1572	85.6102	85.4504	85.5442	85.4978	84.4222	83.0741	79.2501	73.1875	73.3143	38.1766	21.7143	8.058	5.1719
106	BW	G	82.1165	88.528	89.3761	89.4827	89.6192	88.9893	89.226	87.9688	82.5238	79.7638	75.4697	38.9281	22.1877	8.5219	5.5928
106	BE	G	85.3954	89.1712	89.1058	89.166	88.738	88.511	87.6917	84.5214	74.3262	79.8729	63.555	24.5182	13.0821	5.5732	3.9946
107	BW	G	82.3186	88.3601	88.9632	89.7083	89.574	89.6648	88.378	88.1688	81.865	79.3329	74.8976	38.7088	22.1702	8.7593	5.9143
107	BE	G	86.7853	89.0364	88.5455	88.8347	89.6789	88.2958	86.9001	84.3735	73.7396	61.4873	63.0143	23.906	13.0888	5.6631	4.1816
108	BW	G	78.306	87.4316	87.8515	89.0731	89.2587	89.6942	89.122	88.158	82.3731	78.8038	75.4834	38.9068	22.1832	8.6967	5.8296
108	BE	G	84.9372	89.0698	88.8499	88.8325	88.6232	89.2001	86.3749	84.3062	73.8176	62.4009	63.2593	23.986	13.2534	5.5936	4.0607
109	BW	G	85.3509	88.1045	89.0189	89.4132	89.3083	89.7603	89.4428	88.0253	81.4203	79.9487	75.7803	38.9747	22.2013	8.7228	5.8132
109	BE	G	92.8097	89.388	88.6711	89.0994	89.781	88.0688	86.8173	84.3323	72.6565	59.707	62.6817	23.5542	12.9252	5.6819	4.2392
110	BW	G	82.1929	88.4135	89.9636	89.627	89.538	90.6971	89.8552	88.27	80.9702	81.9154	75.3329	39.1281	22.3624	8.582	5.6456
110	BE	G	89.5569	89.0873	88.843	88.7473	88.9254	88.3987	87.0299	84.7712	74.5227	71.6068	64.2411	24.9166	13.257	5.4742	3.8905
111	BW	G	90.6442	89.3441	89.6266	89.9089	89.3349	90.5629	89.7296	88.3673	82.7164	75.1685	75.5182	39.1789	22.5293	8.91	6.0102
111	BE	G	87.4607	88.3422	88.9173	88.9071	89.1175	89.0534	87.4739	84.4882	72.666	80.8684	63.1618	24.2089	13.2368	5.7387	4.12955
111	WE	G	87.906	88.6886	89.0278	88.7825	88.6312	89.1515	87.617	85.7861	76.7024	79.9082	68.0142	28.6096	15.4588	5.7157	3.7042
112	BW	G	77.8891	85.7109	87.7756	88.4885	88.4154	88.3938	90.1095	87.8036	78.2955	73.9377	71.5123	33.3002	18.6067	7.1844	4.7961
113	BW	G	90.7643	88.9968	90.0624	89.4149	89.627	89.718	87.6224	86.02	78.5623	73.3462	70.4803	32.8197	18.1204	6.7922	4.4887
114	BW	G	82.4938	86.1109	86.9912	87.1674	86.8326	87.0227	86.4343	84.472	77.6743	73.3195	70.0634	32.3904	17.921	6.9367	4.8061

Table G.1 AC impedance measurements for specimens in test sequence 1
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
====	===	==	========	========	========	========	========	========	========	========	========	========	========	========	========	========	========
115	BW	G	85.3331	85.3459	85.8697	85.7011	85.6309	85.4125	84.9674	83.9263	77.184	76.99	70.7692	33.7901	18.743	6.9047	4.3639
116	BW	G	80.2672	85.4905	85.6333	85.7219	85.6496	85.6732	84.9182	83.9899	77.5475	75.9126	70.6695	33.9185	18.8024	6.9576	4.4072
102	BW	H	95.6421	90.259267	90.1947	89.8931	90.0541	89.906467	87.990133	85.381633	73.737767	71.831033	63.661067	23.772033	12.511533	4.3234333	2.5916
118	BW	H	85.74	89.4726	89.509	89.3405	89.5545	89.4218	87.6084	84.912	72.9991	71.0286	62.6964	22.8968	12.0146	4.2017	2.5736
104	BW	H	93.4911	90.5139	89.8053	89.8736	89.869	89.818	88.2126	85.7119	74.0847	72.1989	64.036	24.0597	12.6884	4.385	2.6079
105	BW	H	95.9491	90.7913	91.2698	90.4652	90.7388	90.4796	88.1494	85.521	74.1295	72.2656	64.2508	24.3596	12.8316	4.3836	2.5933
106	BW	H	99.5151	91.3105	89.8808	89.753	90.5827	90.4416	89.2226	87.786	78.1047	68.5916	28.0428	15.3948	5.8944	3.8114	
106	BE	H	81.9745	85.3492	89.3648	88.7411	88.5397	88.4712	85.2138	81.6017	66.7234	64.1253	54.8154	18.0652	9.5663	3.5669	2.3615
107	BW	H	94.801	90.9778	90.9243	91.0174	90.6741	90.1995	89.0033	87.1603	77.2722	74.5821	67.7387	27.4136	15.1363	6.3291	4.5411
107	BE	H	87.7679	89.5588	89.3485	89.1226	89.2221	89.2231	87.2701	85.007	68.0098	64.6694	52.1923	15.8851	9.2782	5.2932	4.40823
108	BW	H	85.74	89.4726	89.509	89.3405	89.5545	89.4218	87.6084	84.912	72.9991	71.0286	62.6964	22.8968	12.0146	4.2017	2.5736
108	BE	H	92.601	89.229	89.3878	89.3074	89.1235	88.9852	87.0516	84.6781	74.1699	72.5506	64.6495	25.1961	13.6675	5.3777	3.7514
109	BW	H	94.5012	92.2054	91.2018	90.9678	91.2002	91.0728	89.6563	87.9916	77.6081	75.7188	68.149	68.149	68.149	68.149	68.149
109	BE	H	93.1384	89.2167	88.7459	89.1934	88.6423	88.4998	85.0738	81.3945	66.3573	63.9688	54.2489	17.4814	9.4065	3.7428	2.6193
110	BW	H	85.9011	88.5848	89.9244	88.61	88.1445	87.4843	82.2641	77.8733	60.4994	69.3379	50.4588	20.8645	15.3166	8.985	7.05115
110	BE	H	86.1532	89.3865	89.4507	88.7693	89.1253	88.7608	85.2128	81.6026	66.5859	64.1742	54.6506	19.4153	11.1266	5.6829	4.1459
111	BW	H	99.6377	95.5399	94.3459	93.9679	93.6207	93.5399	90.3925	87.698	77.215	75.2745	67.9726	27.8112	14.9895	5.6107	3.6364
111	BE	H	89.2309	88.9087	89.5158	88.6866	88.6676	88.6603	85.6903	82.0551	67.5399	62.2641	55.5351	17.6616	9.5787	4.1403	2.87281
111	WE	H	88.6963	89.3496	89.2866	88.8657	88.6945	88.694	85.2959	81.9296	68.0099	65.7403	56.3388	18.6986	9.8787	3.7064	2.3844
112	BW	H	96.6043	95.4802	94.1846	93.6261	93.393	93.074	90.1942	88.7499	79.0484	77.3254	70.0034	31.1918	17.8884	7.1619	4.526
113	BW	H	96.9204	98.6972	99.3558	99.2189	99.6172	99.318	90.9312	87.9198	77.8585	76.5622	69.8359	31.4789	17.5252	6.871	4.7283
114	BW	H	95.7682	100.002	99.4293	99.3431	99.1029	98.7829	91.5474	87.8102	77.1293	75.6429	69.0206	31.3029	17.8827	6.9119	4.2932
115	BW	H	90.674	87.1422	86.9774	87.1731	87.202	87.1592	85.9295	84.2916	76.302	74.9507	68.7799	31.1205	16.8132	5.564	3.133
116	BW	H	84.3426	87.636	88.0656	87.9254	87.9974	88.1886	86.8378	85.2272	77.2425	75.7842	69.7509	31.7202	17.1732	5.773	3.3175

Table G.2 AC impedance measurements for specimens in test sequence 2
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
201	BW	A	72.8825	87.7635	88.3061	88.7108	88.998	89.2392	87.922	86.4559	78.0844	77.0311	70.3984	31.3772	16.9601	5.7622	3.2863
201	BR	A	83.4282	87.2911	87.8181	87.9775	88.128	88.0912	87.6342	86.278	78.1494	76.9498	70.5562	31.8491	17.2597	5.7844	3.2347
201	WR	A	84.4284	87.4019	88.0125	87.766	87.9098	87.9081	87.3398	85.815	77.4375	75.9922	69.4981	30.5321	16.4465	5.4876	3.0743
201	BG	A	86.2378	87.9569	90.4738	88.1994	88.8646	88.7282	88.0344	86.6293	78.4141	77.1778	70.7063	31.6539	17.1593	5.842	3.3318
201	WG	A	89.5677	86.3536	87.192	87.6038	87.4683	87.6004	87.2886	85.8724	77.8663	76.4475	70.2489	31.674	15.1531	5.6958	3.1571
201	RG	A	84.1132	87.3078	87.9716	88.0941	87.9145	87.9301	87.4564	85.9666	77.5441	76.4399	69.7211	30.7823	16.5907	5.55072	3.1111
201	BE	A	81.4446	86.4798	86.9815	87.1741	87.0784	87.1824	85.1597	82.4545	70.8532	68.8347	60.7561	22.3954	11.7411	3.9171	2.2068
201	WE	A	85.0727	85.29	86.1415	86.2391	86.0178	86.056	83.9568	81.1131	69.0928	67.1979	58.8182	21.2052	11.0458	3.6178	1.9767
201	RE	A	82.0929	85.4738	86.1373	86.2546	85.8534	86.0656	83.6826	80.9976	69.0219	65.5194	58.2197	20.7877	10.7676	3.501	1.9322
201	GE	A	84.528	85.3322	85.2775	85.8129	86.2182	85.7915	83.9887	81.3013	69.8515	65.2187	59.3271	21.3707	11.2935	3.6567	1.9961
202	BW	A	83.4967	88.0276	88.5461	88.678	88.6202	88.9212	88.1276	86.1664	77.7944	75.7805	69.5624	30.5031	16.4291	5.6178	3.2156
202	BR	A	89.905	87.6593	88.362	88.6054	88.4099	88.3087	88.1681	86.5361	78.3618	76.0899	69.9342	30.7608	16.6149	6.6623	3.255
202	WR	A	85.033	87.7566	87.5813	87.7107	88.2445	88.2244	87.2922	85.6243	77.01	73.4473	68.8361	29.6277	15.9036	5.3611	3.0155
202	BE	A	84.1369	85.9457	86.3507	87.0628	86.9168	86.8754	84.895	82.0994	69.7024	67.6061	59.9821	21.5741	11.3125	3.8398	2.1678
202	WE	A	85.0631	86.1192	86.5515	86.7257	86.5	86.5551	84.428	81.7083	69.763	67.7318	59.3635	21.0569	10.8043	3.4392	1.8573
202	RE	A	88.1413	85.7845	86.6569	86.4371	86.5737	86.4779	84.6609	82.0559	70.4089	68.4614	60.1857	21.6617	11.1463	3.5771	1.9576
203	BW	A	86.1025	87.6107	88.3763	88.6807	88.2546	88.4734	88.2195	86.4366	78.3148	76.147	70.572	31.4972	17.0567	5.8613	3.396
203	BR	A	87.1408	87.1209	87.6859	87.9862	88.1984	88.0576	87.5429	86.3934	78.1598	78.0145	70.428	31.7103	17.2321	5.8674	3.3304
203	WR	A	85.1606	88.0366	87.8886	87.9656	87.8404	88.2077	87.2136	85.694	77.113	75.4207	69.3347	30.4198	16.4146	5.5577	3.1338
203	BG	A	85.7392	88.7702	88.7775	89.1567	89.1661	88.9227	88.2157	86.6631	78.4264	77.991	70.8957	31.8106	17.3511	6.0045	3.4545
203	WG	A	85.0616	86.824	87.7009	88.4903	87.8653	87.7525	87.2001	85.8535	77.8714	77.3441	70.3526	31.8661	17.3559	5.8486	3.2777
203	RG	A	89.4469	87.8375	88.0887	87.7706	88.0118	87.8274	87.2886	85.8964	77.5325	75.7025	69.6232	30.8579	16.6883	5.6535	3.2033
203	BE	A	88.6758	86.6193	86.8577	86.9516	87.1419	87.2911	85.0261	82.3201	70.6504	71.3231	60.3885	22.1656	11.7899	4.0467	2.3123
203	WE	A	81.8208	85.2766	85.987	86.1564	85.9671	86.0933	83.7344	80.89	68.3937	68.4583	58.3171	21.1315	11.0983	3.6978	2.0746
203	RE	A	82.137	85.3834	85.6429	85.9423	85.815	86.0373	83.7046	80.7378	68.4783	65.7846	57.5171	20.6246	10.7136	3.5463	1.9789
203	GE	A	81.3522	85.0319	85.4753	85.8811	85.7073	85.9543	84.0625	81.2445	69.7269	66.5335	59.3132	21.7196	11.5488	3.846	2.1757
204	BW	A	91.86	88.5236	88.6253	88.6892	88.639	88.438	88.2037	86.5262	78.421	76.6034	70.5454	31.5725	17.1636	5.8809	3.3826
204	BR	A	83.1415	87.2756	87.7326	87.8474	88.1805	88.0881	87.3617	86.2841	78.2907	75.5266	70.5341	31.8374	17.265	5.8689	3.3039
204	BG	A	90.3275	88.178	87.7672	88.5906	88.833	88.469	87.79	86.524	78.6792	76.4433	70.6213	31.7626	17.2878	5.7751	3.4508
204	BE	A	83.0573	86.4486	86.3976	87.0248	87.0328	87.1765	84.8661	82.2414	70.2378	71.1175	60.6354	22.5018	11.8486	4.0199	2.3459
204	WE	A	88	85.1431	85.7296	85.8772	85.9319	86.0743	84.5564	82.106	70.7516	68.7232	60.7003	22.1351	11.4229	3.6632	1.9962
204	RE	A	81.9559	85.0191	85.0535	85.2761	85.6774	85.675	83.634	80.7129	68.558	67.5393	57.9932	20.83	10.858	3.534	1.9427
204	GE	A	82.8481	85.0707	85.449	85.7693	85.7748	85.8291	84.4002	81.2794	69.8097	64.8543	59.4389	21.6366	11.3435	3.7987	2.0914
205	BW	A	93.0563	88.0907	87.8572	88.9499	88.809	88.7458	87.5744	86.5316	78.3575	72.2549	70.1466	30.8978	16.806	5.7829	3.3166
205	BR	A	87.5461	87.2856	87.5985	87.7756	87.7792	88.1821	87.5077	86.2132	78.2419	75.8607	70.1368	31.2768	16.9935	5.7107	3.215
205	BG	A	83.5917	87.1284	88.2729	88.461	88.1333	88.8592	87.8639	86.641	78.1466	76.2306	70.4225	31.3238	17.0038	5.8242	3.377
205	BE	A	84.6465	86.2478	86.5053	86.7332	86.9478	86.8021	84.6224	82.2113	70.9989	65.9272	60.4421	22.2017	11.7903	3.9758	2.2527
205	WE	A	81.2601	85.4122	85.5932	86.0324	85.7772	85.8774	83.537	81.0628	68.7774	66.9493	58.7106	21.1076	10.9872	3.6016	1.9696

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
205	RE	A	87.1584	85.1412	85.7305	85.8398	85.9945	85.4664	83.4888	80.6548	67.8588	65.2244	57.7053	20.3916	10.6355	3.4255	1.8494
205	GE	A	88.2848	85.1019	85.8331	86.0376	86.0363	85.9459	84.1869	81.31	68.834	68.8026	59.0702	21.2326	10.9842	3.594	1.9166
206	BW	A	81.5881	86.9199	87.7483	87.9841	88.352	88.2444	87.9107	86.3573	77.7629	72.4316	70.0581	31.0248	16.7873	5.7642	3.2945
206	BR	A	86.0772	86.8702	87.1202	87.6446	87.8283	87.5509	87.3185	86.0801	77.6751	77.3892	70.1699	31.4754	16.9114	5.6883	3.2196
206	BG	A	86.6786	87.7093	88.5418	88.8139	88.8371	88.3722	88.0559	86.6152	78.4045	78.2549	70.4726	31.4477	17.0745	5.8814	3.4101
206	BE	A	83.3853	86.1832	86.9686	87.2088	87.6865	87.2024	85.1486	82.1861	69.9704	68.356	60.2313	22.1684	11.6665	3.9487	2.3002
206	WE	A	87.0796	84.7893	85.8766	86.0893	85.5347	85.711	84.0024	80.801	68.692	67.7859	58.171	21.0769	10.8938	3.611	2.0145
206	RE	A	87.6893	85.0696	85.3941	85.5653	85.7943	85.5876	83.8483	80.5789	67.7804	66.4635	57.6184	20.3215	10.7057	3.5004	1.9192
206	GE	A	82.0762	85.3637	85.2115	85.5682	86.025	86.0051	84.1142	81.1418	68.8551	68.0013	58.9017	21.2751	11.1317	3.7135	2.0616
207	BW	A	93.9634	91.1147	86.761	93.0252	92.7515	89.4774	87.7605	86.7643	78.5536	78.1837	72.03	33.8123	18.6615	6.3812	3.6384
207	BE	A	82.7406	86.3982	86.5203	86.3168	87.9081	87.6111	85.4809	83.0939	72.2168	71.941	62.6341	24.318	12.7842	4.389	2.4983
207	WE	A	81.7831	85.9519	85.7298	86.977	86.1284	86.8248	84.8896	82.0013	70.2569	69.6573	61.0325	22.9846	12.1646	4.035	2.2441
207	RE	A	89.0462	86.019	86.2521	86.3974	87.2082	86.2895	84.501	82.0331	70.749	64.1894	60.3001	23.0073	12.4388	4.3028	2.4234
207	GE	A	84.6521	84.1391	86.8407	86.2972	85.9588	86.214	84.4749	81.8026	69.8703	72.9779	60.4103	22.9946	12.3089	4.3029	2.4373
208	BW	A	88.9093	88.2789	89.1729	89.2761	88.6241	89.5456	88.1903	86.797	79.6895	76.3133	71.7915	33.8937	18.5247	6.3725	3.6398
208	BR	A	91.1993	88.2175	88.4212	88.3719	88.9338	88.528	88.0288	86.3939	78.1915	79.8375	71.7041	34.5334	19.1232	6.636	3.7277
208	WR	A	87.5238	88.0751	88.4744	88.7899	88.8877	88.9463	87.6037	86.0657	78.5498	76.4194	70.8809	33.4558	18.5614	6.3497	3.5946
208	BG	A	83.0576	89.199	88.7211	89.0104	89.5348	89.2683	87.6561	86.4827	78.3186	76.2921	71.8032	33.7481	18.7061	6.506	3.7156
208	WG	A	83.8578	87.5051	87.3899	87.9055	87.3818	86.9644	87.1782	85.8221	77.9578	75.1773	71.3931	33.9792	18.7885	6.4136	3.5912
208	RG	A	82.5229	88.0279	88.6142	86.7852	89.8234	85.3235	87.315	85.9099	78.4504	76.6418	70.957	33.3307	18.4732	6.4429	3.6763
208	BE	A	90.1647	86.276	87.2835	85.7792	87.1871	87.3577	85.3075	82.893	71.7002	65.1169	62.0297	23.6582	12.8029	4.5434	2.6803
208	WE	A	87.4709	85.9125	86.1927	86.0706	86.4145	86.005	84.5826	81.8019	70.1237	65.7091	60.4195	22.9727	12.3294	4.2816	2.4486
208	RE	A	82.6227	85.7728	85.8984	86.6584	87.1249	84.7592	84.31	82.128	70.8513	64.1451	60.7309	23.2236	12.4335	4.2662	2.4205
208	GE	A	85.1458	87.1381	86.3707	86.2925	86.1095	86.5299	84.6316	81.9608	70.5221	64.7401	60.4771	23.0705	12.499	4.2124	2.3469
209	BW	A	90.6673	88.3297	88.5735	88.7631	89.0594	88.6751	87.8459	86.345	78.9207	77.0535	71.3826	33.4784	18.4709	6.4111	3.7216
209	BE	A	85.4115	86.1823	86.9372	91.4801	86.8442	87.2104	85.2974	82.8413	72.425	68.6009	62.1913	24.0223	12.8113	4.2873	2.5261
209	WE	A	86.9409	85.7103	86.7847	86.2351	86.4062	86.3056	84.2254	81.9264	70.5126	74.7008	60.9745	22.9749	12.1126	3.9177	2.1744
209	RE	A	82.5337	85.1138	85.7184	85.7232	86.5415	86.2283	84.5818	82.0996	71.3236	67.1111	61.3139	23.067	11.9855	3.9916	2.132
209	GE	A	89.196	85.1678	84.9994	85.6166	86.4145	85.7239	84.7659	81.8098	70.1814	64.1744	60.9974	23.0755	11.9551	4.0418	2.1953
210	BW	A	76.1055	87.1402	96.1508	97.1003	90.7746	94.1974	88.0345	86.8811	80.5498	80.0581	74.5139	37.9734	21.3628	7.3413	4.1409
210	BR	A	89.2021	88.1664	88.6245	87.5609	85.0726	90.3174	87.95	86.8474	80.5237	80.4634	74.7054	39.0774	22.3913	7.9196	4.5329
210	WR	A	87.0127	87.9463	87.4459	75.0744	104.646	86.713	87.8723	86.7613	80.2767	78.0654	73.9394	38.0317	21.6952	7.6103	4.3276
210	BG	A	88.3874	88.6084	88.5126	88.6952	89.0568	89.0592	89.2982	88.1504	81.7819	80.5855	75.4384	38.1302	21.4565	7.4507	4.2595
210	WG	A	87.844	86.9583	87.9308	88.0836	88.4262	89.2751	87.8127	86.7175	80.6464	79.0192	74.3163	38.4082	21.5854	7.2612	3.9735
210	BE	A	86.3864	87.0486	87.5392	87.4963	87.6075	86.8737	86.0976	84.1717	74.5027	73.0908	66.0136	27.8153	15.1084	5.1907	2.9355
210	WE	A	82.0278	82.7352	86.8338	86.7725	86.9595	86.8124	85.2988	83.3281	73.4167	71.3618	64.6446	26.0909	14.3229	4.7483	2.581
210	RE	A	94.0336	86.3618	86.2768	86.6629	87.0785	86.846	85.5312	83.2747	73.4796	71.4999	64.5075	26.4955	14.1991	4.6301	2.504
210	GE	A	88.2725	86.3611	87.0885	87.1698	86.9524	86.9826	85.4656	83.2545	73.5262	71.1958	64.777	26.7784	14.3458	4.6988	2.5513

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
211	BW	A	89.5207	89.7682	89.4514	92.0026	89.1174	93.9697	87.9335	87.3034	80.9426	80.146	74.6147	38.2047	21.449	7.4371	4.2542
211	BE	A	98.9609	86.7249	87.5535	87.3841	87.722	87.4607	86.2479	84.3094	75.0674	73.4966	66.2656	28.0858	15.1505	5.1463	2.9
211	WE	A	88.279	86.2353	86.8017	86.5432	86.7811	87.0374	85.6158	83.5202	74.1644	72.1039	65.2679	27.0467	14.5109	4.7625	2.603
211	RE	A	89.5712	86.255	86.4796	86.9581	86.9389	86.7783	85.4635	83.4101	73.5136	73.0366	64.9401	26.8499	14.3051	4.6931	2.5497
211	GE	A	58.7549	86.22	86.6353	86.0752	86.7913	87.0537	85.4304	83.3154	73.7075	70.6689	65.1577	26.9966	14.6724	4.8631	2.7077
212	BW	A	87.2776	87.6274	88.4569	88.6036	88.2503	88.6955	87.7375	86.3476	78.3607	79.8528	70.1366	31.1418	16.9215	5.7435	3.3057
212	BR	A	81.8359	86.7928	87.2915	87.8896	87.8147	88.0061	87.6133	85.9904	77.8829	75.9147	70.1002	31.4954	17.0796	5.704	3.1982
212	BG	A	87.4694	87.7727	87.7806	88.0984	88.5234	88.6153	88.1374	86.4077	77.794	78.8064	70.3516	31.4878	17.0329	5.8208	3.3584
212	BE	A	81.6092	86.4631	86.808	87.158	87.0647	87.0359	85.0942	82.2969	69.8881	72.0678	60.2564	22.0499	11.4575	3.8875	2.2253
212	WE	A	87.8673	85.4316	85.7404	85.8279	85.9168	86.1724	84.0876	80.9582	68.5846	67.0951	58.3139	20.9403	10.8488	3.5084	1.9092
212	RE	A	88.5251	85.3202	85.9645	86.124	86.1561	85.6983	83.8266	80.7078	68.7516	66.2287	57.7557	20.2278	10.6319	3.4235	1.8722
212	GE	A	81.6493	85.3671	85.1699	85.5542	86.1077	86.0802	84.1732	81.3028	69.32	66.9651	59.2505	21.5238	11.1801	3.6821	2.0576
213	BW	A	86.6121	86.5204	88.0451	88.285	87.865	88.5899	88.208	86.5438	77.9207	78.6302	70.5725	31.3648	16.9464	5.7159	3.2536
213	BR	A	84.2504	87.3547	87.563	88.0878	87.7153	88.1159	87.6278	86.3052	78.649	76.547	70.5905	31.7934	17.1699	5.7062	3.1687
213	BG	A	90.9958	87.9894	88.6605	88.8016	88.8682	88.3983	87.8111	86.724	78.8915	76.6074	70.9616	31.7711	17.2003	5.8482	3.3451
213	BE	A	81.8467	86.5364	86.753	87.2622	87.4061	87.3186	85.8195	83.5258	72.4933	70.6003	62.615	23.1978	12.0076	3.9182	2.1923
213	WE	A	82.9932	85.4598	85.2847	85.5827	85.8785	85.8292	83.872	80.8697	69.0616	65.0333	58.5479	21.2622	10.9736	3.6247	2.0493
213	RE	A	89.0469	84.686	85.2619	85.6451	86.1468	86.0687	83.8614	80.5848	67.9453	67.0107	57.8062	20.4142	10.6437	3.5148	1.8805
213	GE	A	82.0814	85.3412	85.2502	85.4593	85.8536	85.9554	83.9199	81.2557	69.1547	68.3551	59.3601	21.6894	11.3978	3.7547	2.1038
214	BW	A	83.8979	88.3029	88.6381	88.9495	88.6535	88.7719	87.9265	86.2818	77.5358	73.3884	69.7962	30.7563	16.7072	5.718	3.2966
214	BR	A	87.1256	88.1551	88.2339	88.3471	88.6573	88.7486	87.7203	86.3334	78.2739	79.3831	69.7642	30.6017	16.6336	5.6502	3.2451
214	WR	A	86.6006	88.1574	88.5219	88.5693	88.3885	88.3973	87.316	85.6946	76.8915	73.0524	69.0936	30.1857	16.3061	5.4844	3.1433
214	BE	A	86.3822	86.4203	87.2209	87.4793	87.4445	87.2299	85.0694	82.2032	69.7215	68.4069	59.5592	21.4512	11.2651	3.8033	2.1377
214	WE	A	82.593	86.2595	86.0738	86.1988	86.5116	86.5738	84.4156	81.7692	70.1127	68.1816	59.9066	21.547	11.1048	3.5531	1.9394
214	RE	A	85.0008	85.7981	86.4938	86.1447	86.5696	86.5604	84.6943	82.1106	70.4049	68.4473	60.1564	21.6365	11.1567	3.5902	1.9797
215	BW	A	89.8523	87.9056	87.894	88.1657	88.4397	88.3758	87.7063	86.6932	78.5341	77.9299	71.4138	32.7625	17.8061	6.0955	3.4877
215	BR	A	89.7659	87.1433	87.3256	87.5381	87.8094	88.254	87.7944	86.4396	78.3125	77.972	71.4016	32.8448	17.957	6.053	3.3985
215	BG	A	83.9117	87.9046	87.9804	88.4762	88.7213	88.6375	88.3458	86.8157	78.8397	78.9956	71.6658	33.1419	18.0125	6.1954	3.5317
215	BE	A	82.2368	86.3151	87.1486	87.3671	87.1651	86.9759	85.3874	82.8113	71.5101	71.0448	61.937	23.3968	12.1763	4.1365	2.3373
215	WE	A	81.8879	85.0513	85.6489	86.079	86.0847	86.1606	84.8628	82.5614	71.8898	70.0903	62.2574	23.464	12.1741	3.9135	2.1487
215	RE	A	82.1724	85.3363	86.0175	86.2544	85.944	86.1229	84.6652	82.31	71.125	69.2448	61.2174	22.583	11.6714	3.7255	2.0284
215	GE	A	82.3026	85.4735	86.3054	86.3102	86.2812	86.4662	85.0929	82.927	72.4196	70.6125	62.9162	23.9694	12.4599	4.0272	2.2242
216	BW	A	87.307	88.2302	89.0787	88.8581	89.0086	88.7916	87.914	86.5251	77.8899	78.5138	70.5211	31.5275	17.0331	5.7196	3.2553
216	BR	A	85.5069	88.1059	88.318	88.5156	88.8915	88.2887	87.9389	86.4682	78.5902	79.5583	70.5675	31.5052	16.976	5.7081	3.2624
216	WR	A	82.7428	87.044	88.1104	88.3841	88.6763	87.8941	87.6238	85.9232	77.4472	72.8524	69.5942	30.8095	16.5732	5.568	3.1275
216	BE	A	85.4002	85.7033	86.6665	86.8187	87.0657	87.253	85.7834	83.4713	72.5099	70.6975	62.6579	23.2792	12.0562	3.9317	2.196
216	WE	A	88.896	86.1206	86.6244	86.6199	86.1764	86.1765	83.6466	81.0606	68.5682	68.3505	58.8017	21.0325	10.9191	3.5582	1.9073
216	RE	A	81.1172	85.7411	86.3035	86.6044	86.4287	86.2797	84.2373	81.5698	69.7714	66.5115	58.9371	21.2247	10.9147	3.4759	1.8936

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
217	BW	A	90.3786	87.9954	88.3929	88.5154	88.5892	88.4167	87.3024	85.9757	77.7537	75.6497	69.8605	31.037	16.6552	5.6442	3.1998
217	BR	A	88.5903	87.28	87.8127	88.0478	88.3937	87.8952	87.1968	85.6967	77.6741	75.4648	69.7974	31.1859	16.7845	5.5636	3.12341
217	BG	A	82.0823	86.9921	87.2079	87.9416	88.5611	88.0658	87.4657	86.0966	78.6323	79.0692	70.357	31.4749	16.8339	5.727	3.2895
217	BE	A	81.8854	86.5793	87.3629	87.4498	87.0869	86.9535	85.4742	82.6707	70.6342	67.4287	60.4323	21.7614	11.4243	3.7237	2.0923
217	WE	A	83.0426	85.5033	85.5121	85.9064	86.1569	86.3234	84.675	82.1585	70.774	68.8773	60.7185	22.1058	11.4125	3.6723	2.028
217	RE	A	86.8948	85.1558	86.0248	86.241	85.9813	86.1492	84.515	81.9447	70.2016	68.2415	59.9427	21.493	11.0666	3.5443	1.9482
217	GE	A	86.3978	85.1733	85.3717	85.7792	86.2403	86.2975	94.9387	82.578	71.4389	69.54	61.5165	22.6622	11.7226	3.7962	2.1096
218	BW	A	88.0218	88.1295	88.8837	88.9956	88.569	89.0988	87.5537	86.018	77.6957	78.8161	69.3153	30.153	16.114	5.3521	3.0014
218	BR	A	86.6199	88.6971	88.6931	88.7095	88.5044	88.731	87.4487	86.0098	77.4508	75.2136	69.6091	30.2017	16.2435	5.4206	3.0625
218	WR	A	82.6621	87.4722	87.5534	88.1722	88.3083	88.3996	87.2525	85.3746	76.8299	75.1044	68.421	29.5545	15.6964	5.2241	2.9087
218	BE	A	87.9495	86.1749	86.7262	86.9211	87.2832	87.1808	85.5681	83.0763	71.6044	69.6967	61.4443	22.2907	11.5032	3.7358	2.0832
218	WE	A	85.8683	85.0992	86.0423	86.0987	85.6551	86.1966	83.8522	80.6457	68.4703	65.2584	57.4019	19.9823	10.2545	3.2109	1.7441
218	RE	A	86.7812	85.9593	85.8266	86.1413	86.3784	86.4031	84.133	81.0616	69.0361	66.6761	58.3944	20.3844	10.7587	3.4605	1.872
203	BW	B	87.2956	87.074	87.0658	87.4636	87.6014	87.6145	87.2388	86.6693	81.0905	75.8664	73.7694	36.1221	20.1053	6.9974	4.187
203	BR	B	82.3055	84.2136	85.0168	85.726	85.9913	86.2764	87.2287	86.3815	79.6417	79.2275	73.5904	36.5129	20.3148	7.1712	4.2298
203	BE	B	86.864	86.2038	86.7956	86.9458	86.5471	87.5721	85.7526	83.7553	74.3519	66.1886	63.3463	24.37	12.4833	4.4609	2.8197
203	WE	B	84.2023	82.6389	84.947	83.5999	84.3418	83.5516	85.3993	83.1901	73.2556	82.7841	63.6519	24.1162	12.375	4.3188	2.6534
204	BW	B	83.3953	86.0162	86.8967	86.8015	87.2769	87.2106	86.7537	85.1957	76.6314	75.1769	68.4508	29.1294	15.4876	5.2172	3.0076
204	BR	B	83.9752	85.395	85.9069	86.5243	86.5428	86.5824	87.6666	86.5707	79.0353	90.5385	73.435	36.6095	20.3361	7.1153	4.1383
204	BE	B	90.096	87.0835	87.7438	87.0146	87.6816	88.0977	87.9341	87.2991	81.0043	82.1565	75.3246	36.9633	20.4234	7.2566	4.2632
204	WE	B	84.0328	82.7875	83.8093	83.9318	84.1669	84.5135	85.7329	84.6962	76.7883	75.232	68.7545	29.5302	15.7318	5.3013	3.038
205	BW	B	90.3902	89.6258	86.6411	86.7055	87.2525	86.3482	87.3677	86.4078	79.3304	86.1437	73.2816	35.4896	19.5738	6.9939	4.2234
205	BR	B	84.7611	85.0395	85.8779	85.984	86.4571	86.4914	87.041	86.4635	80.3579	79.041	73.7296	36.8153	20.5763	7.1974	4.228
205	BE	B	85.174	82.6342	83.3231	83.506	83.9181	83.9663	85.3775	84.4088	76.716	75.152	68.6476	29.3634	15.6415	5.2829	3.0322
205	WE	B	86.3755	85.6187	86.556	86.9105	86.828	86.9752	86.6452	85.1181	76.627	75.0964	68.4617	29.118	15.4988	5.2254	2.9941
206	BW	B	89.7124	86.4843	86.8845	86.7945	86.2612	85.8523	86.9498	86.3458	80.8866	72.6365	73.3464	35.7141	19.6695	6.9607	4.1199
206	BR	B	85.029	84.0246	84.1718	84.5721	84.8465	84.8516	86.2738	85.8874	79.5281	77.687	73.1806	35.754	19.831	6.9897	4.1475
206	BE	B	85.6986	85.8007	86.8826	87.1022	87.0951	87.1202	85.9318	83.837	70.5619	68.6839	58.0591	18.6313	9.4843	3.1159	1.7544
206	WE	B	84.604	81.7341	82.9415	83.2793	83.3915	84.9568	84.5293	82.8608	71.3668	62.0683	61.9816	22.9285	11.8684	4.22	2.4687
212	BW	C	89.1527	86.8447	88.9628	86.5639	86.669	86.8169	86.2197	85.8186	80.0388	77.4961	73.2459	36.1299	20.0102	7.0198	4.2616
212	BR	C	88.4167	86.3581	86.0189	85.8369	85.5713	85.839	85.8308	85.1473	79.4874	79.2994	73.4491	36.6101	20.4262	7.161	4.2142
212	BE	C	78.8033	85.2919	85.9791	85.8757	86.023	86.0169	85.5038	83.416	72.6375	71.1944	63.3241	23.9512	12.5357	4.3271	2.5539
212	WE	C	82.2409	82.6702	82.7644	83.0123	82.7467	82.9563	83.4883	82.7781	76.0492	74.6262	68.2418	29.2623	15.5782	5.2419	2.9988
213	BW	C	84.2157	86.6955	86.8218	86.5494	86.4903	86.5259	86.3643	85.6306	80.074	78.1916	73.1229	35.979	19.9646	7.0443	4.1839
213	BR	C	90.2851	86.2289	85.9079	85.5156	85.0909	85.2756	85.5451	85.0932	79.3367	79.558	73.2876	36.6358	20.5114	7.5497	4.8096
213	BE	C	82.5017	85.6538	86.3694	86.1988	85.6738	86.3934	84.7623	83.0403	72.0082	61.761	61.4638	22.2679	11.8875	4.0242	2.3199
213	WE	C	81.0404	82.3216	82.9908	83.0347	82.6383	82.8574	83.6042	81.396	70.994	63.3721	61.9604	23.0424	12.1016	4.1572	2.4702
214	BW	C	86.4325	87.3917	87.4797	87.4174	87.189	86.9347	87.4348	86.356	80.5611	72.9086	73.07	36.5901	20.9253	7.5647	4.4595

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
214	BR	C	92.0598	86.5522	86.7566	86.711	86.7849	86.5246	87.1332	86.2628	79.9452	76.722	73.2616	35.795	19.8729	7.159	4.4343
214	BE	C	84.2778	86.5356	86.685	87.6579	87.42	87.4698	86.7377	85.071	76.1334	74.6627	67.6475	28.0616	14.8588	5.0299	2.9023
214	WE	C	81.5378	83.3964	83.6247	84.0795	84.5697	84.8454	85.7762	84.6379	76.5411	75.0465	68.3483	28.9336	15.3868	5.2387	3.0518
215	BW	C	83.8493	86.1874	86.5991	86.1433	86.6512	86.406	86.7321	86.0989	80.1076	79.2881	74.0077	37.3159	20.7704	7.1461	4.1237
215	BR	C	85.6177	84.9684	85.2597	85.1737	84.8596	85.1329	85.7317	85.3597	80.0742	79.411	74.2573	38.2022	21.3703	7.3513	4.2211
215	BE	C	84.2886	85.3761	86.0821	86.6131	86.4483	86.7036	86.3933	84.8368	76.2033	74.5742	67.654	28.1028	14.841	4.9441	2.0834
215	WE	C	78.2709	81.9759	82.6178	82.6088	83.1391	83.193	84.1682	83.4679	76.1294	74.317	67.9465	28.6521	15.2161	5.0897	2.8994
216	BW	C	84.9423	86.713	86.323	86.9732	87.2906	87.2434	87.361	86.5183	80.0804	78.7353	73.7625	36.7535	20.3538	7.0208	4.0652
216	BR	C	85.6701	87.4698	86.6221	86.4153	86.7684	86.5944	86.406	85.8247	79.8695	79.0564	73.7204	36.7849	20.3781	7.0571	4.0937
216	BE	C	87.1058	86.509	86.4766	86.8114	87.2968	87.3401	86.5582	84.8239	75.5158	73.8384	66.8638	27.0685	14.2585	4.755	2.7073
216	WE	C	81.9329	83.4332	84.1869	84.5407	84.5358	84.7458	85.6854	84.4808	75.9056	67.5198	27.9272	14.779	4.9566	2.8491	-
203	BW	D	87.833	86.6911	86.8229	86.9556	86.6232	86.7925	87.4724	86.4125	79.8978	76.7275	73.1035	35.8081	19.9794	7.3465	4.6194
203	BR	D	85.7573	84.0423	83.8708	84.1856	84.8736	84.8924	86.1796	85.3867	79.431	77.8986	72.8882	36.0841	20.2361	7.4697	4.7465
203	BG	D	90.7942	86.3208	86.0413	85.8832	86.34	86.2618	86.8019	86.0886	79.6683	78.4638	72.9421	35.8228	20.0501	7.3928	4.6923
203	BE	D	85.9061	85.0546	86.9622	86.3098	86.1884	86.3278	85.4195	83.1301	71.7103	71.3123	62.2049	22.943	12.3008	4.614	3.0149
203	WE	D	79.17	82.2769	82.496	82.8557	82.9986	83.2931	84.0726	82.3415	72.3894	70.3467	61.9019	23.1011	12.4211	4.6839	3.0592
203	RE	D	78.4899	81.5654	81.5432	82.0666	82.7034	82.9169	83.7882	81.9701	71.0243	68.0214	60.9677	22.203	11.8533	4.4366	2.9476
203	GE	D	84.6761	82.2389	83.1589	83.4882	83.2336	83.5575	84.0706	82.2878	71.7066	69.5318	61.8776	22.9355	12.2977	4.6837	3.1593
204	BW	D	82.005	86.3977	85.4007	86.1223	85.8145	85.8859	87.0886	86.2485	79.7233	78.5992	73.1066	35.7146	19.8251	7.094	4.3363
204	BE	D	83.0536	84.7972	85.3358	85.6153	86.0919	85.6878	85.98	83.4667	72.5705	71.4056	62.8746	23.512	12.3996	4.3984	2.7467
204	WE	D	86.0943	82.2416	82.9516	82.9182	83.3891	83.2249	84.2312	82.6601	72.7744	70.6094	63.0279	23.6255	12.4758	4.4389	2.7818
205	BW	D	87.4931	85.677	85.8304	86.2457	85.6779	86.4126	86.6871	85.853	79.5412	78.4654	72.9846	35.5646	19.7434	7.0721	4.3524
205	BR	D	84.7818	83.1794	83.5546	84.1745	84.2688	84.4171	86.0579	85.574	79.6574	78.2463	72.8863	36.1577	20.18	7.2285	4.4379
205	BG	D	85.3554	86.1942	85.2903	85.6189	85.7994	85.8946	86.5802	85.878	79.7119	78.4022	72.993	35.7175	19.8774	7.1303	4.3985
205	BE	D	86.4233	84.5644	85.3217	85.7823	86.0261	86.1802	85.5044	83.311	72.6169	71.5175	62.8028	23.4432	12.3091	4.4101	2.7973
205	WE	D	79.3296	82.1092	83.0738	83.308	83.1982	83.5445	84.2472	82.6555	72.4259	70.6816	62.8516	23.4499	12.3728	4.4308	2.7962
205	RE	D	78.3384	81.3259	81.3475	81.3713	82.655	83.4233	84.0424	82.4166	72.1695	70.3798	62.3378	23.047	12.1413	4.3119	2.7129
205	GE	D	78.1966	82.247	82.7804	82.9001	83.3903	83.4997	84.1937	82.4426	72.8285	71.1118	62.9729	23.6178	12.4624	4.4704	2.8402
206	BW	D	79.8772	84.0807	85.6436	86.0349	85.8976	84.9245	86.5676	85.9338	79.6242	78.5736	73.0055	35.6303	19.7868	7.1005	4.3728
206	BE	D	79.7926	86.1402	85.0873	85.1923	86.1099	86.833	85.4981	83.3762	72.1923	68.0968	62.7163	23.3022	12.3739	4.4465	2.815
206	WE	D	78.7119	80.7469	82.243	82.969	83.2291	80.8726	84.093	82.5581	72.8541	70.3531	62.6342	23.4057	12.4264	4.4424	2.7885
212	BW	E	86.4937	85.3266	84.9614	85.2082	85.0984	84.9208	84.9805	84.4681	78.8817	77.1541	72.5018	35.4516	19.8007	7.2653	4.6312
212	BE	E	79.578	83.4892	84.1103	81.7759	84.1616	84.2676	84.3366	82.3428	71.8062	70.0081	62.0139	23.0338	12.2325	4.6268	3.1441
212	WE	E	84.8803	82.4043	82.6155	82.2708	81.8782	81.9213	81.4481	80.2713	71.167	70.2675	61.9777	23.2015	12.3398	4.5772	3.0183
213	BW	E	88.1921	85.2604	84.73	84.8705	85.2318	84.9822	84.8069	84.3153	78.9424	77.1209	72.5578	35.5814	19.8301	7.2069	4.5011
213	BE	E	78.2085	83.5307	83.652	84.0328	84.4647	84.2216	84.1443	82.3389	71.7487	69.4586	61.973	22.9768	12.1616	4.5035	2.9252
213	WE	E	79.8531	82.1975	71.6621	81.5472	81.8292	81.6365	81.4046	80.1362	71.2695	69.6552	61.6507	22.9499	12.1769	4.5036	2.9373
214	BW	E	85.8589	88.5702	85.6013	85.3672	85.1351	85.3947	84.6069	83.7981	78.4972	77.3989	72.3488	35.2398	19.6006	7.0663	4.3983

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
214	BR	E	83.4361	85.4618	85.4498	85.2869	85.083	85.1481	84.1883	83.2003	78.1026	77.0358	72.0476	35.1959	19.566	7.0624	4.3962
214	WR	E	85.1517	86.7254	86.6294	86.1257	85.4429	85.1503	82.7985	81.8004	77.5888	76.9193	71.7125	35.1969	19.5741	7.0846	4.4256
214	BE	E	86.947	81.6821	82.2962	82.2626	82.8208	82.9402	83.5125	81.9168	71.6609	70.3331	61.9127	22.7995	11.9989	4.3473	2.7956
214	WE	E	78.0932	83.9211	83.3992	82.9016	82.4339	82.3984	81.0535	79.6341	71.2801	69.6378	61.9607	23.1718	12.252	4.4641	2.8887
214	RE	E	82.4727	84.149	83.6496	82.4372	82.3639	82.2478	80.3634	78.5424	79.5406	68.996	61.4931	23.0167	12.1726	4.4368	2.8762
215	BW	E	87.9858	86.9035	87.0077	86.7801	86.9656	87.1176	86.6909	85.9194	79.8992	78.4234	73.5974	36.8154	20.6087	7.3897	4.545
215	BR	E	87.7942	84.5985	84.4881	84.6538	85.0472	85.1544	85.9345	85.3781	79.9954	78.7865	73.8363	37.5058	21.1117	7.6018	4.6801
215	BG	E	82.7446	87.3102	87.0225	86.7751	86.9337	86.832	86.1132	85.4083	79.7624	78.1661	73.5946	36.9505	20.7107	7.4373	4.5805
215	BE	E	78.8632	84.058	84.6991	85.1409	85.0022	85.1839	85.34	83.7719	74.8164	73.0037	65.9234	26.5924	14.1889	5.0726	3.1859
215	WE	E	81.9266	82.1585	82.1365	82.1365	81.9512	81.9603	82.5322	81.8518	74.4785	72.9657	66.0729	27.0166	14.4644	5.1993	3.2759
215	RE	E	83.3364	82.4036	81.7809	81.7997	81.489	81.3808	81.2612	80.6864	73.714	72.2713	65.245	26.3426	14.0645	5.0182	3.1474
215	GE	E	86.6967	82.6404	82.6221	82.2273	82.4546	82.4585	82.6915	81.9158	74.5913	73.4335	66.2525	27.2511	14.6037	5.2658	3.3217
216	BW	E	93.3514	87.1978	86.8234	86.291	86.5466	86.1676	85.0985	84.2461	79.0839	77.7773	72.8909	36.0811	20.1357	7.2669	4.5087
216	BR	E	83.8323	86.1874	86.4468	85.8947	86.3547	86.2579	85.9559	84.9739	79.3285	78.2913	73.188	36.3425	20.317	7.3159	4.5125
216	WR	E	85.0716	87.6906	86.8152	86.9348	86.3477	86.2178	84.5111	83.5114	78.8605	77.9052	72.9549	36.4255	20.3906	7.3625	4.5521
216	BE	E	83.9696	81.9863	81.6618	82.0761	82.5669	82.8933	83.9139	82.764	73.9931	72.1615	64.953	25.6602	13.673	4.9305	3.1309
216	WE	E	85.2265	83.6476	82.575	82.9218	82.4087	82.4757	81.746	80.8208	73.7047	72.1389	65.2444	26.3234	14.0932	5.1149	3.2693
216	RE	E	89.3048	84.242	83.309	82.808	82.6116	82.5276	80.6589	79.1097	72.5485	71.0818	64.541	26.1387	13.9633	5.0225	3.165
201	BW	F	87.5785	84.8154	86.0244	86.7631	86.4758	86.6763	86.8366	85.5591	78.1846	76.9675	71.1963	33.3938	18.2807	6.3611	3.7969
201	BR	F	80.6522	84.6561	85.1535	85.965	86.2775	86.5651	86.5832	85.2514	78.0071	76.57	71.0274	33.5911	18.4465	6.4037	3.7914
201	BE	F	78.3984	83.3009	84.9066	85.465	85.5469	85.8096	85.0857	82.7538	71.3777	69.3544	61.2359	22.1704	11.4816	3.9162	2.354
201	WE	F	81.269	84.8543	84.9422	85.4903	85.9243	85.839	84.3747	81.7765	69.9678	67.6839	59.6525	21.1807	10.8707	3.5723	2.0819
202	BW	F	87.3582	85.5839	86.572	86.646	86.7985	87.083	86.8754	85.5081	77.7628	76.3178	70.4349	32.2222	17.5925	6.2588	3.839
202	BR	F	84.3125	85.1925	85.2932	86.0218	86.459	86.5594	86.7514	85.5618	78.081	76.646	70.9187	32.7882	17.8952	6.3094	3.8478
202	BE	F	79.3374	83.0141	83.758	84.4913	85.225	85.3156	84.7695	82.3631	67.8194	65.1436	54.4553	16.4925	8.2361	2.5184	1.3081
202	WE	F	86.7349	84.8356	85.4964	85.1261	85.4079	85.5798	83.8908	81.0515	65.8468	63.1536	52.2912	15.2978	7.4382	1.9952	0.8524
203	BW	F	82.2563	85.1407	85.5151	85.8735	85.5413	85.5387	84.4767	83.2979	77.5809	76.5557	71.5898	35.1782	19.5318	7.0306	4.3602
203	BR	F	84.8516	84.4884	84.7185	84.7939	84.7257	84.5292	82.946	81.8191	76.6038	75.7073	70.8251	35.5445	19.8528	7.2108	4.5175
203	BE	F	81.4966	83.1617	83.9864	83.3706	83.839	83.7847	82.7522	81.135	71.4444	69.8641	61.9103	23.0049	12.0974	4.3756	2.8268
203	WE	F	88.7421	84.2596	83.757	83.3448	83.1751	82.8409	80.0664	78.0617	69.209	67.4417	60.3875	22.7271	11.9373	4.3115	2.7616
204	BW	F	88.5147	85.0557	85.1098	85.5995	85.6113	85.5082	84.4472	83.2113	77.254	76.2298	71.3098	35.0344	19.4461	6.9646	4.29
204	BR	F	89.0588	84.4468	84.7599	84.7682	84.3807	84.4585	82.5703	81.3754	76.2068	75.0033	70.6498	35.5358	19.8666	7.1856	4.4821
204	BE	F	81.8459	82.9352	83.1593	83.3184	83.5112	83.6678	82.508	80.9146	71.5992	69.6838	62.1006	23.2299	12.188	4.358	2.7655
204	WE	F	86.2311	84.5574	83.7237	83.2589	83.2792	83.0661	79.8799	77.9012	69.0943	67.3378	60.4435	22.936	12.0636	4.2917	2.7178
205	BW	F	81.8713	85.4216	85.5214	85.7449	85.7319	85.8481	84.4884	83.2434	77.1944	76.1151	71.2309	35.0513	19.4478	6.9698	4.3009
205	BR	F	87.8233	84.7276	85.2099	84.4348	84.5856	84.4759	82.5798	81.3677	76.1914	75.0364	70.4656	35.5854	19.9425	7.2116	4.4378
205	BE	F	79.5039	83.163	83.4558	83.5924	83.5795	83.6563	82.2339	80.609	71.4464	69.6885	62.071	23.2615	12.219	4.383	2.796
205	WE	F	88.9496	84.9371	84.5259	83.7294	83.4213	83.0593	79.6816	77.6112	68.7493	67.2505	60.2359	22.8923	12.0203	4.292	2.7188

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
206	BW	F	81.8982	85.3907	85.7263	86.0449	85.8302	85.7421	84.446	83.2204	77.2141	76.3221	71.2916	35.0671	19.4588	6.9456	4.2492
206	BR	F	83.2713	84.8085	84.8498	84.5245	84.7785	84.6817	82.7129	81.3992	75.9656	75.2076	70.2566	35.1909	19.638	7.0415	4.3073
206	BE	F	83.2115	83.3164	84.0166	83.6849	83.7169	83.7814	82.35	80.7116	71.5319	69.7405	62.1921	23.3023	12.2293	4.3494	2.7282
206	WE	F	84.9808	84.8453	84.3234	83.816	83.0968	82.8108	79.6351	77.5688	68.8304	67.3838	60.2686	22.8916	12.0245	4.2785	2.7
207	BW	F	86.6512	85.4255	86.4553	86.475	87.0271	87.0356	86.7559	85.3916	77.7092	76.4719	70.5225	32.5107	17.8361	6.4347	4.0171
207	BR	F	81.5076	82.9345	84.4248	84.9562	85.4199	85.4907	86.101	84.9842	77.7458	76.2369	70.7283	33.0474	18.0238	6.2551	3.7707
207	BE	F	85.1951	83.9366	84.697	85.7146	85.8695	86.0973	84.807	82.1871	70.003	67.933	59.4984	21.0317	11.0127	4.0063	2.6017
207	WE	F	80.0893	84.5794	84.8233	85.1742	85.5569	85.7448	84.0087	81.2521	68.6723	66.5922	58.0058	20.0822	10.3864	3.617	2.2688
208	BW	F	87.6075	85.7323	86.1575	86.8442	87.2616	87.2654	86.8995	85.5647	77.9049	76.339	70.6683	32.7486	18.0289	6.4472	3.9176
208	BR	F	82.9868	84.5004	85.6158	85.7754	86.2086	86.1902	86.3499	85.1363	77.7373	76.1921	70.6239	32.8683	17.9689	6.2848	3.7899
208	BE	F	78.3017	84.1571	85.6005	85.8438	85.9452	83.9172	84.6873	82.0227	69.7058	67.9587	59.2103	21.1401	11.1652	4.0093	2.4931
208	WE	F	81.0447	84.7693	84.9709	85.9757	85.8099	85.9222	84.0313	81.1198	68.5625	66.4407	57.9617	20.3999	10.6482	3.6728	2.2008
209	BW	F	86.9512	85.859	86.4126	86.7152	86.903	87.2327	86.7546	85.3707	77.6872	76.1642	70.4027	32.3568	17.7124	6.2952	3.8386
209	BR	F	85.9204	84.522	85.269	85.4173	86.0382	86.171	86.3386	85.1247	77.7191	76.4839	70.609	32.9041	18.0621	6.3425	3.7922
209	BE	F	79.718	84.2808	85.5571	85.5693	85.973	86.0119	84.6788	82.0145	69.7889	67.6879	59.2505	20.8848	10.9085	3.8676	2.4232
209	WE	F	82.7017	84.7618	85.5218	85.3934	85.849	85.7142	83.9617	81.1054	68.511	66.4272	57.8534	20.0179	10.3324	3.5079	2.1097
210	BW	F	90.1186	87.1389	87.5231	87.3026	87.7555	87.8279	87.2401	86.0427	79.4197	78.1716	72.7166	36.0655	20.0948	7.0474	4.1385
210	BR	F	87.9141	87.0657	87.6313	88.4683	88.3584	88.5843	87.7971	86.4288	79.6074	78.664	73.2776	37.1877	20.7289	7.079	4.0773
210	BE	F	84.6441	84.1849	84.9516	85.8297	85.9546	86.2271	85.3866	83.2677	72.9399	70.9423	63.3767	24.3063	12.8662	4.6079	2.9604
210	WE	F	81.1052	85.1912	85.3492	85.8998	86.1696	86.2887	84.8505	82.5948	71.7695	70.11	62.154	23.5141	12.3501	4.2686	2.6218
211	BW	F	85.4555	87.05	87.8522	87.8829	88.0828	88.2596	87.7251	86.5711	79.9341	78.7507	73.3376	36.2001	20.0407	6.7655	3.8129
211	BR	F	87.0665	85.4777	85.9467	86.9655	86.8649	86.9965	87.1168	86.109	79.7107	78.595	73.3978	37.561	21.1265	7.3746	4.3121
211	BE	F	84.0061	84.0725	85.6402	85.8573	86.1061	86.3972	85.6247	83.5518	73.4627	71.7454	64.2262	25.148	13.3325	4.7097	2.9069
211	WE	F	80.5967	85.0368	85.2826	85.6574	86.1879	86.1724	84.8816	82.5405	71.3425	69.4758	61.474	22.4101	11.339	3.3262	1.614
212	BW	F	86.6089	85.4616	86.1996	85.7937	85.8759	85.6935	84.3348	82.954	77.0157	75.8109	71.1372	34.9818	19.5055	7.1876	4.5884
212	BR	F	85.5499	85.0988	85.4232	85.0904	85.1083	84.939	83.1358	81.6827	75.8084	74.7012	69.9614	35.244	19.7574	7.2271	4.532
212	BE	F	85.776	83.7493	84.3291	84.4276	83.5398	83.9709	82.4139	80.7042	71.0672	69.0708	61.4189	22.7936	12.0731	4.5658	3.0911
212	WE	F	87.6719	85.0257	84.3729	83.9456	83.5191	83.3316	79.8718	77.4708	68.1908	66.7133	59.6055	22.4877	11.9294	4.5283	3.0702
213	BW	F	85.9514	85.2071	85.0351	85.2506	85.6139	85.5766	84.3177	82.916	76.5144	75.2251	70.5954	34.912	19.4487	7.0425	4.3987
213	BR	F	83.9075	85.1564	85.0999	84.9831	85.0865	84.9473	82.932	81.2784	74.7414	73.6238	68.6234	33.8268	18.6243	6.3244	3.6263
213	BE	F	79.0559	83.5204	83.6224	83.7713	84.071	84.018	82.228	80.3563	70.9297	68.9149	61.3344	22.7365	11.9873	4.4128	2.8893
213	WE	F	88.412	85.0085	84.4869	84.035	83.7124	83.3791	79.7822	77.3201	67.9205	66.2341	59.2282	22.2901	11.7396	4.2923	2.7932
214	BW	F	87.277	86.9965	85.9354	85.4758	85.5083	85.4582	84.1613	83.2576	77.9878	76.8183	71.8237	34.9934	19.4967	7.2168	4.6011
214	BR	F	86.152	85.8137	85.8298	85.4716	84.9364	84.7626	83.7901	82.6525	77.1569	75.8646	71.1384	34.5614	19.143	6.8859	4.2449
214	BE	F	87.1116	86.6162	81.7348	81.7442	81.5497	81.6435	82.0638	80.7014	71.0077	69.1252	61.2331	22.5817	12.0098	4.5687	3.0794
214	WE	F	88.5503	84.5932	83.6818	83.6304	82.9354	82.7259	80.4253	78.6423	70.2822	68.4577	61.0594	22.8648	12.1504	4.604	3.0897
215	BW	F	83.249	85.7436	85.6126	84.7916	85.0479	84.8977	84.0623	82.802	76.401	75.4541	70.6663	35.6335	19.8844	7.0505	4.2731
216	BW	F	88.8172	85.9962	86.5381	85.8127	85.8979	85.745	82.9496	81.5717	76.7265	75.5289	71.1056	35.1891	19.5123	6.8914	4.1623

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
201	BW	G	82.5513	91.5952	85.8167	87.155	87.0885	87.2766	87.7468	86.6724	78.1077	76.3964	79.9659	33.0779	18.1172	6.3124	3.7465
201	BE	G	84.2205	83.5304	89.9167	84.1772	84.8646	84.936	84.498	82.2298	70.8737	68.9803	60.5995	21.7508	11.2888	3.8317	2.2744
201	WE	G	86.2023	85.0059	84.2587	84.6135	84.7146	84.6989	83.4614	81.0361	69.1556	66.8507	58.6465	20.533	10.6158	3.5858	2.1428
202	BW	G	91.1508	86.0238	85.6436	85.7072	86.0925	86.0119	86.0165	84.8445	77.4891	76.2861	70.2548	32.1668	17.6024	6.2658	3.821
202	BE	G	80.1615	84.9954	82.9994	84.7293	84.361	84.027	83.7864	81.3673	69.5831	68.432	59.4517	21.457	11.3781	4.1182	2.5845
202	WE	G	82.8303	85.7576	85.1738	84.8248	85.0255	84.9264	82.7705	80.1452	67.9127	65.563	57.3844	20.2012	10.572	3.6165	2.1765
203	BW	G	78.7361	85.9198	87.0348	85.9069	86.5716	86.1313	84.7407	83.4574	77.5356	76.3009	71.422	34.9325	19.5095	7.2243	4.5963
203	BE	G	79.1726	84.3705	84.2035	85.0961	84.4467	84.4957	82.8224	80.939	70.5798	68.9081	60.6927	22.2562	11.8604	4.5596	3.086
203	WE	G	83.9535	84.1764	84.1836	83.9999	83.8253	83.2864	80.0375	77.7378	68.1727	66.562	59.0696	21.862	11.6659	4.4629	3.006
204	BW	G	80.9027	86.2342	87.0204	86.9974	86.6361	86.6589	85.1693	83.8439	77.5562	76.7965	71.5341	35.1545	19.6187	7.1659	4.4748
204	BE	G	87.4965	84.3154	85.0234	84.7139	84.7205	84.5244	82.7211	80.8461	71.0724	69.5971	61.5513	22.9157	12.2015	4.5292	2.9487
204	WE	G	84.0134	84.6012	84.8543	84.099	83.5527	83.3981	79.9748	77.7386	68.6423	66.6896	59.7751	22.5902	12.0091	4.4247	2.8635
205	BW	G	86.2683	85.489	86.4495	87.0507	85.5213	85.8486	84.8707	83.4008	77.2047	75.9873	71.1313	34.8683	19.3109	6.8086	4.0914
205	BE	G	83.9527	83.3444	83.8787	83.6502	83.4034	83.4841	81.9448	80.1771	71.1876	69.5589	61.977	23.3759	12.2945	4.2767	2.6108
206	BW	G	88.6309	85.5353	86.4007	86.3875	86.118	86.055	84.9437	83.4608	76.7871	75.7639	70.8513	34.7506	19.2617	6.8139	4.1223
206	BE	G	82.9276	83.3396	83.6481	83.4053	83.6746	83.6878	81.9076	80.1233	71.0711	69.6597	61.717	23.0912	12.0924	4.2495	2.6187
207	BW	G	88.0377	86.0314	87.1548	87.5818	87.4975	87.4937	87.0241	85.5116	77.7444	76.6121	70.6295	32.5492	17.8056	6.2678	3.7922
207	BE	G	86.2521	86.6752	86.4004	86.9726	86.1375	86.8342	86.1928	82.4412	70.1688	68.7032	59.5945	20.9731	10.91	3.7936	2.3339
207	WE	G	82.0607	85.2645	85.7709	85.3342	85.8665	86.1653	84.283	81.4465	68.8518	66.7268	58.1004	20.0791	10.3058	3.4287	2.0286
208	BW	G	81.8577	90.404	87.2314	87.636	87.5554	87.4959	86.7117	85.5977	77.8276	76.6272	79.6697	32.5953	17.8152	6.2184	3.7074
208	BE	G	84.2524	86.8251	85.9567	86.5632	86.6499	86.7553	85.1605	82.5507	70.4317	68.4497	60.001	21.2793	11.0551	3.7925	2.286
208	WE	G	90.3696	85.2201	85.9663	86.1333	86.315	86.3092	84.3729	81.6253	69.2392	67.2523	58.7489	20.5399	10.5485	3.4756	2.0086
209	BW	G	85.6772	87.1855	87.152	87.4381	87.3142	87.3101	86.8956	85.5273	77.7942	76.2529	70.5225	32.4035	17.6919	6.1939	3.7145
209	BE	G	80.8754	84.7798	85.5837	86.1583	86.3693	86.5961	85.0449	82.3947	70.243	68.2478	59.8071	21.0987	10.9687	3.7973	2.3138
209	WE	G	80.7165	84.6635	85.378	85.5444	86.3618	85.6411	84.2343	81.4421	68.9568	67.1351	58.391	20.2068	10.3436	3.3743	1.9323
210	BW	G	83.3939	85.6952	86.4775	87.1391	87.4576	85.6204	87.4209	86.3133	79.7814	78.2374	73.2171	36.8238	20.6327	7.2884	4.3363
210	BE	G	80.16	85.4955	89.4734	86.4249	86.4946	86.8579	85.7752	83.6537	73.1323	72.0862	63.7848	24.5202	12.8935	4.4223	2.6381
210	WE	G	83.0445	85.2731	85.7238	86.1253	86.3407	86.5408	85.1058	82.8726	71.9914	70.1495	62.4507	23.5664	12.2524	4.022	2.2883
211	BW	G	87.5242	84.4342	87.2067	87.6218	88.1277	88.1119	87.9857	86.8272	80.242	79.1652	73.7675	37.34	21.007	7.4687	4.4777
211	BE	G	85.9417	84.6086	85.6483	86.3178	86.851	86.7524	85.7466	83.6908	73.316	72.3208	64.1411	25.0171	13.259	4.5994	2.763
211	WE	G	87.714	85.1811	85.8021	85.8528	86.328	86.2607	85.1438	82.984	72.4551	70.7118	63.167	24.4395	12.8199	4.2648	2.4513
212	BW	G	82.0544	85.9422	86.6676	86.5945	86.4703	86.546	85.0111	83.405	77.0915	76.1369	71.2112	35.114	19.5642	7.0657	4.3953
212	BE	G	79.808	84.5447	85.1464	85.1012	84.7046	84.5832	82.5294	80.7386	71.1647	69.3413	61.549	22.8299	12.0621	4.3789	2.8033
212	WE	G	79.9205	84.9816	84.8393	84.1285	83.7083	83.4812	80.024	77.5844	68.2004	67.0148	59.5626	22.4427	11.8478	4.281	2.7153
213	BW	G	87.8478	85.8467	86.3271	85.9662	85.9769	86.155	84.7362	83.3468	76.8747	75.5659	70.9325	34.9366	19.4975	7.0918	4.389
213	BE	G	86.5932	83.2282	84.301	84.1323	83.9669	83.9319	81.9089	79.8531	70.4126	68.4164	60.8268	22.6517	12.0294	4.4713	2.8849
213	WE	G	84.1865	85.2625	85.1288	85.0074	82.7754	83.987	80.0963	76.9031	67.1418	66.0154	58.6663	22.0138	11.6797	4.2283	2.6841
214	BW	G	87.0679	86.5227	85.788	84.8465	84.8048	84.8296	83.6994	82.922	77.7383	76.2356	71.4871	34.609	19.134	6.7641	4.0939

Table G.2 AC impedance measurements for specimens in test sequence 2
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
214	BE	G	80.2315	83.2646	82.9302	82.3057	81.9715	82.0078	81.4741	80.0693	71.0158	69.0904	61.4437	22.6786	11.8746	4.1754	2.578
214	WE	G	83.9951	85.011	83.9435	83.9023	83.4788	83.1388	80.757	79.0463	70.1687	68.4139	60.5972	22.4453	11.8924	4.3904	2.8616
215	BW	G	90.2206	86.4616	86.0797	86.2555	86.2843	86.3571	84.8984	83.4606	77.4413	76.1947	71.6964	36.1077	20.2092	7.1796	4.341
215	BE	G	87.6605	83.5122	83.6149	83.6531	83.7074	83.8046	82.2415	80.9195	73.2166	71.6389	64.7885	26.3382	14.0665	4.9927	3.0848
215	WE	G	82.5702	84.9506	84.5854	84.1445	83.5148	83.2569	79.8922	77.9957	70.5418	69.3417	63.0786	26.152	13.9799	4.9406	3.0323
216	BW	G	91.7718	87.9982	87.6284	87.6656	86.5975	86.4448	83.7494	82.6783	77.6122	76.7072	71.5776	35.1265	19.4866	6.8561	4.1229
216	BE	G	83.4386	84.4852	84.0814	83.0751	82.8074	82.4571	80.0748	79.1782	72.0853	70.5489	63.475	25.1315	13.304	4.6444	2.8318
216	WE	G	89.9423	85.7012	85.2529	84.875	84.198	84.29	80.8485	79.33	71.9024	70.4026	63.4716	25.2402	13.3491	4.6359	2.8148
201	BW	H	93.4812	89.8753	89.9232	89.5476	89.3777	89.4155	87.0936	84.5218	72.8365	71.1137	62.5748	22.5645	11.7031	4.0183	2.3799
201	BE	H	88.8399	88.4532	87.9711	87.9638	88.1591	88.0629	84.3297	80.1135	63.5586	61.4163	50.8713	15.0877	7.6479	2.5858	1.535
201	WE	H	86.0329	88.8918	88.6515	88.7499	88.259	88.2489	84.0652	79.5626	62.4318	59.715	49.5163	14.399	7.293	2.4439	1.4339
202	BW	H	90.0538	90.1303	89.5317	89.3396	89.4619	89.3114	86.6792	83.9119	71.5949	69.6224	61.0319	21.4651	11.0961	3.7328	2.1694
202	BE	H	87.6101	87.8362	88.1237	87.6751	87.6375	87.5867	83.298	78.7057	61.3563	58.7739	48.5499	14.0313	7.0922	2.3516	1.3429
203	BW	H	93.1449	89.372	89.4004	89.1704	89.1957	89.1184	87.21	84.9713	74.176	72.2882	64.2704	24.095	12.5605	4.312	2.5644
203	BE	H	87.6731	88.5295	88.2402	88.1753	88.231	88.3391	84.6099	80.7306	65.149	62.2909	52.7771	16.0828	8.2108	2.7807	1.6376
203	WE	H	89.1096	88.8695	88.2387	88.1046	88.218	88.1435	84.1326	80.0634	63.8926	61.6923	51.267	15.3566	7.8186	2.648	1.5392
204	BW	H	87.821	90.3446	89.9063	89.7883	89.7829	89.5351	87.1104	84.6012	73.164	71.5783	62.9132	22.911	11.8999	4.071	2.4174
204	BE	H	90.8029	88.5122	88.4385	88.5178	88.3492	88.1005	84.4342	80.3028	63.9848	61.4927	51.3462	15.3167	7.7748	2.6203	1.5366
204	WE	H	90.4188	88.813	88.4556	88.1631	88.2181	88.1132	83.921	79.51	62.6356	60.0926	49.8465	14.6124	7.3924	2.4749	1.4375
205	BW	H	91.4154	90.3959	89.9089	90.1639	89.7627	89.5607	86.9838	84.2987	72.2061	70.3112	61.7487	21.9365	11.3589	3.8728	2.2984
205	BE	H	90.9277	88.8706	88.5587	88.8871	88.337	88.3242	84.2368	79.8949	62.9557	60.5066	50.199	14.7402	7.5071	2.5165	1.4865
205	WE	H	91.768	89.0882	88.8253	87.8603	88.3726	87.7383	83.5463	78.8411	61.1637	58.7046	48.2472	13.8695	7.0301	2.8923	1.5883
206	BW	H	88.3555	90.5414	90.0907	90.0004	87.6569	89.3051	87.0783	84.5552	73.0501	71.0803	62.8741	22.9272	11.9022	4.0627	2.4057
206	BE	H	90.6353	88.8188	88.3359	88.3128	88.4153	88.1618	84.396	80.3781	64.1564	61.6844	51.5877	15.4703	7.8458	2.641	1.5554
206	WE	H	86.4799	89.1578	88.503	88.6385	88.4445	88.3269	83.8958	79.366	62.1817	59.6101	49.3308	14.3964	7.2766	2.4386	1.4214
207	BW	H	90.3744	89.7938	89.8906	89.7753	89.4077	89.2067	86.9832	84.5093	73.1316	71.2537	63.0024	22.9773	11.9341	4.0713	2.4088
207	BE	H	89.2352	88.1661	87.8099	88.4132	87.9232	87.9201	84.2685	80.2105	64.0702	61.6563	51.5096	15.4298	7.8185	2.6355	1.5546
207	WE	H	89.1276	88.7403	88.7178	88.7045	88.1566	87.9733	83.8248	79.4752	62.7738	60.2432	50.0458	14.7296	7.4688	2.5296	1.492
208	BW	H	86.433	89.6511	89.4815	89.7942	89.3299	89.4596	86.9703	84.2875	72.2285	70.1764	61.6967	21.8581	11.3033	3.8599	2.2788
208	BE	H	84.2179	88.4121	88.3956	88.4617	88.1181	87.9923	83.954	79.6375	62.6392	60.1483	49.8069	14.544	7.3715	2.4778	1.4494
208	WE	H	92.1746	88.9532	88.4836	88.2209	88.1582	88.0945	83.5308	78.9279	61.5181	59.0217	48.6178	14.0384	7.1038	2.378	1.3909
209	BW	H	94.9888	90.2538	90.1756	89.3979	89.615	89.4832	87.1729	84.8517	74.0061	72.0216	64.2522	24.1629	12.6028	4.3079	2.5403
209	BE	H	88.1533	87.9867	88.5819	88.2043	87.9131	87.949	84.556	80.7537	65.2515	62.6884	52.9854	16.2447	8.2542	2.7759	1.6194
209	WE	H	86.021	88.8967	88.7377	88.3316	88.2733	88.0965	84.0847	79.9813	63.9536	61.7286	51.4214	15.4643	7.8465	2.6368	1.5381
210	BW	H	90.2932	91.1303	90.0353	89.9615	89.9194	89.9128	87.3973	84.9431	73.5869	71.8137	63.6478	23.5685	12.2515	4.2328	2.5367
210	BE	H	90.8624	88.4431	88.7877	88.5163	88.2022	88.0838	84.4463	80.3155	64.2999	61.973	51.8922	15.6925	7.9804	2.7369	1.6425
210	WE	H	90.5151	89.2282	88.5846	88.4984	88.5397	88.4125	84.3753	80.0868	63.8624	61.4345	51.2809	15.4241	7.8675	2.6817	1.5999
211	BW	H	95.5942	90.7029	89.8527	90.2552	89.7025	89.6987	87.1088	84.5016	72.7161	79.9912	62.3678	22.4061	11.5872	3.9924	2.3849

Table G.2 AC impedance measurements for specimens in test sequence 2 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
211	BE	H	92.0565	88.6314	88.572	88.6994	88.35	88.1705	84.1952	79.9625	63.2142	60.546	50.4332	14.83	7.5541	2.5756	1.5287
211	WE	H	93.0362	89.172	88.8567	88.4502	88.5559	88.3085	84.0862	79.6147	62.7048	60.2337	49.9191	14.6134	7.4203	2.5313	1.5002
212	BW	H	91.8683	91.0706	90.8132	89.881	89.9967	89.8093	86.8961	84.1599	71.8867	70.0765	61.2785	21.5874	11.1648	3.8194	2.2698
212	BE	H	92.1896	88.7109	88.3765	88.2571	88.3494	88.137	84.0835	79.7013	62.6998	60.0492	49.8208	14.572	7.3818	2.4961	1.4733
212	WE	H	88.9575	89.1896	88.412	88.5307	88.2705	88.1593	83.3541	78.494	60.634	57.9904	47.5722	13.5756	6.8633	2.3187	1.3484
213	BW	H	88.0034	89.944	89.7869	89.8108	89.5216	89.2713	86.9094	84.4788	72.8693	70.7931	62.6996	22.8047	11.8413	4.0192	2.3767
213	BE	H	91.8573	87.533	88.5049	88.8079	88.4083	88.2641	84.422	80.3089	64.0534	61.7582	51.4388	15.3974	7.8542	2.6255	1.532
214	BW	H	95.3685	90.3906	90.0944	89.9532	89.6956	89.695	86.9058	84.0754	71.4602	69.5869	60.6607	21.1305	10.8811	3.7177	2.1962
214	BE	H	87.4524	88.5172	88.2896	88.4202	88.1103	88.0989	83.709	79.0127	61.3719	58.8668	48.4369	13.9573	7.0475	2.3785	1.3919
214	WE	H	85.9293	89.1928	88.7224	89.0185	88.4727	88.4293	83.6304	78.678	60.4842	57.7827	47.3214	13.4311	6.8001	2.294	1.3468
215	BW	H	92.6772	90.5417	90.1715	90.3135	89.7424	89.4416	87.5478	85.0479	74.3464	72.0477	64.6432	24.7675	12.9583	4.3967	2.58
215	BE	H	91.3012	88.5592	88.5516	88.2583	88.1689	87.9676	84.5942	80.8621	65.6922	63.152	53.4094	16.6384	8.4784	2.8427	1.6319
216	BW	H	90.1703	89.0534	89.2385	88.8657	88.8059	88.7356	86.6743	84.283	73.0421	71.0345	63.1971	23.5069	12.204	4.1326	2.3953
216	BE	H	81.4596	85.229	85.4527	85.9801	86.0285	85.9089	82.7702	78.7187	62.7388	60.1305	50.2927	15.136	7.7182	2.5535	1.4523
216	WE	H	86.3247	89.1784	89.4221	88.9667	88.6928	88.4014	84.6162	80.3636	63.831	61.3053	51.0964	15.2873	7.8044	2.6566	1.5746

Table G.3 AC impedance measurements for specimens in test sequence 3
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
301	BW	A	83.485	88.3415	88.698	88.9954	89.1773	89.5595	89.1353	88.2062	83.347	86.4848	76.943	42.3737	24.5108	8.8034	5.2835
302	BW	A	95.0444	90.9194	90.9674	90.9744	90.2208	90.8763	89.8069	88.3893	82.8729	76.8253	76.3482	41.0211	23.3397	8.5116	5.2064
302	BR	A	86.8654	90.8011	90.1649	90.3582	90.5133	90.1801	89.7209	88.1683	81.364	85.2105	76.3844	40.1793	22.89	8.2565	5.0338
302	WR	A	91.8381	90.9168	90.5274	90.6575	90.7268	90.7979	88.7606	88.4012	81.8892	82.0703	76.6953	41.0084	23.5182	8.5556	5.2362
302	BE	A	89.8421	89.5743	89.875	89.8286	88.8475	89.0123	87.5085	86.0633	77.648	75.2259	68.6026	28.4941	15.4054	5.3666	3.3024
302	WE	A	93.3875	89.7892	89.9129	89.8794	89.4891	89.6013	88.3725	87.0768	79.8919	78.4512	72.9963	34.669	19.0046	6.7116	4.0756
302	RE	A	88.7304	88.8658	89.505	89.5568	89.3056	89.2127	88.1461	86.7649	78.9063	77.8415	71.6172	32.5434	17.6331	6.1897	3.763
303	BW	A	94.5706	90.9568	91.2109	91.3201	91.2579	90.4019	90.0218	88.4811	82.7107	81.2574	76.4036	41.2191	23.6285	8.5186	5.221
303	BR	A	87.506	91.0719	90.8769	90.6474	90.9604	91.0942	88.871	88.2489	81.3199	82.6646	76.1774	40.2324	22.9348	8.2908	5.0259
303	WR	A	95.1582	91.1153	91.1246	90.8261	90.4581	90.5838	89.1632	88.4927	81.6722	79.3433	76.4044	41.207	23.7161	8.5828	5.2792
303	BE	A	93.3599	89.7164	89.451	89.2313	89.9319	90.0438	87.7129	85.9671	77.594	73.4743	68.5933	28.7143	15.1753	5.3386	3.3202
303	WE	A	92.6109	89.6766	89.5055	89.3338	89.5936	89.6105	88.4471	87.1209	79.9582	78.638	73.1071	34.8135	19.1002	6.7406	4.0949
303	RE	A	93.4722	89.7701	90.0582	89.3414	89.6521	89.5205	88.252	86.8276	79.0139	77.7338	71.6788	32.6017	17.6669	6.2029	3.7635
304	BW	A	92.5413	91.0566	90.8062	90.586	90.9527	91.1179	88.8973	88.4304	82.2895	79.3737	76.4081	40.9743	23.4338	8.457	5.1614
304	BR	A	94.1914	90.8994	90.5563	90.4595	90.4707	91.0109	89.8154	88.2551	81.5987	83.798	76.2491	40.1744	22.8324	8.2456	5.0136
304	WR	A	93.1477	91.5499	90.8327	90.8226	91.544	91.0902	89.9994	88.7248	82.2175	78.347	76.2999	41.3821	23.5359	8.5383	5.2634
304	BE	A	87.4972	89.375	89.8962	89.9296	89.8672	90.0635	87.2248	85.9845	76.8729	73.3334	68.664	28.2779	15.3165	5.2564	3.2457
304	WE	A	92.5885	89.6993	90.1372	89.968	89.5902	89.5865	88.4521	87.1224	79.8721	78.6886	73.0595	34.7305	19.0454	6.7214	4.073
304	RE	A	86.9086	89.6234	89.2524	89.5851	89.6121	89.5451	88.2328	86.7624	78.9404	77.9231	71.6241	32.5361	17.6211	6.1847	3.7476
305	BW	A	89.7005	91.5784	91.7137	91.397	91.2101	91.6599	89.6593	88.4551	82.8657	76.9047	76.4714	41.1051	23.5763	8.5044	5.2021
305	BR	A	94.5223	91.6311	91.9351	91.3903	91.1854	90.9509	88.8236	88.3741	82.5457	80.4664	76.266	40.2913	22.8955	8.2777	5.0438
305	WR	A	86.7931	90.5332	91.4544	91.2535	91.1627	91.5116	89.6865	88.4896	81.2369	77.026	76.4418	40.7882	23.3606	8.463	5.1871
305	BE	A	89.2067	89.6102	89.5477	89.419	89.7377	89.3579	87.1171	86.0478	77.6276	75.8437	68.5339	28.5138	15.3566	5.3567	3.2812
305	WE	A	86.7743	89.6304	89.8639	89.9179	90.2547	89.5503	87.2836	86.3436	77.6935	69.5519	70.7545	31.0927	16.7359	6.0268	3.6738
305	RE	A	86.2263	89.6372	89.9247	89.7362	90.0434	89.5004	87.5628	86.0901	78.4915	76.2343	68.7567	29.3531	15.7449	5.594	3.4144
306	BW	A	92.301	90.3303	90.1115	90.535	90.3014	92.39	89.4013	88.4534	82.9805	80.7462	76.2319	41.1697	23.4949	8.5042	5.1878
306	BR	A	93.5211	91.3449	90.5699	90.6246	90.7504	90.3962	89.5093	88.3618	83.1503	80.9473	76.0545	40.1794	22.8598	8.2325	4.9958
306	WR	A	96.6194	91.1867	91.0357	90.647	90.4051	91.5307	89.4385	88.5149	83.307	79.4144	76.4931	40.979	23.7843	8.4675	5.1415
306	BE	A	86.0587	89.5575	89.5393	89.7229	89.8511	88.9227	86.9735	85.8775	76.0287	73.314	68.3268	28.7711	15.2647	5.3901	3.3235
306	WE	A	90.6483	89.7891	89.6963	89.2842	89.2924	89.6146	86.9399	86.6077	77.0896	70.395	70.7008	31.101	16.8015	5.9753	3.6906
306	RE	A	86.3872	89.699	89.1171	89.1001	89.6896	89.0968	87.823	86.1268	78.1547	74.3401	69.3952	29.446	15.5852	5.6121	3.3741
307	BW	A	92.2925	90.7603	90.9814	90.8881	90.3393	90.5884	90.0301	88.439	82.5556	82.9553	76.5607	41.2482	23.55	8.5422	5.2057
307	BR	A	90.6879	90.7856	91.0758	90.7961	90.6457	90.6744	88.7994	88.3858	81.8566	79.4941	76.5802	40.4367	23.1487	8.3347	5.0959
307	WR	A	85.567	89.7457	89.8442	89.6681	89.7097	89.5709	88.2614	86.515	78.4684	76.2628	70.5244	30.9917	16.6172	5.8091	3.5114
307	BE	A	88.2293	89.76	89.9619	89.7464	89.6277	89.5181	88.3625	86.083	76.8402	76.149	69.0468	28.9335	15.5683	5.4789	3.3654
307	WE	A	87.2309	89.778	89.3277	89.1728	89.6776	89.5245	87.9649	86.6235	78.4345	76.7324	70.8669	31.0431	16.8097	6.0156	3.7467
307	RE	A	98.1539	89.7094	89.8984	89.9795	88.9124	88.7064	87.3725	86.2899	78.4769	74.7827	69.2728	29.7449	15.8728	5.6597	3.453

Table G.3 AC impedance measurements for specimens in test sequence 3
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
308	BW	A	93.5265	90.7521	90.2585	90.2832	90.569	90.6212	89.888	88.52	82.8127	81.4506	76.5665	41.3742	23.6854	8.5554	5.2461
308	BR	A	86.8404	90.3857	90.0207	90.2263	90.3492	90.3449	89.3055	88.2507	82.8969	81.1707	76.0156	40.4649	22.9287	8.31	5.0956
308	WR	A	93.1535	90.647	91.0108	90.678	90.6208	89.972	89.4046	88.5275	83.2209	79.4352	76.4638	41.265	23.7098	8.5978	5.2391
308	BE	A	86.7565	89.6	89.0356	89.4218	89.7165	89.2654	88.1244	86.1525	78.0772	74.5986	69.0374	29.1278	15.4221	5.5335	3.3834
308	WE	A	87.2883	90.0278	90.1566	89.8671	89.5357	89.6951	88.4199	87.1411	79.9847	78.833	73.2295	35.0232	19.248	6.8023	4.128
308	RE	A	92.103	89.8754	89.7963	89.4576	89.5234	89.5433	88.27	86.7916	79.0114	77.8523	71.726	32.6568	17.7187	6.2294	3.7705
309	BW	A	89.4826	90.6701	88.3721	90.7039	90.484	90.4959	90.1466	88.3604	83.0888	79.2788	76.4609	41.1834	23.4935	8.5383	5.1913
309	BR	A	91.1417	90.5853	90.1329	90.1156	90.2724	90.4675	89.3479	88.2953	82.1865	77.3583	76.2654	40.2151	22.874	8.2537	5.0126
309	WR	A	86.5683	89.7972	89.936	89.8266	89.6713	89.5207	88.3712	87.0937	79.8564	78.8132	73.0609	34.7171	19.0457	6.7238	4.0734
309	BE	A	86.472	89.7063	89.0039	89.2252	89.2676	89.3115	87.7483	86.16	76.4746	76.7023	68.8999	29.0009	15.6535	5.4959	3.3668
309	WE	A	88.0318	89.6357	89.6957	89.5819	89.6429	89.5195	88.4073	87.1478	80.0009	78.8291	73.1861	34.9619	19.2121	6.7851	4.12
309	RE	A	91.7639	89.7527	89.4654	90.0039	89.6023	89.5158	88.3159	86.8759	79.1033	77.9887	71.8393	32.8032	17.8049	6.2581	3.7866
310	BW	A	93.5251	90.8719	91.3999	91.0279	90.9649	90.4537	89.0569	88.3968	81.5735	82.2578	76.8536	41.1166	23.5361	8.5242	5.1846
310	BR	A	86.6826	92.1612	90.3782	90.5257	91.0046	90.602	89.7738	88.1263	82.5481	82.5892	76.1223	40.332	23.0084	8.3034	5.0903
310	WR	A	87.9224	89.1984	90.51	90.4981	90.9995	90.5672	89.6	88.445	82.5785	80.4496	76.8725	41.2252	23.7327	8.5605	5.2591
310	BE	A	93.1986	89.0124	90.0667	89.7554	90.1535	90.2434	87.9445	86.0389	76.4787	80.094	68.4042	28.6513	15.4535	5.422	3.3357
310	WE	A	86.1621	89.8828	89.7733	89.4833	89.6626	89.6565	88.4817	87.1636	80.078	78.6621	73.2347	34.9963	19.2139	6.7842	4.1086
310	RE	A	93.3457	89.7021	89.1339	89.6497	89.5761	89.5518	88.3229	86.859	79.1509	77.9136	71.8469	32.8752	17.8352	6.2657	3.7957
311	BW	A	89.8248	90.8995	90.3901	90.5107	90.503	90.8851	88.8345	88.4124	81.7634	86.3668	76.3358	41.0472	23.5147	8.5079	5.2012
311	BR	A	88.5674	90.9253	90.6589	90.3945	90.1509	91.1396	88.9899	88.3518	81.8328	80.8213	76.1835	40.314	22.8958	8.3079	5.0952
311	WR	A	88.7922	91.0029	90.4388	90.5701	90.5621	90.7683	89.568	88.4891	83.1346	79.1307	76.4441	41.3646	23.6364	8.6105	5.2573
311	BE	A	92.9023	89.706	89.8178	89.789	88.5277	88.788	86.2007	86.2619	76.9036	76.9282	69.162	28.8956	15.4199	5.4421	3.3671
311	WE	A	90.0084	89.7823	90.0692	89.9927	89.6098	89.6999	88.4446	87.1639	79.9621	78.8912	73.164	34.9221	19.1723	6.7709	4.11
311	RE	A	86.3872	89.7182	89.4936	89.4053	89.5554	89.6349	88.2916	86.8366	79.0185	77.8701	71.7266	32.6658	17.7123	6.221	3.7741
312	BW	A	88.5316	87.9988	88.4684	88.8696	89.4849	89.1103	88.9609	88.1259	82.0186	79.3188	76.8618	42.5508	24.509	8.8322	5.2862
313	BW	A	80.0653	94.4142	87.8074	88.8754	89.4017	88.3182	89.8641	88.3954	82.7905	84.8717	76.7979	42.2295	24.2997	8.7657	5.2658
314	BW	A	88.205	88.4014	88.9895	89.2903	89.9115	89.1058	89.7296	88.1375	81.8528	76.5447	76.7689	42.351	24.4055	8.7628	5.2817
315	BW	A	84.1111	88.4072	88.6295	88.9952	89.4742	89.4482	89.1759	88.3029	83.2816	85.014	77.0059	42.3575	24.4957	8.7691	5.2611
316	BW	A	86.101	88.0371	88.6261	88.6291	89.0324	88.9499	88.9975	87.7954	82.641	80.1849	76.2213	40.8579	23.4849	8.3683	5.0018
317	BW	A	86.4053	88.654	88.6639	89.1474	89.3634	89.5762	89.7578	88.2171	82.4569	78.6593	76.6805	42.5487	24.6179	8.8333	5.3093
303	BW	B	91.7045	95.8164	95.3119	94.8362	94.5785	94.0272	91.0092	89.0445	82.5922	83.118	76.333	40.4291	23.1042	8.3804	5.1216
303	BR	B	98.2933	93.0063	91.5635	91.4503	90.7859	90.7819	89.4423	87.8727	81.687	81.6339	75.6843	39.6616	22.4424	8.1307	4.9414
303	WR	B	95.297	90.7203	89.6799	90.376	90.5613	89.9907	86.8193	88.7572	84.2078	110.723	78.0434	41.4015	24.0535	9.2956	6.0719
303	BE	B	89.8005	89.4267	90.7476	89.4112	88.7037	88.5494	87.6318	85.8058	75.8419	52.5158	67.7018	28.6207	16.6074	6.2349	4.306
303	WE	B	92.2397	89.8852	89.9814	88.7881	91.576	87.4471	87.5523	86.4137	79.4107	77.5223	70.686	32.1427	17.6632	7.3081	4.5155
303	RE	B	95.2655	89.5754	89.2297	89.4849	88.1761	87.633	89.0567	85.5377	77.2406	77.5141	66.9349	30.1625	16.5716	6.58956	4.1247
304	BW	B	93.152	91.7893	91.3031	90.7196	88.9775	90.3869	89.1576	88.5889	82.3851	79.9303	76.7275	41.5106	24.5192	9.1143	5.756

Table G.3 AC impedance measurements for specimens in test sequence 3
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
304	BR	B	87.5961	91.0938	91.3252	91.1199	91.0687	90.8347	90.0324	88.2971	83.9586	72.6136	76.3257	40.949	24.143	9.0449	5.7191
304	WR	B	96.1538	91.0776	91.1324	90.1517	89.9808	90.3004	89.548	88.3448	81.1746	56.3449	77.2701	41.6	24.3031	9.4179	5.9184
304	BE	B	91.0682	88.2585	89.4726	90.4963	88.0165	89.3269	89.9927	85.7544	76.1531	52.6301	68.131	29.1344	16.6103	6.3337	4.0443
304	WE	B	87.9686	89.5898	88.4146	88.1353	86.8954	91.368	88.014	85.6495	78.1365	59.554	69.3321	31.5831	18.6302	7.0783	4.4538
304	RE	B	90.3816	89.6705	89.3523	90.1438	90.2656	89.9007	88.1694	85.8389	75.1988	57.9278	68.1668	29.8447	17.0444	6.3371	4.1562
305	BW	B	92.0256	90.6516	90.8786	90.1794	90.8038	91.3165	88.8009	88.3808	80.5115	78.3277	77.7881	42.1216	24.3042	9.2705	5.7643
305	BR	B	88.7172	90.8906	89.1117	90.1187	89.6829	90.7692	89.3815	88.4104	80.5387	89.4867	75.8313	41.1495	23.7612	9.0303	5.7023
305	WR	B	87.6105	90.5048	93.5352	91.4298	88.5207	90.2769	88.1062	89.0312	85.4594	73.151	77.5532	41.5357	24.902	9.322	5.8851
305	BE	B	92.9178	89.9171	89.2879	89.5006	89.2964	90.3088	88.9109	85.4467	74.4893	97.0475	66.1703	28.5376	16.4359	6.4069	4.0057
305	WE	B	91.637	89.5824	89.6351	90.0102	91.0316	91.8207	85.8711	86.2696	80.8681	68.5996	69.5644	31.5131	18.5637	7.055	4.4437
305	RE	B	93.299	89.6262	89.7785	89.3965	90.5605	88.6793	86.9932	85.9502	78.0885	68.8237	68.4972	29.7472	16.8976	6.2534	4.1178
306	BW	B	94.5699	91.3031	90.4963	91.0138	90.7836	93.8254	89.0736	88.7688	83.0387	80.8508	77.8578	42.0898	24.3969	9.33408	5.8132
306	BR	B	92.6158	90.617	91.4166	91.0988	92.2064	90.2626	91.4437	88.1821	80.7547	86.9731	77.0001	40.5008	23.4607	8.97814	5.6558
306	WR	B	88.9913	90.0121	89.5343	90.5393	90.8496	89.8504	89.0949	89.4999	82.807	81.0313	77.8163	40.98	23.8514	8.7021	5.3487
306	BE	B	91.5378	89.4916	89.8199	89.9496	91.1107	88.4602	86.0451	85.6198	78.4608	73.1732	68.079	29.5605	16.2971	6.0673	3.8741
306	WE	B	89.1993	89.3365	89.38	89.6877	89.6009	89.0823	88.1599	86.5194	77.4438	46.1495	69.7385	31.3903	17.8328	7.1055	4.4118
306	RE	B	89.6572	89.7786	88.6194	89.7175	87.8773	91.1272	87.9598	85.5637	76.0579	84.2543	67.8754	29.6212	17.1616	6.386	4.229
312	BW	C	87.3469	90.6132	90.9093	90.7064	91.0474	90.4746	90.345	87.8337	79.2157	68.6232	72.758	33.7405	18.8454	6.9505	4.212
313	BW	C	84.4308	90.8705	90.4992	91.1634	90.0006	89.0865	90.3845	88.2456	80.7982	93.5142	73.4145	34.8262	19.3177	7.0554	4.3125
314	BW	C	94.4355	90.9774	90.4578	89.9381	90.424	90.0485	88.5349	87.566	78.9085	92.8201	73.2001	34.911	19.511	7.3122	4.6011
315	BW	C	96.3299	93.5606	91.8141	91.3593	91.163	90.7204	88.371	86.942	78.9828	79.9805	72.183	33.6944	18.4532	6.4718	3.8515
316	BW	C	98.8572	97.1788	95.5598	94.4706	93.8597	92.865	88.7579	87.2232	79.267	79.3133	71.3429	32.4221	17.6488	6.1992	3.7801
317	BW	C	87.3612	90.7948	90.1666	90.1589	91.2708	89.9343	89.2014	86.7252	81.7678	75.9587	72.0972	34.6213	19.3355	7.2387	4.4597
303	BW	D	94.2296	90.6723	90.4563	90.5118	90.4239	90.3515	89.244	88.1154	82.0011	80.9579	75.7845	39.7895	22.8252	8.74002	5.68515
303	BR	D	86.6784	90.6993	90.8322	90.8252	90.4329	90.8136	89.1192	88.018	81.6244	80.4194	75.166	38.643	22.0572	8.5022	5.58617
303	WR	D	90.1636	91.6479	90.4633	90.281	90.5897	90.3925	89.1734	87.9887	81.6393	80.5024	75.2611	38.8739	22.2499	8.62865	5.69584
303	BE	D	88.2511	90.2432	89.4609	89.6334	89.3859	89.2507	87.1367	84.7636	73.7027	72.148	64.1419	24.5942	13.3661	5.35322	3.72576
303	WE	D	93.1889	90.0477	89.2069	89.455	89.3394	89.3408	87.4538	85.3856	75.1905	73.3597	66.1622	26.631	14.6084	5.89038	4.10133
303	RE	D	86.8697	89.6669	89.9553	89.4923	89.335	89.3817	87.2193	84.9298	74.0825	72.3829	64.6068	25.0544	13.6422	5.46919	3.79923
304	BW	D	90.5002	90.7635	90.9098	90.7498	90.3013	90.3392	89.0989	88.0474	81.8847	80.8785	75.6699	39.6203	22.7471	8.79115	5.77648
304	BR	D	91.6425	90.7367	90.7318	90.3351	90.3521	90.2929	89.0515	87.8945	81.4802	80.2964	75.0452	38.4931	21.9776	8.51804	5.63409
304	WR	D	86.9019	89.9639	90.4477	90.0897	89.9764	90.062	88.9156	87.7444	81.4631	80.2134	75.1106	38.7687	22.0167	8.32071	5.41733
304	BE	D	86.5167	89.6947	89.5697	89.6836	89.2288	89.2299	87.1644	84.794	73.6059	71.9272	63.964	24.4351	13.316	5.38952	3.77703
304	WE	D	90.0234	89.5998	89.3584	89.748	89.3253	89.3549	87.4039	85.3257	75.0087	73.0543	65.8966	26.3999	14.5112	5.92985	4.17071
304	RE	D	86.1345	89.6088	89.3388	89.6779	89.2977	89.4049	87.4155	85.2716	74.7907	73.355	65.6137	25.5941	13.7291	5.27165	3.58556
305	BW	D	93.5143	89.9483	90.4475	90.322	90.0507	90.1935	88.9909	87.8898	81.8781	80.6309	75.6639	39.6879	22.6737	8.55356	5.50891
305	BR	D	89.94	91.05	90.1587	90.3258	90.0102	90.0314	88.9275	87.8083	81.4698	80.2634	75.001	38.4814	21.8468	8.2687	5.35403

Table G.3 AC impedance measurements for specimens in test sequence 3
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
305	WR	D	91.6961	90.222	90.0941	89.9868	90.1706	90.0822	88.9644	87.8095	81.5735	80.1801	75.169	38.7869	22.0847	8.39772	5.46297
305	BE	D	87.1735	89.5189	89.2725	89.6354	89.3765	89.1962	87.2675	84.9734	74.1229	72.307	64.6012	24.7607	13.3019	5.15002	3.49273
305	WE	D	86.1219	89.7083	89.3048	89.2386	89.5157	89.3206	87.5696	85.5551	75.5451	74.3238	66.6924	26.8999	14.6049	5.70271	3.88601
305	RE	D	87.2603	89.5318	89.3939	89.6251	89.3538	89.2729	87.3769	85.1074	74.4787	72.7579	65.0692	25.2487	13.5977	5.27806	3.58914
306	BW	D	93.0764	90.1714	89.8797	90.4395	89.8551	90.0945	88.9492	87.8747	81.8406	80.766	75.6593	38.9788	22.6629	8.49714	5.4465
306	BR	D	86.6546	90.1972	90.2334	89.7622	90.0749	89.9614	88.8265	87.7334	81.3367	79.8988	74.938	38.4241	21.7534	8.16753	5.26735
306	WR	D	93.0421	90.1937	90.1363	89.8495	90.0678	90.0759	88.9092	87.7551	81.4344	80.4116	75.1428	38.8132	22.0519	8.31341	5.37796
306	BE	D	93.3335	89.5601	89.8144	89.7085	89.25	89.2917	87.3467	85.136	74.5359	72.5967	65.013	24.9873	13.3723	5.10576	3.4388
306	WE	D	92.2072	89.5744	89.7677	89.3496	89.3259	89.4842	87.6404	85.7169	75.9719	74.2343	67.1558	27.2735	14.7308	5.66115	3.81495
306	RE	D	92.6659	89.6409	89.9634	89.1592	89.4497	89.2432	87.4073	85.2548	74.7135	73.2237	65.4449	25.4883	13.6525	5.21576	3.50618
312	BW	E	90.0651	89.4406	89.1212	89.3648	89.7592	89.7959	88.7605	86.7367	77.8877	76.207	70.0874	31.2878	17.2558	6.67078	4.50246
313	BW	E	93.6744	89.9976	89.3735	89.6425	89.2143	89.1947	87.7558	86.2568	78.0658	76.6756	70.5392	32.9949	20.0942	10.4662	8.40854
314	BW	E	89.9792	88.1939	87.9355	88.5193	88.3919	88.2418	89.5757	85.966	77.8986	76.3256	70.353	32.5327	19.2623	9.14616	6.75607
315	BW	E	98.8342	99.74	99.6139	99.4887	98.6261	98.2391	92.7275	89.8043	80.013	78.5382	72.3354	33.4406	18.4448	6.71698	4.18434
316	BW	E	94.0304	103.844	101.528	99.4605	98.1249	97.4404	90.7688	87.9263	78.5128	77.197	70.7098	31.629	17.2442	6.2007	3.8487
301	BW	F	85.4807	89.2989	88.9756	88.2396	88.0949	87.8063	85.071	84.071	79.8963	78.9351	74.4573	40.127	23.1159	8.64674	5.51944
302	BW	F	94.0571	91.0766	90.7921	90.4343	90.2306	90.0139	88.9704	87.8963	81.766	80.6373	75.6431	39.8341	22.7595	8.58339	5.55212
302	BR	F	94.1372	91.0791	91.0378	90.9176	90.8337	90.7104	89.5651	88.3082	81.6351	80.54	75.2328	38.9128	22.2735	8.71181	5.86988
302	BE	F	87.2698	89.515	89.6635	89.0348	89.1948	89.2018	87.2425	85.1601	74.8127	73.3357	65.6971	25.7571	13.7877	5.23787	3.52312
302	WE	F	87.5734	90.2069	90.132	89.8677	89.4981	89.5518	87.5901	85.6639	76.0149	74.4384	67.4316	27.607	14.9161	5.71347	3.86082
303	BW	F	88.7737	90.4667	90.6546	90.995	90.4115	90.1443	89.3628	88.2565	81.8493	80.722	75.5539	39.4685	23.272	9.03068	6.11316
303	BR	F	100.252	93.0577	92.2645	91.7661	91.6415	91.3941	89.7463	88.3504	81.6044	80.3686	75.0889	38.5229	22.0317	8.64365	5.81484
303	BE	F	78.1031	86.9929	88.09	88.4511	88.2405	88.2958	86.748	84.4257	73.2689	71.6571	63.631	24.4457	13.4652	5.69958	4.15328
303	WE	F	82.7391	89.5246	89.5047	89.32	89.1171	89.1924	87.1829	84.9923	74.5963	72.6343	65.5113	26.2355	14.5716	6.23218	4.57797
304	BW	F	88.6954	89.8932	89.9422	90.0389	90.2685	90.2347	89.3458	88.1654	81.7824	80.5883	75.4441	39.5	22.8097	8.99799	6.02994
304	BR	F	92.8131	90.4849	90.7245	90.2423	90.4539	90.5814	89.4294	88.178	81.4596	80.385	74.9673	38.4243	22.0118	8.70794	5.89401
304	BE	F	92.6268	89.3326	89.7079	89.378	89.2125	89.0244	86.8987	84.5076	73.3385	71.7019	63.7505	24.6777	13.642	5.74288	4.14423
304	WE	F	85.834	89.4647	89.5111	89.1275	89.2926	89.1484	87.179	85.0625	74.7766	73.2236	65.7859	26.7498	14.913	6.30061	4.54812
305	BW	F	85.5956	89.7649	89.7883	90.1285	89.975	89.8367	89.0202	87.9202	81.6912	80.5597	75.4375	39.5332	22.6325	8.6175	5.6173
305	BR	F	95.4776	93.1625	91.6579	91.4641	91.1808	91.0781	89.4274	88.1852	81.3951	80.1797	74.9265	38.3653	21.7965	8.29275	5.42183
305	BE	F	88.1608	89.2957	88.8084	88.9985	89.1625	89.0976	87.1509	84.9899	74.3076	72.6753	64.9569	25.1805	13.5533	5.26015	3.60597
305	WE	F	91.3329	88.9727	89.1173	88.8608	89.1041	89.0087	87.4486	85.4422	75.7364	74.2914	67.0491	27.4296	14.9076	5.81542	3.99346
306	BW	F	93.3779	89.9623	90.1512	89.9691	89.9255	90.023	89.2876	88.1784	81.8601	80.8272	75.6131	39.583	22.5989	8.53552	5.5199
306	BR	F	94.3788	90.3933	89.9581	89.8229	90.0622	89.9392	88.9732	87.8285	81.2605	80.1169	74.8028	38.2837	21.7448	8.3156	5.4799
306	BE	F	92.7706	89.525	89.6879	89.5647	89.2389	89.128	87.1579	84.9372	74.4928	72.9931	65.0282	25.2425	13.5661	5.25283	3.59752
306	WE	F	92.8866	89.5608	89.5246	89.6841	89.2285	89.1282	87.4577	85.5216	75.8439	74.0281	67.2033	27.5511	14.9764	5.83882	4.00648
307	BW	F	88.502	87.7487	88.4667	89.1845	89.2593	89.4755	89.3956	88.721	82.9884	81.6952	76.2416	39.6127	22.6024	8.55711	5.55736

Table G.3 AC impedance measurements for specimens in test sequence 3 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
307	BR	F	91.7833	89.5864	89.9515	90.1667	89.8102	89.9393	89.1568	88.0401	81.744	80.4785	75.4519	39.4423	22.668	8.8396	5.88546
307	BE	F	91.6661	89.0794	88.7552	88.6982	88.9671	88.886	87.1561	85.1888	75.0596	73.5603	66.0564	26.3006	14.201	5.49425	3.73599
307	WE	F	87.4032	88.5764	88.4636	88.9134	88.6997	88.7877	87.3626	85.584	76.3124	74.4201	67.8317	28.2114	15.3499	5.93515	4.03546
308	BW	F	88.4438	90.8537	90.9669	90.5832	90.4716	90.5571	89.3887	88.2534	82.1413	80.9693	76.0454	40.4723	23.4546	9.21271	6.12692
308	BE	F	87.9194	89.5443	89.116	89.1639	89.3013	89.1061	87.2324	85.1043	74.7151	73.1481	65.607	26.2651	14.4754	5.91679	4.15301
308	WE	F	86.0338	89.3491	89.4268	89.6059	89.1662	89.2162	87.4847	85.5708	75.9601	74.2152	67.4088	28.2345	15.6809	6.43456	4.52308
309	BW	F	89.5676	91.3604	91.0366	90.805	90.6868	90.7616	89.8624	89.0829	83.0793	81.8431	76.3222	39.6049	22.7751	8.9417	5.97797
309	BE	F	91.7253	89.5039	89.0631	89.2821	89.1047	89.1366	87.0811	84.8391	74.1462	72.6011	64.8458	25.4753	14.0188	5.82132	4.16072
309	WE	F	92.8187	89.3507	89.516	89.0453	89.1548	89.0117	87.2869	85.3353	75.4186	73.5522	66.6239	27.416	15.1924	6.29874	4.49645
310	BW	F	92.3311	91.1612	90.91	90.8794	91.1562	91.1431	90.1051	88.8792	82.4043	81.3309	76.151	40.3137	23.4141	9.42769	6.4402
310	BE	F	86.0944	89.3734	88.8612	88.9037	89.038	89.1374	86.8362	84.4769	73.2672	71.721	63.7174	24.7641	13.8213	6.05396	4.49463
310	WE	F	88.5909	89.3892	89.2649	89.5033	89.0915	88.9808	87.0484	84.8522	74.3872	72.7295	65.2714	26.349	14.8236	6.53153	4.87331
311	BW	F	92.2226	90.8894	90.867	90.6027	90.6737	90.5055	89.4785	88.3231	82.1174	80.9698	75.984	40.28	23.2276	9.02858	5.97838
311	BE	F	91.2166	89.3691	89.0564	89.4376	89.1197	89.0033	87.1715	85.0605	74.5279	72.9364	65.3063	25.8202	14.1411	5.73407	4.03607
311	WE	F	86.1211	89.4104	89.1863	89.1695	89.2626	89.1369	87.4496	85.467	75.6289	73.791	66.8771	27.5124	15.1901	6.19262	4.36975
312	BW	F	81.3089	83.9861	84.9506	85.3959	86.1552	86.2953	87.0585	85.756	78.0587	76.7293	70.8111	33.0149	19.2042	8.81222	6.6633
313	BW	F	84.7797	88.0274	87.7156	88.1073	88.0595	88.1476	86.9163	85.4678	77.3508	76.1539	69.7417	32.1576	19.3889	10.1362	8.0566
314	BW	F	72.773	81.9597	84.9212	86.0076	86.703	87.0349	88.5517	87.1702	78.6548	77.051	71.0393	33.0348	19.4461	9.03208	6.81815
315	BW	F	87.7516	90.0208	90.0164	89.7959	89.8667	89.7314	86.808	84.9553	77.0619	75.7954	69.8266	31.7679	17.2391	5.9832	3.58849
316	BW	F	41.2995	90.7033	89.1464	88.7264	88.477	88.1507	85.5648	83.7073	75.6989	74.4197	68.0295	29.8376	16.1155	5.69323	3.51841
301	BW	G	86.9431	87.7339	87.762	87.0174	86.8627	86.8587	84.9724	84.1399	79.6168	78.6993	74.0191	39.6177	22.773	8.55381	5.46953
302	BW	G	94.0571	91.0766	90.7921	90.4343	90.2306	90.0139	88.9704	87.8963	81.766	80.6373	75.6431	39.8341	22.7595	8.58339	5.55212
302	BE	G	79.9415	87.5809	87.4073	87.863	88.2025	88.2558	86.8903	84.7994	74.3932	72.8861	65.1769	25.4325	13.6601	5.29501	3.61396
302	WE	G	85.6414	89.3215	89.0338	89.2488	89.1161	88.9863	87.3648	85.4569	75.652	74.1698	66.9639	27.3558	14.8278	5.777	3.94872
303	BW	G	100.649	94.4151	93.1728	92.7756	91.9609	91.6727	89.4312	88.096	81.7004	80.4964	75.4553	39.3774	22.4346	8.49176	5.49525
303	BE	G	87.3544	89.2925	89.2874	88.9586	89.078	88.8275	86.9043	84.7446	74.1966	72.5804	64.6645	25.0081	13.4414	5.24079	3.59123
303	WE	G	90.4788	88.8287	89.2093	89.23	88.9632	88.7813	87.2009	85.2842	75.4731	73.8211	66.7104	27.1662	14.7499	5.79282	3.9765
304	BW	G	91.1997	90.7357	90.3431	90.0492	90.323	90.3665	89.1499	87.9646	81.611	80.4303	75.3599	39.3127	22.4592	8.60397	5.62931
304	BE	G	85.636	88.9542	88.7602	88.5535	88.7853	88.778	86.8302	84.5808	73.975	72.3157	64.3655	24.8025	13.3973	5.33485	3.72016
304	WE	G	86.1831	89.0793	89.0062	88.9789	88.9718	88.8315	87.1667	85.1984	75.2192	73.6135	66.429	26.9433	14.7011	5.88587	4.1083
305	BW	G	85.2736	89.5691	89.4679	89.9597	89.6918	89.7098	88.8154	87.6994	81.584	80.4826	75.4309	39.4857	22.4913	8.45566	5.4323
305	BE	G	90.9478	89.1377	88.6708	88.9169	89.0081	88.8714	87.0171	84.8631	74.506	72.9006	65.0926	25.3082	13.5559	5.19417	3.50016
305	WE	G	87.9879	89.0951	88.6109	88.8885	88.9202	88.9778	87.3275	85.4516	75.8356	74.307	67.2316	27.5754	14.9161	5.74152	3.87481
306	BW	G	91.4036	89.3138	89.6852	89.8082	89.7126	89.5992	88.88	87.7516	81.6879	80.444	75.5065	39.5866	22.6408	8.69095	5.70625
306	BE	G	86.4229	90.5178	89.632	89.3612	88.9963	89.0202	86.9699	84.6769	74.0108	72.055	64.3778	24.9017	13.5047	5.45579	3.84909
306	WE	G	92.5612	89.3498	89.4616	88.8836	89.1693	88.9456	87.2504	85.239	75.3208	73.96	66.5452	27.1255	14.8507	6.03245	4.2642
307	BW	G	91.6497	90.1157	90.0488	89.8987	90.2283	90.0454	89.186	88.0153	81.946	80.8653	75.8975	40.441	23.418	9.21037	6.11426

Table G.3 AC impedance measurements for specimens in test sequence 3
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
307	BE	G	87.7789	88.929	88.4567	88.5309	88.8413	88.6026	86.8804	84.7665	74.3913	72.8837	65.288	25.9604	14.2562	5.87119	4.1403
307	WE	G	84.011	88.7487	88.471	88.5618	88.8844	88.8951	87.2548	85.323	75.6414	73.8958	67.0194	27.8292	15.4225	6.38318	4.50895
308	BW	G	96.6918	94.6905	93.204	93.2101	92.714	92.68	89.9563	88.4365	82.1175	81.0228	76.0438	40.4747	23.4087	9.15465	6.04579
308	BE	G	92.1488	89.1241	88.7151	88.9732	88.8506	88.9391	87.0024	84.8627	74.4543	72.8546	65.2895	26.009	14.2722	5.82014	4.06666
308	WE	G	85.1971	88.7364	89.0565	89.0409	88.7817	88.853	87.2547	85.3661	75.7163	74.1386	67.0918	27.9627	15.4849	6.34876	4.44123
309	BW	G	94.0582	92.8466	92.269	91.6897	91.6778	91.3381	89.4776	88.1656	81.9181	80.8502	75.7823	40.1812	23.2421	9.13853	6.0766
309	BE	G	89.8782	89.2639	89.3215	89.4279	88.8871	88.9268	86.9064	84.718	74.1076	72.5718	64.8627	25.4884	13.9622	5.7639	4.09121
309	WE	G	90.5176	89.1366	88.8498	88.7364	88.8931	88.9885	87.2985	85.2131	75.3602	73.7914	66.5822	27.3077	15.0901	6.25976	4.45136
310	BW	G	84.3434	88.4635	89.579	89.7413	89.9311	90.1231	89.4766	88.3422	82.061	80.9613	75.925	40.2765	23.4427	9.50003	6.48758
310	BE	G	90.8126	89.114	89.1805	88.7742	88.8079	88.7145	86.6699	84.3066	73.1063	71.4443	63.4786	24.7479	13.9023	6.2196	4.6516
310	WE	G	82.614	87.919	88.1241	88.7005	88.4725	88.5195	86.8366	84.6787	74.1867	72.4874	65.0436	26.2448	14.8207	6.66458	4.98953
311	BW	G	94.8289	90.6147	90.3591	90.6281	90.4397	90.3641	89.2949	88.1103	81.9964	80.8329	75.8769	40.1797	23.2146	9.12676	6.07368
311	BE	G	89.0058	88.6519	88.6658	88.9268	88.7148	88.7891	86.9132	84.7035	74.1132	72.4995	64.8297	25.5651	14.0519	5.8329	4.15414
311	WE	G	87.9739	88.7351	88.7333	88.9257	88.741	88.7705	87.1412	85.1673	75.2238	73.4487	66.4216	27.2377	15.075	6.29268	4.49018
312	BW	G	79.4922	87.2023	87.2261	87.0148	86.8279	86.8495	85.6101	84.2257	76.5497	75.0876	69.0915	31.3113	17.6198	7.09108	4.83178
313	BW	G	84.6004	82.8603	84.5346	84.7983	84.9463	85.0791	85.0566	83.6966	75.8778	74.3256	68.4183	31.7364	18.9864	9.00243	6.43276
314	BW	G	84.386	85.2516	85.5042	85.9189	86.2252	85.9633	85.3293	84.0589	76.4897	75.0192	68.9519	31.1108	17.7517	7.81389	5.53241
315	BW	G	84.4257	86.3567	86.0972	85.9374	85.5091	85.2797	83.8183	82.41	74.8459	73.6435	67.5776	30.0597	16.1792	5.50604	3.21996
316	BW	G	100.026	92.2585	90.639	90.4711	89.6394	89.3154	85.4426	83.194	74.5806	73.2085	66.807	29.0738	15.6223	5.35545	3.15111
301	BW	H	92.8682	89.2793	89.1058	88.7707	89.0157	88.8141	86.8375	84.694	74.0434	72.2856	64.4745	24.1492	12.8087	4.28019	2.6694
302	BW	H	94.1157	90.5587	90.4715	91.019	90.5961	90.5073	88.5709	86.9446	77.85	75.7899	68.1767	27.988	14.4799	5.43144	3.8163
302	BE	H	92.7275	89.4037	88.9182	89.2173	88.5901	88.6067	84.4382	80.0998	64.9811	62.565	53.0229	15.931	8.71373	3.74194	2.59976
302	WE	H	91.2879	89.2827	89.0798	88.6295	88.7495	88.6545	84.6801	80.4198	64.3073	61.3452	51.5372	14.9689	8.36234	3.48109	2.54802
303	BW	H	95.5498	90.9721	90.8744	90.1429	90.3505	90.2193	88.1261	86.1425	75.8608	74.9459	66.354	26.0838	13.9049	4.83675	3.18124
303	BE	H	85.7323	89.3675	88.8581	89.8508	88.6583	88.6649	84.4877	80.3509	63.5991	61.7466	51.2517	15.6617	8.01083	3.00208	2.04251
303	WE	H	87.0846	89.226	89.052	88.6134	88.8446	88.5712	84.712	80.4246	63.8783	61.7257	51.9059	15.4625	8.09205	3.287	2.26422
304	BW	H	87.9413	90.126	90.3189	90.1533	89.7698	89.7816	87.8759	85.835	75.8974	73.9581	66.5111	26.4385	14.3212	6.19862	4.9316
304	BE	H	90.6926	89.378	89.18	89.2491	88.9065	88.7756	85.0958	80.5742	63.4191	61.5734	52.0259	15.5381	9.03754	4.01382	3.70992
304	WE	H	93.1398	89.5096	88.9279	89.1658	88.813	88.7142	85.133	81.1196	65.4937	62.9132	52.8884	15.3066	8.63175	3.35908	2.44336
305	BW	H	95.3244	90.8201	90.5511	90.3955	90.1377	90.2484	87.4736	85.9565	76.3549	75.6162	65.9467	26.0407	13.9956	5.26611	3.50917
305	BE	H	89.4115	90.0886	89.1359	89.0169	88.7207	88.7357	84.5119	80.4533	65.1982	64.5976	51.6672	15.3161	8.30714	3.21115	2.05151
305	WE	H	86.3221	89.3032	89.0572	88.6921	88.8857	88.721	84.8974	80.9321	65.0763	62.6132	52.2827	17.3833	8.14147	2.9683	1.86601
306	BW	H	88.5991	90.8215	91.0282	90.0391	90.3547	90.5634	87.5563	85.6889	74.9014	73.291	65.8505	24.8113	13.7175	4.63878	3.14928
306	BE	H	92.3573	89.5112	89.06	88.9078	88.6703	88.7021	84.8219	80.2684	63.7591	60.1963	51.5745	15.0564	8.31742	3.13243	1.57956
306	WE	H	88.8579	89.3708	89.2649	88.7415	89.3145	88.1902	84.8349	79.8403	63.0119	56.4998	50.6801	15.5899	6.94642	2.90257	1.93142
307	BW	H	93.862	90.5033	90.2726	89.8075	90.0032	89.7994	87.7523	85.4176	74.5647	73.4344	65.0214	25.416	12.9127	4.73131	2.72903
307	BE	H	92.0817	89.3147	88.7764	88.8761	88.7683	88.449	84.3415	79.9338	62.9871	60.407	50.1217	16.2755	7.85655	3.0463	1.91943

Table G.3 AC impedance measurements for specimens in test sequence 3 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
307	WE	H	93.111	89.2894	89.178	89.0875	88.8253	88.5926	84.3681	80.1684	63.3866	61.2718	50.6829	14.3731	7.52969	2.88632	1.89321
308	BW	H	89.4394	91.0832	90.9334	90.7315	89.7621	90.0561	88.272	85.4288	73.9529	79.8801	65.2854	24.4624	13.5094	5.96274	5.06203
308	BE	H	90.9578	89.4012	89.0239	89.1028	88.5683	88.5431	84.4854	79.9173	62.8238	63.8958	49.8869	14.6351	8.00494	3.535	3.23672
308	WE	H	91.9601	89.4238	89.2825	88.9264	89.0235	88.6945	84.5162	80.1681	63.661	60.2219	50.9302	14.9164	8.85071	3.58517	2.81892
309	BW	H	92.2992	90.8123	90.2178	90.5307	90.7978	90.1245	87.6411	85.6594	75.6195	72.745	65.8113	24.4125	13.7424	5.35614	3.93516
309	BE	H	88.4187	89.3019	89.2723	88.9475	88.9706	88.8495	83.8314	80.6325	64.2155	68.6326	51.652	16.6175	8.2137	3.52082	2.68064
309	WE	H	86.173	89.3502	89.3313	88.9376	88.8477	88.7383	84.7283	80.8622	64.7499	69.2362	52.3338	15.7016	8.6163	3.50194	2.29814
310	BW	H	100.511	93.4296	92.1762	91.6836	91.4896	91.1691	88.9359	86.1238	74.5771	83.1905	66.3791	25.5356	13.7104	4.86623	3.20932
310	BE	H	87.6133	89.155	89.0081	89.1878	88.7531	88.3213	83.9988	79.5326	62.9118	60.9259	50.5611	14.8637	7.86593	3.33194	2.16298
310	WE	H	85.6192	89.1367	88.8192	88.7324	88.6381	88.7001	84.6443	79.7409	63.2276	64.7867	50.7836	15.9043	7.56767	2.37804	2.78431
311	BW	H	86.9121	90.0468	89.6244	89.4646	89.7696	89.6447	87.6952	85.5953	75.2866	73.7206	66.1625	26.6203	14.6547	6.76178	5.18708
311	BE	H	93.0581	89.4639	88.9312	89.1109	88.9226	88.8167	84.8938	80.9992	64.7464	62.2321	52.7574	17.0005	8.88492	4.75946	4.24953
311	WE	H	92.8433	89.377	89.4808	88.7375	88.9666	88.6399	85.1382	81.2263	65.4293	63.1282	53.3358	16.6407	8.79114	3.26375	2.3924
312	BW	H	103.663	105.955	103.915	103.054	101.806	99.1734	93.7375	90.3247	75.9987	83.0657	64.1091	27.8491	17.2137	8.22654	6.77693
313	BW	H	3.50173	9.53703	14.0522	18.3785	22.1321	24.3863	67.533	78.1013	74.7332	72.9139	65.6438	27.076	16.0584	8.05623	5.514
314	BW	H	84.9238	91.9476	92.5493	93.0813	93.2343	93.2019	94.1775	93.4066	82.9981	80.8539	73.8027	33.2471	19.9646	10.6621	8.64056
315	BW	H	86.8094	88.7991	88.5232	88.5914	89.1489	88.6764	87.7957	86.4695	78.6467	77.8382	71.4984	32.7859	17.7435	6.11269	3.55376
316	BW	H	86.3218	89.204	88.8662	89.058	88.8731	89.108	87.9079	86.5276	79.207	76.6616	71.7259	33.58	18.1959	6.331	3.74376

Table G.4 AC impedance measurements for specimens in test sequence 4 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
401	BW	A	81.9685	87.4091	88.2027	88.6968	88.8769	88.7243	88.8813	88.2465	81.9969	82.2312	76.3782	41.2215	23.5242	8.26704	4.84173
401	BR	A	85.3727	87.5253	88.5144	88.8758	88.9996	88.6638	88.8371	88.119	82.0619	79.1051	76.0923	40.5115	23.075	8.09144	4.73156
401	WR	A	83.6053	87.6514	88.7596	88.9814	88.6507	88.7365	88.7056	87.8761	82.2051	80.9886	75.9671	40.6366	23.098	8.10568	4.76177
402	RP	A	86.8295	90.0054	89.5759	89.6031	89.9101	89.91	89.12	87.9212	81.534	79.5548	75.1525	38.3211	21.5083	7.59024	4.50338
402	PE	A	89.9355	89.0713	89.3323	89.3451	89.1253	88.9782	87.7007	86.1092	77.6955	76.2127	69.6505	30.0578	16.0726	5.54014	3.26375
402	RE	A	85.8319	88.9486	88.6187	89.2866	88.939	89.0498	87.7143	86.1283	77.8777	76.3905	69.9493	30.4742	16.3283	5.6262	3.30733
403	PE	A	87.313	89.187	89.349	89.3128	89.5076	89.3139	86.6064	87.4969	81.5122	89.1595	77.9899	46.9198	28.1252	10.5322	6.45282
404	PR	A	88.7811	89.8491	90.4801	89.7573	90.0489	90.0513	89.0305	87.9118	81.2812	82.0139	75.109	38.211	21.4075	7.56235	4.4896
404	PE	A	90.3165	88.9395	89.3234	89.0042	89.1366	88.994	87.7009	86.0789	77.6997	76.2311	69.6497	30.0468	16.0678	5.53785	3.26178
404	RE	A	86.0966	88.9182	89.1416	88.9684	88.9994	88.9883	87.7158	86.0779	77.8611	76.402	69.9219	30.4413	16.3157	5.62193	3.30835
405	RE	A	89.0333	87.7905	88.8251	88.397	88.4533	87.9131	89.2787	87.1961	82.919	69.9533	77.8591	46.3575	27.9926	10.4395	6.3775
406	PR	A	88.6004	89.5414	89.4832	89.3001	89.2944	89.0652	86.5627	83.7581	70.8636	68.4338	59.9047	20.4812	10.5695	3.60219	2.11715
406	PE	A	88.7416	88.765	89.0117	88.774	88.4772	88.4053	84.4672	80.127	63.2181	60.7142	50.4547	14.8032	7.50385	2.52574	1.47199
406	RE	A	90.7393	88.6172	89.0891	88.8879	88.3953	88.3562	84.5791	80.364	63.7841	61.3004	51.1079	15.1353	7.67715	2.58274	1.50159
407	BE	A	94.3528	89.1856	89.4435	89.4308	88.7591	89.2015	87.5104	86.9824	83.1284	80.2794	76.7348	42.9846	25.1918	9.25825	5.59228
408	BW	A	91.1863	89.3038	89.2579	89.34	89.7338	89.6329	88.2535	87.4878	80.1197	78.3312	73.2716	35.2206	19.081	5.581	2.35083
408	BR	A	85.8927	90.1172	89.7809	90.0808	90.0856	90.0941	89.0661	87.6672	80.3874	78.7021	73.3155	35.3251	18.9903	5.3459	2.07679
408	WR	A	86.5619	89.8938	90.3301	89.7371	90.0763	90.0984	88.9531	87.6272	80.1621	78.4535	73.2839	35.1694	18.8845	5.29915	2.03411
409	BE	A	88.1441	86.7077	86.9506	86.6226	86.3231	86.1433	84.2941	84.297	81.4663	77.0674	76.1169	44.0041	26.1699	9.58193	5.80329
410	BW	A	81.7461	87.4983	87.6966	88.0283	88.4516	88.4081	86.8041	84.3926	72.7451	70.6902	62.3681	22.4697	11.6268	3.87403	2.20386
410	BR	A	85.7324	87.5942	88.3597	88.5415	88.3371	88.4515	86.8067	84.2214	72.1734	70.8786	61.8223	21.973	11.367	3.7883	2.16196
410	WR	A	89.3985	87.6874	88.6204	88.7316	88.5096	88.4373	86.6914	84.2558	72.37	70.9048	61.8592	22.0551	11.3903	3.8254	2.20728
411	BW	A	88.933	87.4292	87.7743	88.0871	88.3984	88.3383	86.8875	84.4528	73.0232	71.2548	62.7076	22.7694	11.7866	3.93102	2.22896
411	BR	A	81.7968	87.3354	88.0327	88.3507	88.2355	88.4955	86.7917	84.3225	72.5041	70.2741	62.1876	22.3201	11.5476	3.8398	2.18812
411	WR	A	86.8618	87.5675	87.8185	88.0253	88.4395	88.4523	86.8804	84.3291	72.6759	70.9297	62.3264	22.4432	11.6385	3.88494	2.22745
412	RE	A	92.3281	89.0832	89.0408	88.0098	88.831	87.994	88.5089	87.3341	82.1895	78.5669	78.1569	46.4548	28.0861	10.5866	6.46058
413	PR	A	90.1663	89.1141	88.9259	89.3027	89.1265	88.9591	87.6737	86.0081	77.5835	76.0865	69.4994	29.8697	15.9591	5.49969	3.23725
413	PE	A	82.8842	88.4167	88.604	88.8424	88.8733	88.8192	87.6007	85.9667	77.5851	76.1645	69.5393	29.9325	16.0055	5.5226	3.257
413	RE	A	88.0255	88.9306	88.7137	88.673	88.9239	88.9306	87.6355	86.0368	77.6543	76.105	69.6084	30.0491	16.0747	5.5423	3.26263
414	RE	A	86.8421	88.084	87.981	87.9116	88.7938	87.2735	87.3076	86.7405	84.7004	66.736	78.462	47.096	28.3515	10.6792	6.52498
415	PR	A	92.5847	89.4192	89.4295	89.3462	89.1796	89.0405	86.5669	83.7511	70.9613	68.9191	60.0839	20.6079	10.6076	3.61231	2.11898
415	PE	A	90.843	88.5466	89.0122	88.5245	88.5032	88.2517	84.5718	80.4287	63.8199	61.3121	51.159	15.1629	7.69089	2.58779	1.50557
416	PR	A	90.847	89.4148	89.1397	88.9999	89.0253	89.1006	86.4924	83.6593	70.7833	68.9156	59.8139	20.7063	10.7292	3.68952	2.17726
416	PE	A	89.6431	88.7885	88.9269	88.6767	88.5151	88.3286	84.4136	80.0819	63.0148	60.4759	50.2162	14.6861	7.44257	2.50535	1.46201
416	RE	A	86.4757	88.7966	88.4266	88.7861	88.3212	88.3215	84.53	80.3148	63.5562	61.0448	50.8412	15.0032	7.60708	2.55906	1.48795
417	BW	A	89.4676	88.8958	89.4665	89.6725	89.7345	89.5621	88.9462	87.5015	80.1734	78.0432	73.0999	34.8638	18.7717	5.27843	2.08217
417	BR	A	93.295	90.111	90.0837	90.1588	90.0813	89.8744	89.1937	87.6718	80.121	78.0596	73.1332	35.0793	18.8077	5.2695	2.04291
417	WR	A	87.8216	89.6333	89.4419	89.5932	89.7807	89.9523	88.9339	87.5684	80.1813	78.5835	73.0962	34.7773	18.6388	5.19064	1.97138

Table G.4 AC impedance measurements for specimens in test sequence 4
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
418	PR	A	84.9051	88.9106	88.432	88.4593	88.4407	88.3566	84.4505	80.1469	63.1604	60.6228	50.3893	14.7706	7.48564	2.5214	1.46324
418	PE	A	91.8185	88.9685	89.1369	88.8039	88.9296	88.9614	87.6771	86.0343	77.7218	76.2112	69.7203	30.1892	16.1575	5.5637	3.27584
418	RE	A	85.7671	89.7469	89.5412	89.6062	89.7242	89.8047	89.0497	87.7714	81.0433	78.7864	74.8622	38.0147	21.2969	7.5175	4.45731
403	PE	D	85.1942	88.9899	89.5541	89.3735	89.5413	88.9831	89.2716	88.5375	84.3902	82.9414	79.0903	47.8264	28.8896	10.8316	6.684
404	PR	D	88.829	88.7662	88.6825	88.7002	89.0666	89.0141	88.2937	86.7335	78.6014	82.2331	71.3439	33.1409	18.4573	7.05356	4.61094
404	PE	D	88.6212	87.1359	88.0161	88.0584	87.9841	87.8566	85.948	84.1551	72.8241	70.7125	63.0226	23.3609	12.6648	4.97112	3.42561
405	RE	D	81.5549	86.2606	87.4203	87.7942	87.4834	88.2069	88.8271	87.9465	82.9803	80.6794	77.5569	43.5499	25.4501	9.45004	5.82578
406	PR	D	91.4737	88.1999	88.7043	88.4705	88.234	88.2525	86.1476	83.3356	70.9175	67.934	59.6947	20.5164	10.7464	3.90574	2.51498
406	PE	D	87.6424	87.5578	88.0866	87.7582	87.5543	87.4379	83.2596	78.3272	60.0796	58.1283	47.004	13.4951	7.09608	2.65218	1.75563
407	BE	E	91.1853	89.5836	89.1366	89.2189	89.0541	89.5353	89.1084	88.1254	82.9791	81.6443	77.2896	43.3117	25.1889	9.17052	5.58281
408	BW	E	83.4316	87.517	88.3913	88.4558	87.9527	88.762	87.5456	85.8972	78.1207	73.3771	69.8129	31.0734	16.8171	5.62672	3.06316
408	BE	E	88.9763	86.7197	86.5128	86.8189	87.2211	87.2056	86.9379	85.7541	79.9187	77.6347	73.9677	38.5787	21.676	7.1617	3.85221
409	BE	E	91.4025	90.0277	89.5578	89.2785	89.4532	89.5797	88.9705	87.9635	81.4841	82.9806	75.777	39.5347	22.4562	8.20196	5.07554
410	BW	E	82.2846	83.7056	83.2655	83.4707	83.8978	83.9541	83.5746	82.0374	72.3253	70.027	62.7188	23.5627	12.4206	4.41259	2.70504
410	BE	E	77.5085	77.1241	81.0984	81.5695	82.3128	82.5473	83.6044	83.1136	77.6957	75.6624	71.1728	35.0479	19.4365	6.96071	4.28469
411	BW	E	83.5418	82.993	84.149	83.8728	83.6166	83.9195	83.6252	82.1618	71.9141	70.814	62.5856	23.5315	12.387	4.40351	2.74185
411	BE	E	82.2465	82.4342	83.5823	83.7066	84.2059	84.3525	84.9815	84.2189	78.2945	75.1092	71.8435	35.2517	19.5867	6.99405	4.33927
412	RE	E	90.5445	88.7299	88.4933	88.8346	89.0397	89.4181	89.0441	88.0818	82.5901	81.6569	77.7677	44.6972	26.3838	9.75374	5.98625
413	PR	E	84.9241	87.4468	88.0948	87.9242	88.0952	87.9794	87.4145	86.2302	78.1344	81.2786	70.9715	32.4321	17.9234	6.6557	4.29267
413	PE	E	81.6554	81.2108	83.9957	85.021	85.2021	85.7025	87.0735	86.5484	81.7164	80.2403	76.1341	41.8427	24.1634	8.66577	5.19994
414	*RE	E	91.1436	88.3786	88.9921	88.035	89.2839	89.3448	89.1566	88.1172	82.6209	81.0031	77.4644	43.3679	25.3721	9.41087	5.84186
415	PR	E	87.6394	87.9351	88.014	88.206	88.2201	88.2122	86.2047	83.2986	70.4183	68.7242	59.5965	20.438	10.6334	3.81851	2.42112
415	PE	E	81.0263	80.7965	83.9434	85.1788	85.9472	86.0396	86.5633	85.8125	79.9011	77.2143	73.0953	36.0348	20.1035	7.1407	4.35365
416	PR	E	91.1463	88.0773	88.2927	88.1611	88.3989	88.4256	86.2893	83.3838	70.7219	68.8778	59.7247	20.5449	10.7206	3.82285	2.44029
416	PE	E	75.9819	82.4216	83.9954	84.7296	82.1842	84.9015	86.3166	85.4171	79.481	76.8201	72.5857	35.3985	19.7077	7.03135	4.32674
401	BW	H	10.6943	27.5796	39.051	46.8059	51.422	53.206	75.0106	78.9538	74.7341	71.9108	66.505	27.2608	14.5144	4.89659	2.81418
401	BE	H	81.5403	77.0396	76.0108	73.0714	72.5825	72.4507	77.7352	79.3779	74.8246	71.0055	67.6903	29.8722	15.9588	5.12115	2.75771
401	WE	H	81.164	73.998	74.89	77.4849	78.9476	79.3544	84.3015	83.1794	76.6312	76.552	68.982	31.2528	16.7472	5.43086	2.93879
402	RP	H	92.0109	89.3354	89.6733	89.3444	89.2842	89.3051	87.8098	86.0886	77.1349	75.0353	68.7239	29.0309	15.4679	5.33306	3.17053
402	PE	H	87.1968	86.8254	98.0958	87.1582	87.139	91.8831	86.3023	84.8616	77.4908	75.5069	70.9083	33.5552	18.394	6.38994	3.73393
402	RE	H	82.0762	86.2886	87.221	87.3832	87.3792	87.4064	86.5498	85.2384	78.5007	76.9975	71.4168	33.9576	18.5513	6.45854	3.79007
403	PE	H	94.3359	94.5077	88.4003	88.7757	87.6954	91.8837	87.6732	86.5278	81.4678	77.6044	76.8583	44.6053	26.4965	9.68244	5.84489
404	PR	H	110.349	88.9442	88.806	89.2739	88.884	89.0273	87.3294	85.328	76.2421	74.0409	67.613	27.9469	14.8799	5.1152	2.9974
404	PE	H	73.8703	81.379	83.3268	83.9152	84.5792	84.6622	84.5795	83.2879	76.2791	75.4813	69.374	31.3993	16.9833	5.77622	3.28421
404	RE	H	141.069	81.1679	82.4326	84.1453	84.2681	84.6147	84.4972	83.092	76.2084	74.9012	69.2548	31.3314	16.9309	5.72856	3.26982
405	RE	H	0.241971	85.5864	86.1823	86.8007	87.205	87.0663	86.3284	85.3819	80.3095	76.9631	74.1856	39.5555	22.8391	8.09494	4.79307
406	PR	H	87.3922	90.9283	89.0906	89.4601	89.0027	89.016	86.3712	83.5394	70.891	68.8447	60.0153	20.7982	10.6579	3.5698	2.06097
406	PE	H	86.3238	85.594	87.5984	88.0276	87.5189	87.4269	82.769	77.8625	60.0491	57.632	47.2109	13.4902	6.83025	2.20336	1.25149

Table G.4 AC impedance measurements for specimens in test sequence 4 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
406	RE	H	86.2115	88.3991	87.9897	87.6973	87.8157	87.6074	82.8377	77.8303	59.6691	57.2983	46.699	13.2949	6.70265	2.17401	1.23651
407	BE	H	83.7737	81.9892	84.8625	85.7883	86.8662	87.1586	86.7548	84.9419	80.1056	77.125	75.0559	40.6306	23.2488	8.29651	4.95983
408	BW	H	83.6595	75.0351	72.1771	71.3096	72.3797	73.3259	82.8395	82.7965	73.9619	72.5768	64.8035	25.1718	13.1524	4.30256	2.46105
408	BE	H	24.112	45.5891	53.781	59.3665	63.7134	65.898	78.9658	79.3869	72.0711	69.8719	64.0097	26.7965	14.3172	4.35498	2.15546
408	RE	H	74.2676	76.7982	79.0822	79.9778	80.9809	81.208	82.5692	80.9288	72.4376	69.0258	64.149	26.6501	14.0812	4.33863	2.13202
409	BE	H	77.8736	85.5001	86.8451	85.975	85.9152	84.5403	86.4891	85.4701	79.9333	71.3825	73.6189	36.2873	20.2499	7.16922	4.26903
410	BW	H	90.8543	89.0738	90.2655	90.3678	90.12	89.7813	86.9252	83.8688	70.3198	67.5582	59.2191	20.0101	10.2777	3.4771	2.01231
410	BE	H	72.229	84.05	82.7136	82.0935	81.3401	83.0014	77.4043	73.7282	61.3316	59.62	51.6719	18.0092	9.23106	2.66029	1.16194
411	BW	H	84.4679	74.4099	70.8183	70.4158	72.5808	73.8557	82.6689	81.4545	69.3886	68.3009	58.3432	19.514	10.0338	3.33216	1.93162
411	BE	H	5.42649	19.6941	28.5699	43.0971	47.8131	51.1293	63.9113	64.1247	59.0448	59.2215	50.8063	18.3719	9.57705	2.79476	1.38237
412	RE	H	22.4359	80.4659	82.3169	82.8018	81.6723	83.0923	84.3396	83.9856	80.9169	88.3136	72.4739	37.4433	22.1313	7.68788	4.6765
413	PR	H	92.075	90.629	90.0395	90.1372	89.6483	89.4997	87.2177	84.9375	74.6811	72.9796	65.2637	25.4168	13.369	4.53391	2.64079
413	PE	H	69.3985	68.2572	70.0024	70.7285	72.2069	79.5582	78.9761	78.0988	73.1421	71.2318	66.6882	30.7733	16.5562	5.44814	3.01051
413	RE	H	72.2458	69.0142	69.5583	71.6059	73.0251	76.7558	79.2598	78.5502	73.4034	70.6452	67.1987	30.956	16.7814	5.50903	3.05491
414	RE	H	78.732	81.5772	84.5546	83.7576	83.2742	84.2118	84.1474	83.3159	78.4785	69.5695	73.6407	39.3798	22.3594	7.91967	4.65202
415	PR	H	78.9915	93.7308	89.3619	89.0203	88.9537	88.5525	85.7011	82.5024	68.9645	66.3622	57.6639	19.1839	9.8508	3.27717	1.89937
415	PE	H	82.9146	87.6747	87.0269	87.1849	86.786	86.7278	81.0203	75.4634	56.3609	54.1098	43.435	11.961	6.06896	1.96226	1.0929
415	RE	H	88.4168	87.8342	87.9527	87.9405	87.5105	87.4554	82.2733	76.8347	58.1624	55.8366	45.1165	12.5754	6.34745	2.09186	1.19393
416	PR	H	89.2727	89.4297	88.9814	89.1924	91.0006	89.0068	86.036	82.7208	69.0271	65.975	57.6457	19.2007	9.8877	3.29048	1.88801
416	PE	H	84.7606	89.227	87.8452	86.9222	86.9919	86.6534	81.016	75.3626	56.2744	53.4018	43.4055	11.9822	6.0166	1.96174	1.09324
416	RE	H	89.856	88.9593	89.3899	88.0504	87.6599	87.4972	82.2985	76.9188	58.0093	55.7889	45.0855	12.5292	6.33711	2.1015	1.18437

Table G.5 AC impedance measurements for specimens in test sequence 5
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
501	BE	A	90.1586	88.8895	89.6479	89.1016	88.2388	89.4886	88.8276	87.2832	80.8044	70.4986	76.2799	42.8027	25.0819	9.261	5.61373
502	BW	A	87.2832	89.5064	90.0151	89.6919	89.6734	89.8382	88.6811	87.7001	80.647	78.8364	74.1306	36.5316	20.2868	7.14856	4.27246
502	BE	A	91.2061	88.7909	89.3807	89.2767	88.7612	88.6958	87.0693	85.2399	75.5768	72.7524	66.7619	26.8731	14.272	4.95798	2.97188
502	WE	A	87.5845	88.5707	88.6858	88.7691	88.7291	88.7225	86.9148	84.9556	75.215	74.5117	65.6701	25.8386	13.6327	4.71371	2.80843
503	BW	A	84.3308	86.9858	87.0778	87.5888	88.164	88.1621	88.9262	88.1431	82.4534	82.8973	76.2443	40.9566	23.3891	8.21034	4.80882
503	BR	A	81.088	86.9548	87.8478	88.3893	88.4833	88.353	88.9553	88.1399	81.752	81.7551	75.9106	40.41	22.947	8.0369	4.69827
503	WR	A	83.5398	87.3169	87.5272	87.978	88.5175	88.7558	89.1614	88.1528	82.3252	80.1352	76.2291	40.5779	23.1405	8.1393	4.78065
504	BE	A	85.8136	139.229	89.0253	88.9655	88.7563	88.8528	88.581	86.8465	82.6758	71.0882	76.5109	43.5448	25.6632	9.46437	5.78841
505	BE	A	88.5386	89.2661	88.8928	88.9247	89.1102	89.5071	87.0072	86.9847	82.8841	75.276	76.5968	42.498	24.8021	9.0831	5.52752
506	BW	A	90.8071	89.4981	89.6382	89.6397	89.8171	89.7463	88.9955	87.6882	80.9229	79.2535	74.1891	36.6235	20.3524	7.19117	4.27804
506	BE	A	86.8965	88.8121	88.9176	88.9171	88.8526	88.9005	87.1496	85.2414	75.9389	73.3626	66.8121	26.8577	14.2111	4.93678	2.9641
506	WE	A	85.487	88.6128	89.1422	88.7033	88.7067	88.7525	87.0015	84.9518	75.0187	74.7047	65.7163	25.665	13.5106	4.65699	2.7925
507	BW	A	91.052	90.0399	89.8309	89.8753	89.9184	89.8927	89.0159	87.7895	80.9597	78.9892	74.1833	36.6069	20.3323	7.16096	4.28396
507	BE	A	86.6996	88.7696	89.2674	89.2483	89.0837	88.7773	87.3286	85.1882	75.6939	72.7094	66.6224	26.7029	14.1679	4.93081	2.94385
507	WE	A	84.1941	88.4308	88.5301	88.5616	88.793	88.9401	86.9867	84.8792	74.8998	74.3779	65.6603	25.7287	13.576	4.66649	2.79988
508	BW	A	90.8536	86.9071	88.043	87.9343	88.1213	88.349	88.8939	88.1331	82.2112	79.7731	76.2095	40.9198	23.3204	8.19296	4.79826
508	BR	A	87.54	86.9776	87.1549	87.8798	88.5092	88.3619	88.8119	88.0014	81.8846	82.0947	76.0544	40.5875	23.059	8.09302	4.71686
508	WR	A	88.0006	86.9894	87.843	88.2528	88.4445	88.702	88.9874	88.0724	82.3611	82.754	76.0744	40.7681	23.2078	8.16446	4.78743
509	BW	A	88.0399	87.0936	87.3755	88.2398	88.1425	88.3948	88.9811	88.1219	82.0011	80.684	76.3225	40.9482	23.4013	8.23237	4.80946
509	BR	A	87.7402	87.1985	88.294	87.9084	88.5933	88.2708	88.9463	88.0105	82.017	80.9989	75.9526	40.4931	23.0185	8.07284	4.71805
509	WR	A	81.5904	87.2977	88.1598	88.6777	88.2819	88.5589	88.7588	88.0908	81.9158	80.0502	76.161	40.6815	23.1695	8.14858	4.77374
510	BE	A	91.1619	88.9988	88.7836	89.1319	89.1771	89.6719	88.0076	86.8128	82.3777	86.3915	76.4795	43.5918	25.5547	9.4594	5.76192
511	BE	A	92.8653	89.263	89.5615	89.3385	89.1379	88.7398	87.9883	86.8911	83.0832	75.9454	76.2234	42.6726	24.8828	9.19214	5.63635
512	BE	A	90.3829	89.1075	88.3222	88.7561	89.2394	88.7513	86.8209	86.9689	81.9234	74.719	76.4428	43.5185	25.298	9.41829	5.71258
513	BW	A	90.8666	89.5796	89.7752	89.8145	89.8992	89.484	89.1	87.6573	80.8774	78.7776	74.0103	36.4322	20.2122	7.11384	4.23439
513	BE	A	91.8819	88.9788	88.8633	89.3133	88.9487	88.9798	87.1257	85.3145	75.41	74.1056	66.5763	26.6034	14.1043	4.88081	2.92529
513	WE	A	87.6752	88.6376	89.1817	89.13	88.8741	88.6208	87.0608	84.9396	74.8225	71.6554	65.5095	25.5597	13.4068	4.63414	2.75479
514	BW	A	85.9791	89.4404	89.2234	89.3057	89.6336	89.6895	88.9359	87.6808	80.6583	78.5528	74.0622	36.3357	20.1483	7.07919	4.22115
514	BE	A	84.6573	88.7588	89.2771	89.2137	88.9322	88.6894	87.2453	85.2015	75.5618	72.3108	66.541	26.5566	14.0147	4.85926	2.9167
514	WE	A	84.6246	88.7528	88.5351	88.5551	88.8355	88.7869	86.9228	84.9083	74.7884	74.42	65.3924	25.4619	13.3563	4.60149	2.73836
515	BW	A	88.7258	87.1511	88.0069	87.9897	88.2671	88.486	88.9917	88.1608	82.5056	83.5352	76.3194	40.9298	23.3418	8.18559	4.7915
515	BR	A	88.5763	87.1242	87.9142	88.2391	88.5068	88.6843	88.63	88.0497	81.6749	81.7853	76.0544	40.3737	22.938	8.04599	4.70109
515	WR	A	88.9245	87.314	87.8125	88.0177	88.4213	88.5207	88.8864	87.9903	81.8556	80.3975	76.0526	40.4628	23.07	8.09479	4.73833
516	BW	A	82.5545	87.0715	87.9262	87.4269	88.2277	88.2971	89.1031	88.1135	82.3604	78.4792	76.1895	41.0138	23.4093	8.21904	4.8124
516	BR	A	88.5868	87.2697	88.2054	88.529	88.5421	88.5214	88.9357	87.9966	81.7417	80.8392	75.8472	40.2723	22.9024	8.01999	4.69267
516	WR	A	83.3471	86.7672	87.7892	88.2751	88.3949	88.7268	88.7854	88.0745	82.4088	80.71	76.0567	40.6617	23.1708	8.14945	4.77384
517	BW	A	88.9406	89.2352	89.6711	89.5891	89.624	88.7257	87.716	87.2521	81.6597	84.2636	76.8097	43.2193	25.2604	9.34244	5.73243
518	BW	A	88.9801	89.4277	89.2836	89.8326	89.5925	89.8889	88.7079	87.6222	80.928	78.8864	74.1046	36.5119	20.2821	7.14773	4.2569

Table G.5 AC impedance measurements for specimens in test sequence 5 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
518	BE	A	85.8371	88.8782	88.6043	88.5897	88.9503	88.9177	87.2875	85.3091	75.5557	74.3984	66.6997	26.8269	14.2132	4.93521	2.95041
518	WE	A	89.6484	88.7777	89.1346	89.087	88.7586	88.7257	86.9635	84.9155	74.7214	74.203	65.609	25.7103	13.5081	4.67014	2.77257
519	BW	A	87.4086	86.9635	88.1992	88.422	88.1362	88.2843	89.276	88.9643	83.404	80.3935	76.659	40.3613	22.9024	8.0134	4.67683
519	BR	A	85.6057	87.1035	88.11	88.4593	88.1829	88.6081	89.0861	88.5972	82.7016	82.5371	76.4657	39.8063	22.5076	7.85177	4.58246
519	WR	A	85.6956	87.6735	88.8385	88.9965	88.9456	89.0551	89.2737	88.1998	82.0241	81.8001	76.1609	40.7243	23.203	8.14087	4.78794
504	BE	D	84.1206	85.7744	85.8134	86.6406	86.5679	86.6703	86.7054	86.038	80.7696	81.3552	75.557	41.4174	23.9112	8.61621	5.17081
505	BE	D	89.3092	86.1396	86.2259	86.6015	87.284	86.9808	86.8342	86.0518	80.626	79.668	75.2457	41.0274	23.5687	8.38804	5.00348
506	BW	D	91.9596	88.5504	88.9334	88.9419	88.9554	88.8082	87.6608	86.1497	78.1075	76.872	70.5966	31.3881	17.2324	6.38378	4.09725
506	BE	D	85.6021	87.5434	87.5225	88.0507	88.1627	88.4057	85.9899	83.71	71.7297	70.9156	61.9737	22.3877	12.0092	4.56782	3.03207
507	BW	D	86.0155	88.7836	88.8468	89.0022	89.0447	89.2312	87.7414	86.3668	78.397	76.8341	70.824	31.8467	17.6429	6.83747	4.51971
507	BE	D	90.6875	87.8651	87.9731	88.4131	88.4676	88.3121	86.8558	84.8332	74.7233	72.8272	65.3383	25.3289	13.3158	4.65555	2.81217
508	BW	D	79.2557	84.2047	85.4246	86.5621	86.1063	86.5916	87.4266	86.4831	79.5073	80.0593	73.658	36.2682	20.5089	7.90588	5.2115
508	BE	D	76.5286	84.456	85.3519	86.2344	86.3812	89.2053	86.167	84.2142	74.6226	111.518	66.2946	30.8933	18.7248	10.0626	8.13919
509	BW	D	84.0655	83.3102	84.1591	85.3112	86.21	86.3269	87.7049	86.3462	80.4363	74.3442	73.124	36.1463	20.3397	7.8658	5.13599
509	BE	D	86.181	85.0457	85.5993	86.2742	86.9026	87.3509	88.0314	87.3131	81.7391	80.9306	76.2912	41.741	23.9838	8.58883	5.11625
510	BE	E	61.8664	73.1349	77.0542	78.8031	80.2595	80.4959	84.3311	84.3816	80.5126	79.2833	75.5132	43.2218	25.2936	9.05908	5.3836
511	BE	E	67.8938	76.1814	78.7241	80.223	80.9697	81.5154	83.7225	83.4817	79.2957	78.1878	74.1367	41.0843	23.6855	8.37099	4.92921
512	BE	E	67.436	69.8103	71.2667	72.6637	73.4646	73.7825	79.3887	79.9303	76.8438	76.7802	72.0045	38.2332	21.6777	7.56692	4.42614
513	BW	E	89.3572	87.6923	87.8401	88.3747	87.9609	88.2804	87.3274	85.9615	78.2308	75.9889	69.9876	31.1655	17.1479	6.46026	4.1979
513	BE	E	83.3402	86.9512	87.9314	87.4034	87.8708	87.8149	86.5569	84.4396	74.2953	72.349	64.8624	24.9048	13.0542	4.52766	2.7227
514	BW	E	83.5407	87.2754	88.1105	88.4887	88.1151	88.3767	87.4561	85.9821	77.3751	77.018	70.3166	31.4025	17.3048	6.60629	4.36305
514	BE	E	87.5154	86.9208	87.1914	87.363	87.9949	87.3655	85.9538	83.3679	71.8908	69.0619	61.1476	22.2028	11.9031	4.79977	3.29493
515	BW	E	82.0643	84.0997	84.8172	85.6498	85.822	85.6639	85.9691	85.4042	78.9048	76.7842	71.8555	30.747	16.903	6.48783	4.2498
515	BE	E	79.7035	82.8712	83.9871	84.5892	85.4655	85.5613	86.6173	86.1183	80.8957	81.6137	75.5758	41.3522	23.7765	8.45766	5.01211
515	WE	E	76.9375	84.7395	84.3785	84.9838	85.0775	85.4812	86.529	86.0357	81.0656	79.8919	75.6549	41.7419	24.0959	8.55005	4.9841
516	BW	E	84.416	84.0747	85.0758	85.5849	85.1116	85.5809	85.8397	85.5032	79.7536	73.61	72.2903	35.0396	19.89	7.69216	5.17563
516	BE	E	77.6271	82.3487	83.9164	84.5865	84.8239	85.0601	86.611	85.8444	80.6716	80.7806	75.4018	41.1185	23.6282	8.3469	4.93029
516	WE	E	78.5661	82.5214	83.3728	84.6629	84.8265	85.1205	86.4958	85.8765	81.2138	79.8286	75.6907	41.9148	24.1969	8.57957	5.06772
501	BE	H	77.9577	123.566	79.2934	79.8837	79.6665	81.8845	83.0464	82.7839	79.4826	75.4527	71.9848	37.8699	21.2014	6.97398	3.89427
502	BW	H	93.1805	90.3331	89.7313	89.8367	90.2381	89.9028	88.2838	86.2008	77.3237	74.8494	69.3076	30.0275	16.1195	5.52942	3.23757
502	BE	H	87.6531	87.1362	86.9914	87.6516	89.2649	89.5186	86.9395	85.8364	78.979	75.3635	73.2388	36.2511	19.8582	7.01385	4.17505
503	BW	H	86.6574	88.0596	93.3086	88.5321	87.4362	88.867	86.6355	85.4425	76.8682	76.0797	71.2267	32.3356	17.5581	5.5395	2.96593
503	BE	H	103.319	89.6888	91.6173	90.3246	93.0943	91.1021	88.7077	86.8024	77.3427	77.5082	69.6246	30.1498	16.1824	5.52481	3.14936
504	BE	H	66.246	72.6222	69.5442	72.4142	71.8693	77.6601	79.7631	76.2636	75.5638	71.4783	37.2148	20.7587	7.04054	4.05647	5.78841
505	BE	H	73.764	75.3926	76.425	72.649	76.8783	76.5346	79.5687	79.8188	74.6877	51.4929	69.8684	34.3674	18.7751	6.33243	3.59184
506	BW	H	94.3044	92.2939	90.4249	90.7991	90.5557	89.7804	87.5413	85.6731	75.8315	72.195	67.5559	27.9238	14.8579	5.05518	2.97152
506	BE	H	58.9783	80.3193	79.21	79.1407	84.2688	90.3707	84.6319	84.2136	77.682	87.1025	71.0708	32.9098	17.8727	6.00838	3.4509
507	BW	H	90.06	90.8497	90.3949	90.9152	90.5028	90.1485	87.7223	85.741	76.7432	75.6222	67.8182	28.2091	14.9744	5.08928	3.0032

Table G.5 AC impedance measurements for specimens in test sequence 5
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
507	BE	H	77.2139	72.0283	71.9929	72.2325	72.0749	73.1304	79.3291	80.554	76.9412	70.9759	69.8314	31.5659	17.1424	5.82368	3.33555
508	BW	H	34.7915	65.0681	72.5491	75.7299	77.3445	78.0431	73.1208	68.1072	69.8058	67.3262	65.6598	29.8554	16.0162	5.46791	3.16596
508	BE	H	0.819675	1.44175	2.07834	2.74825	3.38493	3.80038	16.6904	28.893	53.6675	53.2226	50.0178	19.7022	9.68955	2.05161	0.526469
508	WE	H	36.0977	67.7846	76.052	79.4505	80.9524	81.8683	83.9696	81.0962	67.8329	63.8202	56.3558	20.6336	10.1073	2.13788	0.504605
509	BW	H	66.3445	60.3976	70.7593	74.5443	76.4699	78.7849	86.2187	85.4405	77.4783	77.1527	69.7686	30.4083	16.3477	5.57614	3.24444
509	BE	H	69.2891	82.7102	84.6757	86.0657	86.0473	87.0211	85.0541	82.0043	67.0798	63.6776	56.1007	18.9722	8.71375	0.557967	-0.81187
510	BE	H	70.9193	77.3576	78.6104	79.2141	79.5123	79.0973	75.1511	73.4284	67.3213	69.7883	65.3534	29.0278	14.3507	2.15206	-0.395726
511	BE	H	91.7512	86.7921	87.2126	87.1268	87.4309	85.0249	82.1696	80.5823	74.3132	72.952	65.5475	31.5508	16.1103	3.11107	0.24701
512	BE	H	83.8835	86.0632	85.0062	84.4737	85.0173	84.0798	82.4611	80.8422	73.9964	70.6415	65.5435	29.5815	15.126	2.99093	0.290035
513	BW	H	83.3916	90.7347	90.8184	91.5209	90.4542	90.2735	87.5564	85.3466	75.6619	72.276	66.6935	26.8893	14.1602	4.85551	2.8432
513	BE	H	87.2673	81.9388	79.3824	76.5525	74.8916	73.7975	67.2845	68.8828	70.6097	68.1539	64.5993	29.4989	15.8276	5.16641	2.84552
513	WE	H	9.44811	75.4143	78.5248	80.4974	81.8267	82.1188	84.8088	84.0865	76.9429	74.6158	70.2865	32.1221	17.3565	5.85623	3.2678
514	BW	H	94.1498	90.8116	90.5747	90.5296	90.6376	90.5405	87.6705	85.6841	76.0599	71.9554	66.8908	27.0184	14.2093	4.84116	2.85639
514	BE	H	87.0436	81.4805	79.0722	76.7453	74.8442	73.5464	65.831	68.3366	70.4748	75.7249	66.2014	31.2644	16.9907	5.71805	3.19938
515	BW	H	61.1014	75.8491	76.4947	75.933	75.3944	74.7254	73.2729	77.0688	75.5444	72.4794	67.6898	29.0179	15.5609	5.26034	3.06969
515	BE	H	1.30963	4.31317	7.09892	9.83092	12.243	13.991	48.2479	61.2562	64.8212	65.1416	55.5665	18.432	8.54499	1.0213	-0.848715
515	WE	H	30.1731	83.4398	85.2872	85.9689	86.7046	86.6708	84.5448	81.1432	66.7649	63.8058	55.1361	20.4332	10.2698	2.04536	0.259661
516	BW	H	84.0245	79.2248	76.2656	74.0135	72.5814	72.7015	80.2351	81.9715	76.5524	79.2076	69.2818	30.3596	16.3091	5.52892	3.2395
516	BE	H	4.81205	9.99675	15.2794	20.1968	24.4536	27.2095	59.5704	62.3961	58.5296	61.1572	57.3685	29.2372	15.8309	5.15409	2.75751
516	WE	H	84.6489	75.4443	71.8321	72.6493	71.0813	71.6149	80.2315	81.9349	76.9135	75.0635	69.8106	31.5662	17.0043	5.5413	3.07105

Table G.6 AC impedance measurements for specimens in test sequence 6
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
====	===	==	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======
601	BE	A	87.2446	89.0253	89.5155	89.2653	89.0103	89.0648	88.3518	87.0389	80.7772	83.9033	76.1086	41.6517	24.7405	8.88987	5.40693
602	BW	A	78.5156	89.0936	89.0293	89.2513	89.2999	89.2451	88.8686	87.6458	81.3905	76.5554	74.1802	36.4317	20.2397	7.14559	4.27434
602	BE	A	86.8683	88.5843	89.1452	89.1	88.5463	88.478	86.7475	85.0594	75.0185	72.7568	66.1383	26.3501	14.0193	4.8547	2.9422
602	WE	A	86.0468	88.359	88.7197	87.2091	88.7154	88.4879	86.3354	84.8502	74.0538	71.4177	65.5691	25.6088	13.6444	4.68196	2.77997
603	BW	A	85.9307	88.3302	88.2169	88.3336	88.7722	88.5798	87.8895	86.492	78.6203	77.3552	71.8657	33.4861	18.3818	6.04809	3.40326
603	BR	A	90.2459	88.2964	88.9693	88.7368	85.9592	88.4683	87.9882	86.7113	79.7263	77.6057	72.2615	33.9304	18.636	6.26163	3.47466
603	WR	A	84.5545	87.7003	88.2348	88.8723	87.9688	88.6537	87.182	86.1721	79.1079	77.1013	71.522	33.4006	18.0543	5.97103	3.2349
603	BE	A	82.5154	86.5535	86.7471	87.0798	87.5035	87.51	86.1676	84.2008	74.3993	72.7454	65.3922	26.0373	13.6388	4.41946	2.41721
603	WE	A	81.75	86.0514	86.2878	86.4866	86.6988	86.5895	85.043	82.8108	72.5015	70.8089	63.2588	24.5385	12.7845	3.91157	2.14181
603	RE	A	84.9319	86.0007	86.165	86.4025	86.8134	86.7632	85.4206	83.3713	73.3789	71.6456	64.333	25.4165	13.2948	4.25799	2.29623
604	BW	A	78.7756	88.446	88.9911	89.4717	89.5653	89.459	89.3969	88.3421	82.4031	83.5748	77.0189	42.8207	24.7842	8.9233	5.3856
605	BE	A	89.1077	89.2316	89.79	89.5203	88.9712	90.0951	89.3197	87.2615	83.649	78.6858	76.7278	44.0145	25.758	9.63984	5.89391
606	BE	A	88.7629	89.0818	88.4889	88.9788	89.1197	89.2123	87.5395	87.0088	80.531	86.134	75.5298	40.5265	23.5696	8.5353	5.2015
607	BE	A	87.1985	89.379	88.7678	89.2255	89.1581	89.4175	88.8673	87.2163	83.1547	82.4121	76.1762	43.0011	25.4461	9.44084	5.76699
608	BW	A	88.7747	89.2595	89.8327	89.8524	89.8295	89.4937	88.9364	87.631	80.9512	78.2452	74.1679	36.568	20.3339	7.18363	4.29178
608	BE	A	88.959	88.7832	89.2127	89.0647	88.8939	89.023	87.0763	85.1744	75.2915	75.1052	66.4152	26.6303	14.1397	4.90435	2.96112
608	WE	A	86.945	88.6004	88.8878	88.9689	88.7382	88.8044	87.3619	85.5598	76.39	74.8	67.7685	27.8163	14.7262	5.05306	2.99755
609	BW	A	92.2188	89.4917	89.4326	89.3513	89.8928	89.5599	88.6751	87.5466	81.3388	78.4681	74.2238	36.5507	20.3358	7.16572	4.27283
609	BE	A	90.1811	99.7729	89.0205	88.799	88.6745	88.9655	87.7623	85.0724	74.8454	72.5533	66.1681	26.6559	13.9939	4.86661	2.92973
609	WE	A	84.1272	88.4647	88.873	89.0501	88.5799	88.8415	87.1153	84.8928	75.2026	74.1915	65.8292	25.8507	13.6798	4.74997	2.81669
610	BW	A	91.0868	89.3829	89.2363	89.2621	89.6133	89.3949	88.7189	87.5823	80.5734	80.3645	74.239	36.5582	20.331	7.17901	4.29424
610	BE	A	91.0846	88.7495	88.9505	88.5945	88.9387	88.8476	87.4497	85.6768	76.5726	75.0579	68.0213	28.0857	14.8902	5.12762	4.04715
610	WE	A	84.121	88.646	89.0235	89.0196	88.6853	88.8078	87.3224	85.4461	76.2049	74.5725	67.5141	27.5571	14.5864	5.01199	2.97065
611	BW	A	90.8033	88.5788	88.7015	89.142	88.8287	89.1165	87.9817	86.6779	78.9132	78.7554	71.7166	33.6751	18.3289	6.12268	3.39316
611	BR	A	85.6217	88.4943	89.1003	89.1681	88.9017	88.86	88.0644	86.7876	79.1783	77.0547	72.1767	34.0808	18.6029	6.2295	3.48164
611	WR	A	87.1986	88.1459	88.8086	88.728	88.5283	88.5872	87.6713	86.183	78.2455	77.1018	71.2794	33.2359	18.0817	5.93342	3.26226
611	BE	A	88.5641	86.6677	87.4562	87.6405	87.451	87.5249	85.739	83.5866	72.9734	70.5042	63.5733	24.3315	12.6605	4.07246	2.19224
611	WE	A	89.6124	86.2379	86.7635	86.8498	86.4731	86.8159	84.6461	82.1592	71.1933	68.0998	61.3425	22.8548	11.856	3.67556	1.8782
611	RE	A	82.0614	83.0504	88.246	86.5148	86.7816	86.1611	85.1788	82.6648	72.1844	70.6943	62.5117	23.7476	12.2881	3.86978	2.06239
612	BW	A	90.3578	89.1845	89.2533	89.2277	89.3739	89.1926	88.495	86.837	78.9634	75.9101	71.6853	34.0022	18.5681	6.21741	3.47501
612	BR	A	87.7445	88.6411	88.4624	88.7924	89.1166	89.3124	88.1346	86.8408	79.2988	77.5647	72.0557	33.9829	18.5468	6.18722	3.45585
612	WR	A	91.6932	88.4712	88.3766	88.4521	88.7629	88.534	87.7412	86.181	77.9652	77.6076	70.9232	32.9116	17.8068	5.83631	3.1616
612	BE	A	88.0429	86.7652	87.2717	87.4178	87.2895	87.5773	85.7203	83.704	73.1792	70.1791	63.9291	24.6336	12.7985	4.15815	2.25829
612	WE	A	85.1708	86.3306	86.2404	86.3305	86.6994	86.6971	84.9849	82.7441	72.343	70.6212	63.0857	24.4458	12.7401	4.02919	2.13569
612	RE	A	89.1083	86.3508	86.4176	86.6874	86.976	86.9053	85.2425	83.0217	72.5382	70.7917	63.2527	24.556	12.797	4.05392	2.15832
613	BW	A	86.6509	88.2658	88.2757	88.5183	88.8997	88.7945	88.2764	86.8389	79.396	79.4646	72.6288	35.0067	19.2327	6.39879	3.54973
613	BR	A	86.5256	87.5798	87.559	87.7699	88.3011	88.3117	87.6886	86.5449	79.1509	79.4486	72.6485	35.378	19.4294	6.3369	3.44578

Table G.6 AC impedance measurements for specimens in test sequence 6 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
613	BG	A	90.2292	88.5264	88.3795	88.8244	88.931	89.1452	88.1081	87.0645	79.4391	79.35	72.9506	35.2907	19.4007	6.49119	3.63942
613	WR	A	83.9359	87.5624	88.2736	88.3711	88.0701	88.4731	87.4241	86.2353	78.8542	78.1426	71.657	33.8364	18.4768	6.05392	3.29661
613	WG	A	83.1458	87.0671	87.551	87.6383	87.8782	88.1034	87.3974	86.2682	79.188	76.6137	72.3043	35.0823	19.246	6.29487	3.41459
613	RG	A	90.232	87.581	88.5295	88.3972	88.18	88.2274	87.6349	86.343	78.6779	77.9522	71.942	34.2485	18.7158	6.17033	3.37122
613	BE	A	84.23	86.8599	86.8529	87.1017	87.4536	87.6151	86.3493	84.462	75.1829	73.4847	66.5764	27.2675	14.3732	4.7028	2.61092
613	WE	A	83.8389	85.7566	86.043	86.3049	86.5042	86.4557	85.2954	83.3104	73.5333	71.8028	64.6208	25.8173	13.5277	4.32967	2.33737
613	RE	A	84.5756	85.5942	86.445	85.9905	86.3659	86.3502	85.1899	83.1332	73.0608	71.3229	63.9675	25.1787	13.1492	4.18332	2.23903
613	GE	A	82.4555	85.8453	86.5815	86.2916	86.5027	86.6017	85.5187	83.6282	74.1361	72.4623	65.3967	26.5025	13.9268	4.4892	2.44205
614	BW	A	90.6146	88.742	89.8277	89.7599	89.8509	89.7096	89.7614	88.594	83.1912	81.9718	77.084	42.8305	24.7866	8.9336	5.4041
615	BW	A	90.9415	88.5702	88.7298	88.9812	89.5976	89.2707	89.4464	88.3943	82.4184	83.707	77.0119	42.7924	24.7772	8.9461	5.3857
616	BW	A	85.9024	88.5947	89.0523	89.7692	89.6411	89.8308	89.5606	88.4433	83.2626	80.877	77.2508	42.9423	24.8604	8.9777	5.3945
617	BE	A	86.4812	88.5923	89.0823	89.7386	88.3635	88.6498	87.8334	87.0278	83.594	88.229	76.7493	43.532	25.8637	9.5828	5.82917
618	BW	A	86.4713	89.4386	90.0129	90.0425	89.8407	89.8417	89.0173	87.6154	80.8977	78.9177	74.0457	36.3438	20.1549	7.11461	4.25008
618	BE	A	91.7065	88.8347	89.1159	89.1625	88.9776	88.8049	87.1938	85.0438	75.4557	74.2728	66.1298	26.1577	13.8826	4.82918	2.9074
618	WE	A	89.2156	88.6505	88.2566	88.7928	88.8009	88.7645	87.187	84.9539	74.7931	71.5454	65.7099	25.8453	13.7194	4.73205	2.83835
619	BW	A	85.5292	88.6188	89.4487	89.5449	89.4142	89.4912	88.5455	86.9685	79.5125	79.4262	72.0874	34.0565	18.6165	6.21874	3.48937
619	BR	A	84.7556	88.4544	89.2853	89.4278	89.21	89.1713	88.3166	86.8863	79.4143	79.0528	72.1493	34.0525	18.5777	6.21537	3.47423
619	WR	A	90.9088	88.4132	88.198	88.3344	88.7321	88.7566	87.6796	86.2115	78.4992	76.3711	71.0824	32.9838	17.8825	5.8526	3.17972
619	BE	A	87.7872	86.6517	87.0339	87.3325	87.6361	87.5659	86.316	84.34	74.7432	73.098	65.9047	26.5391	13.9354	4.5421	2.50904
619	WE	A	88.3786	86.3522	86.5581	86.7757	86.6938	86.8297	85.0332	82.8192	72.4221	70.7243	63.2026	24.5581	12.8009	4.05281	2.15452
619	RE	A	84.9211	86.2424	86.2094	86.7157	86.8723	86.8708	85.1994	82.9816	72.6403	70.8211	63.3941	24.6784	12.8628	4.08212	2.18043
620	BW	A	87.9008	88.8657	89.128	84.4971	90.0172	89.5173	89.5302	88.4642	82.5146	82.7092	77.0855	42.885	24.8297	8.9645	5.4006
621	BW	A	90.0815	87.8855	88.6662	88.8745	89.1907	89.1629	88.7665	87.8413	82.9419	78.0628	76.8096	42.0618	24.1271	8.66938	5.1946
622	BW	A	90.0284	87.828	88.6816	88.8087	89.0857	89.269	88.4438	87.8163	82.8071	79.037	76.595	41.9858	24.1905	8.65247	5.1919
623	BW	A	83.8947	87.9463	88.5058	88.978	89.5823	89.5987	89.3078	88.1155	81.5036	83.9007	76.6738	42.1073	24.1627	8.67915	5.22987
624	BW	A	84.2305	88.013	88.7927	88.8914	89.3719	88.9129	88.9972	87.9972	82.1511	83.3741	76.7513	42.1974	24.1362	8.70132	5.20018
614	BW	B	91.9306	91.3636	89.934	90.4632	90.9318	89.3672	89.4241	87.2443	81.5311	74.7615	72.9532	34.703	19.2466	7.3717	4.62093
615	BW	B	87.478	90.1408	89.2133	89.8359	90.6246	89.2569	87.8781	86.711	80.9245	75.3464	71.974	33.7906	18.9382	6.96047	4.17844
616	BW	B	96.9892	94.1223	93.281	92.4724	91.4792	91.3069	88.904	87.2284	78.9965	79.8933	72.3955	33.8455	18.5425	6.55779	3.91336
620	BW	B	80.6753	87.5167	88.7228	89.8453	89.3533	88.1186	89.0477	86.7792	81.5176	72.2286	73.3542	34.5881	19.5318	7.35772	4.6377
601	BE	C	78.4714	86.3335	86.9225	87.4186	87.1853	87.5189	87.6772	86.8936	81.2978	79.945	75.4718	40.4997	23.1206	8.16689	4.88869
602	BW	C	86.583	90.4486	90.1746	90.3824	90.0615	89.9418	89.1372	87.6003	79.7033	78.0872	72.3506	33.6041	18.3806	6.61072	4.06808
602	BE	C	92.1268	88.9442	89.017	89.1088	88.9835	89.0077	87.457	85.3835	75.2274	73.5773	65.9505	25.759	13.5387	4.65262	2.80257
602	WE	C	91.5188	88.6099	88.6526	88.6432	88.9666	88.8731	87.2035	85.128	74.9882	73.0674	65.5786	25.4223	13.3275	4.56996	2.74581
603	BW	C	100.452	94.2531	92.9734	92.6566	91.6636	91.8988	89.3801	87.2659	77.859	75.2046	70.4473	31.1671	16.9051	5.89943	3.41079
603	BE	C	81.308	86.9895	87.2721	87.8787	87.5525	87.4778	85.7959	83.0118	71.2467	67.7192	61.4236	22.4799	12.0083	4.10666	2.40121
603	WE	C	88.8664	86.3208	86.7434	87	86.7472	86.7173	84.9893	82.6142	71.4394	69.7369	61.668	22.9521	11.8561	3.73848	2.01159

Table G.6 AC impedance measurements for specimens in test sequence 6
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
604	BW	C	90.4526	88.2308	89.0282	89.3715	89.5927	89.3858	89.7708	88.7115	81.8951	79.5413	75.7581	38.806	22.0687	8.13936	5.02076
605	BE	C	87.778	86.3949	85.6729	85.413	84.8592	84.6121	76.3445	70.675	57.8935	57.165	53.4499	28.5541	15.5763	4.30342	1.80759
606	BE	C	90.0336	84.8164	83.7023	82.8265	82.1955	81.7959	75.8162	70.9992	59.1954	58.1329	54.9944	29.9008	16.6421	4.78812	2.17571
607	BE	C	82.3319	84.7521	83.3051	82.7284	82.014	81.303	69.3087	63.0455	58.5909	58.2909	56.1444	30.6554	16.9152	4.72105	2.02111
608	BW	C	89.3008	89.7119	89.4383	89.774	89.5097	89.3828	88.022	86.6512	78.7567	77.8288	71.0313	32.2951	17.59	6.31187	3.82519
608	BE	C	85.5458	88.5952	88.3701	88.5418	88.3981	88.4971	86.5479	84.3337	73.9308	72.2454	64.4874	24.6339	12.9041	4.42244	2.65192
609	BW	C	85.2728	89.2498	89.3476	89.8489	89.4079	89.2422	88.0766	86.6964	79.0719	78.0335	71.7441	33.0802	18.3339	6.53321	4.03602
609	BE	C	91.5949	88.5613	88.3813	88.7687	88.5804	88.6209	86.8099	84.7798	74.8398	73.2178	65.7179	25.8646	13.6193	4.6841	2.81329
609	WE	C	86.3945	88.322	88.8615	88.472	88.498	88.3923	86.6116	84.5141	74.3876	72.8667	65.1844	25.2864	13.2926	4.56868	2.74505
610	BW	C	85.1677	89.1978	89.441	89.3067	89.3115	89.2397	88.0506	86.2392	78.644	77.402	70.6801	32.68765	17.96195	6.42254	3.930605
610	BE	C	86.0709	88.4816	88.6746	88.0386	88.4235	88.3261	86.4842	84.2445	73.6868	71.9678	64.1486	24.3257	12.7175	4.3649	2.62911
611	BW	C	83.6472	87.0431	86.858	87.021	86.936	86.89	85.7253	84.676	77.8741	76.2679	70.4767	32.6703	17.749	6.10681	3.65209
611	BE	C	84.8493	85.9699	85.983	85.9611	85.9737	86.0111	85.2547	83.6156	74.3788	72.5584	65.4169	26.0445	13.6887	4.59704	2.6704
612	BW	C	84.9054	87.0212	86.9048	87.2415	87.154	86.6217	85.893	84.4695	77.5565	76.0412	70.3621	32.2843	17.6896	6.21633	3.74771
612	BE	C	87.2697	83.9786	85.892	85.9399	85.5788	85.575	84.7683	82.7763	72.9998	69.9395	63.204	24.1616	12.7602	4.479	2.76893
613	BW	C	87.7988	87.7232	88.7091	88.0031	87.7284	87.5283	86.4191	85.0491	77.7795	77.5906	71.3375	33.5769	18.3803	6.4134	3.84272
613	BE	C	82.708	86.1979	85.7645	85.7023	85.8863	85.2491	84.0171	82.4691	73.3732	71.8241	63.9379	24.919	13.106	4.61433	2.77337
617	BE	C	79.509	85.0122	85.3443	85.7727	86.3055	86.2136	85.9379	85.1827	80.5621	79.7215	75.9542	45.6554	27.3054	9.66211	5.62103
618	BW	C	84.5467	87.492	87.8495	87.8056	88.4463	88.1361	87.1937	85.9761	79.2141	77.9132	72.4645	34.8998	19.2808	6.77959	4.04304
618	BE	C	90.1763	88.0114	88.0078	88.1716	88.0273	87.9948	86.443	84.5604	75.2694	73.6489	66.5333	26.8925	14.1919	4.8591	2.9095
619	BW	C	77.711	84.1292	84.8437	84.8413	84.8654	84.9371	84.4572	83.6758	78.2077	76.2902	71.8177	34.8982	19.3981	6.65704	3.87163
619	BE	C	82.1869	85.548	85.5468	85.7457	85.8606	85.6154	84.9761	83.2807	74.4026	71.3103	65.0542	25.6822	13.5329	4.58317	2.69091
621	BW	C	90.5129	90.8861	90.8774	90.938	91.1152	90.6937	89.7097	87.729	79.1299	80.0312	71.1241	31.8039	17.4773	6.35585	3.9259
622	BW	C	87.1409	91.5782	90.705	90.592	90.8146	90.4236	89.2586	87.5515	78.9556	79.7155	70.8809	31.8525	17.187	6.23811	3.88758
623	BW	C	88.5334	90.6887	91.3548	90.9748	90.6482	90.7815	89.8439	87.9797	78.8481	78.4284	70.8417	31.1443	17.2973	6.17657	3.83581
624	BW	C	86.3494	88.8383	88.8528	89.1339	89.0624	89.0826	87.8756	86.4703	78.7813	77.6915	71.7064	33.301	18.1441	6.23326	3.70233
605	BE	E	84.2188	82.79	81.9127	80.9807	80.6834	80.0451	72.417	67.5713	56.2863	56.8091	51.1192	23.0299	11.3855	2.42074	0.623016
606	BE	E	85.0958	81.1715	80.763	79.9931	79.1372	78.8453	71.2778	64.8737	55.3534	54.1423	51.9867	24.9926	12.8203	3.23697	1.26483
607	BE	E	65.4712	66.0758	68.3615	70.3168	71.1498	71.3908	67.2838	66.9785	67.1869	64.5622	60.8096	26.9837	14.6508	5.80843	4.22892
608	BW	E	87.7184	86.3315	85.8499	86.6298	86.5196	86.7456	86.6644	85.2409	77.3699	75.527	69.0949	29.8563	15.9785	5.497	3.2306
608	BE	E	75.2334	80.8531	81.3863	81.954	82.3396	82.4084	76.8036	69.8773	50.7444	48.1844	38.9887	12.897	7.75621	3.44433	2.32122
608	WE	E	82.8559	84.0857	85.2246	85.3121	85.5706	85.5999	84.7482	82.202	69.9398	64.9012	58.9584	20.4924	10.9847	4.51362	3.19232
609	BW	E	88.2237	85.9386	85.722	86.3226	84.7095	86.4798	86.8154	85.5727	77.9153	76.7176	70.6677	31.9273	17.2222	5.96644	3.52619
609	BE	E	83.2541	84.272	85.1238	85.7782	86.0287	86.8429	85.6021	83.4964	72.643	70.4847	62.7191	23.027	11.973	4.10391	2.44015
609	WE	E	80.3414	83.9186	84.4239	84.7947	85.6327	85.3442	84.8872	82.5312	70.7532	66.5471	60.07	21.5252	11.5491	4.72703	3.32246
610	BW	E	82.3323	85.0156	85.5831	86.1139	85.7552	86.6296	86.7539	85.2784	77.4702	75.2527	69.4395	30.5361	16.7224	6.40342	4.27449
610	BE	E	80.5295	84.7683	85.5785	83.7959	85.8602	86.0788	84.9508	82.5015	70.5016	67.902	59.5507	20.9815	11.1988	4.49804	3.17575

Table G.6 AC impedance measurements for specimens in test sequence 6
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
610	WE	E	81.9968	83.7515	84.25	84.7849	85.3169	85.4656	84.8726	82.1621	69.8133	67.8485	59.2024	20.7212	11.0412	4.4254	3.10872
611	BW	E	82.0425	84.6318	83.4587	84.6764	85.136	85.1385	84.7714	83.6862	75.2934	76.4743	68.4887	30.1746	16.7165	6.32882	4.07168
611	BE	E	78.8531	82.3385	83.8909	83.3306	84.0821	83.2843	83.9242	81.3486	70.5545	67.5234	59.4817	21.5809	11.5707	4.53898	3.07496
611	WE	E	85.0056	81.7321	81.8488	81.6189	82.0527	81.8303	80.4639	78.6436	68.0745	61.8824	57.0505	19.9292	10.5015	3.87779	2.57063
612	BW	E	88.2725	85.035	84.8252	85.1342	84.9122	85.952	85.1253	83.7614	76.3602	74.9223	68.6098	30.725	16.943	6.45206	4.29952
612	BE	E	78.7701	83.0129	83.2346	83.2608	83.2684	84.1298	83.677	81.152	69.1882	67.0675	59.9861	21.7248	11.4719	4.77112	3.43174
612	WE	E	86.4302	81.7018	81.3821	81.1781	81.3115	81.2329	80.0569	78.3648	67.6891	66.5283	56.5946	19.8304	10.4983	4.11709	2.81455
613	BW	E	89.8316	86.7056	87.2987	86.9314	86.7751	86.1718	84.4553	82.8103	77.3066	80.0928	69.7393	32.0802	17.9263	6.967	4.64827
613	BE	E	80.0832	85.6422	85.7074	86.4426	85.4955	86.465	85.0663	81.9821	71.0933	65.4531	60.5907	22.2316	12.3836	5.03173	3.61373
613	WE	E	83.6241	82.912	84.5136	84.7729	84.1316	84.696	82.8466	80.7778	69.802	67.4097	58.8117	21.4909	11.404	4.70515	3.37581
621	BW	E	91.7784	89.5021	87.2209	89.7986	89.7554	90.2121	88.428	86.9136	78.8725	77.2308	70.9458	31.8136	17.9288	7.6111	5.42283
621	BE	E	84.57	93.0906	84.923	84.0443	84.4965	84.3489	81.7318	77.9169	62.9848	57.1871	54.6036	20.7161	12.7089	8.49632	7.92266
621	WE	E	32.304	87.4516	87.9957	87.9267	87.3025	86.6488	83.0656	79.6506	69.3578	85.7584	57.5225	22.9802	13.1823	5.90527	4.21654
622	BW	E	94.1627	91.7736	91.4886	90.5749	89.8583	89.9489	88.0974	86.5489	79.0585	75.0693	70.4696	31.4943	17.6531	7.38269	5.20377
622	BE	E	82.5511	87.3041	86.9323	87.57	88.248	87.2135	82.0516	78.3202	67.2642	54.5603	57.4179	22.403	13.8406	7.47925	6.23475
622	WE	E	83.8212	87.0814	87.9723	87.046	86.2242	86.3279	82.8626	77.7814	64.9878	70.2258	56.0225	22.4181	13.6835	7.50974	6.09674
623	BW	E	87.5831	89.3175	89.8128	89.9111	89.8285	89.1735	88.5968	87.0062	78.5791	78.6203	70.8311	31.9719	18.174	7.78595	5.46808
623	BE	E	83.7522	87.3693	85.9524	86.7785	86.3651	84.9246	80.6018	75.5095	58.9315	65.5978	50.6178	18.9104	13.4744	9.52765	9.01808
623	WE	E	84.7225	87.0187	87.3374	86.0735	85.6435	85.7002	79.2305	75.3921	62.0061	56.5426	50.0154	19.2615	13.1565	9.40412	8.64027
601	BE	F	80.123	85.7732	86.1999	87.0495	86.9972	87.2741	87.4629	86.0626	78.5985	74.7796	70.9147	32.295	17.7944	6.96441	4.7802
602	BW	F	83.5172	88.7541	88.8503	89.172	89.4575	89.4039	87.9295	86.3241	78.3469	76.0139	70.973	32.0797	17.3978	6.2088	3.85595
602	BE	F	83.0647	87.6653	88.4803	88.3293	88.417	88.3157	86.861	84.814	74.6806	65.3557	25.3305	13.2523	4.56004	2.73736	2.9422
602	WE	F	88.7575	87.4412	88.3156	87.8127	87.9073	88.151	86.6965	84.5691	74.4266	72.6579	65.0583	25.1184	13.1292	4.50712	2.6977
603	BW	F	91.6184	88.5608	87.0425	89.1398	87.1936	87.7214	85.6345	84.6679	79.2295	78.7372	73.1884	36.7496	20.6731	7.85438	5.16669
603	BE	F	80.5996	82.5812	82.6903	82.62	82.346	82.9097	81.2858	79.9787	72.7248	74.1754	65.0424	28.5016	16.2655	8.19398	6.92287
603	WE	F	81.8561	82.5013	82.0522	82.4391	82.0045	82.7669	81.1002	80.0183	74.1281	68.4948	65.5286	28.2206	16.2094	8.17543	6.8545
604	BW	F	91.6184	88.5608	87.0425	89.1398	87.1936	87.7214	85.6345	84.6679	79.2295	78.7372	73.1884	36.7496	20.6731	7.85438	5.16669
604	BE	F	80.5996	82.5812	82.6903	82.62	82.346	82.9097	81.2858	79.9787	72.7248	74.1754	65.0424	28.5016	16.2655	8.19398	6.92287
604	WE	F	81.8561	82.5013	82.0522	82.4391	82.0045	82.7669	81.1002	80.0183	74.1281	68.4948	65.5286	28.2206	16.2094	8.17543	6.8545
605	BE	F	78.5531	82.1718	81.5606	80.8972	79.8882	79.7576	70.4338	65.76	53.5987	48.498	45.3805	16.3068	8.70913	4.30775	3.9228
606	BE	F	79.8071	81.4292	79.7595	78.5676	77.8105	77.1864	70.4194	66.5544	54.4883	52.2957	47.9544	19.7616	11.4807	6.27003	5.68445
607	BE	F	58.7534	64.3198	68.5267	67.2997	62.2479	63.8086	82.976	81.097	71.4948	66.484	61.3267	24.9173	15.0846	8.77909	7.92003
608	BW	F	88.862	85.0697	85.4782	85.4773	85.9456	85.8614	86.1059	84.8883	77.0062	75.3763	69.2763	30.2799	16.3903	6.00106	3.85607
608	BE	F	79.6663	84.0596	84.3149	84.8406	85.3002	85.5156	84.7468	82.4652	70.6867	69.1601	60.2894	21.3703	11.2137	4.20873	2.81323
608	WE	F	87.2393	84.0277	84.8995	85.4067	85.563	85.7029	84.822	82.4031	70.4136	68.0353	59.8356	21.0277	11.0225	4.13441	2.76866
609	BW	F	82.814	85.8425	86.0119	86.3163	86.6334	86.557	86.6493	85.4053	77.7221	76.649	70.1762	31.5503	17.3614	6.73406	4.56047
609	BE	F	86.4656	84.3149	85.131	85.7813	85.7833	85.8734	85.1915	82.7272	70.8864	69.6346	60.7125	21.8377	11.7899	4.85047	3.51424

Table G.6 AC impedance measurements for specimens in test sequence 6 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
609	WE	F	84.9157	83.6074	84.0316	84.5737	85.2744	85.1826	84.5451	82.3533	70.6587	68.1974	59.9163	21.3707	11.5184	4.70684	3.38922
610	BW	F	85.4658	85.5483	85.7462	86.2391	86.4228	86.4521	86.4797	85.0374	76.8779	75.2034	68.9692	30.0964	16.4079	6.22004	4.1383
610	BE	F	84.5636	84.3368	85.3128	85.3717	85.6641	85.5444	84.9191	82.1799	69.8326	70.4348	59.274	20.6911	11.0973	4.42755	3.12829
610	WE	F	78.4739	83.7433	83.7845	84.4619	85.2056	85.4087	84.3774	81.8796	69.5938	69.7533	58.8365	20.3671	10.9346	4.33534	3.04892
611	BW	F	87.9059	86.0132	85.0913	84.8204	85.0803	84.9978	84.3218	83.2575	75.8195	74.8301	68.2233	30.0974	16.4562	6.20249	4.07619
611	BE	F	82.613	83.0599	82.4271	82.4571	82.1958	82.2367	81.7116	79.9788	69.6546	66.8429	59.3139	21.3435	11.3224	4.51564	3.16415
611	WE	F	83.3574	82.0256	81.5924	81.3377	81.5908	81.0977	80.4127	78.3578	67.2193	64.9583	56.668	19.7166	10.3865	3.90789	2.64664
612	BW	F	82.3073	85.5221	85.461	85.4625	85.0057	85.1068	84.4669	83.2949	75.8048	74.4413	68.4988	30.2986	16.5397	6.15827	4.01446
612	BE	F	82.3721	83.4269	82.4436	82.8867	82.5011	82.6343	82.3884	80.5379	70.2914	67.4301	60.1078	21.7385	11.5147	4.47596	3.08557
612	WE	F	85.51	81.953	81.4258	81.4146	81.4327	81.2822	80.2744	78.4621	67.7406	65.5584	57.4172	20.1103	10.4481	3.84714	2.57459
613	BW	F	82.8919	86.5425	87.1812	87.3966	87.4625	87.637	86.0736	84.5202	76.823	74.9224	69.4608	31.0751	16.896	6.07998	3.84103
613	BE	F	81.2071	84.4213	84.1261	84.287	84.5873	84.6613	83.2698	81.2968	71.0408	68.7659	61.0856	22.4327	11.7387	4.18071	2.7873
613	WE	F	84.6342	84.8165	84.8222	84.495	84.4025	83.7721	81.3408	79.3236	69.3398	67.9822	59.6438	21.5514	11.2217	3.98295	2.53279
621	BW	F	92.1158	89.0333	88.7207	89.0528	88.8259	88.398	87.7102	85.9729	77.387	75.8751	69.4143	30.5696	17.3416	7.49755	5.52156
621	BE	F	87.3524	85.8116	85.9231	84.7797	85.6055	86.0555	82.612	79.0597	65.7555	70.1793	56.3191	23.0065	15.4757	10.8038	9.8403
621	WE	F	87.5572	86.1205	85.509	85.7323	85.2063	85.709	82.66	79.1334	66.5298	63.8799	56.4764	22.7874	15.1767	10.66	9.63164
622	BW	F	89.2617	88.4341	88.9899	89.0835	88.6927	88.8417	87.7425	86.1301	77.7516	76.5504	70.1304	30.9449	17.2438	6.92778	4.81101
622	BE	F	84.3252	86.6685	85.4921	86.4888	86.1771	86.0216	81.9912	77.9853	66.5579	64.3947	57.7218	22.7198	13.0603	6.70794	5.45845
622	WE	F	93.3842	85.001	83.8105	83.0922	82.5569	83.6188	77.1994	73.9161	64.245	68.2462	57.6834	23.7329	14.0913	7.91927	6.97271
623	BW	F	87.1991	89.5694	89.7717	89.7931	89.6204	89.4093	87.8096	86.0151	77.2076	75.5433	68.9999	29.8379	16.4914	6.76916	4.81314
623	BE	F	86.9224	82.4053	77.8749	79.7707	80.4911	79.8496	79.0485	75.8129	64.4106	61.3399	55.1412	23.1055	15.7041	11.1014	10.5102
623	WE	F	81.993	79.5345	79.8457	79.7783	79.9603	80.3892	79.3221	76.2072	63.971	71.4656	55.8646	24.2768	15.9937	11.2635	10.6612
601	BE	G	77.1631	82.4269	83.7303	84.2751	83.9582	84.8409	86.3928	83.5493	74.9314	58.2	65.5741	27.7473	17.3267	9.81795	8.46754
602	BW	G	86.6162	89.0153	89.916	89.7597	89.8024	89.6975	88.3836	86.5455	78.0097	79.6546	70.5762	31.8014	17.343	6.40495	4.11658
602	BE	G	88.8794	87.388	87.6119	87.9564	87.9363	88.4111	86.3205	83.7833	71.8667	70.3767	62.1949	22.638	11.959	4.53233	2.99287
602	WE	G	86.3476	86.9701	87.147	87.37	87.5248	88.795	86.2344	83.5103	72.2773	70.3604	61.7103	22.3091	11.7384	4.41778	2.6977
603	BW	G	91.5961	88.3389	88.3911	88.9997	88.5366	89.2807	87.3049	85.6095	76.5779	76.4517	68.8247	29.9223	16.1889	5.84391	3.61974
603	BE	G	85.4955	85.1074	85.1797	85.9839	85.9987	86.4236	84.8794	82.271	70.0993	70.7331	59.3519	20.9047	10.9569	3.98077	2.51127
603	WE	G	85.7845	88.8089	88.3196	88.5628	88.4917	88.3376	87.1484	85.3976	76.3324	76.6666	68.7107	29.6988	16.0122	5.81126	3.62457
604	BW	G	87.3876	90.2004	88.0399	90.17	89.5905	89.1281	87.7706	86.5095	79.0209	80.3523	73.0785	36.1647	20.3268	7.8538	5.24096
604	BE	G	-27.817	78.9971	81.2504	84.3842	83.2782	79.6118	81.6743	81.6004	76.5099	60.6343	63.9276	28.038	16.1796	9.01228	7.78541
604	WE	G	81.6227	81.7273	82.385	81.7518	82.2567	83.5166	78.0258	81.2973	72.9279	84.0515	64.3245	28.7872	16.3562	8.76184	7.65569
605	BE	G	83.6321	79.6637	78.5948	77.5373	73.0472	76.0162	69.4096	66.5403	55.0627	56.7696	48.6707	19.1323	10.5787	5.14759	4.48191
606	BE	G	68.4412	73.6335	69.6481	69.8974	69.1065	68.3176	65.8234	66.3925	63.7383	47.3818	54.3362	21.8533	12.7049	6.55134	5.57207
607	BE	G	71.1232	65.2996	67.4234	68.6946	68.7413	68.9791	73.7874	75.3187	66.0746	66.485	62.1993	26.3366	16.1242	9.04711	7.46793
608	BW	G	90.2315	86.6709	87.0771	87.6744	87.3282	87.8856	87.943	86.5312	77.4168	75.6697	69.5233	30.4068	16.4245	6.04027	3.85239
608	BE	G	82.3617	84.7603	85.1721	85.7642	85.9008	86.1552	85.5992	83.5959	73.0064	70.9558	63.2419	23.5914	12.2784	4.2201	2.51202

Table G.6 AC impedance measurements for specimens in test sequence 6 (phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
608	WE	G	84.5615	83.7065	84.0876	84.6674	85.3392	85.4743	85.2405	83.2397	72.3681	70.7926	62.6023	23.1083	12.0028	4.12268	2.45032
609	BW	G	89.133	85.7588	85.7401	86.4764	86.2837	86.6203	86.359	85.1738	77.7144	75.8921	70.0788	31.397	17.3314	6.9719	4.76392
609	BE	G	85.1638	83.8662	85.3102	84.9671	85.7471	85.6999	84.743	82.1371	70.6247	69.626	60.1045	21.7807	11.9173	4.9941	3.68262
609	WE	G	85.619	83.5684	84.6646	84.8862	85.1542	85.4779	84.4711	81.9339	70.502	66.5847	59.375	21.3862	11.5366	4.92911	3.53183
610	BW	G	89.3015	87.9715	89.6056	87.4926	88.8426	88.4734	86.6447	85.1613	77.087	74.2692	68.858	29.9133	16.3	6.24573	4.07886
610	BE	G	81.7339	84.7247	84.8684	85.6838	85.891	85.9038	85.3107	83.1755	72.545	70.937	62.7842	23.2823	12.1166	4.19455	2.51987
610	WE	G	80.4154	84.0626	84.6362	85.5812	85.6176	85.9513	85.0722	82.9897	72.2033	70.3578	62.4238	22.9731	11.9017	4.14592	2.47672
611	BW	G	90.6298	83.5319	86.4929	86.6905	86.2174	86.0013	84.935	83.6767	76.2433	72.7362	68.2265	30.0099	16.4791	6.32496	4.17066
611	BE	G	86.0479	83.3127	83.4065	83.1572	83.4964	83.142	82.7218	80.6436	69.6007	66.9447	59.0648	21.268	11.5178	4.62031	3.23926
611	WE	G	79.6127	83.0307	82.9063	82.8792	82.1823	82.3088	80.4175	78.3666	67.0973	67.4904	56.7353	19.8196	10.4805	3.9998	2.69992
612	BW	G	81.7044	85.3237	85.7365	85.4685	85.4699	85.448	85.0605	83.6733	76.4091	74.7319	68.5285	30.4357	16.5478	6.08449	3.85252
612	BE	G	84.797	83.1965	83.8014	83.6034	83.4969	83.5248	82.9677	81.0546	70.1614	67.7275	60.6332	21.9749	11.6846	4.42654	2.97566
612	WE	G	79.317	82.6659	82.2675	82.2042	82.1755	82.126	80.5303	78.5692	67.9217	63.096	57.9244	20.4588	10.6783	3.82169	2.44101
613	BW	G	88.3109	86.432	86.3101	86.3853	85.911	85.8653	84.0497	82.6782	76.4188	74.7214	69.3437	31.7623	17.243	6.16496	3.77626
613	WE	G	85.9172	84.9337	85.0388	84.4506	84.1446	84.0279	81.399	79.7117	71.7223	70.0304	63.0236	24.6633	12.8684	4.26272	2.394
613	BE	G	86.4758	84.899	84.7625	84.8226	84.9523	84.8613	83.3391	81.7278	73.2062	71.9499	64.6277	25.7769	13.5051	4.5417	2.60528
621	BW	G	85.86	89.1418	88.6897	88.0783	88.4958	88.0306	86.1215	84.5151	75.565	75.477	68.0072	30.2733	17.6001	8.24009	6.20197
621	BE	G	84.1965	84.9345	84.7738	85.016	85.4757	84.9113	81.5379	76.85	63.3029	55.9602	51.1098	19.8287	12.6204	7.93283	6.46414
621	WE	G	83.3791	80.9582	81.9189	82.5184	82.3704	82.7268	81.7877	76.4968	64.0644	78.0658	54.359	21.7908	14.2727	7.88918	5.73536
622	BW	G	93.0711	92.7623	91.5615	90.3864	89.5306	89.7694	86.0494	84.6414	75.6144	74.5041	67.8916	29.5027	16.3783	6.8967	4.95381
622	BE	G	82.4293	86.4304	82.0611	85.1766	85.0851	85.8948	82.4941	80.6886	68.7207	59.6791	58.0731	21.3257	11.3597	4.87554	3.46314
622	WE	G	87.3061	86.2197	86.0579	86.2736	86.116	86.4945	83.0391	80.6667	68.4872	56.4816	56.7214	19.7193	10.5843	4.51958	3.03881
623	BW	G	93.8204	102.925	96.1672	96.524	95.3985	95.2314	88.5358	85.8213	75.6705	74.9599	67.7365	29.6512	17.1795	7.61938	5.48188
623	BE	G	80.1055	83.5148	83.5161	83.4845	84.1385	83.2448	80.9401	77.1489	63.6913	58.8851	52.7337	18.0428	10.9088	5.92901	5.03594
623	WE	G	82.2079	82.9231	82.6406	83.0561	82.827	84.2969	80.6145	76.5653	61.5823	32.216	52.1136	18.6117	10.2394	5.68492	4.83832
601	BE	H	84.6154	83.4448	84.1683	83.9955	84.4346	84.4912	84.0392	82.9947	76.1336	74.4041	69.9706	32.7096	17.8115	5.82954	3.20605
602	BW	H	90.3818	88.3913	88.226	88.3209	88.6768	88.2606	87.0891	85.5656	77.074	74.6153	68.3482	28.9448	15.4277	5.28423	3.10171
602	BE	H	88.3699	84.9606	87.9877	87.9926	87.493	87.55	85.1012	82.1768	69.8052	67.1526	58.7114	20.251	10.4038	3.40943	1.92082
602	WE	H	84.9545	97.8727	87.4742	87.8214	87.8427	87.7446	85.3149	82.409	69.7793	68.0349	58.8812	20.2415	10.4464	3.4644	1.9531
603	BW	H	56.5769	73.0346	78.6783	80.8901	81.9582	82.6431	82.6538	79.0669	62.3887	59.7856	49.5585	15.4259	7.83941	2.30573	1.14802
603	BE	H	0.5179	0.67153	0.740784	0.845951	1.01074	1.11639	4.12127	7.69475	17.2708	17.2505	14.3737	7.13072	1.013612	2.02579	0.795853
603	WE	H	50.4342	71.426	76.6692	77.6625	79.2761	79.7226	77.9303	72.4255	48.9075	46.2192	35.9701	12.7955	8.65915	6.74341	7.31744
604	BW	H	85.9585	90.8835	89.5251	89.9033	89.8391	89.6265	88.5521	86.7934	77.9329	79.8068	70.4553	31.0964	16.8452	5.82663	3.44447
604	BE	H	89.1719	82.6968	83.9961	82.4232	81.7645	81.2638	79.4345	78.3263	71.9368	73.0752	64.4012	27.69	14.7444	4.59289	2.38029
604	WE	H	88.4982	83.8749	83.296	82.7839	81.9676	82.3035	79.5528	78.6715	71.7578	69.2576	64.6732	28.1286	15.0088	4.69587	2.45325
605	BE	H	3.62774	3.80272	4.03097	4.35754	4.61584	4.82552	10.6278	16.5818	38.2358	41.3313	41.578	21.7778	10.5327	0.915012	-1.4704
606	BE	H	1.42024	0.733361	0.95445	1.00038	1.12967	1.24383	4.24278	7.36587	18.648	21.0094	20.9944	14.465	7.61392	0.416122	-1.5086

Table G.6 AC impedance measurements for specimens in test sequence 6
(phase angle at various frequencies of applied test voltage)

			FREQUENCY (Hertz)														
CBL	Cnd	CM	0.1	0.3	0.5	0.7	0.9	1	5	10	50	60	100	500	1000	3000	5000
607	BE	H	0.801535	1.48447	2.11041	2.80697	3.38513	3.86319	14.7268	23.1709	40.5245	37.813	39.2689	17.7923	8.74114	0.435017	-1.7003
608	BW	H	86.0824	89.0661	88.7088	88.942	88.7448	88.9105	87.1093	85.0472	74.7686	73.7711	65.6171	25.6499	13.4572	4.61478	2.74863
608	BE	H	86.8634	87.9134	88.3885	88.0636	87.7237	87.704	84.6815	81.14	66.2524	64.8997	54.5351	17.3338	8.86101	3.001	1.78838
608	WE	H	84.3533	88.0358	87.4691	87.3275	87.287	87.4926	84.4557	80.6822	65.7414	63.1701	53.5334	16.6341	8.48073	2.88872	1.70306
609	BW	H	88.5587	87.7277	87.9537	87.5528	88.1254	88.0777	86.4921	83.9506	73.632	71.4377	64.232	24.9686	13.0143	4.35422	2.5051
609	BE	H	87.5219	86.3733	86.8687	86.7744	86.2938	86.3246	83.2555	79.7124	65.3979	63.1426	53.5315	16.989	8.7202	2.84303	1.64148
609	WE	H	81.8659	87.1352	86.6363	87.3416	86.8013	86.8273	83.5199	79.7495	64.5273	61.3026	52.2979	16.2346	8.22074	2.76179	1.57508
610	BW	H	92.0255	88.939	88.9271	88.8966	89.0467	88.8306	87.2151	84.9919	74.5983	74.1641	65.443	25.47	13.4224	4.5495	2.68824
610	BE	H	85.6662	88.0254	88.3163	87.939	87.7173	87.4788	84.3752	80.5708	65.2509	62.6682	53.2264	16.64	8.46865	2.84571	1.67819
610	WE	H	90.358	88.1513	87.9154	87.7516	88.0329	87.7759	84.5998	81.0203	66.1835	64.2808	54.2556	17.1649	8.79479	2.93826	1.73762
611	BW	H	2.14577	6.01394	9.67205	13.2013	16.4468	18.5645	53.3131	61.7512	56.0864	53.1359	45.4052	16.5106	8.77068	2.8766	1.60667
611	BE	H	2.24237	6.59189	10.4098	13.968	17.1912	19.4337	54.8541	63.5289	59.3052	56.3817	47.83	14.2227	7.17306	2.34902	1.33078
611	WE	H	0.56985	0.69132	0.784941	0.907805	1.03112	1.12466	4.2501	7.77745	16.7746	16.3243	14.2939	6.02273	3.16547	0.890311	0.392267
612	BW	H	1.16695	2.33296	3.36386	4.4	5.36488	6.04792	24.0904	37.3133	51.4892	51.3193	48.0828	19.9851	10.509	3.54444	2.08701
612	BE	H	0.213425	0.38117	0.546567	0.712369	0.87218	0.980777	4.26602	7.9548	22.7971	23.3112	24.9818	10.1054	5.20802	1.76306	1.03892
612	WE	H	1.0963	2.34254	3.52813	4.66575	5.7402	6.45638	25.4838	39.9122	56.2412	55.9711	48.4354	15.5725	7.9762	2.67863	1.58123
613	BW	H	13.5752	29.3704	40.9932	49.5245	54.6691	57.8128	72.3748	69.211	61.6217	61.0787	58.5093	26.3601	14.0621	4.65985	2.63701
613	BE	H	0.999889	1.18144	1.21755	1.33755	1.49252	1.60594	5.78836	10.637	33.4427	34.5646	36.8696	15.3782	7.89709	2.48717	1.3428
613	WE	H	11.1786	27.6631	39.4076	48.1181	53.6617	56.8954	74.0963	72.0761	56.3686	54.1254	44.0411	13.1138	7.1166	3.09137	2.37322
621	BW	H	81.8565	85.3539	84.9744	85.001	84.907	85.0125	82.5701	79.668	68.1654	65.251	58.1398	21.0331	10.8303	3.32986	1.70922
621	BE	H	81.1109	82.6616	82.6078	81.3635	81.2663	80.8869	74.6702	70.6574	59.5253	58.6404	50.0919	17.5414	8.53915	1.4712	-0.272862
621	WE	H	81.8806	82.2862	81.8713	81.0373	80.7367	80.1625	73.2026	69.1057	58.4286	56.3989	48.9426	16.9221	8.1022	1.17033	-0.518973
622	BW	H	84.6373	86.2665	86.1327	86.1106	86.0564	85.8624	83.0911	79.7973	66.6944	65.045	56.3413	19.4764	9.94797	2.97855	1.47794
622	BE	H	77.6116	77.8842	76.2549	75.9704	74.9487	74.7471	68.9552	66.5979	59.7483	59.2431	53.9197	23.8443	12.6057	3.36904	1.15574
622	WE	H	84.603	77.7898	75.414	74.4756	73.3943	73.0729	67.8879	65.8769	59.4556	56.0395	53.6199	22.7244	11.7189	2.67252	0.425789
623	BW	H	86.0594	84.9774	84.953	84.5552	84.667	84.5642	81.3762	77.982	64.7874	62.3676	53.953	17.9877	9.18476	2.76324	1.39285
623	BE	H	80.2441	79.3677	78.4325	77.8622	77.6326	77.2437	70.9599	65.498	51.574	49.7095	43.5116	17.1736	8.25577	0.89679	-0.729894
623	WE	H	85.4571	80.5727	80.128	79.4045	78.5507	78.3374	72.3597	67.2183	53.0077	49.3001	44.454	17.6578	8.5431	1.09679	-0.559243

Appendix H

Insulation Resistance Data

Tables

Title **Page**

Table H.1 Insulation resistance measurements for specimens in test sequence 1

		C	IR in Giga-ohms		Temp	Polrizatn		C	IR in Giga-ohms		Temp	Polrizatn		C	IR in Giga-ohms		Temp	Polrizatn		C	IR in Giga-ohms		Temp	Polrizatn		C	IR in Giga-ohms		Temp	Polrizatn		C	IR in Giga-ohms		Temp	Polrizatn	
CBL	Cnd	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
101	BW	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
102	BW	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
118	BW	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
104	BW	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
105	BW	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
106	BW	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
106	BE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
106	WE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
107	BW	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
107	BE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
107	WE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
108	BW	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
108	BE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
108	WE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
109	BW	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
109	BE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
109	WE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
110	BW	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
110	BE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
110	WE	A	> 2	> 2	-	> 1	-	B	> 2	> 2	-	> 1	-	D	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
111	BW	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
111	BE	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
111	WE	A	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	> 1	-
112	BW	A	> 2	> 2	-	> 1	-	C	> 2	> 2	-	> 1	-	E	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	unknw	-
113	BW	A	> 2	> 2	-	> 1	-	C	> 2	> 2	-	> 1	-	E	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	< 1	-
114	BW	A	> 2	> 2	-	> 1	-	C	> 2	> 2	-	> 1	-	E	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	unknw	-
115	BW	A	> 2	> 2	-	> 1	-	C	> 2	> 2	-	> 1	-	E	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	unknw	-
116	BW	A	> 2	> 2	-	> 1	-	C	> 2	> 2	-	> 1	-	E	> 2	> 2	-	> 1	-	F	> 2	> 2	-	> 1	-	G	> 2	> 2	-	> 1	-	H	> 2	> 2	-	unknw	-
117	BW	A	> 2	> 2	-	> 1	-	C	> 2	> 2	-	> 1	-	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-

Table H.2 Insulation resistance measurements for specimens in test sequence 2

CBL	Cnd	C M	IR in Tera-ohms @ 1 Min	IR in Tera-ohms @ 10 Mi	Temp (F)	Polrizatn Index	RH %	C M	IR in Tera-ohms @ 1 Min	IR in Tera-ohms @ 10 Mi	Temp (F)	Polrizatn Index	RH %	C M	IR in Tera-ohms @ 1 Min	IR in Tera-ohms @ 10 Mi	Temp (F)	Polrizatn Index	RH %	C M	IR in Tera-ohms @ 1 Min	IR in Tera-ohms @ 10 Mi	Temp (F)	Polrizatn Index	RH %	C M	IR in Tera-ohms @ 1 Min	IR in Tera-ohms @ 10 Mi	Temp (F)	Polrizatn Index	RH %	C M	IR in Tera-ohms @ 1 Min	IR in Tera-ohms @ 10 Mi	Temp (F)	Polrizatn Index	RH %
201	BW	A	8	15	74	1.875	49	--	-	-	-	-	-	--	-	-	-	-	-	F	0.22	0.35	80.6	1.59091	44	G	0.94	1.45	70	1.54255	27.5	H	0.49	3.15	75.5	6.42857	39
201	BR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.26	0.28	80.6	1.07692	44	G	0.89	1.41	69	1.58427	27.5	H	-	-	-	-	-
201	WR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.58	0.68	80.6	1.17241	44	G	0.7	0.92	69	1.31429	27.5	H	-	-	-	-	-
201	BG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.21	0.28	80.6	1.33333	44	G	0.94	1.38	68.9	1.46809	27.5	H	-	-	-	-	-
201	WG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.32	80.6	1.06667	44	G	0.69	0.895	69.3	1.2971	27.5	H	-	-	-	-	-
201	RG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.35	0.52	80.6	1.48571	44	G	0.645	0.82	69.7	1.27132	27.5	H	-	-	-	-	-
201	BE	A	1.5	3	74	2	49	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.46	0.815	70.2	1.77174	27.5	H	0.03	0.0395	75.5	1.31667	39
201	WE	A	1.7	2.5	74	1.47059	49	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.32	0.405	70.3	1.26563	27.5	H	0.038	0.043	75.5	1.13158	39
201	RE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.27	0.38	70.6	1.40741	27.5	H	-	-	-	-	-
201	GE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.245	0.315	71.5	1.28571	27	H	-	-	-	-	-
202	BW	A	50	100	74	2	49	--	-	-	-	-	-	--	-	-	-	-	-	F	0.15	0.22	78.8	1.46667	44	G	0.86	1.1	71.9	1.27907	27	H	0.395	2.05	73.7	5.18987	41
202	BR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.15	0.22	78.8	1.46667	44	G	0.69	1	72	1.44928	27	H	-	-	-	-	-
202	WR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.09	0.13	78.8	1.44444	44	G	0.57	0.87	72.1	1.52632	27	H	-	-	-	-	-
202	BE	A	1.5	5.5	74	3.66667	49	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.31	0.53	72.2	1.70968	27	H	0.00365	0.0042	73.7	1.15068	41
202	WE	A	2	100	74	50	49	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.24	0.34	72.4	1.41667	27	H	0.004	0.00435	73.9	1.0875	41
202	RE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.215	0.305	72.5	1.4186	27	H	-	-	-	-	-
203	BW	A	15	15	74	1	49	B	3	13	71	4.33333	46	D	0.88	1.4	70.8	1.59091	54	F	0.5	0.75	77	1.5	34	G	0.275	0.41	74.3	1.49091	25.5	H	0.76	3.1	87.8	4.07895	35
203	BR	A	-	-	-	-	-	B	2	5	71	2.5	46	D	0.45	0.62	75.5	1.37778	77	F	0.62	0.72	77	1.16129	34	G	0.24	0.35	74.3	1.45833	25.5	H	-	-	-	-	-
203	WR	A	-	-	-	-	-	B	3	12	71	4	46	D	0.39	0.52	75.9	1.33333	77	F	0.5	0.58	77	1.16	34	G	0.156	0.205	74.5	1.3141	25.5	H	-	-	-	-	-
203	BG	A	-	-	-	-	-	B	1.6	2.8	71	1.75	46	D	0.73	1.21	75.7	1.65753	77	F	0.58	0.68	77	1.17241	34	G	0.214	0.36	74.4	1.68224	25.5	H	-	-	-	-	-
203	WG	A	-	-	-	-	-	B	1.6	8	71	5	46	D	0.85	1.38	76	1.62353	77	F	0.5	0.55	77	1.1	34	G	0.172	0.222	74.5	1.2907	25.5	H	-	-	-	-	-
203	RG	A	-	-	-	-	-	B	2.5	9	71	3.6	46	D	1.07	1.55	76.2	1.4486	77	F	0.375	0.475	77	1.26667	34	G	0.125	0.15	74.6	1.2	25.5	H	-	-	-	-	-
203	BE	A	1.3	3	74	2.30769	49	B	1.1	6.8	71	6.18182	46	D	0.24	0.3	72	1.25	54	F	-	-	-	-	-	G	0.175	0.26	74.7	1.48571	25	H	0.024	0.031	78.8	1.29167	35
203	WE	A	1.7	2	74	1.17647	49	B	1.2	4	71	3.33333	46	D	0.28	0.35	72.5	1.25	54	F	-	-	-	-	-	G	0.096	0.122	75	1.27083	25	H	0.029	0.034	78.8	1.17241	35
203	RE	A	-	-	-	-	-	B	0.25	0.4	71	1.6	46	D	0.17	0.25	75.1	1.47059	77	F	-	-	-	-	-	G	0.054	0.069	75.1	1.27778	25	H	-	-	-	-	-
203	GE	A	-	-	-	-	-	B	0.2	0.2	71	1	46	D	0.28	0.94	75.3	3.35714	77	F	-	-	-	-	-	G	0.056	0.066	75.2	1.17857	25	H	-	-	-	-	-
204	BW	A	15	20	74	1.33333	43	B	1.3	2.4	71	1.84615	47	D	0.88	1.11	72.8	1.26136	54	F	0.52	0.72	78.8	1.38462	35	G	0.235	0.335	75.9	1.42553	25	H	0.36	1.52	78.9	4.22222	35
204	BR	A	-	-	-	-	-	B	1	3	71	3	47	D	1.08	1.4	76.4	1.2963	54	F	0.4	0.55	78.8	1.375	35	G	0.2	0.285	76	1.425	25	H	-	-	-	-	-
204	WR	A	-	-	-	-	-	B	1.5	3.1	71	2.06667	47	D	1.05	2.2	73.3	2.09524	77	F	0.45	0.58	78.8	1.28889	35	G	0.15	0.198	76	1.32	25	H	-	-	-	-	-
204	BG	A	-	-	-	-	-	B	0.85	1.25	71	1.47059	47	D	0.4	0.63	76.5	1.575	54	F	0.4	0.5	78.8	1.25	35	G	0.235	0.295	76	1.25532	25	H	-	-	-	-	-
204	WG	A	-	-	-	-	-	B	2	3	71	1.5	47	D	0.37	0.93	74.1	2.51351	77	F	0.45	0.54	78.8	1.2	35	G	0.176	0.21	76.1	1.19318	25	H	-	-	-	-	-
204	RG	A	-	-	-	-	-	B	1.5	4	71	2.66667	47	D	0.39	0.66	74.1	1.69231	77	F	0.28	0.35	78.8	1.25	35	G	0.127	0.152	76.2	1.19685	25	H	-	-	-	-	-
204	BE	A	1.1	3	74	2.72727	43	B	1.1	5	71	4.54545	47	D	0.34	0.52	73.1	1.52941	54	F	-	-	-	-	-	G	0.152	0.193	76.2	1.26974	25	H	0.0146	0.0205	78.9	1.40411	34
204	WE	A	2	5	74	2.5	43	B	1.1	4	71	3.63636	47	D	0.3	0.53	73.3	1.76667	54	F	-	-	-	-	-	G	0.097	0.124	76.3	1.27835	25	H	0.0158	0.0218	79.1	1.37975	35
204	RE	A	-	-	-	-	-	B	0.35	0.5	71	1.42857	47	D	0.29	0.79	76.4	2.72414	54	F	-	-	-	-	-	G	0.055	0.069	76.4	1.25455	25	H	-	-	-	-	-
204	GE	A	-	-	-	-	-	B	0.2	1	71	5	47	D	0.28	0.34	76.4	1.21429	54	F	-	-	-	-	-	G	0.058	0.075	76.4	1.2931	25	H	-	-	-	-	-
205	BW	A	20	15	77	0.75	55	B	1.2	4	71	3.33333	47	D	0.95	1.7	73.4	1.78947	54	F	0.47	0.77	78.8	1.6383	44	G	0.24	0.35	78.3	1.45833	34.5	H	0.33	1.31	78.9	3.9697	34
205	BR	A	-	-	-	-	-	B	1.8	5	71	2.77778	47	D	0.87	1.23	74.3	1.41379	54	F	0.3	0.45	78.8	1.5	44	G	0.26	0.31	78.3	1.19231	34.5	H	-	-	-	-	-
205	WR	A	-	-	-	-	-	B	0.55	0.7	71	1.27273	47	D	1.17	1.88	74.6	1.60684	54	F	0.3	0.68	78.8	2.26667	44	G	0.23	0.285	78.3	1.23913	34	H	-	-	-	-	-
205	BG	A	-	-	-	-	-	B	2	3	71	1.5	47	D	0.3	0.43	74.5	1.43333	54	F	0.35	0.54	78.8	1.54286	44	G	0.28	0.315	78.3	1.125	34.5	H	-	-	-	-	-
205	WG	A	-	-	-	-	-	B	0.6	0.7	71	1.16667	47	D	0.48	0.65	74.7	1.35417	54	F	0.45	0.6	78.8	1.33333	44	G	0.295	0.41	69.3	1.38983	31	H	-	-	-	-	-
205	RG	A	-	-	-	-	-	B	0.72	1	71	1.38889	47	D	0.37	0.53	74.7	1.43243	54	F	0.4	0.53	78.8	1.325	44	G	0.305	0.375	71.3	1.22951	31	H	-	-	-	-	-
205	BE	A	2	5	77	2.5	55	B	1.1	5	71	4.54545	47	D	0.27	0.42	73.6	1.55556	54	F	-	-	-	-	-	G	0.195	0.255	72.4	1.30769	31	H	0.022	0.0305	78.9	1.38636	34
205	WE	A	1.5	3	77	2	55	B	1.25	4	71	3.2	47	D	0.38	0.44	73.8	1.15789	54	F	-	-	-	-	-	G	0.164	0.21	73.1	1.28049	31	H	0.0295	0.035	79.1	1.18644	35
205	RE	A	2.5	5	77	2	55	B	0.45	1.5	71	3.33333	47	D	0.25	0.38	74.1	1.52	54	F	-	-	-	-	-	G	0.125	0.16	73.6	1.28	31	H	-	-	-	-	-
205	GE	A	2	5	77	2.5	55	B	0.75	1.4	71	1.86667	47	D	0.19	0.24	74.2	1.26316	54	F	-	-	-	-	-	G	0.125	0.162	73.9	1.296	31	H	-	-	-	-	-
206	BW	A	15	13	77	0.86667	55	B	1	4	71	4	47	D	0.45	0.84	75.5	1.86667	92	F	0.3	0.35	78.8	1.16667	44	G	0.11	0.16	77.5	1.45455	34	H	0.475	1.58	75.3	3.32632	39
206	BR	A	-	-	-	-	-	B	1.5	3	71	2	47	D	0.96	1.39	76.1	1.44792	92	F	0.35	0.45	78.8	1.28571	44	G	0.135	0.16	77.9	1.18519	34	H	-	-	-	-	-
206	WR	A	-	-	-	-	-	B	1.5	2.5	71	1.66667	47	D	0.88	1.41	76.2	1.60227	92	F	0.4	0.62	78.8	1.55	44	G	0.19	0.27	78.1	1.42105	34	H	-	-	-	-	-
206	BG	A	-	-	-	-	-	B	1.6	5.5	71	3.4375	47	D	0.67	0.84	76.2	1.25373	92	F	0.3	0.4	78.8	1.33333	44	G	0.24	0.32	78	1.33333	34	H	-	-	-	-	-
206	WG	A	-	-	-	-	-	B	0.85	2.8	71	3.29412	47	D	0.7	0.93	76.3	1.32857	92	F	0.3	0.35	78.8	1.16667	44	G	0.24	0.29	78.1	1.20833	34	H	-	-	-	-	-
206	RG	A	-	-	-	-	-	B	2.2	5.4	71	2.45455	47	D	0.74	1.07	76.4	1.44595	92	F	0.35	0.45	78.8	1.28571	44	G	0.22	0.26	78.2	1.18182	34	H	-	-	-	-	-
206	BE	A	1.7	4	77	2.35294	55	B	0.5	0.75	71	1.5	47	D	0.17	0.24	75.7	1.41176	92	F	-	-	-	-	-	G	0.13	0.166	78.2	1.27692	34.5	H	0.039	0.063	75.3	1.61538	39
206	WE	A	2.5	3	77	1.2	55	B	1.5	4	71	2.66667	47	D	0.25	0.35	75.9	1.4	92	F	-	-	-	-	-	G	0.12	0.15	78.3	1.25	34.5	H	0.057	0.0675	75.3	1.18421	39
206	RE	A	3	4	77	1.33333	55	B	1.3	2.8	71	2.15385	47	D	0.26	0.37	76	1.42308	92	F	-	-	-	-	-	G	0.09	0.118	78.3	1.31111	34.5	H	-	-	-	-	-
206	GE	A	2	3	77	1.5	55	B	1.8	5.5	71	3.05556	47	D	0.17	0.26	76	1.52941	92	F	-	-	-	-	-	G	0.094	0.12	78.3	1.2766	34.5	H	-	-	-	-	-
207	BW	A	50	100	64	2	33	--	-	-	-	-	-	--	-	-	-	-	-	F	0.4	0.5	75.2	1.25	35	G	0.32	0.415	72.6	1.29688	27	H	0.49	2.18	74.3	4.44898	41
207	BR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.45	0.53	75.2	1.17778	35	G	0.35	0.42	72.7	1.2	27	H	-	-	-	-	-
207	WR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.4	0.5	75.2	1.25	35	G	0.38	0.52	72.8	1.36842	27	H	-	-	-	-	-
207	BG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.45	0.52	75.2	1.15556	35	G	0.35	0.415	72.7	1.18571	27	H	-	-	-	-	-
207	WG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.4	0.5	75.2	1.25	35	G	0.53	0.54	72.9	1.01887	27	H	-	-	-	-	-
207	RG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.425	0.5	75.2	1.17647	35	G	0.32	0.43	73.2	1.34375	27	H	-	-	-	-	-
207	BE	A	2.5	10	64	4	33	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.105	0.143	73.5	1.3619	26.5	H	0.039	0.0575	74.1	1.47436	41
207	WE	A	2.5	3.5	64	1.4	33	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.15	0.205	73.7	1.36667	26.5	H	0.049	0.0615	74.3	1.2551	41
207	RE	A	3	5	64	1.66667	33	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.16	0.21	73.8	1.3125	26.5	H	-	-	-	-	-

Table H.2 Insulation resistance measurements for specimens in test sequence 2

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
207	GE	A	3	5	64	1.66667	33	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.149	0.192	74	1.28859	26.5	H	-	-	-	-	-
208	BW	A	20	30	68	1.5	45	--	-	-	-	-	-	--	-	-	-	-	-	F	0.28	0.35	78.8	1.25	40	G	0.235	0.315	74.2	1.34043	26.5	H	0.34	1.88	79.3	5.52941	35
208	BR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.35	78.8	1.16667	40	G	0.25	0.3	74.3	1.2	26.5	H	-	-	-	-	-
208	WR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.25	0.3	78.8	1.2	40	G	0.295	0.36	74.4	1.22034	26.5	H	-	-	-	-	-
208	BG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.21	0.3	78.8	1.42857	40	G	0.262	0.304	74.4	1.16031	26.5	H	-	-	-	-	-
208	WG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.28	0.3	78.8	1.07143	40	G	0.33	0.38	74.5	1.15152	26	H	-	-	-	-	-
208	RG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.25	0.29	78.8	1.16	40	G	0.305	0.355	74.6	1.16393	26	H	-	-	-	-	-
208	BE	A	2.5	5	68	2	45	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.082	0.107	74.7	1.30488	26	H	0.0255	0.032	79.3	1.2549	35
208	WE	A	2	5	68	2.5	45	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.15	0.181	74.7	1.20667	26	H	0.0245	0.034	79.3	1.38776	35
208	RE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.124	0.167	74.8	1.34677	26	H	-	-	-	-	-
208	GE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.127	0.157	74.9	1.23622	26	H	-	-	-	-	-
209	BW	A	50	40	71	0.8	43	--	-	-	-	-	-	--	-	-	-	-	-	F	0.23	0.35	80.6	1.52174	43	G	0.2	0.27	74.9	1.35	26	H	0.515	2.42	73.5	4.69903	42
209	BR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.35	80.6	1.16667	43	G	0.23	0.266	75	1.15652	26	H	-	-	-	-	-
209	WR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.35	80.6	1.16667	43	G	0.25	0.3	75	1.2	26	H	-	-	-	-	-
209	BG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.35	80.6	1.16667	43	G	0.23	0.264	75	1.14783	26	H	-	-	-	-	-
209	WG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.35	80.6	1.16667	43	G	0.26	0.315	75.1	1.21154	26	H	-	-	-	-	-
209	RG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.35	80.6	1.16667	43	G	0.255	0.3	75.1	1.17647	26	H	-	-	-	-	-
209	BE	A	3	5	71	1.66667	43	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.0775	0.102	75.2	1.31613	26	H	0.038	0.0538	73.5	1.41579	42
209	WE	A	2.5	4	71	1.6	43	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.145	0.188	71.9	1.29655	26	H	0.042	0.0546	73.4	1.3	42
209	RE	A	2.5	5	71	2	43	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.126	0.18	72.4	1.42857	26	H	-	-	-	-	-
209	GE	A	2.5	4	71	1.6	43	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.14	0.172	72.7	1.22857	26	H	-	-	-	-	-
210	BW	A	30	50	68	1.66667	45	--	-	-	-	-	-	--	-	-	-	-	-	F	0.35	0.5	80.6	1.42857	35	G	0.31	0.345	72.8	1.1129	26	H	0.505	4.6	73.9	9.10891	42
210	BR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.325	0.4	80.6	1.23077	35	G	0.355	0.44	73	1.23944	26	H	-	-	-	-	-
210	WR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.25	0.4	80.6	1.6	35	G	0.38	0.535	73.4	1.40789	26	H	-	-	-	-	-
210	BG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.425	0.52	80.6	1.22353	35	G	0.36	0.43	73.2	1.19444	26	H	-	-	-	-	-
210	WG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.4	0.52	80.6	1.3	35	G	0.41	0.53	73.5	1.29268	26	H	-	-	-	-	-
210	RG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.375	0.4	80.6	1.06667	35	G	0.36	0.475	73.6	1.31944	26	H	-	-	-	-	-
210	BE	A	3	9	68	3	45	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.118	0.153	73.8	1.29661	26	H	0.0083	0.0111	73.7	1.33735	42
210	WE	A	2.8	5	68	1.78571	45	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.175	0.238	73.9	1.36	26	H	0.0099	0.0114	73.7	1.15152	42
210	RE	A	3	5	68	1.66667	45	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.153	0.171	74.1	1.11765	25.5	H	-	-	-	-	-
210	GE	A	3	5	68	1.66667	45	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.137	0.205	74.2	1.49635	25.5	H	-	-	-	-	-
211	BW	A	100	100	77	1	55	--	-	-	-	-	-	--	-	-	-	-	-	F	0.28	0.4	80.6	1.42857	35	G	0.24	0.35	75.2	1.45833	25	H	0.435	2.95	75	6.78161	39
211	BR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.35	0.45	80.6	1.28571	35	G	0.295	0.345	75.3	1.16949	25	H	-	-	-	-	-
211	WR	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.375	0.45	80.6	1.2	35	G	0.325	0.4	75.4	1.23077	25	H	-	-	-	-	-
211	BG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.4	0.45	80.6	1.125	35	G	0.3	0.345	75.3	1.15	25	H	-	-	-	-	-
211	WG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.45	0.475	80.6	1.05556	35	G	0.355	0.41	75.4	1.15493	25	H	-	-	-	-	-
211	RG	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	0.35	0.45	80.6	1.28571	35	G	0.352	0.39	75.5	1.10795	25	H	-	-	-	-	-
211	BE	A	3	4	77	1.33333	55	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.095	0.132	75.6	1.38947	25	H	0.0075	0.00859	75	1.14533	39
211	WE	A	2.5	3	77	1.2	55	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.152	0.2	75.7	1.31579	25	H	0.0084	0.00855	75.2	1.01786	39
211	RE	A	2.5	3	77	1.2	55	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.147	0.19	75.7	1.29252	25	H	-	-	-	-	-
211	GE	A	3	4	77	1.33333	55	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.147	0.182	75.8	1.2381	25	H	-	-	-	-	-
212	BW	A	11	15	77	1.36364	55	C	1.7	3.5	71	2.05882	46	E	0.46	0.78	78.3	1.69565	65	F	0.35	0.6	80.6	1.71429	35	G	0.31	0.44	75.2	1.41935	29.5	H	0.495	2.2	73.9	4.44444	40
212	BR	A	-	-	-	-	-	C	1.5	3	71	2	46	E	0.54	0.82	71.8	1.51852	63	F	0.325	0.35	80.6	1.07692	35	G	0.31	0.355	75.2	1.14516	29.5	H	-	-	-	-	-
212	WR	A	-	-	-	-	-	C	2	3	71	1.5	46	E	0.63	0.83	74.6	1.31746	63	F	0.5	0.58	80.6	1.16	35	G	0.26	0.35	75.2	1.34615	29.5	H	-	-	-	-	-
212	BG	A	-	-	-	-	-	C	1.3	4	71	3.07692	46	E	0.58	0.78	73.4	1.34483	63	F	0.3	0.4	80.6	1.33333	35	G	0.31	0.395	75.2	1.27419	29.5	H	-	-	-	-	-
212	WG	A	-	-	-	-	-	C	1.5	3.1	71	2.06667	46	E	0.64	0.77	75	1.20313	63	F	0.5	0.57	.80.6	1.14	35	G	0.31	0.38	75.2	1.22581	29.5	H	-	-	-	-	-
212	RG	A	-	-	-	-	-	C	1.2	2.5	71	2.08333	46	E	0.51	0.685	75.2	1.34314	63	F	0.325	0.375	80.6	1.15385	35	G	0.225	0.275	75.3	1.22222	29.5	H	-	-	-	-	-
212	BE	A	1.5	5	77	3.33333	55	C	0.25	0.3	71	1.2	46	E	0.23	0.35	75.5	1.52174	63	F	-	-	-	-	-	G	0.164	0.23	75.3	1.40244	29.5	H	0.038	0.0575	73.9	1.51316	39
212	WE	A	2	3.5	77	1.75	55	C	0.22	0.25	71	1.13636	46	E	0.27	0.35	75.7	1.2963	63	F	-	-	-	-	-	G	0.158	0.22	75.2	1.39241	29	H	0.0455	0.06	74.1	1.31868	39
212	RE	A	2	5	77	2.5	55	C	1.1	2.8	71	2.54545	46	E	0.21	0.29	75.9	1.38095	63	F	-	-	-	-	-	G	0.86	0.112	75.6	0.13023	29	H	-	-	-	-	-
212	GE	A	2	5	77	2.5	55	C	0.85	2.5	71	2.94118	46	E	0.18	0.25	76	1.38889	63	F	-	-	-	-	-	G	0.1	0.13	75.7	1.3	29	H	-	-	-	-	-
213	BW	A	20	100	74	5	43	C	1	3.5	71	3.5	46	E	0.62	0.94	77.7	1.51613	65	F	0.35	0.4	77	1.14286	34	G	0.395	0.592	74.1	1.49873	30.5	H	0.65	1.75	74.3	2.69231	38
213	BR	A	-	-	-	-	-	C	0.9	3	71	3.33333	46	E	0.43	0.69	78.1	1.60465	65	F	0.45	0.52	77	1.15556	34	G	0.4	0.572	74.2	1.43	30.5	H	-	-	-	-	-
213	WR	A	-	-	-	-	-	C	1	2.5	71	2.5	46	E	0.46	0.69	78.3	1.5	65	F	0.45	0.5	77	1.11111	34	G	0.36	0.54	74.4	1.5	30.5	H	-	-	-	-	-
213	BG	A	-	-	-	-	-	C	0.8	1	71	1.25	46	E	0.48	0.76	78.2	1.58333	65	F	0.375	0.45	77	1.2	34	G	0.48	0.65	74.5	1.35417	30.5	H	-	-	-	-	-
213	WG	A	-	-	-	-	-	C	1.1	2.1	71	1.90909	46	E	0.57	0.78	78.3	1.36842	65	F	0.4	0.5	77	1.25	34	G	0.49	0.65	74.7	1.32653	30	H	-	-	-	-	-
213	RG	A	-	-	-	-	-	C	1	2	71	2	46	E	0.5	0.67	78.3	1.34	65	F	0.375	0.4	77	1.06667	34	G	0.43	0.585	74.8	1.36047	30	H	-	-	-	-	-
213	BE	A	2	25	74	12.5	43	C	0.66	0.62	71	0.93939	46	E	0.16	0.27	77.9	1.6875	65	F	-	-	-	-	-	G	0.181	0.245	74.9	1.35359	30	H	0.0355	0.0548	74.4	1.54366	38
213	WE	A	2.5	5	74	2	43	C	0.8	0.75	71	0.9375	46	E	0.215	0.27	78	1.25581	65	F	-	-	-	-	-	G	0.198	0.26	75.1	1.31313	30	H	0.0475	0.0575	74.4	1.21053	38
213	RE	A	-	-	-	-	-	C	0.5	0.3	71	0.6	46	E	0.17	0.25	78	1.47059	65	F	-	-	-	-	-	G	0.158	0.22	75.2	1.39241	30	H	-	-	-	-	-
213	GE	A	-	-	-	-	-	C	0.2	0.25	71	1.25	46	E	0.145	0.3	78	2.06897	65	F	-	-	-	-	-	G	0.21	0.26	75.2	1.2381	30	H	-	-	-	-	-
214	BW	A	100	100	74	1	43	C	1.2	20	71	16.6667	46	E	0.54	1.03	78.3	1.90741	65	F	0.35	0.53	77	1.51429	34	G	0.27	0.355	76.2	1.31481	28	H	0.38	2.22	72.8	5.84211	40
214	BR	A	-	-	-	-	-	C	0.16	1.4	71	8.75	46	E	0.41	0.82	78.3	2	65	F	0.35	0.45	77	1.28571	34	G	0.345	0.415	76.2	1.2029	28	H	-	-	-	-	-
214	WR	A	-	-	-	-	-	C	0.8	1.3	71	1.625	46	E	0.43	0.72	78.3	1.67442	65	F	0.425	0.54	77	1.27059	34	G	0.34	0.4	76.2	1.17647	28	H	-	-	-	-	-
214	BE	A	4	20	74	5	43	C	1.7	50	71	29.4118	46	E	0.19	0.33	78.3	1.73684	65	F	-	-	-	-	-	G	0.145	0.2	76.2	1.37931	28	H	0.0041	0.0044	72.6	1.07317	41

Table H.2 Insulation resistance measurements for specimens in test sequence 2

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
214	WE	A	4	12	74	3	43	C	1.2	4.5	71	3.75	46	E	0.2	0.3	78.3	1.5	65	F	-	-	-	-	-	G	0.122	0.17	76.2	1.39344	28	H	0.0034	0.00445	72.6	1.30882	41
214	RE	A	-	-	-	-	-	C	0.5	0.8	71	1.6	46	E	0.145	0.22	78.3	1.51724	65	F	-	-	-	-	-	G	0.151	0.22	76.2	1.45695	28	H	-	-	-	-	-
215	BW	A	11	16	73	1.45455	48.5	C	1.5	4.5	71	3	47	E	0.47	0.69	73.8	1.46809	50	F	0.74	0.95	84.2	1.28378	41	G	0.94	1.58	75.8	1.68085	29	H	0.68	1.44	78	2.11765	40
215	BR	A	-	-	-	-	-	C	2.5	12	71	4.8	47	E	0.37	0.58	76.6	1.56757	77	F	0.54	0.67	84.2	1.24074	41	G	1.01	1.47	75.9	1.45545	29	H	-	-	-	-	-
215	WR	A	-	-	-	-	-	C	2.2	6	71	2.72727	47	E	0.44	0.62	76.8	1.40909	77	F	0.71	0.92	84.2	1.29577	41	G	1.32	2.1	75.8	1.59091	29	H	-	-	-	-	-
215	BG	A	-	-	-	-	-	C	3.5	12	71	3.42857	47	E	0.29	0.605	76.7	2.08621	77	F	0.5	0.58	84.2	1.16	41	G	1	1.55	75.9	1.55	29	H	-	-	-	-	-
215	WG	A	-	-	-	-	-	C	2	5.2	71	2.6	47	E	0.45	0.65	76.9	1.44444	77	F	0.72	0.85	84.2	1.18056	41	G	1.7	2.4	75.8	1.41176	29	H	-	-	-	-	-
215	RG	A	-	-	-	-	-	C	3.5	7	71	2	47	E	0.35	0.53	77.4	1.51429	77	F	-	-	-	-	-	G	1.4	2.1	75.9	1.5	29	H	-	-	-	-	-
215	BE	A	2	5	73	2.5	48.5	C	0.4	0.74	71	1.85	47	E	0.18	0.24	73.8	1.33333	50	F	-	-	-	-	-	G	0.28	0.39	76	1.39286	29	H	0.148	0.2	78.6	1.35135	36
215	WE	A	1.5	3	73	2	48.5	C	0.35	0.55	71	1.57143	47	E	0.2	0.28	74	1.4	50	F	-	-	-	-	-	G	0.62	0.86	76	1.3871	29	H	0.132	0.17	78.6	1.28788	37
215	RE	A	3	5	73	1.66667	48.5	C	0.7	2	71	2.85714	47	E	0.18	0.24	74	1.33333	50	F	-	-	-	-	-	G	0.475	0.75	76.1	1.57895	29	H	-	-	-	-	-
215	GE	A	1.8	3	73	1.66667	48.5	C	0.8	1.8	71	2.25	47	E	0.16	0.24	76.5	1.5	77	F	-	-	-	-	-	G	0.49	0.815	76.1	1.66327	28.5	H	-	-	-	-	-
216	BW	A	10	10	74	1	49	C	2.2	15	71	6.81818	46	E	0.6	0.86	70.9	1.43333	50	F	0.61	0.7	84.2	1.14754	41	G	0.6	0.89	76.1	1.48333	28.5	H	0.615	1.02	78.8	1.65854	41
216	BR	A	-	-	-	-	-	C	1	3	71	3	46	E	0.46	0.77	71.4	1.67391	50	F	0.5	0.58	84.2	1.16	41	G	0.76	1.09	76.1	1.43421	28.5	H	-	-	-	-	-
216	WR	A	-	-	-	-	-	C	1.4	3	71	2.14286	46	E	0.41	0.645	71.9	1.57317	50	F	0.55	0.64	84.2	1.16364	41	G	0.82	1.1	76.2	1.34146	28.5	H	-	-	-	-	-
216	BE	A	2	4	74	2	49	C	1.7	22	71	12.9412	46	E	0.18	0.24	72.4	1.33333	50	F	-	-	-	-	-	G	0.25	0.35	76.2	1.4	28.5	H	0.018	0.021	78	1.16667	41
216	WE	A	5	3	74	0.6	49	C	1.1	3	71	2.72727	46	E	0.14	0.195	72.9	1.39286	50	F	-	-	-	-	-	G	0.28	0.365	76.2	1.30357	28	H	0.023	0.028	78	1.21739	40
216	RE	A	2	3	74	1.5	49	C	0.5	0.8	71	1.6	46	E	0.13	0.17	73.4	1.30769	50	F	-	-	-	-	-	G	0.325	0.44	76.2	1.35385	28	H	-	-	-	-	-

Table H.3 Insulation resistance measurements for specimens in test sequence 3

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
301	BW	A	4.35	49.5	70	11.3793	47	--	-	-	-	-	-	--	-	-	-	-	-	F	2.2	8	72.1	3.63636	65	G	2.2	12	69.8	5.45455	64	H	0.69	2.1	76.8	3.04348	26
302	BW	A	39	200	68	5.12821	26	--	-	-	-	-	-	--	-	-	-	-	-	F	8	35	71.6	4.375	64.5	G	12	200	68	16.6667	64	H	1.6	5.6	71.4	3.5	26
302	BR	A	38	195	68	5.13158	26	--	-	-	-	-	-	--	-	-	-	-	-	F	8	25	71.6	3.125	64.5	G	30	200	68	6.66667	64	H	-	-	-	-	-
302	WR	A	27	200	68	7.40741	26	--	-	-	-	-	-	--	-	-	-	-	-	F	3	16	71.6	5.33333	64.5	G	20	200	68	10	64	H	-	-	-	-	-
302	BE	A	3.9	11.4	68	2.92308	26	--	-	-	-	-	-	--	-	-	-	-	-	F	7.5	17	71.6	2.26667	64.5	G	0.04	0.054	68	1.35	64	H	0.105	0.16	71.6	1.52381	26
302	WE	A	4.6	12.9	68	2.80435	26	--	-	-	-	-	-	--	-	-	-	-	-	F	5.5	13	71.6	2.36364	64.5	G	0.055	1	68	18.1818	64	H	0.152	0.195	71.7	1.28289	26
302	RE	A	8.6	21.5	68	2.5	26	--	-	-	-	-	-	--	-	-	-	-	-	F	11	18	71.6	1.63636	64.5	G	0.85	1	68	1.17647	64	H	-	-	-	-	-
303	BW	A	16	200	68	12.5	26	B	3.9	46	73.7	11.7949	68	D	14.8	200	73.1	13.5135	62.3	F	5	30	73.4	6	62.1	G	0.7	15	68	21.4286	69	H	1.1	2.95	76.8	2.68182	26
303	BR	A	16	120	68	7.5	23	B	5.1	35	73.9	6.86275	67	D	17	185	73.1	10.8824	62.2	F	5	45	73.4	9	62.1	G	16	200	68	12.5	69	H	-	-	-	-	-
303	WR	A	100	200	68	2	23	B	19.5	190	73.7	9.74359	66	D	7.5	80	73.3	10.6667	61.3	F	12	50	73.4	4.16667	62.1	G	5	14	68	2.8	69	H	-	-	-	-	-
303	BE	A	3.2	10.3	69	3.21875	23	B	0.48	1.58	73.7	3.29167	66	D	0.96	2.75	73.2	2.86458	61.1	F	0.3	0.4	73.4	1.33333	62.1	G	0.4	1	68	2.5	69	H	0.066	0.158	76.8	2.39394	26
303	WE	A	4.8	14.7	69	3.0625	23	B	0.86	1.72	73.9	2	66	D	1.11	3.05	73.3	2.74775	61.1	F	0.3	0.45	73.4	1.5	62.1	G	0.2	0.45	68	2.25	69	H	0.12	0.171	76.6	1.425	26
303	RE	A	6.5	18.5	69	2.84615	23	B	0.88	2.02	73.9	2.29545	66	D	1.74	3.55	73.3	2.04023	61.2	F	0.4	0.54	73.4	1.35	62.1	G	0.2	0.3	68	1.5	69	H	-	-	-	-	-
304	BW	A	38	200	69	5.26316	22	B	15.3	195	73.2	12.7451	64	D	3.95	6.6	78.8	1.67089	58.5	F	0.09	0.075	70.9	0.83333	65	G	0.4	0.4	68	1	69	H	0.845	3.45	76.8	4.08284	26
304	BR	A	49	200	69	4.08163	22	B	10.7	72	73.2	6.72897	64	D	6.3	17.5	78.8	2.77778	58.5	F	0.065	0.08	70.9	1.23077	65	G	9	200	68	22.2222	69	H	-	-	-	-	-
304	WR	A	39	200	69	5.12821	22	B	48	200	73.2	4.16667	64	D	11	26.5	77	2.40909	58.5	F	0.015	0.016	70.9	1.06667	65	G	25	200	68	8	69	H	-	-	-	-	-
304	BE	A	3.8	13.6	69	3.57895	22	B	0.775	1.71	73.9	2.20645	61	D	0.74	1.65	75.2	2.22973	58.5	F	0.045	0.045	70.9	1	65	G	0.07	0.075	68	1.07143	69	H	0.098	0.139	76.6	1.41837	26
304	WE	A	5.1	21.5	69	4.21569	22	B	0.455	1.39	73.7	3.05495	62	D	0.825	2.15	75.2	2.60606	58.5	F	0.003	0.0047	70.9	1.56667	65	G	0.0055	0.0068	68	1.23636	69	H	0.098	0.141	76.8	1.43878	26
304	RE	A	3.8	11	70	2.89474	22	B	0.49	1.57	73.5	3.20408	62	D	1.26	2.8	75	2.22222	58.5	F	0.15	0.11	70.9	0.73333	65	G	0.3	0.4	68	1.33333	69	H	-	-	-	-	-
305	BW	A	75	200	70	2.66667	22	B	6.7	48	73.9	7.16418	65	D	20.5	200	72	9.7561	62.5	F	2.6	50	71.6	19.2308	63.5	G	0.5	0.55	68	1.1	68	H	1.01	4.9	71	4.85149	26
305	BR	A	70	200	70	2.85714	22	B	12.1	41.5	73.7	3.42975	65	D	19.5	200	72.3	10.2564	62.6	F	1.55	50	71.6	32.2581	63.5	G	15	200	68	13.3333	68	H	-	-	-	-	-
305	WR	A	52	200	70	3.84615	22	B	15.2	61	73.9	4.01316	65	D	31	200	72.7	6.45161	61.5	F	5	30	71.6	6	63.5	G	7	200	68	28.5714	68	H	-	-	-	-	-
305	BE	A	2.2	7.6	69	3.45455	29	B	0.538	1.75	73.9	3.25279	65	D	0.855	2.58	72.5	3.01754	61.9	F	22	50	71.6	2.27273	63.5	G	0.4	0.6	68	1.5	68	H	0.0935	0.147	71.2	1.57219	26
305	WE	A	4.9	13.1	69	2.67347	29	B	1.08	1.95	73.9	1.80556	65	D	1.19	2.95	72.9	2.47899	61.9	F	0.02	0.02	71.6	1	63.5	G	0.07	0.08	68	1.14286	68	H	0.117	0.16	71.4	1.36752	26
305	RE	A	5.2	17.2	69	3.30769	29	B	0.405	1.64	73.2	4.04938	63	D	1.57	3.65	72.7	2.32484	62.1	F	0.025	0.02	71.6	0.8	63.5	G	0.45	0.75	68	1.66667	68	H	-	-	-	-	-
306	BW	A	39	200	69	5.12821	28	B	7.6	46	73.2	6.05263	63	D	11.3	57.5	74.4	5.0885	59.5	F	0.005	0.0054	71.6	1.08	65	G	3	200	68	66.6667	67	H	0.48	5.3	73.9	11.0417	39
306	BR	A	37	180	69	4.86486	28	B	15.5	75	73.2	4.83871	63	D	12.5	170	74.3	13.6	59.5	F	3	50	71.6	16.6667	65	G	0.25	0.25	68	1	67	H	-	-	-	-	-
306	WR	A	44	200	69	4.54545	28	B	30.5	110	73.2	3.60656	63	D	12.7	200	70.9	15.748	63.9	F	7.8	50	71.6	6.41026	65	G	4.5	200	68	44.4444	67	H	-	-	-	-	-
306	BE	A	3.7	13.2	69	3.56757	28	B	0.66	1.57	73.4	2.37879	62	D	0.633	1.56	71	2.46445	63.7	F	0.0062	0.007	71.6	1.12903	65	G	15	200	68	13.3333	67	H	0.0505	0.043	74.3	0.85149	39
306	WE	A	6.9	15.4	69	2.23188	28	B	0.94	1.87	73.2	1.98936	63	D	0.864	1.75	70.5	2.02546	64.4	F	0.0078	0.007	71.6	0.89744	65	G	0.025	0.02	68	0.8	67	H	0.0685	0.0985	74.1	1.43796	38
306	RE	A	7	21	69	3	28	B	0.885	2.02	73.4	2.28249	63	D	0.99	2.17	70.6	2.19192	64.4	F	0.35	0.5	71.6	1.42857	65	G	0.02	0.025	68	1.25	67	H	-	-	-	-	-
307	BW	A	16.8	130	68	7.7381	34	--	-	-	-	-	-	--	-	-	-	-	-	F	3.5	50	71.6	14.2857	66	G	12	40	69.8	3.33333	66	H	0.54	4.8	73.7	8.88889	35
307	BR	A	16.5	80	68	4.84848	34	--	-	-	-	-	-	--	-	-	-	-	-	F	1.4	8	71.6	5.71429	66	G	1	15	69.8	15	66	H	-	-	-	-	-
307	WR	A	17.4	120	68	6.89655	34	--	-	-	-	-	-	--	-	-	-	-	-	F	12	40	71.6	3.33333	66	G	5	200	69.8	40	66	H	-	-	-	-	-
307	BE	A	1.64	3.1	68	1.89024	34	--	-	-	-	-	-	--	-	-	-	-	-	F	0.125	0.15	71.6	1.2	66	G	0.15	0.05	69.8	0.33333	66	H	0.036	0.077	73.9	2.13889	35
307	WE	A	4.7	16.9	68	3.59574	35	--	-	-	-	-	-	--	-	-	-	-	-	F	0.6	1	71.6	1.66667	66	G	0.05	0.008	69.8	0.16	66	H	0.0675	0.0765	74.3	1.13333	36
307	RE	A	7.7	28.3	68	3.67532	35	--	-	-	-	-	-	--	-	-	-	-	-	F	0.8	1.4	71.6	1.75	66	G	0.3	0.4	69.8	1.33333	66	H	-	-	-	-	-
308	BW	A	26	200	68	7.69231	35	--	-	-	-	-	-	--	-	-	-	-	-	F	8	13	73.4	1.625	64	G	0.5	1	69.8	2	65	H	0.56	3.9	76.8	6.96429	27
308	BR	A	33	200	68	6.06061	35	--	-	-	-	-	-	--	-	-	-	-	-	F	15	27	73.4	1.8	64	G	3	3	69.8	1	65	H	-	-	-	-	-
308	WR	A	28	200	68	7.14286	35	--	-	-	-	-	-	--	-	-	-	-	-	F	14	40	73.4	2.85714	64	G	0.28	0.6	69.8	2.14286	65	H	-	-	-	-	-
308	BE	A	2.9	9.5	67	3.27586	36	--	-	-	-	-	-	--	-	-	-	-	-	F	0.45	5.5	73.4	12.2222	64	G	0.08	0.08	69.8	1	65	H	0.0645	0.146	76.8	2.26357	27
308	WE	A	5.7	14.1	67	2.47368	36	--	-	-	-	-	-	--	-	-	-	-	-	F	0.64	0.64	73.4	1	64	G	0.0058	0.01	69.8	1.72414	65	H	0.112	0.136	77	1.21429	27
308	RE	A	7.2	21.8	67	3.02778	36	--	-	-	-	-	-	--	-	-	-	-	-	F	0.6	0.64	73.4	1.06667	64	G	0.03	0.02	69.8	0.66667	65	H	-	-	-	-	-
309	BW	A	65	200	67	3.07692	36	--	-	-	-	-	-	--	-	-	-	-	-	F	2.8	4	73.4	1.42857	62	G	1.5	50	69.8	33.3333	65	H	0.82	4.1	77	5	31
309	BR	A	41	200	67	4.87805	36	--	-	-	-	-	-	--	-	-	-	-	-	F	2.5	2.8	73.4	1.12	62	G	2.8	200	69.8	71.4286	65	H	-	-	-	-	-
309	WR	A	41	200	67	4.87805	36	--	-	-	-	-	-	--	-	-	-	-	-	F	4	7	73.4	1.75	62	G	0.7	5.5	69.8	7.85714	65	H	-	-	-	-	-
309	BE	A	4.2	15.4	67	3.66667	27	--	-	-	-	-	-	--	-	-	-	-	-	F	0.3	0.52	73.4	1.73333	62	G	0.025	0.025	69.8	1	65	H	0.0805	0.107	77	1.32919	31
309	WE	A	3.3	7.1	67	2.15152	27	--	-	-	-	-	-	--	-	-	-	-	-	F	0.4	0.56	73.4	1.4	62	G	0.02	0.025	69.8	1.25	65	H	0.09	0.11	77	1.22222	30
309	RE	A	7	12	67	1.71429	27	--	-	-	-	-	-	--	-	-	-	-	-	F	0.55	0.8	73.4	1.45455	62	G	0.022	0.026	69.8	1.18182	65	H	-	-	-	-	-
310	BW	A	26	200	67	7.69231	27	--	-	-	-	-	-	--	-	-	-	-	-	F	0.006	0.006	73.4	1	60	G	0.125	0.16	66.2	1.28	70	H	0.88	3.1	75.7	3.52273	34
310	BR	A	31	200	67	6.45161	27	--	-	-	-	-	-	--	-	-	-	-	-	F	30	50	73.4	1.66667	60	G	0.14	0.16	66.2	1.14286	70	H	-	-	-	-	-
310	WR	A	49	200	67	4.08163	27	--	-	-	-	-	-	--	-	-	-	-	-	F	0.05	0.065	73.4	1.3	60	G	0.13	0.175	66.2	1.34615	70	H	-	-	-	-	-
310	BE	A	5	15.3	67	3.06	27	--	-	-	-	-	-	--	-	-	-	-	-	F	0.9	1.7	73.4	1.88889	60	G	0.125	0.15	66.2	1.2	70	H	0.0685	0.101	76.1	1.47445	33
310	WE	A	8	13.9	67	1.7375	27	--	-	-	-	-	-	--	-	-	-	-	-	F	0.003	0.0045	73.4	1.5	60	G	0.045	0.06	66.2	1.33333	70	H	0.0745	0.081	76.4	1.08725	33
310	RE	A	7.7	25.5	67	3.31169	27	--	-	-	-	-	-	--	-	-	-	-	-	F	1.1	2	73.4	1.81818	60	G	0.125	0.125	66.2	1	70	H	-	-	-	-	-
311	BW	A	29	200	67	6.89655	27	--	-	-	-	-	-	--	-	-	-	-	-	F	50	50	69.8	1	65	G	0.11	0.14	66.2	1.27273	70	H	1.03	4.6	77	4.46602	27
311	BR	A	41	200	67	4.87805	27	--	-	-	-	-	-	--	-	-	-	-	-	F	40	50	69.8	1.25	65	G	0.12	0.14	66.2	1.16667	70	H	-	-	-	-	-
311	WR	A	15.1	78	68	5.16556	32	--	-	-	-	-	-	--	-	-	-	-	-	F	25	50	69.8	2	65	G	0.18	0.2	66.2	1.11111	70	H	-	-	-	-	-
311	BE	A	4.1	11.6	69	2.82927	32	--	-	-	-	-	-	--	-	-	-	-	-	F	1.4	1.6	69.8	1.14286	65	G	0.05	0.058	66.2	1.16	70	H	0.094	0.13	76.8	1.38298	27
311	WE	A	6.5	15.7	69	2.41538	32	--	-	-	-	-	-	--	-	-	-	-	-	F	2	2.5	69.8	1.25	65	G	0.06	0.072	66.2	1.2	70	H	0.115	0.138	76.6	1.2	26
311	RE	A	8.9	26.2	69	2.94382	32	--	-	-	-	-	-	--	-	-	-	-	-	F	2	2.5	69.8	1.25	65	G	0.082	0.1	66.2	1.21951	70	H	-	-	-	-	-
312	BW	A	12.9	190	69	14.7287	32	C	3.8	21.5	73.5	5.65789	62	E	0.195	0.305	74.5	1.5641	59.4	F	0.28	0.11	72.32	0.39286	64.1	G	0.0045	1.4	68	311.111	64	H	0.0305	0.0395	73.9	1.29508	62
313	BW	A	15.2	200	69	13.1579	31	C	1.65	43	73.5	26.0606	62	E	0.112	0.152	80.6	1.35714	59.4	F	0.05	0.066	71.96	1.32	65	G	0.65	1.5	69.8	2.30769	64	H	2.9E-06	4.1E-06	73.7	1.41379	59
314	BW	A	15.4	200	69	12.987	31	C	2.7	36	73.2	13.3333	62	E	0.56	0.96	80.6	1.71429	59.4	F	0.52	1.7	72.32	3.26923	64.1	G	0.52	1.8	69.8	3.46154	65	H	0.0018	0.00148	74.6	0.82222	61
315	BW	A	9.1	56	68	6.15385	44	C	0.77	7.2	73.5	9.35065	62	E	0.395	0.56	80.6	1.41772	59.4	F	0.6	1.7	71.6	2.83333	61	G	0.4	0.95	69.8	2.375	64	H	0.00053	0.00077	74.4	1.45283	61

Table H.3 Insulation resistance measurements for specimens in test sequence 3

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
316	BW	A	11.8	62	68	5.25424	44	C	0.675	75	73.5	111.111	62	E	0.44	1.19	80.6	2.70455	59.4	F	0.5	1.3	71.6	2.6	61	G	0.085	0.11	68	1.29412	64	H	0.0004	0.00056	75.5	1.4	60
317	BW	A	10.2	70	68	6.86275	44	C	1.43	33	73.4	23.0769	62																								

Table H.4 Insulation resistance measurements for specimens in test sequence 4

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@1 Min	@10 Mi	(F)	Index	RH %	M	@1 Min	@10 Mi	(F)	Index	RH %	M	@1 Min	@10 Mi	(F)	Index	RH %
401	BE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-
401	BR	A	2.7	200	68	74.0741	20	--	-	-	-	-	-	--	-	-	-	-	-
401	BW	A	0.3	0.48	68	1.6	20	--	-	-	-	-	-	--	-	-	-	-	-
401	WE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-
401	WR	A	4	200	68	50	20	--	-	-	-	-	-	--	-	-	-	-	-
402	PE	A	1.3	12	69	9.23077	22	--	-	-	-	-	-	--	-	-	-	-	-
402	PR	A	7	40	69	5.71429	22	--	-	-	-	-	-	--	-	-	-	-	-
402	RE	A	1	8	69	8	22	--	-	-	-	-	-	--	-	-	-	-	-
403	PE	A	30	200	69	6.66667	22	B	-	-	-	-	-	D	0.0017	0.0018	71	1.05882	59
404	PE	A	1	8	68	8	21	B	-	-	-	-	-	D	0.074	0.25	71	3.37838	59
404	PR	A	5	30	68	6	21	B	-	-	-	-	-	D	2	11.5	71	5.75	59
404	RE	A	1.2	5	68	4.16667	21	B	-	-	-	-	-	D	0.15	0.4	71	2.66667	59
405	RE	A	10	200	69	20	21	B	-	-	-	-	-	D	0.00089	0.001	71	1.1236	59
406	PE	A	0.52	5.5	69	10.5769	19	B	-	-	-	-	-	D	0.08	0.22	71	2.75	59
406	PR	A	3	15	69	5	19	B	-	-	-	-	-	D	4	5	71	1.25	59
406	RE	A	0.58	6	69	10.3448	19	B	-	-	-	-	-	D	0.15	0.32	71	2.13333	59
407	BE	A	40	200	69	5	22	C	-	-	-	-	-	E	0.00003	0.00003	72	1	59
408	BE	A	-	-	-	-	-	C	-	-	-	-	-	E	5.6E-05	0.00007	72	1.25	59
408	BR	A	5.2	200	69	38.4615	22	C	-	-	-	-	-	E	-	-	-	-	-
408	BW	A	4	22	69	5.5	22	C	-	-	-	-	-	E	0.75	4	72	5.33333	59
408	WE	A	-	-	-	-	-	C	-	-	-	-	-	E	-	-	-	-	-
408	WR	A	4	30	69	7.5	22	C	-	-	-	-	-	E	-	-	-	-	-
409	BE	A	10	200	69	20	34	C	-	-	-	-	-	E	0.00004	0.00005	71	1.25	60
410	BE	A	-	-	-	-	-	C	-	-	-	-	-	E	2.8E-05	0.00004	72	1.42857	60
410	BR	A	0.8	11	68	13.75	21	C	-	-	-	-	-	E	0.9	3.5	72	3.88889	60
410	BW	A	0.8	6.8	68	8.5	21	C	-	-	-	-	-	E	0.6	1.6	72	2.66667	60
410	WR	A	0.85	15	68	17.6471	21	C	-	-	-	-	-	E	1.6	5	72	3.125	60
411	BE	A	-	-	-	-	-	C	-	-	-	-	-	E	0.027	0.04	68	1.48148	58
411	BR	A	0.8	10	68	12.5	21	C	-	-	-	-	-	E	0.9	4	68	4.44444	58
411	BW	A	0.65	6.8	68	10.4615	21	C	-	-	-	-	-	E	0.8	3.5	68	4.375	58
411	WE	A	-	-	-	-	-	C	-	-	-	-	-	E	-	-	-	-	-
411	WR	A	1.2	14	68	11.6667	21	C	-	-	-	-	-	E	1.6	4.5	68	2.8125	58
412	RE	A	17	200	69	11.7647	22	C	-	-	-	-	-	E	0.0045	0.0062	72	1.37778	59
413	PE	A	2	15	69	7.5	30	C	-	-	-	-	-	E	0.1	0.25	69	2.5	58
413	PR	A	5.5	200	69	36.3636	30	C	-	-	-	-	-	E	3	7.2	69	2.4	58
413	RE	A	2.5	20	69	8	30	C	-	-	-	-	-	E	0.2	0.5	69	2.5	58
414	RE	A	18	200	69	11.1111	21	C	-	-	-	-	-	E	0.05	0.055	69	1.1	58
415	PE	A	5	5.5	68	1.1	21	C	-	-	-	-	-	E	0.16	0.4	70	2.5	57
415	PR	A	1.2	6.8	68	5.66667	21	C	-	-	-	-	-	E	2.5	5	70	2	57
415	RE	A	0.6	5.2	68	8.66667	21	C	-	-	-	-	-	E	0.2	0.5	70	2.5	57
416	PE	A	0.5	4	69	8	19	C	-	-	-	-	-	E	0.03	0.05	69	1.66667	58
416	PR	A	3	8	69	2.66667	19	C	-	-	-	-	-	E	0.5	1.9	69	3.8	58
416	RE	A	0.5	5	69	10	19	C	-	-	-	-	-	E	0.055	0.1	69	1.81818	58
417	BR	A	4.5	25	69	5.55556	21												
417	BW	A	3	20	69	6.66667	21												
417	WR	A	2.5	28	69	11.2	21												
418	PE	A	2	18	69	9	34												
418	PR	A	0.22	0.3	69	1.36364	34												
418	RE	A	2.2	17	69	7.72727	34												

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@1 Min	@10 Mi	(F)	Index	RH %	M	@1 Min	@10 Mi	(F)	Index	RH %	M	@1 Min	@10 Mi	(F)	Index	RH %
401	BE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0113	0.0076	85.1	0.67257	32
401	BR	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
401	BW	F	-	-	-	-	-	G	-	-	-	-	-	H	0.00024	0.00024	85.1	1.02128	32
401	WE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.00475	0.0044	85.2	0.92632	32
401	WR	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
402	PE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0174	0.0185	79.8	1.06322	43
402	PR	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0645	0.049	78.4	0.75969	45
402	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0088	0.00975	80.7	1.10795	42
403	PE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.00995	0.00915	80.7	0.9196	43
404	PE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.00805	0.0078	81.1	0.96894	43
404	PR	F	-	-	-	-	-	G	-	-	-	-	-	H	0.385	1.43	80.4	3.71429	43
404	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0108	0.0076	81.3	0.7037	43
405	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0093	0.009	81.5	0.96774	41
406	PE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0196	0.019	83.1	0.96939	40
406	PR	F	-	-	-	-	-	G	-	-	-	-	-	H	0.265	2.42	82.2	9.13208	42
406	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0196	0.0202	83.3	1.03061	40
407	BE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0255	0.027	84	1.05882	37
408	BE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.00022	0.00013	84.7	0.60465	32
408	BR	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
408	BW	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0285	0.021	84.5	0.73684	32
408	WE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0033	0.00395	84.9	1.19697	32
408	WR	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
409	BE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0166	0.0159	81.5	0.95783	41
410	BE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0029	0.00835	82.7	2.87931	38
410	BR	F	-	-	-	-	-	G	-	-	-	-	-	H	0.27	2.25	82.7	8.33333	40
410	BW	F	-	-	-	-	-	G	-	-	-	-	-	H	0.52	3.6	82.2	6.92308	41
410	WR	F	-	-	-	-	-	G	-	-	-	-	-	H	0.38	7.2	82.7	18.9474	39
411	BE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.014	0.01305	85.4	0.93214	31
411	BR	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
411	BW	F	-	-	-	-	-	G	-	-	-	-	-	H	0.17	2.15	85.2	12.6471	32
411	WE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.013	0.0123	85.8	0.94615	31
411	WR	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
412	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0355	0.0345	86	0.97183	31
413	PE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.01005	0.00965	74.1	0.9602	53
413	PR	F	-	-	-	-	-	G	-	-	-	-	-	H	0.235	0.225	73.9	0.95745	52
413	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0097	0.01035	73.9	1.06701	51
414	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0158	0.0141	86	0.89241	31
415	PE	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
415	PR	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
415	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
416	PE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0075	0.0205	75.5	2.73333	44
416	PR	F	-	-	-	-	-	G	-	-	-	-	-	H	0.245	5.95	75.7	24.2857	45
416	RE	F	-	-	-	-	-	G	-	-	-	-	-	H	0.018	0.025	75.5	1.38889	43
417	BR																		
417	BW																		
417	WR																		
418	PE																		
418	PR																		
418	RE																		

Table H.5 Insulation resistance measurements for specimens in test sequence 5

CBL	Cnd	C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
		M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
501	BE	A	8.2	28	69	3.4146	59	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.131	0.178	76.4	1.3588	37	H	0.009	0.011	73	1.2222	31
502	BE	A	1.6	15	68	9.375	24	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.0245	0.0235	74.3	0.9592	39	H	0.85	2.2	66	2.5882	26
502	BW	A	3	21	68	7	24	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	1.8	4.95	75	2.75	39	H	0.5	1.6	66	3.2	26
502	WE	A	1.4	25	68	17.857	24	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.0235	0.023	73.9	0.9787	40	H	4.5	6.8	66	1.5111	26
503	BE	A	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.0096	0.025	74.1	2.6178	53	H	1	4.5	73	4.5	46
503	BR	A	2.5	17	69	6.8	35	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
503	BW	A	0.54	0.75	69	1.3889	35	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	0.37	1.36	73.9	3.6757	53	H	5.1	7.9	73	1.549	46
503	WR	A	5	30	69	6	35	--	-	-	-	-	-	--	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
504	BE	A	0.08	0.09	69	1.125	59	B	-	-	-	-	-	D	0.05	0.062	70	1.24	60	F	-	-	-	-	-	G	0.024	0.039	77.1	1.625	31	H	0.011	0.011	75	1	34
505	BE	A	7.5	30	69	4	59	B	-	-	-	-	-	D	0.05	0.052	70	1.04	59	F	-	-	-	-	-	G	0.134	0.135	76.8	1.0075	37	H	0.4	0.56	76	1.4	37
506	BE	A	0.8	7	70	8.75	22	B	-	-	-	-	-	D	0.15	0.3	70	2	59	F	-	-	-	-	-	G	0.028	0.0305	75.2	1.0893	49	H	1.4	4	74	2.8571	30
506	BW	A	11	40	70	3.6364	22	B	-	-	-	-	-	D	1.3	7.2	70	5.5385	59	F	-	-	-	-	-	G	0.38	2.6	75	6.8421	50	H	0.9	3	74	3.3333	30
506	WE	A	1.3	10	70	7.6923	22	B	-	-	-	-	-	D	0.22	0.4	70	1.8182	59	F	-	-	-	-	-	G	0.03	0.038	75.5	1.2667	46	H	1.3	3.5	74	2.6923	30
507	BE	A	0.85	5.5	69	6.4706	25	B	-	-	-	-	-	D	2.5	20	70	8	59	F	-	-	-	-	-	G	0.0555	0.069	76.1	1.2432	41	H	1.2	3	72	2.5	37
507	BW	A	6	30	69	5	25	B	-	-	-	-	-	D	2	9	70	4.5	59	F	-	-	-	-	-	G	0.66	5.1	75.9	7.7273	43	H	1	2.8	72	2.8	37
507	WE	A	1	5.6	69	5.6	25	B	-	-	-	-	-	D	1.3	15	70	11.538	59	F	-	-	-	-	-	G	0.061	0.076	76.1	1.2459	39	H	0.9	2	72	2.2222	37
508	BE	A	-	-	-	-	-	B	-	-	-	-	-	D	0.03	0.04	71	1.3333	56	F	-	-	-	-	-	G	0.0238	0.0239	83.3	1.0042	37	H	2E-05	2E-05	66	1.0455	25
508	BR	A	3.2	25	69	7.8125	30	B	-	-	-	-	-	D	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
508	BW	A	3	25	69	8.3333	30	B	-	-	-	-	-	D	2	7.5	71	3.75	56	F	-	-	-	-	-	G	0.795	0.66	83.3	0.8302	37	H	2E-05	2E-05	66	1.465	25
508	WE	A	-	-	-	-	-	B	-	-	-	-	-	D	0.04	0.045	71	1.125	56	F	-	-	-	-	-	G	-	-	-	-	-	H	0.0006	0.0011	66	1.8333	25
508	WR	A	1.4	2	69	1.4286	30	B	-	-	-	-	-	D	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
509	BE	A	-	-	-	-	-	B	-	-	-	-	-	D	0.03	0.04	68	1.3333	60	F	-	-	-	-	-	G	0.086	0.102	76.1	1.186	37	H	0.0095	0.012	72	1.2632	31
509	BR	A	3	9	69	3	35	B	-	-	-	-	-	D	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
509	BW	A	1.8	16	69	8.8889	35	B	-	-	-	-	-	D	2.5	7.5	68	3	60	F	-	-	-	-	-	G	1.92	4.6	76.2	2.3958	37	H	0.0035	0.0078	72	2.2286	31
509	WE	A	-	-	-	-	-	B	-	-	-	-	-	D	0.035	0.04	68	1.1429	60	F	-	-	-	-	-	G	0.097	0.102	75.9	1.0515	37	H	0.0001	0.0001	72	1	31
509	WR	A	4.5	22	69	4.8889	35	B	-	-	-	-	-	D	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
510	BE	A	9	30	68	3.3333	55	C	-	-	-	-	-	E	0.025	0.028	67	1.12	65	F	-	-	-	-	-	G	0.038	0.0825	83.1	2.1711	37	H	0.011	0.008	75	0.7273	34
511	BE	A	0.052	0.062	68	1.1923	55	C	-	-	-	-	-	E	0.06	0.08	67	1.3333	65	F	-	-	-	-	-	G	0.0205	0.023	74.3	1.122	51	H	0.0017	0.0017	73	1	31
512	BE	A	7	17	68	2.4286	55	C	-	-	-	-	-	E	0.076	0.12	67	1.5789	65	F	-	-	-	-	-	G	0.112	0.178	77	1.5893	37	H	0.17	0.28	76	1.6471	33
513	BE	A	0.9	8	70	8.8889	22	C	-	-	-	-	-	E	0.15	0.3	69	2	60	F	-	-	-	-	-	G	0.0051	0.0585	83.3	11.471	37	H	0.004	1.4	70	350	31
513	BW	A	5.5	28	70	5.0909	22	C	-	-	-	-	-	E	1.25	5	69	4	60	F	-	-	-	-	-	G	0.89	2.95	83.3	3.3146	37	H	3	7.5	70	2.5	31
513	WE	A	1.4	13	70	9.2857	22	C	-	-	-	-	-	E	0.26	0.45	69	1.7308	60	F	-	-	-	-	-	G	-	-	-	-	-	H	1.1	55	70	50	31
514	BE	A	1.6	14	70	8.75	21	C	-	-	-	-	-	E	5E-05	6E-05	69	1.1	60	F	-	-	-	-	-	G	0.079	0.093	76.6	1.1772	37	H	0.5	0.6	78	1.2	43
514	BW	A	5	200	70	40	21	C	-	-	-	-	-	E	8E-05	1E-04	69	1.3067	60	F	-	-	-	-	-	G	0.78	2.4	77.1	3.0769	37	H	0.4	0.75	78	1.875	43
514	WE	A	1.6	20	70	12.5	21	C	-	-	-	-	-	E	6E-05	6E-05	69	1	60	F	-	-	-	-	-	G	0.056	0.0635	76.8	1.1339	37	H	0.9	2	78	2.2222	43
515	BE	A	-	-	-	-	-	C	-	-	-	-	-	E	0.0075	0.01	69	1.3333	60	F	-	-	-	-	-	G	0.0975	0.093	75.5	0.9538	37	H	4E-05	4E-05	73	1.0625	30
515	BR	A	1.9	5	69	2.6316	27	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
515	BW	A	2	28	69	14	27	C	-	-	-	-	-	E	0.13	0.15	69	1.1538	60	F	-	-	-	-	-	G	1.25	2.15	75.7	1.72	37	H	4E-05	4E-05	73	1.0417	30
515	WE	A	-	-	-	-	-	C	-	-	-	-	-	E	0.01	0.012	69	1.2	60	F	-	-	-	-	-	G	0.0915	0.103	75.3	1.1257	37	H	4E-05	4E-05	73	0.875	30
515	WR	A	4.5	50	69	11.111	27	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
516	BE	A	-	-	-	-	-	C	-	-	-	-	-	E	0.05	0.065	69	1.3	60	F	-	-	-	-	-	G	0.07	0.0765	76.2	1.0929	38	H	8E-05	5E-05	72	0.6667	40
516	BR	A	4	200	69	50	27	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
516	BW	A	1.3	30	69	23.077	27	C	-	-	-	-	-	E	5	20	69	4	60	F	-	-	-	-	-	G	1.25	6.4	76.1	5.12	39	H	0.022	0.0175	72	0.7955	40
516	WE	A	-	-	-	-	-	C	-	-	-	-	-	E	0.055	0.06	69	1.0909	60	F	-	-	-	-	-	G	0.074	0.0765	76.2	1.0338	38	H	0.013	0.013	72	1	40
516	WR	A	3	200	69	66.667	27	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
517	BW	A	3	3.5	69	1.1667	30	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	G	-	-	-	-	-						
518	BE	A	0.9	50	69	55.556	24	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	G*	0.32	0.52	73.7	1.625	41						
518	BW	A	3	20	69	6.6667	24	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	G*	1.9	4.3	73.4	2.2632	41						
518	WE	A	0.8	7	69	8.75	24	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	G*	0.42	0.47	74	1.119	41						
519	BR	A	2.6	11	69	4.2308	25	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	G*	0.115	0.35	74.8	3.0435	41						
519	BW	A	2	17	69	8.5	25	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	G*	1.95	5.1	74.3	2.6154	41						
519	WR	A	5	200	69	40	25	--	-	-	-	-	-	--	-	-	-	-	-	--	-	-	-	-	-	G*											

G* - specimen was 233cm long

Table H.6 Insulation resistance measurements for specimens in test sequence 6

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
601	BE	A	12	50	70	4.16667	27	C	0.0008	0.0012	69	1.5	79	-	-	-	-	-	-	F	1.8	6.8	78	3.77778	18.3	G	0.0022	0.003	72	1.36364	41	H	0.81	0.35	85.4	0.4321	38
602	BE	A	0.1	0.2	69	2	44	C	0.22	0.3	69	1.36364	80	-	-	-	-	-	-	F	0.75	1.7	77.4	2.26667	18.5	G	0.3	0.65	73	2.16667	40	H	0.137	0.096	84.3	0.70073	39
602	BW	A	0.8	4	69	5	44	C	1.3	3.5	69	2.69231	80	-	-	-	-	-	-	F	2.75	6.8	77.4	2.47273	18.5	G	3	5.2	73	1.73333	40	H	0.165	0.305	84.7	1.84848	39
602	WE	A	0.65	7	69	10.7692	44	C	0.65	2.5	69	3.84615	80	-	-	-	-	-	-	F	0.72	1.5	77.4	2.08333	18.5	G	0.5	0.8	73	1.6	40	H	0.0004	0.0002	83.6	0.495	40
603	BE	A	0.6	2	70	3.33333	25	C	0.0088	0.026	69	2.95455	81	-	-	-	-	-	-	F	0.3	0.5	76	1.66667	19	G	0.12	0.175	72	1.45833	41	H	0.00002	1.9E-05	81.6	0.94	42
603	BR	A	5.2	17	70	3.26923	25	C	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
603	BW	A	3.5	7	70	2	25	C	0.011	0.015	69	1.36364	81	-	-	-	-	-	-	F	0.45	0.7	76	1.55556	19	G	0.5	0.58	72	1.16	41	H	3.5E-05	2.4E-05	82.2	0.69275	41
603	RE	A	1.2	1.6	70	1.33333	25	C	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
603	WE	A	1	2	70	2	25	C	0.016	0.035	69	2.1875	81	-	-	-	-	-	-	F	0.175	0.25	76	1.42857	19	G	0.125	0.16	72	1.28	41	H	1.9E-07	2.1E-07	82	1.07813	42
603	WR	A	5	15	70	3	25	C	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
604	BE	A	-	-	-	-	-	C	2.5E-06	2.5E-06	68	1	81	-	-	-	-	-	-	F	1.5	5.4	76	3.6	19.5	G	0.0072	0.009	73	1.25	40	H	0.75	1.5	82.9	2	41
604	BW	A	9.3	48	68	5.16129	44	C	0.8	1.5	68	1.875	81	-	-	-	-	-	-	F	2	5.4	76	2.7	19.5	G	1.25	4	73	3.2	40	H	1.07	2.3	83.1	2.14953	40
604	WE	A	-	-	-	-	-	C	2E-06	2.5E-06	68	1.25	81	-	-	-	-	-	-	F	1.3	4	76	3.07692	19.5	G	0.0085	0.0092	73	1.08235	40	H	0.69	1.4	82.4	2.02899	41
605	BE	A	0.45	0.62	69	1.37778	44	C	0.0012	0.0015	69	1.25	82	E	0.132	0.275	72	2.08333	24.8	F	0.2	0.58	76	2.9	20	G	0.012	0.0225	72	1.875	41	H	7.5E-06	2.4E-05	87	3.13333	38
606	BE	A	10	50	70	5	25	C	0.00095	0.0012	69	1.26316	79	E	0.155	0.33	72	2.12903	25	F	0.275	0.65	76	2.36364	19.8	G	0.007	0.01	72	1.42857	41	H	1.2E-06	1.3E-06	84.2	1.09917	43
607	BE	A	10	35	70	3.5	25	C	0.0014	0.00125	69	0.89286	79	E	0.168	0.405	70.6	2.41071	26.3	F	0.2	0.62	76	3.1	20	G	0.0025	0.00325	72	1.3	41	H	2.2E-06	2.8E-06	84.2	1.26147	43
608	BE	A	1	4	69	4	25	C	0.08	0.09	68	1.125	80	E	0.79	3.4	72.2	4.3038	23.5	F	0.5	1.25	76	2.5	20	G	1.1	6	70	5.45455	40	H	0.46	0.64	84.7	1.3913	44
608	BW	A	7	15	69	2.14286	25	C	0.3	1	68	3.33333	80	E	2.1	8.7	72	4.14286	24.6	F	1.5	6.5	76	4.33333	20	G	0.8	5	70	6.25	40	H	0.98	2.85	84.5	2.90816	44
608	WE	A	0.9	5	69	5.55556	25	C	0.05	0.058	68	1.16	80	E	0.83	2.8	72.3	3.37349	23.4	F	0.5	1.5	76	3	20	G	1.2	6.5	70	5.41667	40	H	0.405	1.35	85.1	3.33333	45
609	BE	A	1	7	69	7	44	C	0.00008	8.5E-05	68	1.0625	80	E	0.88	1.6	72.3	1.81818	23.3	F	0.45	1.1	76	2.44444	20	G	1.25	5.5	70	4.4	40	H	0.0053	0.00255	75.7	0.48113	56
609	BW	A	5.8	16	69	2.75862	44	C	7.5E-05	7.5E-05	68	1	80	E	1.75	5.1	72.4	2.91429	23.3	F	1.2	5	76	4.16667	20	G	0.7	4	70	5.71429	40	H	0.0215	0.0151	76.1	0.70233	55
609	WE	A	1	6.5	69	6.5	44	C	0.00007	7.5E-05	68	1.07143	80	E	0.71	1.6	72.3	2.25352	22.7	F	0.58	1.2	76	2.06897	20	G	0.6	4	70	6.66667	40	H	0.00225	0.0014	75.7	0.62222	55
610	BE	A	1	9	69	9	29	C	0.82	2.8	68	3.41463	78	E	0.385	1.42	70.8	3.68831	25.4	F	0.16	0.29	73	1.8125	20	G	1.2	6	71	5	40	H	0.39	0.555	86	1.42308	44
610	BW	A	2.8	200	69	71.4286	29	C	0.06	0.07	68	1.16667	78	E	1.22	7.25	70.8	5.94262	25.8	F	0.9	3	73	3.33333	20	G	0.5	0.8	71	1.6	40	H	1.08	2.6	85.6	2.40741	44
610	WE	A	0.9	13	69	14.4444	29	C	0.08	0.1	68	1.25	78	E	0.46	1.57	71	3.41304	25.1	F	0.2	0.35	73	1.75	20	G	0.45	0.85	71	1.88889	40	H	0.255	0.3	86.7	1.17647	43
611	BE	A	1	5	69	5	24	C	0.13	0.13	68	1	74	E	0.405	0.81	71.4	2	25.3	F	0.275	0.4	73	1.45455	24	G	0.05	0.075	71	1.5	40	H	0.00048	0.0008	86.9	1.66667	43
611	BR	A	4	20	69	5	24	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
611	BW	A	6.5	19	69	2.92308	24	C	0.06	0.07	68	1.16667	74	E	0.43	1.05	71.4	2.44186	25.2	F	0.45	0.75	73	1.66667	24	G	0.5	0.58	71	1.16	40	H	0.00032	0.0004	86.9	1.25	43
611	RE	A	0.425	0.58	69	1.36471	24	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
611	WE	A	1.4	5	69	3.57143	24	C	0.06	0.078	68	1.3	74	E	0.146	0.27	71.4	1.84932	25.1	F	0.13	0.25	73	1.92308	24	G	0.068	0.09	71	1.32353	40	H	8.2E-07	2.3E-06	87	2.80488	42
611	WR	A	5.5	30	69	5.45455	24	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
612	BE	A	0.85	2	69	2.35294	24	C	0.028	0.058	69	2.07143	67	E	0.355	0.85	71.7	2.39437	25.1	F	0.275	0.4	74	1.45455	25	G	0.065	0.12	71	1.84615	40	H	5.9E-07	1.1E-06	87.9	1.83051	40
612	BR	A	1.7	7.8	69	4.58824	24	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
612	BW	A	1.3	2.5	69	1.92308	24	C	0.013	0.015	69	1.15385	67	E	0.5	1.34	71.4	2.68	25.4	F	0.5	0.95	74	1.9	25	G	0.5	0.6	71	1.2	40	H	9.6E-05	0.00029	87.9	3.02083	40
612	RE	A	0.85	2.5	69	2.94118	24	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
612	WE	A	0.003	0.55	69	183.333	24	C	0.04	0.075	69	1.875	67	E	0.205	0.4	71.8	1.95122	24.9	F	0.13	0.25	74	1.92308	25	G	0.1	0.15	71	1.5	40	H	8.4E-05	2.2E-05	88.1	0.25749	40
612	WR	A	1.6	4	69	2.5	24	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
613	BE	A	1	2.8	69	2.8	49	C	0.07	0.12	69	1.71429	66	E	0.48	0.725	70	1.51042	26	F	0.2	0.3	74	1.5	25	G	0.078	0.095	72	1.21795	40	H	5.4E-05	0.00025	88.1	4.57944	38
613	BG	A	3	8.5	69	2.83333	49	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
613	BR	A	5.8	8	69	1.37931	49	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
613	BW	A	3	5.5	69	1.83333	49	C	0.045	0.055	69	1.22222	66	E	0.445	0.89	73.3	2	37.7	F	0.5	0.72	74	1.44	25	G	0.35	0.52	72	1.48571	40	H	4.1E-05	0.00035	88.5	8.53659	38
613	GE	A	0.00175	0.0025	69	1.42857	49	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
613	RE	A	0.9	1.6	69	1.77778	49	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
613	RG	A	3	7	69	2.33333	49	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
613	WE	A	0.58	0.8	69	1.37931	49	C	0.09	0.13	69	1.44444	66	E	0.435	0.445	70.4	1.02299	26.8	F	0.13	0.15	74	1.15385	25	G	0.21	0.3	72	1.42857	40	H	4.1E-06	3.5E-06	88.7	0.85366	38
613	WG	A	4	6.5	69	1.625	49	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
613	WR	A	1	4	69	4	49	C	-	-	-	-	-	E	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
614	BW	A	9.8	58	68	5.91837	44	B	3.6	24.8	73.5	6.88889	62	C	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
615	BW	A	9.1	49	68	5.38462	44	B	0.232	0.242	73	1.0431	61	C	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
616	BW	A	9.4	51.5	68	5.47872	44	B	3.7	23.4	74.3	6.32432	64	C	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
617	BE	A	11	200	69	18.1818	25	C	0.0035	0.0023	69	0.65714	51	E	0.098	1.21	72.5	12.3469	22.6	F	0.3	1.1	75	3.66667	25	G	-	-	-	-	-	H	-	-	-	-	-
618	BE	A	0.9	13	69	14.4444	25	C	7.5E-06	8E-06	69	1.06667	51	E	1.53	14.5	72.5	9.47712	22.8	F	5	20	75	4	24	G	-	-	-	-	-	H	-	-	-	-	-
618	BW	A	2	4	69	2	25	C	1.6E-05	1.7E-05	69	1.0625	51	E	3.45	34	72.5	9.85507	22.7	F	2.75	12	75	4.36364	24	G	-	-	-	-	-	H	-	-	-	-	-
618	WE	A	2	9	69	4.5	25	C	6.8E-05	8.4E-05	69	1.23529	51	E	1.35	11.5	72.7	8.51852	22.9	F	3	16	75	5.33333	24	G	-	-	-	-	-	H	-	-	-	-	-
619	BE	A	0.65	5	70	7.69231	25	C	1.7E-05	1.7E-05	69	1	52	E	0.85	1.6	69.7	1.88235	25.1	F	0.4	0.5	75	1.25	24	G	-	-	-	-	-	H	-	-	-	-	-
619	BR	A	5	9	70	1.8	25	C	0.0001	0.0001	69	1	52	E	0.49	1.57	69.2	3.20408	25.1	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
619	BW	A	3	10	70	3.33333	25	C	5.7E-05	5.7E-05	69	1	52	E	0.275	1.26	72.8	4.58182	23.3	F	0.3	0.5	75	1.66667	2424	G	-	-	-	-	-	H	-	-	-	-	-

Table H.6 Insulation resistance measurements for specimens in test sequence 6

		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn		C	IR in Tera-ohms		Temp	Polrizatn	
CBL	Cnd	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %	M	@ 1 Min	@ 10 Mi	(F)	Index	RH %
619	RE	A	5	10	70	2	25	C	0.00004	0.00004	69	1	52	E	0.097	0.123	70.1	1.26804	24.8	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
619	WE	A	13	17	70	1.30769	25	C	5.4E-06	7.5E-06	69	1.38889	52	E	0.0335	0.039	69.9	1.16418	24.9	F	0.065	0.08	75	1.23077	24	G	-	-	-	-	-	H	-	-	-	-	-
619	WR	A	6	13	70	2.16667	25	C	0.00005	5.6E-05	69	1.12	52	E	0.147	0.195	69.5	1.32653	25	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
620	BW	A	14.6	95	68	6.50685	44	B	3.4	34.5	73.2	10.1471	62	C	-	-	-	-	-	F	-	-	-	-	-	G	-	-	-	-	-	H	-	-	-	-	-
621	BE	A	-	-	-	-	-	C	1.5E-05	1.7E-05	70	1.1	64	E	0.011	0.0166	73.2	1.50909	38.7	F	0.6	0.78	74	1.3	25	G	0.004	0.006	72	1.5	40	H	0.27	0.61	84.2	2.25926	42
621	BW	A	1.1	200	69	181.818	29	C	8.5E-05	9.2E-05	70	1.08235	64	E	0.95	5.6	72.9	5.89474	39.2	F	1.4	4	74	2.85714	25	G	0.35	1	72	2.85714	40	H	0.38	1.01	84.7	2.65789	41
621	WE	A	-	-	-	-	-	C	1.6E-05	0.00002	70	1.25	64	E	0.0157	0.0168	73.2	1.07006	38.7	F	0.5	0.6	74	1.2	25	G	0.0055	0.0068	72	1.23636	40	H	0.18	0.45	84.2	2.5	43
622	BE	A	-	-	-	-	-	C	0.02	0.025	69	1.25	62	E	0.22	0.238	73.2	1.08182	37.7	F	0.72	1	74	1.38889	25	G	0.02	0.026	72	1.3	39	H	0.25	0.45	85.6	1.8	33
622	BW	A	1.4	4.5	69	3.21429	29	C	0.8	7	69	8.75	62	E	2	4.9	73.3	2.45	37.7	F	2.5	5	74	2	25	G	0.5	1.5	72	3	39	H	0.29	0.825	85.6	2.84483	34
622	WE	A	-	-	-	-	-	C	0.025	0.027	69	1.08	62	E	0.242	0.29	73.3	1.19835	37.7	F	0.65	0.9	74	1.38462	25	G	0.025	0.03	72	1.2	39	H	0.145	0.285	85.6	1.96552	33
623	BE	A	-	-	-	-	-	C	0.052	0.062	69	1.19231	51	E	0.018	0.02	73.2	1.11111	38.6	F	0.75	1.7	75	2.26667	25	G	0.0065	0.0085	72	1.30769	38	H	0.154	0.33	84.5	2.14286	41
623	BW	A	0.95	200	69	210.526	29	C	0.15	0.16	69	1.06667	51	E	0.83	2.5	73.2	3.01205	37.8	F	1.3	4	75	3.07692	25	G	0.35	1.2	72	3.42857	38	H	0.26	0.51	84.5	1.96154	41
623	WE	A	-	-	-	-	-	C	0.125	0.13	69	1.04	51	E	0.018	0.0215	73	1.19444	38.4	F	0.62	1.75	75	2.82258	25	G	0.0082	0.009	72	1.09756	38	H	0.175	0.38	84.7	2.17143	41
624	BE	A	-	-	-	-	-	C	0.00008	0.0001	71	1.25	38	E	0.195	0.255	70.5	1.30769	24.4	F	0.009	0.011	75	1.22222	25	G	-	-	-	-	-	H	-	-	-	-	-
624	BW	A	1.1	200	69	181.818	29	C	1.7	9	71	5.29412	38	E	3.9	19.5	70.5	5	24.7	F	1.75	7.5	75	4.28571	25	G	-	-	-	-	-	H	-	-	-	-	-
624	WE	A	-	-	-	-	-	C	0.00007	8.2E-05	71	1.17143	38	E	0.218	0.27	70.5	1.23853	24.2	F	0.01	0.012	75	1.2	25	G	-	-	-	-	-	H	-	-	-	-	-

604	BW	B	3.95	29.4	73.2	7.44304	62
614	BW	B	3.6	24.8	73.5	6.88889	62
615	BW	B	0.225	0.247	73	1.09778	62
616	BW	B	3.7	23.4	74.3	6.32432	64
620	BW	B	3.4	34.5	73.2	10.1471	62

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40 yrs thermal
aging, then

Appendix I

Submerged Voltage Withstand Data

Tables

Table I.1 Results of submerged voltage withstand test on specimens in test sequence 1

Group	Specimen No.	Manufacturer	Applied Voltage (Vac)	Leakage (microamps)		Pass/Fail
				White Conductor	Black Conductor	
1.1 (no aging)	0101	Rockbestos	2,400	640	640	Pass
	0102		2,400	690	660	Pass
	0118 (a)		2,400	560	560	Pass
	0104		2,400	690	680	Pass
	0105		2,400	690	680	Pass
1.2 (aged to match Group 1.3)	0106	Rockbestos	2,400	720	740	Pass
	0107		2,400	350	400	Pass
	0108		2,400	690	760	Pass
	0109		2,400	720	740	Pass
	0110		2,400	720	760	Pass
1.3 (naturally aged)	0111	Rockbestos	2,400	680	720	Pass
1.4 (aged to 20 years)	0112	Rockbestos	2,400	480	480	Pass (b)
	0113		2,400	550	700	Pass (b)
	0114		2,400	920	940	Pass (b)
	0115		2,400	820	730	Pass (b)
	0116		2,400	740	760	Pass (b)

(a) Specimen 0103 was found to be damaged during baseline visual examination and was replaced with specimen 0118.
(b) Specimens in Group 1.4 passed the voltage withstand test after removing the Raychem® splices from the cable ends.

Table I.2 Results of submerged voltage withstand test on specimens in test sequence 2

Group	Specimen No.	Manufacturer	Applied Voltage (Vac)	Leakage (microamps)		Pass/Fail
				White Conductor	Black Conductor	
2.1 (no aging)	0201	AIW	2,400	780	840	Pass
	0202		2,400	1,000	1,000	Pass
	0203		2,400	770	820	Pass
	0204		2,400	900	1,200	Pass
	0205		2,400	780	920	Pass
2.2 (aged to match Group 2.3)	0206	AIW	2,400	810	900	Pass
	0207		2,400	780	820	Pass
	0208		2,400	740	790	Pass
	0209		2,400	790	770	Pass
	0210		2,400	860	900	Pass
2.3 (naturally aged)	0211	AIW	2,400	730	760	Pass
2.4 (aged to 20 years)	0212	AIW	2,400	870	940	Pass
	0213		2,400	820	930	Pass
	0214		2,400	940	940	Pass
	0215		2,400	800	890	Pass
	0216		2,400	940	930	Pass

Table I.3 Results of submerged voltage withstand test on specimens in test sequence 3

Group	Specimen No.	Manufacturer	Applied Voltage (Vac)	Leakage (microamps)		Pass/Fail
				White Conductor	Black Conductor	
3.1 (no aging)	0301	Rockbestos	2,400	590	550	Pass
	0302		2,400	500	520	Pass
3.2 (aged to match Group 3.3)	0303(a)	Rockbestos	2,400	450	590	Pass
	0304		2,400	510	600	Pass
	0305		2,400	510	525	Pass
	0306(a)		2,400	350	375	Pass
3.3 (naturally aged)	0307	Rockbestos	2,400	520	580	Pass
	0308		2,400	550	590	Pass
	0309		2,400	500	520	Pass
	0310		2,400	580	600	Pass
	0311(a)		2,400	350	360	Pass
3.4 (aged to 40 years)	0312(a)	Rockbestos	2,400	1,200	1100	Pass
	0313(a)		200(b)	> 5000	> 5000	**Fail**
	0314(a)		2,400	1300	1150	Pass
	0315(a)		2,400	1,400	1275	Pass
	0316(a)		2,400	950	1050	Pass

(a) Splices were removed from specimen ends prior to voltage withstand testing.
(b) Specimen would not hold 2,400 volts; test performed at lower voltage noted.

Table I.4 Results of submerged voltage withstand test on specimens in test sequence 4

Group	Specimen No.	Manufacturer	Applied Voltage (Vac)	Leakage (microamps)		Pass/Fail
				White Conductor	Black Conductor	
4.1 (no aging)	0401	Anaconda	2,400	800	800	Pass
	0402	Samuel Moore	2,400	800	800	Pass
4.2 (aged to 20 years)	0403	Samuel Moore	2,400	600	NA	Pass
	0404		2,400	1,000	1,000	Pass
	0405		2,400	1,000	NA	Pass
	0406		2,400	1600	1600	Pass
4.3 (aged to 40 years)	0407	Anaconda	2,400	1,000	NA	Pass
	0408		2,400	1,400	1,000	Pass
	0409		2,400	1,000	NA	Pass
	0410		2,400	1600	1600	Pass
	0411		2,400	1600	1600	Pass
	0412	Samuel Moore	2,400	800	NA	Pass
	0413 (a)		1,200 (a)/2,400	> 10 mA	1,400	**Fail**
	0414		2,400	800	NA	Pass
	0415		2,400	2000	2200	Pass
	0416 (a)		2,400/1,000 (a)	2000	> 10 mA	**Fail**

(a) Specimen would not hold 2,400 volts; test performed at lower voltage noted.
NA = Not applicable; single conductor cable specimen

Table I.5 Results of submerged voltage withstand test on specimens in test sequence 5

Group	Specimen No.	Manufacturer	Applied Voltage (Vac)	Leakage (microamps)		Pass/Fail
				White Conductor	Black Conductor	
5.1 (no aging)	0501	Okonite	2,400	780	NA	Pass
	0502	Samuel Moore	2,400	790	710	Pass
	0503	Anaconda	2,400	780	720	Pass
5.2 (aged to 20 years)	0504	Okonite	2,400	1,000	NA	Pass
	0505 [(a)]		< 200	> 10mA	NA	**Fail**
	0506	Samuel Moore	2,400	1,000	1,000	Pass
	0507		2,400	1,200	1,400	Pass
	0508	Anaconda	2,400	780	1,000	Pass
	0509		2,400	790	850	Pass
5.3 (aged to 40 years)	0510 [(a)]	Okonite	< 200	> 10mA	NA	**Fail**
	0511 [(a)]		< 200	> 10mA	NA	**Fail**
	0512 [(a)]		< 200	> 10mA	NA	**Fail**
	0513	Samuel Moore	2,400	1,800	1,000	Pass
	0514		2,400	1,200	1,000	Pass
	0515	Anaconda	2,400	790	850	Pass
	0516		2,400	820	780	Pass

(a) Specimen would not hold 2,400 volts; test performed at lower voltage noted.
NA = Not applicable; single conductor cable specimen

Table I.6 Results of submerged voltage withstand test on specimens in test sequence 6

Group	Specimen No.	Manufacturer	Applied Voltage (Vac)	Leakage (microamps)		Pass/Fail
				White Conductor	Black Conductor	
6.1 (no aging)	0601	Okonite	2,400	< 1,000	NA	Pass
	0602	Samuel Moore	2,400	< 1,000	< 1,000	Pass
	0603	AIW	2,400/1,500	1,500	> 10mA	**Fail**
	0604	Rockbestos	2,400	< 1,000	< 1,000	Pass
6.2 (aged to 60 years)	0605 (a)	Okonite	< 200	> 10mA	NA	**Fail**
	0606 (a)		< 200	> 10mA	NA	**Fail**
	0607 (a)		< 200	> 10mA	NA	**Fail**
	0608	Samuel Moore	2,400	4,000	2,200	Pass
	0609 (a)		500/2,400	> 10mA	1,400	**Fail**
	0610		2,400	3,200	4,400	Pass
	0611 (a)	AIW	1,000/2,400	> 10mA	1,400	**Fail**
	0612 (a)		2,400/1,500	1,400	> 10mA	**Fail**
	0613 (a)		500/2,400	> 10mA	4,200	**Fail**
	0621 (b)	Rockbestos	2,400	2,000	1,800	Pass
	0622 (a,b)		2,400/500	2,000	> 10mA	**Fail**
	0623 (b)		2,400	3,000	3,600	Pass

(a) Specimen would not hold 2,400 volts; test performed at lower voltage noted.
(b) Specimens 0614, 0615 and 0616 were replaced with 0621, 0622 and 0623 to allow splice application prior to pre-aging.
NA = Not applicable; single conductor cable specimen

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR- 6704
BNL-NUREG-52610

2. TITLE AND SUBTITLE

Assessment of Environmental Qualification Practices and Condition Monitoring Techniques for Low-Voltage Electric Cables - Condition Monitoring Test Results (Volume 2)

3. DATE REPORT PUBLISHED

MONTH	YEAR
February	2001

4. FIN OR GRANT NUMBER
W-6465

5. AUTHOR(S)

R. Lofaro, E. Grove, M. Villaran, P. Soo, and F. Hsu

6. TYPE OF REPORT

NUREG

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Energy Sciences and Technology Department
Brookhaven National Laboratory
Upton, NY 11973-5000

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

This report documents the results of a research program addressing issues related to the qualification process for low-voltage instrumentation and control (I&C) electric cables used in commercial nuclear power plants. Three commonly used types of I&C cable were tested: Cross-Linked Polyethylene (XLPE) insulation with a Neoprene® jacket, Ethylene Propylene Rubber (EPR) insulation with an unbonded Hypalon® jacket, and EPR with a bonded Hypalon® jacket. Each cable type received accelerated aging to simulate 20, 40, and 60 years of qualified life. In addition, naturally aged cables of the same types were obtained from decommissioned nuclear power plants and tested. The cables were subjected to simulated loss-of-coolant-accident (LOCA) conditions, which included the sequential application of LOCA radiation followed by exposure to steam at high temperature and pressure, as well as to chemical spray. Periodic condition monitoring (CM) was performed using nine different techniques to obtain data on the condition of the cable, as well as to evaluate the effectiveness of those CM techniques for in situ monitoring of cables.

Volume 1 of this report presents the results of the LOCA tests, and Volume 2 discusses the results of the condition monitoring tests.

12 KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

electric cables, aging, performance testing, environmental effects, nuclear power plants, electrical equipment, electrical insulation, loss of coolant, materials testing, monitoring, radiation effects, service life

13. AVAILABILITY STATEMENT
Unlimited

14. SECURITY CLASSIFICATION
(This Page)
Unclassified
(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300