Attachment 1

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March 6, 2000

Mr. Satish K. Aggarwal
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U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Results of Test 5 on Bonded Jacket Electric Cables

Dear Satish:

As you know, we have recently completed the fifth test in our research program on low-voltage electric cables (JCN W-6465). The objective of this test was to determine if bonded jacket cables have any unique failure mechanisms that are not present in unbonded jacket cables. To achieve this objective, EPR insulated cables with both a bonded and unbonded CSPE jacket were preaged and accident tested. The cables were manufactured by Okonite, Samuel Moore, and Anaconda. As a result of this test, one of the two Okonite cables preaged to simulate 20 years of qualified life, and three of the three Okonite cables preaged to simulate 40 years of qualified life failed catastrophically by splitting open. These results call into question the qualification basis for these cables. The Samuel Moore and Anaconda cables performed acceptably. The enclosed letter report documents the findings of this test.

If you have any questions on this, please contact me.

Sincerely,

Robert J. Lofaro
Program Manager, Aging and Equipment Testing
Engineering Mechanics and Infrastructure Group

RJL/jmfL11
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Brookhaven National Laboratory

RESULTS OF TEST SEQUENCE 5 ON ELECTRIC CABLES WITH ETHYLENE PROPYLENE RUBBER INSULATION AND BONDED HYPALON® JACKET

February 23, 2000

1. INTRODUCTION

1.1 Background

The U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), is conducting research to resolve issues related to the process used for the Environmental Qualification (EQ) of certain electric components used in nuclear power plants. The initial focus of this program is on low-voltage electric cables used for instrumentation and control applications. Brookhaven National Laboratory (BNL) was selected as the lead laboratory to assist RES in performing this research. The issues to be addressed are documented in NUREG/CR-6384 [1] and BNL Technical Report TR-6169-9/97 [2]. To resolve these issues, BNL developed a research program which includes testing of various electric cables commonly used in nuclear power plants. The testing is performed on new cables that have been artificially aged, as well as on unaged and naturally aged cables obtained from nuclear power plants.

The BNL EQ testing program is structured such that unaged cable specimens are first artificially aged to the desired equivalent service life, then exposed to high temperature and high pressure steam and chemical sprays, which simulate a design basis loss-of-coolant-accident (LOCA). Unaged and, for some tests, naturally aged cables are exposed to the same LOCA simulations, after which comparisons are made. Hold points are built into the program to allow the condition and performance of the cables to be monitored periodically throughout the preaging and LOCA testing process. Various condition monitoring (CM) methods are used at each hold point to obtain data on the cables. The preaging/LOCA test plan is described in BNL Technical Report TR-6168/69-04-95 [3]. The condition monitoring research is described in BNL Technical Report TR-6168/69-03-95 [4].

Six preaging/LOCA testing sequences are planned for this research program. In each sequence, one or more of the three cable types being studied is tested (see Section 1.4). The preaging/LOCA testing parameters may be different for each type of cable tested. The results of the first three test sequences are reported in BNL Technical Reports TR-6465-01-98 [5], TR-6465-05-98 [6], and TR-6465-01-99 [7].

The objective of the fifth test, which is reported herein, is to determine if cables with a chloro-sulfinated polyethylene (CSPE), also known as Hypalon®, jacket bonded to ethylene propylene rubber (EPR) insulation have any unique failure mechanisms compared to cables with unbonded jackets. This issue is being addressed due to results of past testing by Sandia National Laboratory in which Samuel Moore and Okonite cables with bonded jackets experienced failures [8, 9]. In light of the stated objective, EPR insulated cables with bonded CSPE jackets manufactured by Samuel Moore and Okonite were artificially aged and accident tested. For comparative purposes, a cable with an unbonded jacket manufactured by Anaconda was also included in this test.

1.2 Purpose of This Report

This interim report presents the results of the fifth test sequence in the BNL EQ Research Program. It presents the results of the artificial aging and accident testing on the three types of cables tested. Each of the condition monitoring methods being evaluated as part of the BNL program was performed throughout this test sequence, and detailed results and analysis will be reported in a final NUREG/CR report for the program.

1.3 Cables Tested

To achieve the objective of this test, cables with EPR insulation and a bonded CSPE jackets from two manufacturers, Samuel Moore and Okonite, were included. For comparison, a cable with EPR insulation and an unbonded CSPE jacket manufactured by Anaconda was also included in the test. A description of the cables tested is presented in Table 1.

Table 1 Cable Types Included in Test Sequence 5

Cable Manufacturer	Cable Type	Cable Description
Anaconda	P	• 0.045" CSPE outer jacket • 0.030" EPR insulation • 0.015" CSPE un-bonded individual jacket • 3/C #12 AWG • 1,000 V
Samuel Moore	I&C	• 0.045" CSPE outer jacket • 0.020" EPDM insulation • 0.010" CSPE bonded individual jacket • 2/C #16 AWG with shield and ground • 600 V
Okonite	I&C	• No outer jacket • 0.030" EPR insulation • 0.015" CSPE bonded individual jacket • 1/C #12 AWG • 600 V

I&C = Instrumentation and Control, P = Power, EPR = Ethylene Propylene Rubber, CSPE = Chlorosulfinated Polyethylene

1.4 Condition Monitoring Hold Points

Periodically throughout the test sequence, testing was halted and condition monitoring (CM) data were obtained. Each of these specified hold points corresponds to a different condition for the cable specimens and is identified by a letter. The test results, which will be reported in the final NUREG/CR report for this program, are reported based on these CM points, which are as follows:

"A" - Baseline for cable in as-received condition.
"B" - After completion of accelerated thermal aging to simulate 20 years of service.
"C" - After completion of accelerated thermal aging to simulate 40 years of service.
"D" - After completion of radiation aging to simulate 20 years of service.

"E" - After completion of radiation aging to simulate 40 years of service.
"F" - After completion of one half of the accident radiation aging.
"G" - After completion of full accident radiation aging.
"H" - After completion of steam/chemical spray exposure.

1.5 Quality Assurance

To ensure that the results of this research are traceable and defensible, a Quality Assurance (QA) program was developed and implemented 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 [8].

2. PREPARATION OF TEST SPECIMENS

2.1 Cable Acquisition

The cable samples used in the test were acquired from Sandia National Laboratory. They are the same cables used in past Sandia tests. Since the cables were originally purchased by Sandia in the early to mid 1980s, they were approximately 15 to 20 years old at the time of testing by BNL. Visual inspection and elongation-at-break (EAB) testing were performed on the as-received cables to verify they were in excellent condition with no observable signs of degradation. Once received at BNL, the cables were maintained in an environmentally controlled storage area and continuously monitored for temperature and humidity to ensure no additional degradation occurred.

2.2 Sizing and Mounting of Test Specimens

Upon selecting a specific cable for testing, it was retrieved from the BNL cable storage area and cut to length. For this testing program, the cable samples were cut into both long (10 foot) and short (6 inch) specimens for testing. The long specimens were energized during the steam exposure and monitored for cable functional performance. The short specimens were made from the same source as the long specimens and were used for destructive testing to determine the condition of the cable materials at various hold points. Two-foot specimens were also prepared and included for materials testing using the Ogden Indenter Polymer Aging Monitor.

The long specimens were installed on stainless steel mandrels to simulate actual qualification testing. The mandrel diameter of approximately 13.5 inches was used. The specimens were tied to the mandrel using stainless steel wire, which was applied by hand just tight enough to hold the cable snugly and keep 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.

The mandrels included a 2-foot Unistrut® arm to support the ends of the test specimen as they came off the mandrel. In addition, short (2 to 3 foot) pigtails were spliced to the test specimens using Raychem nuclear grade splices prior to any accelerated aging to avoid handling damage to the test specimens. The pigtails were shielded from the conditions of thermal and radiation aging, to the extent possible, to keep them from becoming brittle. After preaging had been completed, the facility test lead wires were connected to the pigtails using a second splice.

Preparation of the 6-inch short specimens involved removing the cable outer jacket from the individual conductors (Samuel Moore and Anaconda cables) and removing the copper conductors from the insulation. This allowed for individual jacket and conductor insulation testing. For the Anaconda specimens, since the inner CSPE jacket was not bonded to the EPR insulation, it was removed and both were tested independently. The outer CSPE jackets from the Samuel Moore and Anaconda specimens were stamped into a "dog bone" configuration for EAB testing. The insulation specimens were left in a tubular configuration for testing. The short specimens were placed in stainless steel mesh baskets. Five short cable jacket and insulation specimens were inserted into each basket. The baskets were then designated for removal at specific CM points for materials testing.

In order to ensure that the long specimens would not be damaged by repeated indenter testing, an additional 2-foot specimen was prepared from the same source for each long specimen. This 2-foot specimen followed the parent long specimen throughout the test sequence and was used for indenter testing. Approximately 6 inches of jacket material was removed from both ends of the 2-foot specimen to allow indenter testing of the insulation material.

2.3 Identification of Test Specimens

Throughout this program, 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, an identification scheme was developed, and a unique identification number was assigned 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 typically obtained as 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. These unaged source cables are referred to as cable "samples" and were used as the source cable for preparing the test specimens. The cable test "specimens" are the 10-foot, 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 manufacturer of cable: "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.).

The 10-foot cable test specimens were labeled using a 4-digit code, such as "0101." The first two digits represent the number of the preaging/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 identification 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.

The 6-inch specimens were prepared from the same source as the 10-foot specimens. Therefore, their identification code is linked to the parent specimen. The small specimen code 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 10-foot 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.

Table 2 provides the identification number, along with the materials of construction, the manufacturer and the wire size for each of the test specimens in Test Sequence 5.

Table 2 Specimens in Test Sequence 5

Group	Cable Specimen ID. No.	Sample ID	Configuration	Manufacturer	Insulation Material	Jacket Material	No. of Conductors	Wire Gauge (AWG)	Cable Diameter (in.)	Cable Type
1 Control	0501	LNI81OK020	10 FT-MAN	OK	EPR/CSPE	None	1	12	0.18	I
	0502	DNI80SM010	10 FT-MAN	SM	EPDM/CSPE	CSPE	2 w/shield & gnd	16	0.36	I
	0503	DNP78AN008	10 FT-MAN	AN	EPR/CSPE	CSPE	3	12	0.48	P
2 (20 Yr.)	0504	LNI81OK020	10 FT-MAN	OK	EPR/CSPE	None	1	12	0.18	I
	0505	LNI81OK020	10 FT-MAN	OK	EPR/CSPE	None	1	12	0.18	I
	0506	DNI80SM010	10 FT-MAN	SM	EPDM/CSPE	CSPE	2 w/shield & gnd	16	0.36	I
	0507	DNI80SM010	10 FT-MAN	SM	EPDM/CSPE	CSPE	2 w/shield & gnd	16	0.36	I
	0508	DNP78AN008	10 FT-MAN	AN	EPR/CSPE	CSPE	3	12	0.48	P
	0509	DNP78AN008	10 FT-MAN	AN	EPR/CSPE	CSPE	3	12	0.48	P
3 (40 yr.)	0510	LNI81OK020	10 FT-MAN	OK	EPR/CSPE	None	1	12	0.18	I
	0511	LNI81OK020	10 FT-MAN	OK	EPR/CSPE	None	1	12	0.18	I
	0512	LNI81OK020	10 FT-MAN	OK	EPR/CSPE	None	1	12	0.18	I
	0513	DNI80SM010	10 FT-MAN	SM	EPDM/CSPE	CSPE	2 w/shield & gnd	16	0.36	I
	0514	DNI80SM010	10 FT-MAN	SM	EPDM/CSPE	CSPE	2 w/shield & gnd	16	0.36	I
	0515	DNP78AN008	10 FT-MAN	AN	EPR/CSPE	CSPE	3	12	0.48	P
	0516	DNP78AN008	10 FT-MAN	AN	EPR/CSPE	CSPE	3	12	0.48	P

MAN = Mandrel
I = Instrumentation
P = Power

OK = Okonite
AN = Anaconda
SM = Samuel Moore

EPR = Ethylene Propylene Rubber
CSPE = Chlorosulfinated Polyethylene

3. DESCRIPTION OF ACCELERATED AGING AND ACCIDENT TESTING

3.1 Selection of Aging Parameters

As part of this test, various unused cables were exposed to accelerated thermal and radiation aging to simulate actual service conditions. In all cases, sequential thermal aging followed by radiation aging was used.

The accelerated aging parameters (i.e., activation energy, thermal aging temperature, radiation dose, and dose rate) were selected to match those used for the original qualification testing of the cables. Table 3 lists the qualification test reports obtained and reviewed for this information. 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 or 40 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. 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 3 Qualification Reports Used to Determine Preaging Parameters

Cable Tested	Report Author	Report Title	Report Number	Report Date
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

The accelerated aging parameters selected for the test specimens are presented in Table 4.

3.2 Accelerated Aging Procedure

Prior to thermal aging, the test specimens were prepared and installed on their test fixture, as discussed previously. Accelerated thermal aging was then performed by Wyle Laboratories in Huntsville, Alabama. All specimens with the same specified aging temperature were loaded into one oven. The specimens were not energized during the thermal aging exposure. Oven temperature was controlled to ± 4°F with a thermal trip setting +10°F above the specified aging temperature. Thermal aging duration was controlled to +2, -0 % 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 one hours). A continuous circular chart recording was used to monitor the thermal aging process. All work was performed in accordance with Wyle Laboratories' preaging procedure under an Appendix B Quality Assurance program.

Table 4 Accelerated Aging Parameters for Test Sequence 5 Specimens

Group	Manufacturer	Thermal Aging		Service Radiation [a]	
		Temp. (± 4 °F)	Duration (hours) (+2, -0%)	Total Integrated Dose (Mrad) (± 10%)	Dose Rate (Mrad/hr.) (± 10%)
1 (no aging)	Okonite	None	-	None	-
	Sam Moore	None	-	None	-
	Anaconda	None	-	None	-
2 (20 yr.)	Okonite	302	252	25	0.65
	Sam Moore	250	84	25	0.75
	Anaconda	302	84	25	0.35
3 (40 yr.)	Okonite	302	504	50	0.65
	Sam Moore	250	168	50	0.75
	Anaconda	302	168	50	0.35

(a) Radiation exposures for long specimens and/or basket specimens in the same group were performed in multiple runs due to restrictions on the number of sources allowed in the hot cell at one time. Therefore, the radiation doses and dose rates varied slightly between specimens.

After completion of thermal aging, accelerated service radiation, followed by accident radiation exposures were performed by 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 an accident 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.

The hot cell in which the specimens were irradiated is large enough to accommodate the long specimens on their mandrel assemblies. Several mandrels were stacked on top of each other, and the sources 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. The designated sources are 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.

3.3 Accident Testing Procedure

The accident test included a sequential exposure to gamma radiation followed by high temperature/pressure steam and chemical spray. As previously mentioned, the accident irradiation was performed at the Georgia Institute of Technology immediately after completion of the service irradiation. The accident (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 an Appendix B Quality Assurance program.

The accident irradiation was administered in two exposures to 75 Mrad of radiation at 0.75 Mrad/hr for a total exposure of 150 Mrad. This was performed in two exposures to allow condition monitoring data to be obtained at the midpoint.

As was done for the selection of preaging parameters, the LOCA test profile was chosen to be consistent with, and to envelop, the original qualification tests used for all three cables. The profile used in this test included a double peak at a maximum temperature of 346°F and a pressure of 113 psig. Temperature and pressure were then stepped down to 212°F and ambient pressure. Chemical spray was included during the steam exposure starting at approximately 15 hours. The chemical spray was delayed to allow test chamber pressure to decay to approximately 32 psig to accommodate the available head for the test facility chemical spray pump. The duration of the accident steam exposure was ten days for this test. The profile is shown in Figure 1.

3.4 Accident Test Setup

The LOCA test chamber used is a larger diameter pressure vessel (59-inch diameter), which was suitable for loading the mandrel mounted specimens. 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. 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 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 cable specimens to be energized 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 pigtails 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 are sealed with a potting compound. 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.

3.5 Accident Test Performance

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

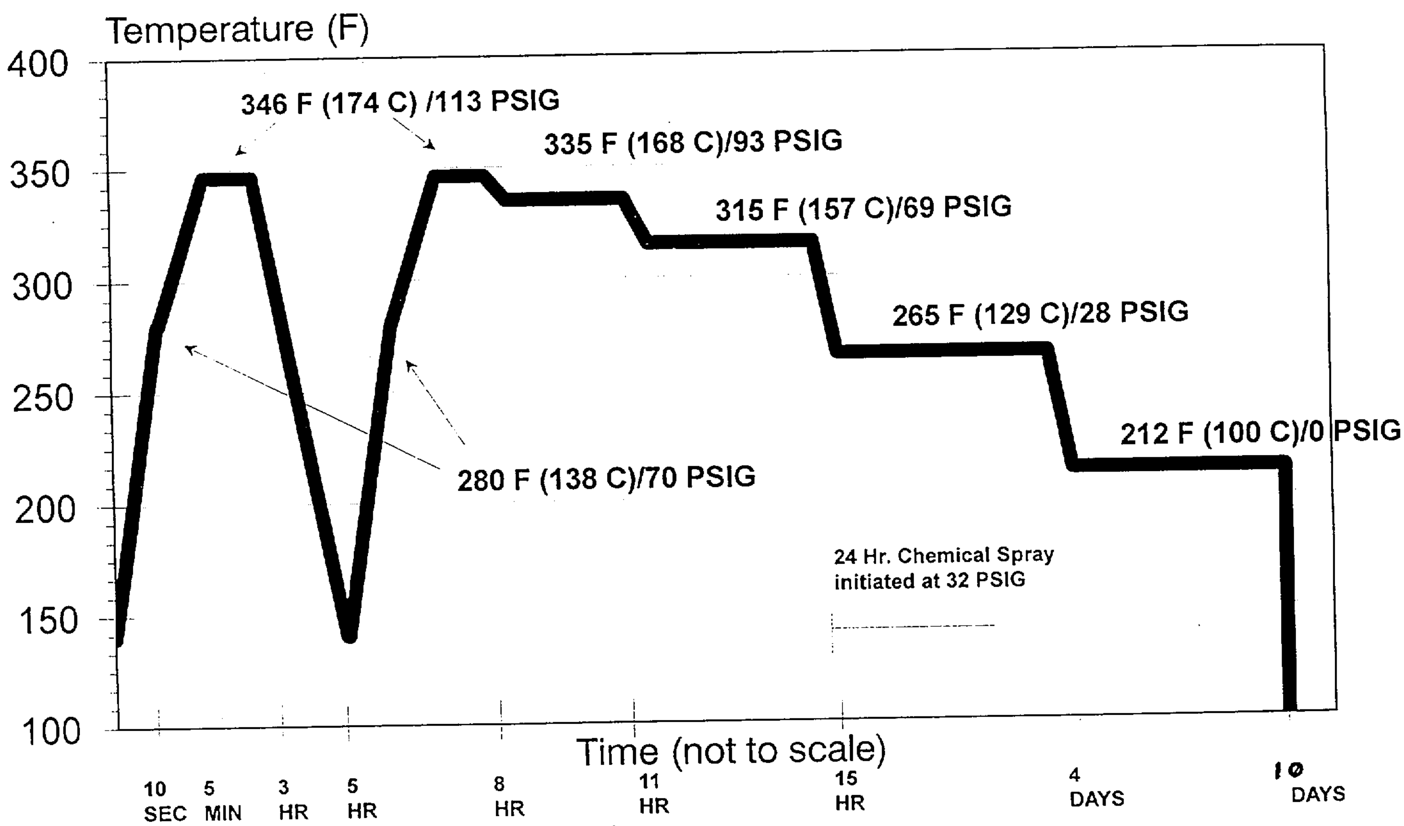

Figure 1 Temperature/pressure profile for LOCA 5 accident simulation

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, as suggested by Appendix A to 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 8.5 by the end of spray test.

3.6 Functional Performance Monitoring During the Accident Test

The long specimens (except the sacrificial specimens that were cut up for archiving at each hold point) were each powered and loaded as detailed in Figure 2. Each of these specimens was powered separately with 28 Vdc. A pressure transmitter was connected to the chamber leads of each long cable specimen to simulate an instrumentation load. A source tank and header supplied a constant pressure or approximately 15 psig, to which the 16 pressure transmitters were connected. 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 in Figure 2. Nominal values for the initial healthy circuits are 28 volts dc applied voltage, 12.8 milliamps for "A" and "B" currents, and 0 milliamps for leakage current. The pressure source was maintained at approximately 15 psig.

3.7 Post LOCA Inspection and Voltage Withstand Test

Upon completion of the accident steam/chemical spray exposure, the test chamber was opened and the specimens were inspected. The specimens were then removed from the test chamber and post-LOCA CM tests were performed. The CM tests included indenter, insulation resistance, ac impedance, and visual inspection. Following these CM tests, the long cable specimens were submerged in tap water at room temperature while still mounted on their mandrel, and a voltage withstand test was performed at 2400 volts ac for a 5-minute duration.

4. RESULTS OF PREAGING AND ACCIDENT TESTING

This section discusses the cable condition at various points during the preaging, as well as the performance during the various stages of the steam/chemical spray exposure. All preaging and accident testing data, including thermal aging charts, irradiation reports and plots of test chamber temperatures and pressure, are included in Wyle Test Report 45120-5 [11].

4.1 Baseline Condition of Cable Specimens

Prior to performing any accelerated aging of the cable specimens, the condition of the cable was measured using various condition monitoring techniques. For reference purposes, elongation-at-break (EAB) was used to judge the condition of the cable since it is the most widely accepted measure of polymer condition. As shown in Table 5, the baseline EAB measurements for all test specimens was high (350 to 470 percent), indicating excellent condition of the cable insulation prior to accelerated aging.

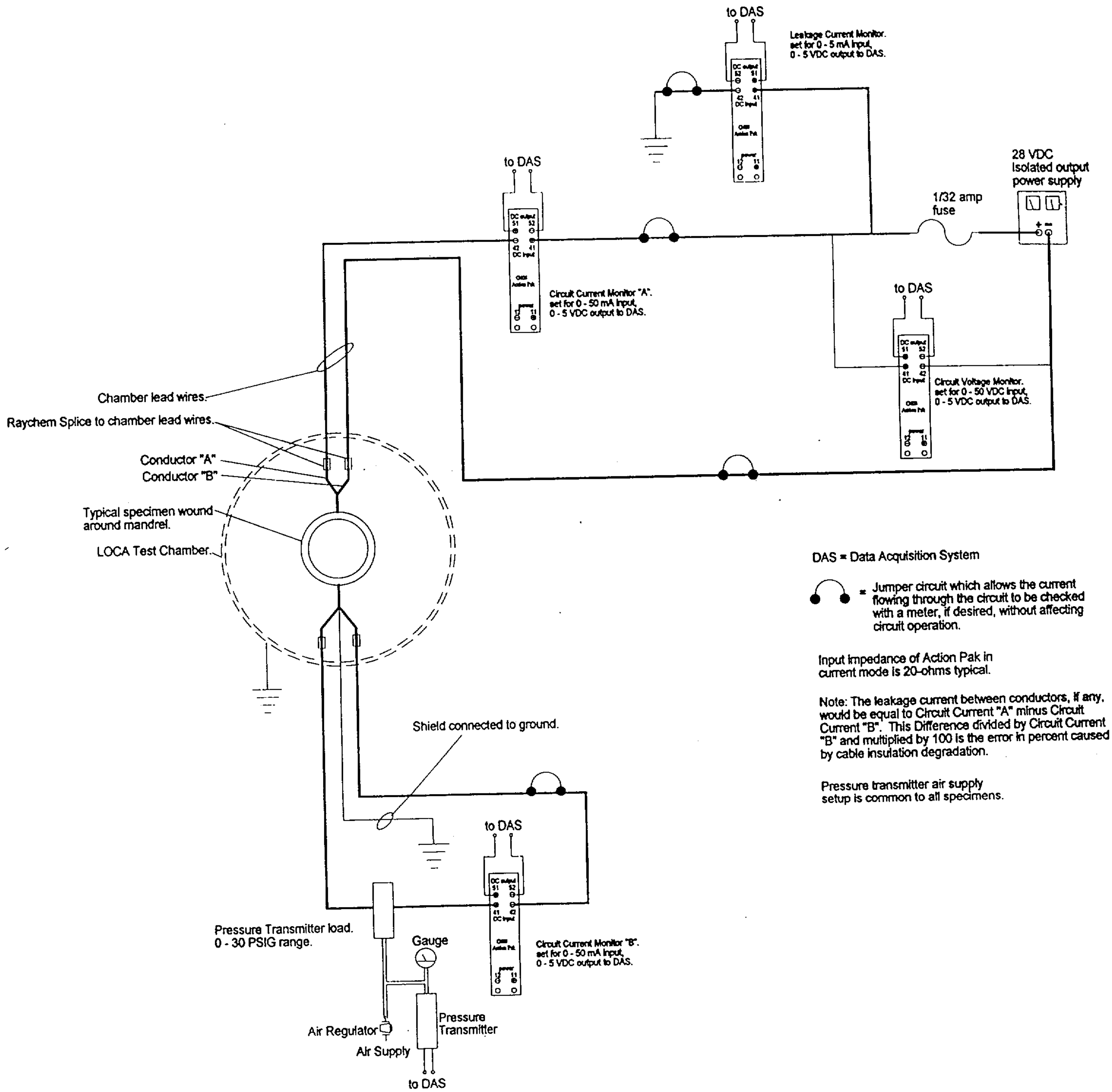

Figure 2 Monitoring circuit diagram for mandrel-mounted specimens

Table 5 Average Elongation-at-Break Values for Insulation [a] on Test Sequence 5 Specimens

Group	Manufacturer	Average Elongation-at-Break (%)			
		Baseline	Post Service Aging	Post Accident Irradiation	Post LOCA Testing
1 (no aging)	Okonite	471	-	232	134
	Sam Moore	418	-	163	74
	Anaconda	356	-	140	(b)
2 (20 yr.)	Okonite	471	8	<5	<5
	Sam Moore	418	147	74	59
	Anaconda	356	166	84	(b)
3 (40 yr.)	Okonite	471	4	<5	<5
	Sam Moore	418	94	58	36
	Anaconda	356	22	14	(b)

(a) EAB values for Okonite and Samuel Moore specimens are for the composite EPR insulation with bonded CSPE jacket. EAB values for Anaconda specimens are for EPR insulation alone (CSPE jacket removed).
(b) Specimens were badly distorted and could not be tested.

4.2 Results of Artificial Preaging

The cable specimens in Groups 2 and 3 received artificial preaging, as discussed in Section 3. Periodically throughout the preaging, visual inspections and various condition monitoring tests were performed to determine the cable condition.

The Group 2 cables were artificially aged to simulate 20 years of qualified life, as determined from the original qualification report. The EAB tests, as well as the visual inspections, indicated that the Samuel Moore and Anaconda cables were in acceptable condition throughout the preaging sequence. No cracks were evident and the cables remained relatively flexible. This is confirmed by the relatively high EAB values shown in Table 5. The Okonite cables in Group 2 appeared degraded; however, no cracking was evident. The Okonite cables were relatively stiff, as confirmed by the low EAB values shown in Table 5.

The Group 3 cables were artificially aged to simulate 40 years of service. The EAB tests and 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 with an EAB of 22 percent; however, no cracking was evident. The Okonite cables also appeared degraded and were very stiff with an EAB of 4 percent. Also, minor circumferential cracking was noted in the jackets of two of the three Okonite cables in this group.

The accident irradiation further reduced the EAB values for all specimens, as shown in Table 5. The EAB for the Okonite specimens had been reduced to less than 5 percent even prior to accident irradiation, indicating severe hardening.

4.3 Functional Performance During Preheat

Prior to the initiation of the accident steam profile, the test chamber was preheated to approximately 140°F with saturated steam and conditions were held for approximately one hour. Chamber pressure during this hold period ranged from 4 to 5 psig. No anomalies were noted for any of the test specimens during this period.

4.4 Functional Performance During the Accident Steam Exposure

Following preheat, the first LOCA transient was initiated with chamber temperature and pressure being ramped up to approximately 346°F and 115 psig, respectively, in approximately five minutes. At approximately 8.6 minutes into the test, a pressure regulator on the test chamber failed causing the temperature and pressure to drop to approximately 200°F and ambient pressure, respectively, over a period of approximately 25.7 minutes. At that point, replacement of the regulator was completed, and the test chamber conditions were returned to peak conditions. Conditions were then held for approximately three hours, after which the temperature and pressure were reduced to preheat conditions. Pressure in the common manifold was relatively constant at approximately 15 psig throughout the LOCA test.

Following the cooldown to preheat conditions, the second LOCA transient was initiated with chamber temperature and pressure being ramped up to approximately 346°F and 113 psig, respectively, in approximately five minutes. Conditions were then held for approximately three hours.

Throughout both transients, no anomalies were noted for any of the test specimens. Circuit currents and voltages remained at their nominal value and no leakage current was present.

4.5 Functional Performance During Post Transient Cooldown

After completion of the second 3-hour hold period, test chamber temperature and pressure were gradually reduced in four steps to 212°F and 0 psig, respectively, over the next ten days. At each step, conditions were held and allowed to stabilize. During this cooldown, at approximately15 hours from test initiation, when test chamber pressure reached 32 psig, the chemical spray was initiated and maintained for 24 hours.

Immediately upon chemical spray initiation, leakage currents were noted for the Group 3 Okonite specimens (0510, 0511 and 0512). The leakage currents ranged from 0.2 mA to 0.6 mA. Upon completion of the chemical spray, the leakage currents ceased. No other anomalies were noted for any of the other specimens.

4.6 Results of Post-LOCA Visual Inspection

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 1 cables appeared to be in good condition with no cracking evident. Small (1-mm to 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.

The visual inspection of the Group 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 (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 section had split open exposing the bare conductor underneath.

Visual inspection of the Group 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 insulated 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 2 specimens. In addition, a large circumferential crack was noted in the overall jacket of one cable exposing the insulated 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.

4.7 Results of Post-LOCA Voltage Withstand Testing

After post-LOCA inspections were completed, a voltage withstand test was conducted on each of the cable specimens. The cables were submerged in tap water at room temperature and subjected to 2400 Vac for five minutes. All of the Samuel Moore and Anaconda cables performed acceptably. For the Okonite cables, one of the two specimens aged to simulate 20 years and all three specimens aged to simulate 40 years could not hold the 2400 Vac test voltage.

5. DISCUSSION OF RESULTS

This section discusses the results of the accident tests, including the performance of the cable specimens in each of the groups. Any anomalies noted are discussed, as well as the causes of the anomalies.

5.1 Results for Samuel Moore Specimens

As discussed in Section 4, all of the Samuel Moore cable specimens in Groups 1, 2, and 3 performed acceptably in that no performance anomalies were noted for these specimens. Post-LOCA examination of the specimens showed cracks in the outer jacket of the Group 3 specimens; however, the underlying insulation was in good condition. This was confirmed by the post-LOCA voltage withstand test, in which all of the specimens passed. The jacket material had a spongy feel indicating that moisture absorption had occurred during the steam exposure.

5.2 Results for Anaconda Specimens

As discussed in Section 4, all of the Anaconda cable specimens in Groups 1, 2, and 3 performed acceptably in that no performance anomalies were noted for these specimens. Post-LOCA examination of the specimens showed cracking in the outer jacket of the Group 2 and 3 specimens; however, the underlying insulation was in good condition. This was confirmed by the post-LOCA voltage withstand test, which all of the specimens passed. The outer jacket cracking appeared to be due to swelling of the jacket during the steam exposure.

5.3 Results for Okonite Specimens

The Okonite specimens in Group 1 performed acceptably in that no anomalies were noted during the steam exposure or in the post-LOCA examination. The specimens in Group 2 experienced longitudinal cracking of the insulation on both specimens, and one of the two specimens failed the post-LOCA submerged voltage withstand test. All three of the specimens in Group 3 experienced longitudinal cracking of the jacket and the underlying insulation, which subsequently split open exposing the bare copper conductor. This is considered a catastrophic failure of the cable. All of the Group 3 specimens failed the post-LOCA submerged voltage withstand test.

The failure of the aged Okonite specimens indicates a potential generic problem with the composite insulation systems constructed of EPR insulation with a bonded CSPE jacket. From a review of the qualification report for the Okonite/Okolon cable (NQRN-1A) and discussions with Okonite, it was found that the specific cable configuration tested in the BNL test program was not tested in the qualification process. The NQRN-1A report describes Okonite's testing of a 600 V, 1/C #12 AWG cable with 0.030 inches of extruded Okonite (EPR) insulation and a 2 kV, 1/C #6 AWG cable with 0.055 inches of extruded Okonite (EPR) insulation and 0.030 inches of Okolon (CSPE) jacket bonded to the EPR. The 600 V, 1/C #12 AWG cable that was tested to failure in the BNL test program had been qualified by Okonite through extrapolation of the type test results for the two aforementioned cables described in the NQRN-1A qualification test.

A possible explanation for the Okonite cable failures observed is that the CSPE jacket degrades more rapidly than the EPR insulation and becomes brittle. This imposes a hoop stress on the CSPE jacket and a compression stress on the underlying EPR insulation. During exposure to steam conditions, moisture absorption by the EPR insulation causes swelling, which, in turn, places additional stress on the brittle CSPE jacket causing it to crack. Since the CSPE jacket is bonded to the underlying EPR insulation, the crack propagates through the bonded interface down into the insulation causing catastrophic failure of the cable. Depending of the amount of aging experienced by the cable, the insulation can split, as observed for the Group 2 Okonite specimens, or it can completely open, as observed in the Group 3 Okonite specimens.

Based on the post-LOCA condition of the Okonite specimens, the circuit used to monitor the leakage currents was reviewed to understand why greater leakage currents were not observed during the steam exposure. It was determined that, for the circuit design used, one leg of the test specimen is referenced to ground for leakage current measurement (Figure 2). Consequently, leakage cannot be monitored for the leg referenced to ground since there is essentially no potential difference between that circuit leg and ground. For the single conductor Okonite specimens, the test specimen was inadvertently placed in the leg referenced to ground, and the return leg was jumpered to complete the circuit. This arrangement prevented accurate measurement of leakage current in the Okonite specimens. Therefore, the magnitude and initiation time of the small leakage currents measured during the test are not considered indicative of the actual leakage currents occurring in the Okonite test specimens.

A nonconformance is being issued to identify the problem and implement corrective action in subsequent testing.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions Regarding Cable Performance

Based on a review and analysis of the test results and the results of the post-LOCA inspections, the following conclusions are drawn:

- The Samuel Moore and Anaconda cables in this test sequence performed acceptably in that they were able to maintain a circuit current for an applied load with minimal deviation from a nominal value under simulated accident conditions. In addition, the test specimens were able to pass a submerged voltage withstand test after being subjected to accelerated aging and accident testing. No generic problems were found with these cables, and these test results confirm the original qualification basis for these cables.

- Composite insulation consisting of EPR insulation with bonded CSPE in the 600 volt 1/C #12 AWG configuration has been shown to perform poorly in LOCA exposure testing following preaging to the parameters of the original Okonite qualification test NQRN-1A. It should be noted that the accelerated aging performed was severe resulting in EAB measurements for the composite EPR/CSPE insulation of less than 5 percent following preaging to the equivalent of 40 years service at 90°C. Nevertheless, one of two specimens preaged to the equivalent of 20 years service, and three of three specimens preaged to the equivalent of 40 years service at 90°C to the parameters of the original qualification test could not pass the post-LOCA submerged voltage withstand test.

- The extrapolation of test results for the Okonite/Okolon cables in configurations other than the 1/C #6 AWG 2kV configuration tested in NQRN-1A should be re-evaluated.

6.2 Recommendation for Future Testing

Current plans are to perform a sixth test sequence in which several cables will be accident tested after receiving the equivalent of 60 years of accelerated aging based on their original qualification. It is recommended that Okonite specimens aged to 60 years be included in the sixth test to enable more accurate information on failure timing and magnitude to be obtained.

7. REFERENCES

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2. Lofaro, R., et al., "Supplemental Literature Review on the Environmental Qualification of Safety-Related Electric Cables," BNL Technical Report TR-6169-9/97, October 3, 1997.

3. Villaran, M., "Preaging and LOCA Test Plan for Low-Voltage Electric Cables," BNL Technical Report TR-6168/69-04-95, Revision 1, March 14, 1996.

4. Lee, B., "Condition Monitoring Research Plan for Low-Voltage Electric Cables," BNL Technical Report TR-6168/69-03-95, February 1996.

5. Lofaro, R., et al., "Interim Report: Results of Test Sequence 1 on Electric Cables with Cross-Linked Polyethylene Insulation and Neoprene Jacket," BNL Technical Report TR-6465-01-98, March 23, 1998.

6. Lofaro, R., et al., "Interim Report: Results of Test Sequence 2 on Electric Cables with Ethylene Propylene Rubber Insulation and Hypalon Jacket," BNL Technical Report TR-6465-05-98, November 1998.

7. Lofaro, R., et al., "Interim Report: Results of Test Sequence 3 on Electric Cables with Cross-Linked Polyethylene Insulation and Neoprene Jacket Preaged to 40 Years," BNL Technical Report TR-6465-01-99, January 1999.

8. Jacobus, M., "Aging, Condition Monitoring and Loss-Of-Coolant Accident (LOCA) Tests of Class 1E Electrical Cables," NUREG/CR-5772, November 1992.

9. Vigil, R., et al., "Aging, Loss-of-Coolant Accident (LOCA), and High Potential Testing of Damaged Cables," NUREG/CR-6095, April 1994.

10. Grove, E., "Environmental Qualification Research Program Quality Plan," BNL Technical Report TR-6169-05-95, April 1996.

11. Wyle Test Report 45120-5, "Nuclear Environmental Test Program on Low Voltage Electric Cables (Task 5)," February 19, 2000.

Attachment 2

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Nuclear and Infrastructure Systems Division

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March 8, 2000

Mr. Satish K. Aggarwal
RES/DET/MEB/LRSM
Mail Stop T-10-E10
Two White Flint North
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Minutes of February 8, 2000 NRC Meeting with Okonite

Dear Satish:

Attached are the minutes of the NRC meeting with representatives of the Okonite Company held February 8, 2000. The purpose of this meeting was to present and discuss the performance of single conductor EPR insulated Okonite cables with bonded CSPE jackets that were tested to failure in our research program on Environmental Qualification of Low-Voltage Electric Cables (JCN W-6465).

Please note, I did not receive a copy of the final attendance sheet; therefore, the attendance list provided herein is a partial list based on my notes.

If you have any questions on this, please contact me.

Sincerely,

Robert J. Lofaro
Program Manager, Aging and Equipment Testing
Engineering Mechanics and Infrastructure Group

RJL/jmfL14
Enclosure
Copies to:
E. Hackett, NRC/RES (w/o Encl.)
R. E. Hall (w/o Encl.)
W. Horak (w/o Encl.)
M. Mayfield, NRC/RES (w/o Encl.)
J. Taylor
M. Villaran
J. Vora, NRC/RES

MINUTES OF NRC MEETING WITH THE OKONITE COMPANY

Meeting Date:	February 8, 2000
Meeting Location:	NRC Meeting Room T7-A1 Two White Flint North Rockville, Maryland
Meeting Purpose:	Discuss Results of Accident Testing on Okonite Bonded Jacket Cables
Meeting Sponsor:	NRC Office of Nuclear Regulatory Research

On February 8, 2000, a meeting was held with representatives of the Okonite Company. The purpose of this meeting was to discuss the results of a test performed as part of a research program on low-voltage electric cables being sponsored by the NRC Office of Nuclear Regulatory Research (RES). Brookhaven National Laboratory (BNL) is the lead organization supporting RES in this research program. In addition to NRC and BNL staff, three representatives of the Okonite Company were in attendance along with a representative of EPRI (Attachment 1).

The following are minutes of the meeting:

1. The meeting was opened by S. Aggarwal of NRC/RES with the following remarks:

    - The purpose of this meeting is to discuss the results of accident testing on Okonite bonded jacket cables performed as part of an ongoing research program. In this test, 1/C #12 AWG 600 V Okonite cables with EPR insulation and bonded CSPE (Okolon) jackets failed catastrophically by splitting open, exposing the bare copper conductor of the cable.

    - The criteria in IEEE Standards 323-74 and 383-74 for qualification of cables are not an issue for discussion in this meeting; these standards were the requirements used and accepted.

    - Past tests performed by Sandia National Laboratory found similar results, which were discussed in a previous meeting with Okonite.

    - In the previous meeting with Okonite, the Sandia results were attributed to overly severe aging since the cables were exposed to full service radiation plus accident radiation prior to thermal aging; this sequence was not appropriate and was contrary to what was performed in the original qualification.

    - In the current NRC program performed by BNL, all preaging and testing was performed according to the Okonite Qualification Report NQRN-1A, and the cables again failed catastrophically.

    - The NRC is interested in obtaining information to understand the cause of the failures observed and the impact to the qualification basis for these cables.

2. A presentation was made by R. Lofaro of BNL in which the cable test procedures and results were presented (Attachment 2).

- Cable samples from three manufacturers were tested: Okonite (EPR with bonded CSPE jacket), Samuel Moore (EPR with bonded CSPE jacket), and Anaconda (EPR with un-bonded CSPE jacket).

- The Okonite cables were tested in the single conductor configuration, while the Samuel Moore and Anaconda were tested in the multiconductor configuration.

- All preaging was performed according to the original qualification test for the respective cable.

- Only the preaged Okonite cables failed catastrophically by splitting open (one of two aged to 20 years, and three of three aged to 40 years). The Okonite control cable (no aging) did not fail.

3. Okonite representatives provided the following comments regarding the test results:

- Okonite confirmed that the cables tested to failure in the current program are a qualified configuration based on Okonite Qualification Report NQRN-1A, as determined from a sample obtained from BNL and tested by Okonite.

- Okonite confirmed that the testing performed by BNL is the same as that used by Okonite in the NQRN-1A qualification test.

- The comparison of Okonite single conductor cables to Samuel Moore and Anaconda multiconductor cables is not felt to be a fair comparison for the following reasons:
  - Multiconductor cables do not age as much as single conductor cables since less oxygen is present inside the multiconductor configuration
  - The aging for the Okonite cables was much more severe than the other cables

- The aging used by Okonite in the NQRN-1A qualification test was based on qualifying the insulation for 40 years at a service temperature of 90°C. It is now known that the aging used is overly severe compared to actual operating service temperatures. However, at the time of the test, a conservative preaging protocol was used since there was little information available as to how to simulate actual service life.

- Testing a single conductor configuration was thought to be more severe than testing a multiconductor configuration (outer jacket thought to provide additional protection to the insulation); therefore, single conductor cables were tested in the qualification test.

- Okonite qualified the 600 V, #12 AWG, 1/C cable tested in the current program by extrapolating the results of the tests reported in NQRN-1A.
  - A 600 V, #12 AWG EPR insulated cable with no jacket was successfully tested in NQRN-1A
  - A 2 kV, #6 AWG cable with EPR insulation and bonded CSPE jacket was also successfully tested in NQRN-1A to verify no chemical interaction between the bonded CSPE jacket and the EPR insulation

- Since the 600 V EPR cable passed alone, and no chemical interaction between the EPR and bonded CSPE was evident from the 2 kV test, it was concluded that the bonded jacket insulation system used on the 600 V 1/C #12 EPR insulated cable tested in the current program was qualified

- The bonded CSPE jackets were used to provide fire protection to the cables. Bonding was used to prevent the jacket from slipping on the insulation due to pulling during installation.

- Okonite believes that the failures observed are probably due to the severe aging causing hardening and shrinking of the CSPE jackets. Due to the bonding, cracks initiating in the CSPE jacket propagated into the EPR insulation and caused it to split open.

- Okonite does not feel it is justifiable to base conclusions on the performance of the Okonite/Okolon cable on test protocols developed 30 years ago.

- Okonite does not feel it is justifiable to compare the performance of their cables, which received more severe aging, to other cables with less severe aging.

4. G. Toman of EPRI provided the following information:

   - Over 90 percent of cables in containment are multiconductor cables; not single conductor cables.

   - Many Okonite cables installed in plants have been tested, and all were found to be in good condition. In one application, Okonite cables were installed in an area with a temperature of 200°F for eight years; none of the cables were cracked and only one hard section was found.

   - EPR ages much slower than CSPE, which probably contributed to the failures experienced with the severe aging.

5. M. Mayfield of NRC/RES provided the following concluding remarks:

   - NRC is interested in obtaining additional information on the applications of the EPR insulated cables with bonded CSPE jackets.

   - There is a need to reconcile the original qualification basis with the BNL test results.

   - Okonite should consider whether issuing a Part 21 notification is appropriate.

6. Okonite stated that they would like to obtain a copy of the test report documenting the results of the Okonite cable failures and review it prior to providing a further response.

Attachment 1

NRC Meeting with Okonite
February 8, 2000

Partial Attendance List

S. Aggarwal	NRC/RES
J. Vora	NRC/RES
M. Mayfield	NRC/RES
J. Calvo	NRC/NRR
D. Thatcher	NRC/NRR
P. Shemanski	NRC/NRR
R. Lofaro	BNL
J. Taylor	BNL
J. Cancelosi	Okonite
J. Faranetta	Okonite
J. Lasky	Okonite
G. Toman	EPRI

Attachment 2

ENVIRONMENTAL QUALIFICATION RESEARCH ON BONDED JACKET ELECTRIC CABLES

Presented at: NRC Meeting with Okonite

Presented by: Brookhaven National Laboratory
February 8, 2000

Sponsor: U.S. NRC, Office of Nuclear Regulatory Research

Brookhaven Science Associates
U.S. Department of Energy

BROOKHAVEN NATIONAL LABORATORY

PURPOSE OF THIS MEETING

- Review results of Test 5 on bonded jacket cables
- Discuss findings on Okonite cables with the manufacturer
- Determine impact of findings on qualification of Okonite cables tested

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OBJECTIVE OF TEST 5

- Determine if bonded jacket cables have a unique failure mechanism not present in unbonded jacket cables
- Past testing by Sandia found failures of bonded jacket cables
  - Okonite
  - Samuel Moore

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CABLES INCLUDED IN TEST 5

- Samuel Moore Dekoron Dekorad
  - 0.020" EPDM insulation
  - 0.010" CSPE bonded individual jacket
  - 0.045" CSPE overall jacket
  - 2/C #16 TSP 600V
- Anaconda Flame Guard EP
  - 0.030" EPR insulation
  - 0.015" CPSE unbonded individual jacket
  - 0.045" CSPE overall jacket
  - 3/C #12 1000V
- Okonite Okolon
  - 0.030" EPR insulation
  - 0.015" CSPE bonded individual jacket
  - no overall jacket
  - 1/C #12 600V

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NUMBER OF SPECIMENS IN TEST 5

Cable	No. of Specimens: No Aging	20 Yrs	40 Yrs
Samuel Moore EPDM/Bonded CSPE 2/C #16	1	2	2
Anaconda EPR/Unbonded CSPE 3/C #12	1	2	2
Okonite EPR/Bonded CSPE 1/C # 12	1	2	3

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OVERVIEW OF TEST SEQUENCE

- Select, prepare, and baseline test cables
  - Unused cable
- Perform Accelerated Aging
  - Thermal + irradiation
- Accident steam/chemical spray exposure
  - Specimens loaded with PT circuit
- Submerged voltage withstand test
  - 2400 volts

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TEST FACILITIES UTILIZED

- Wyle Laboratories
  - Thermal aging
  - LOCA testing
- Georgia Institute of Technology
  - Irradiation
- Brookhaven National Laboratory
  - Condition monitoring tests

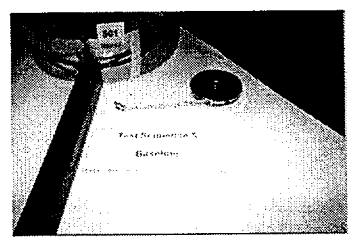
QUALITY ASSURANCE

- Work performed according to 10 CFR 50, Appendix B, Quality Assurance Program

CABLE SPECIMEN CONFIGURATIONS

- 10-foot specimens mounted on metal mandrels
  - Mandrel diameter 13.5 in.
- 6-inch basket specimens
  - for destructive testing

TYPICAL CABLE TEST SPECIMEN MOUNTED ON MANDREL



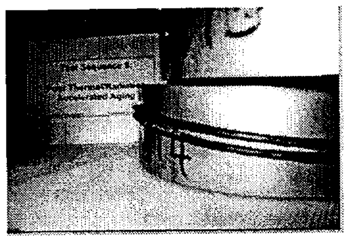
SAMUEL MOORE CABLES: *PREAGING PERFORMED*

- Parameters based on original qualification
  - Isomedix report LOCA XLPO/EPDM, 6/78
- Three preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 20 years of qualified life
     - 84 hrs @ 250 F + 25 Mrad @ 0.75 Mrad/hr
  3. Preaging to simulate 40 years of qualified life
     - 168 hrs @ 250 F + 50 Mrad @ 0.75 Mrad/hr

SAMUEL MOORE CABLE: *RESULTS OF PREAGING*

- Group 2 appeared in good condition
  - Insulation flexible; no cracks visible
  - Relatively high elongation-at-break (147%)
- Group 3 appeared in good condition
  - Insulation flexible; no cracks visible
  - Moderately high elongation-at-break (94%)

SAMUEL MOORE CABLE:
CONDITION AFTER PREAGING TO 40 YRS.



ANACONDA CABLES:
PREAGING PERFORMED

- Parameters based on original qualification
  - FIRL Report F-C4350-3, 7/76
- Three preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 20 years of qualified life
     - 84 hrs @ 302 F + 25 Mrad @ 0.35 Mrad/hr
  3. Preaging to simulate 40 years of qualified life
     - 168 hrs @ 302 F + 50 Mrad @ 0.35 Mrad/hr

ANACONDA CABLE:
RESULTS OF PREAGING

- Group 2 appeared in good condition
  - Insulation flexible; no cracks visible
  - Relatively high elongation-at-break (166%)
- Group 3 appeared degraded
  - Insulation stiff; no cracks visible
  - Relatively low elongation-at-break (22%)

ANACONDA CABLE:
CONDITION AFTER PREAGING TO 40 YRS.

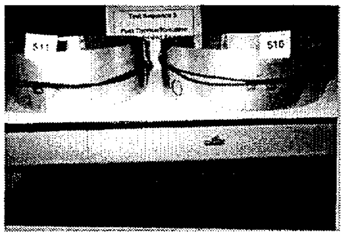
OKONITE CABLES:
PREAGING PERFORMED

- Parameters based on original qualification
  - Okonite Report NQRN-1A, Rev. 5 10/24/88
- Three preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 20 years of qualified life
     - 252 hrs @ 302 F + 25 Mrad @ 0.65 Mrad/hr
  3. Preaging to simulate 40 years of qualified life
     - 504 hrs @ 302 F + 50 Mrad @ 0.65 Mrad/hr

OKONITE CABLE:
RESULTS OF PREAGING

- Group 2 appeared degraded
  - Insulation stiff; no cracks visible
  - Relatively low elongation-at-break (8%)
- Group 3 appeared degraded
  - Insulation stiff; circumferential cracks visible
  - Relatively low elongation-at-break (4%)

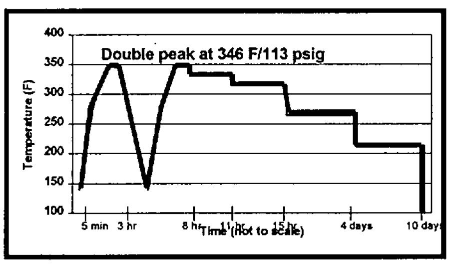
OKONITE CABLE:
CONDITION AFTER PREAGING TO 40 YRS.



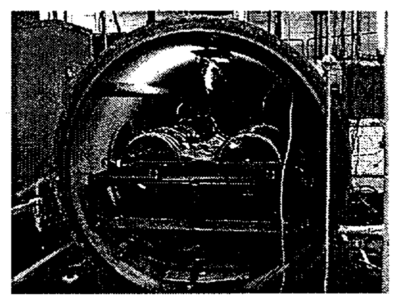
LOCA TEST 5:
OVERVIEW OF ACCIDENT SIMULATION

- Accident radiation
  - 150 Mrad @ 0.75 Mrad/hr
  - Administered after preaging
- Accident steam/chemical spray
  - After accident irradiation
  - Profile from original qualification
  - Duration shortened to 10 days
  - Specimens energized with PT loop
  - 24 hrs of chemical spray

LOCA TEST 5:
ACCIDENT PROFILE USED



SPECIMENS LOADED IN LOCA TEST CHAMBER AT WYLE LABORATORIES



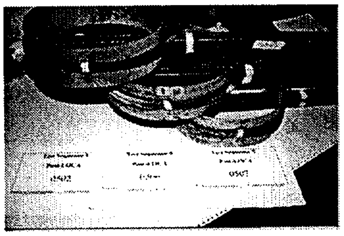
PERFORMANCE DURING LOCA TEST 5

- Specimens energized and monitored
  - 28V dc, 4-20 mA PT circuit
  - 1/32 amp fuse in circuit
  - Circuit and leakage current monitored
- All specimens showed acceptable performance
  - nominal circuit current and voltage
  - little or no leakage current
  - no blown fuses
- Okonite specimens aged to 40 years showed leakage upon initiation of chemical spray at 15 hours
  - Leakage 0.2 to 0.6 mA; may not be maximum
  - Test specimen referenced to ground

SAMUEL MOORE CABLES:
POST-LOCA VISUAL INSPECTION

- Group 1 (no aging):
  - Good condition; no cracking
  - Small water bubbles noted on jacket surface
- Group 2 (aged to 20 yrs):
  - Cable still flexible; spongy feel
  - Small (2-5 cm) cracks noted in jacket
  - Insulated conductor not exposed
- Group 3 (aged to 40 yrs):
  - One crack (5 cm) noted in overall jacket on both cables
  - Jacket opened in one spot exposing insulated conductors
  - Exposed insulation appeared in good condition
  - Cable still flexible; spongy feel

SAMUEL MOORE AGED TO 20 YEARS: *POST-LOCA CONDITION*



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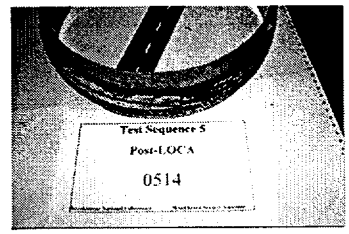
SAMUEL MOORE AGED TO 40 YEARS: *POST-LOCA CONDITION*



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ANACONDA CABLES: *POST-LOCA VISUAL INSPECTION*

- Group 1 (no aging):
  - Good condition; no cracking
  - Small water bubbles noted on jacket surface
- Group 2 (aged to 20 yrs):
  - Multiple longitudinal cracks noted on overall jacket; not through-wall; appears due to swelling
  - Large circumferential crack noted in overall jacket of one cable exposing insulated conductors
- Group 3 (aged to 40 yrs):
  - Multiple longitudinal cracks noted on overall jacket; not through-wall; appears due to swelling
  - Large circumferential crack noted in overall jacket of one cable exposing insulated conductors

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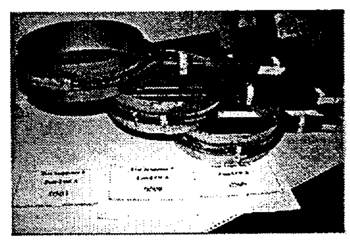
ANACONDA CABLES AGED TO 20 YEARS: *POST-LOCA CONDITION*



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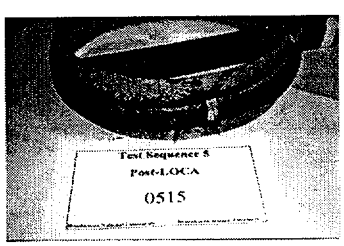
ANACONDA CABLES AGED TO 40 YEARS: *POST-LOCA CONDITION*



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OKONITE CABLES: *POST-LOCA VISUAL INSPECTION*

- Group 1 (no aging):
  - Good condition; no cracking
  - Small water bubbles noted on jacket surface
- Group 2 (aged to 20 yrs):
  - Longitudinal cracks along jacket
  - Section on one cable opened exposing conductor
- Group 3 (aged to 40 yrs):
  - Longitudinal cracks along jacket on all cables
  - Jacket opened on all cables exposing bare conductor

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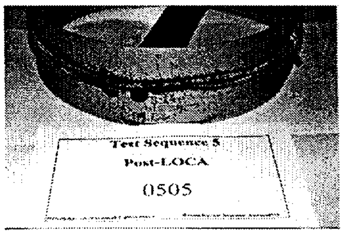
OKONITE CABLES AGED TO 20 YEARS: *POST-LOCA CONDITION*



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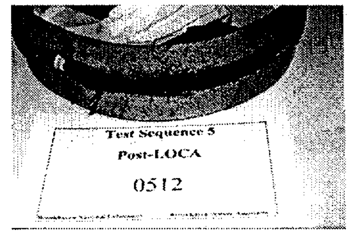
OKONITE CABLES AGED TO 40 YEARS: *POST-LOCA CONDITION*



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LOCA TEST 5: *RESULTS OF VOLTAGE WITHSTAND TEST*

SPECIMENS	TEST VOLTAGE	RESULT
Samuel Moore	2400 VOLTS	5 OF 5 PASSED
Anaconda	2400 VOLTS	5 OF 5 PASSED
Okonite	2400 VOLTS	4 OF 6 FAILED

1 of 2 in Group 2 (aged to 20 years) Failed
3 of 3 in Group 3 (aged to 40 years) Failed

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RESULTS OF TEST 5

- Both the Samuel Moore and Anaconda cables artificially aged to 40 years performed acceptably in this test program
- The Okonite cables artificially aged to 40 years failed catastrophically by splitting open and exposing the bare conductor
- The Okonite failures appear to be due to exposure to the LOCA steam/chemical spray environment after being aged, during which moisture absorption caused swelling and splitting of the insulation

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Attachment 3

Energy Science and Technology Department
Nuclear and Infrastructure Systems Division

BROOKHAVEN
NATIONAL LABORATORY

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for the U.S. Department of Energy

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March 8, 2000

Mr. Satish K. Aggarwal
RES/DET/MEB/LRSM
Mail Stop T-10-E10
Two White Flint North
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Minutes of February 16, 2000 NRC Public Meeting on EQ Program

Dear Satish:

Attached are the minutes of the NRC public meeting held February 16, 2000. The purpose of this meeting was to present and discuss the results of Test 4 on multiconductor cables and Test 5 on bonded jacket cables in our research program on Environmental Qualification of Low-Voltage Electric Cables (JCN W-6465).

If you have any questions on this, please contact me.

Sincerely,

Robert J. Lofaro

Robert J. Lofaro
Program Manager, Aging and Equipment Testing
Engineering Mechanics and Infrastructure Group

RJL/jmfL14
Enclosure
Copies to:
E. Hackett, NRC/RES (w/o Encl.)
R. E. Hall (w/o Encl.)
W. Horak (w/o Encl.)
M. Mayfield, NRC/RES (w/o Encl.)
J. Taylor
M. Villaran
J. Vora, NRC/RES

**MINUTES OF PUBLIC MEETING ON
QUALIFICATION OF LOW-VOLTAGE ELECTRIC CABLE RESEARCH PROGRAM**

Meeting Date:	February 16, 2000
Meeting Location:	NRC Public Meeting Room T2-B3 Two White Flint North Rockville, Maryland
Meeting Purpose:	Present Results of Test 4 on Multiconductor Cables and Test 5 on Bonded Jacket Cables
Meeting Sponsor:	NRC Office of Nuclear Regulatory Research

On Wednesday, February 16, 2000, a public meeting was held to present the results from a research program on qualification of low-voltage instrumentation and control (I&C) electric cables. This research program is sponsored by the NRC Office of Nuclear Regulatory Research (RES). Brookhaven National Laboratory (BNL) is the lead organization supporting RES on this research program. In addition to NRC and BNL staff, there were approximately 12 attendees from industry (Attachment 1).

The purpose of this meeting was to present the results of the fourth and fifth tests in a series of six tests planned for this research program. Results from the first three tests were presented in prior public meetings after the completion of those tests. Plans for the sixth, and final test, were also presented in this meeting.

The following are the highlights of this public meeting.

1. The meeting was opened by M. Mayfield and S. Aggarwal of NRC/RES with the following introductory comments:

    - This meeting is a continuation of the series of meetings between NRC and industry to communicate status and findings of this research effort

    - The purpose of this meeting is to present the results of Tests 4 and 5

    - The objective of Test 4 was to determine if multiconductor cables have any unique failure mechanisms compared to single conductor cables

    - The objective of Test 5 was to determine if bonded jacket cables have any unique failure mechanisms compared to un-bonded jacket cables

    - The staff does not necessarily agree with all of the conclusions drawn by BNL on the results of Test 4

2. A presentation was made by R. Lofaro and M. Villaran of BNL in which the performance, the results, and preliminary conclusions of Tests 4 and 5 were presented (Attachment 2).

3. S. Aggarwal of NRC/RES provided an overview of a meeting held with Okonite on February 6, 2000 to discuss failures of Okonite cables in Test 5

   - Okonite cables aged according to NQRN-1A failed catastrophically in BNL tests

   - Okonite's position was that the aging was too severe

   - Questions that now need to be answered are:
     - What is the significance of the failures?
     - How will PRA help resolve this issue?
     - What initiative will industry take to address these failures?
     - In what applications are the cables used?

4. B. Horin of Winston and Strawn made the following comments:

   - There has been good communication between NRC and industry throughout this research program.

   - Utility members were queried regarding application of the Okonite cables; they are used inside containment and for 50.49 applications.

   - Licensees have been following this issue closely to address plant safety.

   - Utility members have been alerted to the results of the tests on Okonite cables and will look at the significance of these results for their plants and respond in their own programs to address any problems.

   - Another formal program is not needed to address concerns with these cables.

5. R. Wessman of NRC/NRR provided the following comments:

   - At this time,there is no required response; the staff is trying to get a handle on the effects and, therefore, the risks associated with failure of these cables.

   - The staff would like to determine where and how much of this cable is in use.

   - The question now is whether a voluntary industry initiative would be an appropriate response to these findings, or if the NRC should approach this in a traditional regulatory manner.

   - The January 21, 2000 NRC memorandum on the risk significance of these cable failures is not the final word on this; it was a preliminary estimate of the potential risk using the best information available at the time and will be refined once better information becomes available.

6. P. Holzman of ST&R, Inc. presented data comparing the expected service life of various cables based on the severity of aging, different activation energies, and different service temperatures, as reported in various test reports.

   - Data show cables are acceptable for continued service based on actual service temperatures, which are lower than originally assumed in qualification tests.

7. J. White of Texas Utilities provided insights on past experience at their plants:

   - Actual service temperatures were approximately 90°F, which are lower than design values of 104°F.
   - Temperatures are typically 10 to 20 degrees below design specifications.
   - In their plants, cables are manipulated periodically, e.g., for maintenance or inspection of end devices. If they are cracked or feel stiff, they are replaced.
   - Most cable failures are found outside the containment building, e.g., in the turbine building.

8. J. Calvo of NRC/NRR provided the following comments:

   - Need to know where the hot spots are in the plants; how are they found and how they are monitored.
   - It is unclear if all plants have a monitoring program such as that described by Texas Utilities.
   - Single conductor cables are used for certain applications in plants; NRC would like to know where they are used to determine the significance of their failure.

9. M. Mayfield of NRC/RES provided the following comments:

   - GSI 168 needs to look at the PRA aspect of this issue; PRA models are no better than their underlying assumptions.
   - NRC wants real information on when, where, and how much so that PRA models can be refined.
   - Risk significance is required to be considered to resolve this issue.

10. G. Toman of EPRI presented the following insights from past experience:

   - Hot spots can be identified by looking at the end devices.
   - MSIV limit switches and RTD cables probably see the highest temperatures, and these cables are typically replaced every one to two outages.

- There are currently three EPRI-sponsored programs ongoing to address aging of cables:
  - Long-term aging program started in November 1999; cables are being aged at 175°F, 185°F, and 195°F and will run approximately four years
  - Natural versus artificial aging program currently has 12 years' worth of data

The following action items were identified in this meeting:

- NRC will issue a letter report on the test results to the PDR in approximately one month.
- Another meeting with industry will be held at a date and time to be determined to discuss this issue further.

Attachment 1

NRC Public Meeting
February 16, 2000

List of Attendees

PLEASE PRINT

NAME	AFFILIATION
JOHN LINN	SOUTHERN COMPANY
JOHN [illegible]	SOUTHERN COMPANY
John White	TXU
[illegible]	[illegible]
JOHN FARANETTA	OKONITE
Jim [illegible]	GLS [illegible] Inc.
John Taylor	BNL
[illegible]	BNL
[illegible]	BNL
Michael Villaran	BNL
Don Palmrose	NUS-LIS
John [illegible]	Okonite
[illegible]	BECHTEL
Gary Toman	EPRI
[illegible]	NEI
Phil Holzman	NUGEQ / STAR. Inc
Bill [illegible]	Winston + Strawn

PLEASE PRINT

Attachment 2

ENVIRONMENTAL QUALIFICATION RESEARCH
ON LOW-VOLTAGE I&C ELECTRIC CABLES

Presented at: NRC Public Meeting

Presented by: Brookhaven National Laboratory
February 16, 2000

Sponsor: U.S. NRC, Office of
Nuclear Regulatory Research

PURPOSE OF THIS MEETING

- Review results of Test 4 on multi-conductor cables
- Review results of Test 5 on bonded jacket cables
- Present plans for Test 6

OVERVIEW OF TEST SEQUENCE

- Select, prepare, and baseline test cables
  - Unused cable
- Perform Accelerated Aging
  - Sequential thermal + irradiation
- Accident steam/chemical spray exposure
  - Sequential radiation + steam
  - Specimens energized in PT circuit
- Submerged voltage withstand test
  - 2400 volts

TEST FACILITIES UTILIZED

- Wyle Laboratories
  - Thermal aging
  - LOCA testing
- Georgia Institute of Technology
  - Irradiation
- Brookhaven National Laboratory
  - Condition monitoring tests

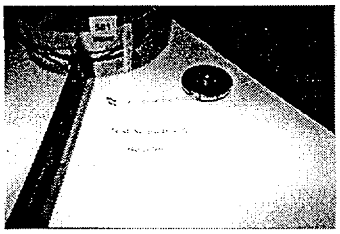
QUALITY ASSURANCE

- Work performed according to 10 CFR 50, Appendix B, Quality Assurance Program

CABLE SPECIMEN CONFIGURATIONS

- 10-foot or 30-foot specimens mounted on metal mandrels
  - Mandrel diameter 13.5 in.
  - Support arm on mandrel to protect specimens
  - Splices attached prior to aging
- 2-foot straight specimens
  - For indenter testing
- 6-inch specimens in stainless-steel baskets
  - For destructive testing

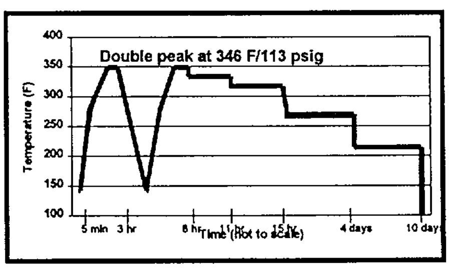
TYPICAL CABLE TEST SPECIMEN MOUNTED ON MANDREL



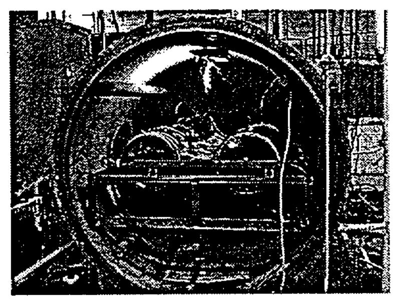
OVERVIEW OF ACCIDENT SIMULATION

- Accident radiation
  - 150 Mrad @ 0.75 Mrad/hr
  - Administered after preaging
- Accident steam/chemical spray
  - After accident irradiation
  - Profile from original qualification (similar to IEEE-323)
  - Duration shortened to 10 days
  - 24 hrs of chemical spray
- Specimens energized and monitored
  - 28V dc, 4-20 mA PT circuit
  - 1/32 amp fuse in circuit
  - Circuit and leakage currents monitored

LOCA TEST 5: *ACCIDENT PROFILE USED*



SPECIMENS LOADED IN LOCA TEST CHAMBER AT WYLE LABORATORIES



OBJECTIVE OF TEST 4

- Determine if multi-conductor cables have a unique failure mechanism not present in single-conductor cables
- Past testing by Sandia found failures of cables in the multi-conductor configuration in which the insulation split open
  - NUREG/CR-3538: Anaconda aged to 40 yr. @ 55 C
  - NUREG/CR-4536: Anaconda aged to 40 yr. @ 55 C
  - NUREG/CR-5772: Sam Moore aged to 20 & 40 yr. @ 55 C
    BIW aged to 0, 20, 40, & 60 yr. @ 55 C

SANDIA TESTS

- Differed from original qualification
  - Aging based on 40 yr. @ 55 C
  - Lower aging acceleration factors
  - Simultaneous aging and accident testing
  - No chemical spray
- Test Chamber Penetrations
  - No splice inside test chamber
  - Swagelok penetrations used

CABLES INCLUDED IN TEST 4

- Samuel Moore Dekoron Dekorad
  - 0.020" EPDM insulation
  - 0.010" CSPE bonded individual jacket
  - 0.045" CSPE overall jacket
  - 2/C #16 TSP 600V
  - 1/C #16 made from disassembled multi-conductor cable
- Anaconda Flame Guard EP
  - 0.030" EPR insulation
  - 0.015" CPSE un-bonded individual jacket
  - 0.045" CSPE overall jacket
  - 3/C #12 1000V
  - 1/C #12 made from disassembled multi-conductor cable

NUMBER OF SPECIMENS IN TEST 4

Cable	No. of Specimens No Aging	20 Yrs.	40 Yrs.
Samuel Moore			
1/C #16 (Swagelok)		1	1
1/C #16 (Wyle)		1	1
2/C #16 (Swagelok)		1	2
2/C #16 (Wyle)	1	1	1
Anaconda			
1/C #12 (Swagelok)			1
1/C #12 (Wyle)			1
3/C #12 (Swagelok)			2
3/C #12 (Wyle)	1		1

SAMUEL MOORE CABLES: *PREAGING PERFORMED*

- Parameters based on original qualification
  - Isomedix Report LOCA XLPO/EPDM, 6/78
- Three preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 20 years of qualified life
     - 84 hrs @ 250 F + 25 Mrad @ 0.75 Mrad/hr
  3. Preaging to simulate 40 years of qualified life
     - 168 hrs @ 250 F + 50 Mrad @ 0.75 Mrad/hr

SAMUEL MOORE CABLE: *RESULTS OF PREAGING*

- Group 2 appeared in good condition
  - Insulation flexible; no cracks visible
  - Relatively high elongation-at-break
    - EPR/CSPE composite insulation 261%
    - CSPE outer jacket 422%
- Group 3 appeared in good condition
  - Insulation flexible; no cracks visible
  - Moderately high elongation-at-break
    - EPR/CSPE composite insulation 173%
    - CSPE outer jacket 312%

ANACONDA CABLES: *PREAGING PERFORMED*

- Parameters based on original qualification
  - FIRL Report F-C4350-3, 7/76
- Two preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 40 years of qualified life
     - 168 hrs @ 302 F + 50 Mrad @ 0.35 Mrad/hr

ANACONDA CABLE: *RESULTS OF PREAGING*

- Group 2 appeared degraded
  - Insulation stiff; no cracks visible
  - Relatively low elongation-at-break
    - EPR insulation 13%
    - CSPE inner jacket 9%
    - CSPE outer jacket 11%

PERFORMANCE DURING LOCA TEST 4

- All specimens showed acceptable performance
  - Nominal circuit current and voltage
  - No blown fuses due to test specimens
  - No leakage current
  - No error in PT loop

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SAMUEL MOORE CABLES: *POST-LOCA VISUAL INSPECTION*

- Group 1 (no aging):
  - Good condition; no cracking noted
  - White/tan deposits noted on jacket surface
- Group 2 (aged to 20 yr.):
  - Multi-conductor
    - large (5-10 cm) cracks noted in outer jacket
    - insulation appeared in good condition
    - cable stiff compared to baseline
    - Swelling noted: outer jacket 21%; inner jacket/insulation 33%
  - Single conductor
    - CSPE inner jacket appeared torn, shriveled and dis-bonded from insulation only near cable ends in Unistrut; not on mandrel cable
    - EPR insulation appeared in good condition
    - cable stiff compared to baseline
    - swelling noted: inner jacket/insulation 26%

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SAMUEL MOORE CABLES: *POST-LOCA VISUAL INSPECTION (cont.'d)*

- Group 3 (aged to 40 yr.):
  - Multi-conductor
    - multiple large (5-10 cm) cracks noted in outer jacket
    - insulation appeared in good condition
    - small bubbles noted in surface of outer CSPE jacket
    - white, powdery deposits noted on surface of outer CSPE jacket
    - cable stiff compared to baseline
    - swelling noted: outer jacket 23%; inner jacket/insulation 29%
  - Single conductor
    - CSPE inner jacket appeared torn, shriveled and dis-bonded from insulation only near cable ends in Unistrut; not on mandrel cable
    - white, powdery deposits noted on surface of CSPE inner jacket
    - EPR insulation appeared in good condition
    - cable stiff compared to baseline
    - swelling noted: inner jacket/insulation 26%

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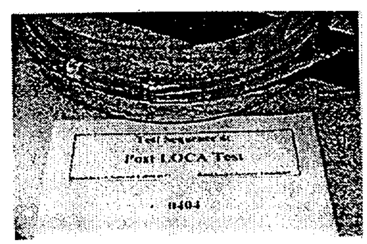
SAMUEL MOORE AGED TO 20 YEARS: *POST-LOCA CONDITION*



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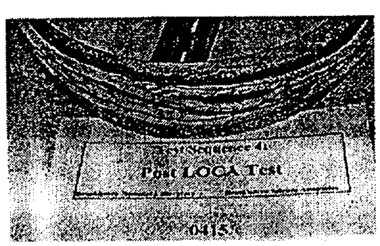
SAMUEL MOORE AGED TO 40 YEARS: *POST-LOCA CONDITION*



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ANACONDA CABLES: *POST-LOCA VISUAL INSPECTION*

- Group 1 (no aging):
  - Good condition; one small crack noted in outer jacket
  - White, powdery deposit noted on jacket surface
  - Cable fairly flexible
- Group 2 (aged to 40 yr.):
  - Multi-conductor
    - multiple large cracks and ruptures noted in outer jacket
    - white, powdery deposits noted on surface
    - cable fairly stiff
    - swelling noted: outer jacket: 21%; inner jacket/insulation 17%
  - Single conductor
    - multiple superficial surface cracks (crazing) noted on inner jacket
    - white, powdery deposits noted on surface
    - cable fairly flexible
    - swelling noted: insulation only (no CSPE jacket) 12%

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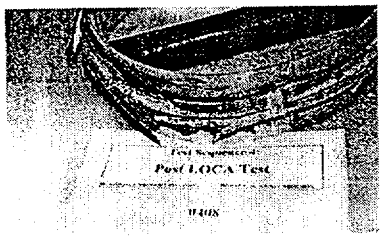
ANACONDA CABLES AGED TO 40 YEARS: *POST-LOCA CONDITION*



LOCA TEST 4: *RESULTS OF VOLTAGE WITHSTAND TEST*

SPECIMENS	TEST VOLTAGE	RESULT
Samuel Moore		
Group 1: 2/C	2400 Volts	1 of 1 PASSED
Group 2: 1/C	2400 Volts	2 of 2 PASSED
2/C	2400 Volts	2 of 2 PASSED
Group 3: 1/C	2400 Volts	2 of 2 PASSED
2/C	2400 Volts	2 of 3 FAILED Red-to-Ground
Anaconda		
Group 1: 3/C	2400 Volts	1 of 1 PASSED
Group 2: 1/C	2400 Volts	2 of 2 PASSED
3/C	2400 Volts	3 of 3 PASSED

POST-LOCA INSPECTION OF FAILED SPECIMENS

- Two failed specimens examined
  - 0413 - Samuel Moore 2/C using standard Wyle penetration with splice inside test chamber
  - 0416 - Samuel Moore 2/C using Swagelok penetration with no splice
- Isolated and dissected failed sections
  - Found one puncture hole in red conductor of each specimen
  - No global degradation of insulation evident
  - No damage noted on black conductors

RESULTS OF TEST 4

- The Anaconda cables artificially aged to 40 years performed acceptably in this test program
- The Samuel Moore cables artificially aged to 20 years and 40 years performed acceptably in this test program with the exception of two multi-conductor specimens, which failed the post-LOCA submerged voltage withstand test
- The cause of the failure on the two Samuel Moore specimens was determined to be due to localized damage to the insulation, which was punctured due to the high voltage administered in the voltage withstand test
- Swelling was evident in all of the specimens as a result of the accident steam exposure

PRELIMINARY CONCLUSIONS FROM TEST 4

- These test results confirm the original qualification basis for the Samuel Moore and Anaconda cables
- The failures of the two Samuel Moore cables were due to localized damage of the insulation and do not negate the original qualification
- The past failures of multi-conductor cables tested by Sandia were not caused by the penetrations used or the test set-up
- The cause of the multi-conductor failures in past Sandia tests is most likely due to swelling of the insulation

OBJECTIVE OF TEST 5

- Determine if bonded jacket cables have a unique failure mechanism not present in unbonded jacket cables
- Past testing by Sandia found failures of bonded jacket cables in which the insulation split open
  - NUREG/CR-5772: Samuel Moore aged to 20 & 60 yr. @ 55 C
    Okonite aged to 60 yr. @ 55 C
  - NUREG/CR-6095: Okonite aged to 60 yr. @ 65 C

SANDIA TESTS

- Differed from original qualification
  - NUREG/CR-5772
    - aging based on 40 yr. @ 55 C
    - lower aging acceleration factors
    - simultaneous aging and accident testing
    - no chemical spray
  - NUREG/CR-6095
    - aging based on 60 yr. @ 60 C
    - all radiation done prior to thermal aging
    - no chemical spray

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CABLES INCLUDED IN TEST 5

- Samuel Moore Dekoron Dekorad
  - 0.020" EPDM insulation
  - 0.010" CSPE bonded individual jacket
  - 0.045" CSPE overall jacket
  - 2/C #16 TSP 600V
- Anaconda Flame Guard EP
  - 0.030" EPR insulation
  - 0.015" CPSE unbonded individual jacket
  - 0.045" CSPE overall jacket
  - 3/C #12 1000V
- Okonite Okolon
  - 0.030" EPR insulation
  - 0.015" CSPE bonded individual jacket
  - no overall jacket
  - 1/C #12 600V

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NUMBER OF SPECIMENS IN TEST 5

Cable	No. of Specimens No Aging	20 Yr.	40 Yr.
Samuel Moore EPDM/Bonded CSPE 2/C #16	1	2	2
Anaconda EPR/Unbonded CSPE 3/C #12	1	2	2
Okonite EPR/Bonded CSPE 1/C # 12	1	2	3

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SAMUEL MOORE CABLES: *PREAGING PERFORMED*

- Parameters based on original qualification
  - Isomedix Report LOCA XLPO/EPDM, 6/78
- Three preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 20 years of qualified life
     - 84 hrs @ 250 F + 25 Mrad @ 0.75 Mrad/hr
  3. Preaging to simulate 40 years of qualified life
     - 168 hrs @ 250 F + 50 Mrad @ 0.75 Mrad/hr

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SAMUEL MOORE CABLE: *RESULTS OF PREAGING*

- Group 2 appeared in good condition
  - Insulation flexible; no cracks visible
  - Relatively high elongation-at-break (147%)
- Group 3 appeared in good condition
  - Insulation flexible; no cracks visible
  - Moderately high elongation-at-break (94%)

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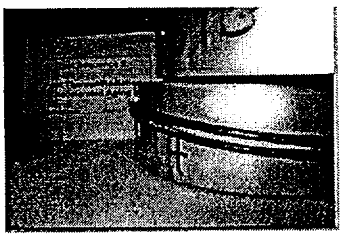
SAMUEL MOORE CABLE: *CONDITION AFTER PREAGING TO 40 YRS.*



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BROOKHAVEN NATIONAL LABORATORY

ANACONDA CABLES: *PREAGING PERFORMED*

- Parameters based on original qualification
  - FIRL Report F-C4350-3, 7/76
- Three preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 20 years of qualified life
     - 84 hrs @ 302 F + 25 Mrad @ 0.35 Mrad/hr
  3. Preaging to simulate 40 years of qualified life
     - 168 hrs @ 302 F + 50 Mrad @ 0.35 Mrad/hr

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ANACONDA CABLE: *RESULTS OF PREAGING*

- Group 2 appeared in good condition
  - Insulation flexible; no cracks visible
  - Relatively high elongation-at-break (166%)
- Group 3 appeared degraded
  - Insulation stiff; no cracks visible
  - Relatively low elongation-at-break (22%)

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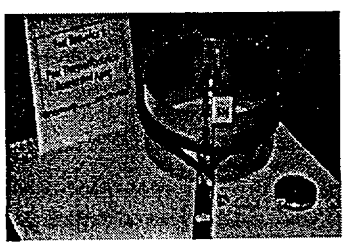
ANACONDA CABLE: *CONDITION AFTER PREAGING TO 40 YRS.*



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OKONITE CABLES: *PREAGING PERFORMED*

- Parameters based on original qualification
  - Okonite Report NQRN-1A, Rev. 5 10/24/88
- Three preaging groups
  1. No preaging (control specimens)
  2. Preaging to simulate 20 years of qualified life
     - 252 hrs @ 302 F + 25 Mrad @ 0.65 Mrad/hr
  3. Preaging to simulate 40 years of qualified life
     - 504 hrs @ 302 F + 50 Mrad @ 0.65 Mrad/hr

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OKONITE CABLE: *RESULTS OF PREAGING*

- Group 2 appeared degraded
  - Insulation stiff; no cracks visible
  - Relatively low elongation-at-break (8%)
- Group 3 appeared degraded
  - Insulation stiff; circumferential cracks visible
  - Relatively low elongation-at-break (4%)

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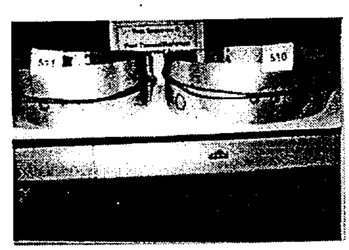
OKONITE CABLE: *CONDITION AFTER PREAGING TO 40 YRS.*



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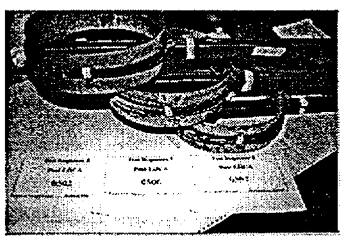
PERFORMANCE DURING LOCA TEST 5

- All specimens showed acceptable performance
  - Nominal circuit current and voltage
  - Little or no leakage current
  - Little or no error in PT loop
  - No blown fuses
- Okonite specimens aged to 40 years showed leakage upon initiation of chemical spray at 15 hours
  - Test specimen leakage to ground 0.2 to 0.6 mA; may not be maximum

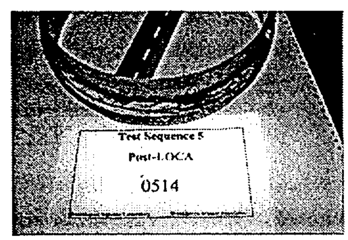
SAMUEL MOORE CABLES: *POST-LOCA VISUAL INSPECTION*

- Group 1 (no aging):
  - Good condition; no cracking
  - Numerous small water-filled bubbles on jacket surface
- Group 2 (aged to 20 yr.):
  - Cable still flexible; spongy feel
  - Small (2-5 cm) cracks noted in jacket
  - Insulated conductor not exposed
- Group 3 (aged to 40 yr.):
  - One crack (5 cm) noted in overall jacket on both cables
  - Jacket opened in one spot exposing insulated conductors
  - Exposed insulation appeared in good condition
  - Cable still flexible; spongy feel

SAMUEL MOORE AGED TO 20 YEARS: *POST-LOCA CONDITION*



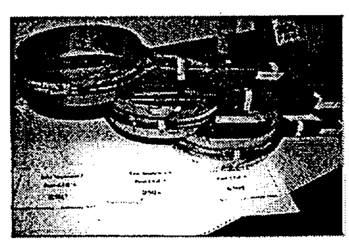
SAMUEL MOORE AGED TO 40 YEARS: *POST-LOCA CONDITION*



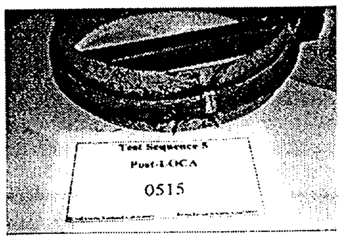
ANACONDA CABLES: *POST-LOCA VISUAL INSPECTION*

- Group 1 (no aging):
  - Good condition; no cracking
  - Numerous small water-filled bubbles on jacket surface
- Group 2 (aged to 20 yr.):
  - Multiple longitudinal cracks noted on overall jacket; not through-wall; appears to be due to swelling
  - Large circumferential crack noted in overall jacket of one cable exposing insulated conductors
- Group 3 (aged to 40 yr.):
  - Multiple longitudinal cracks noted on overall jacket; none through-wall; appears to be due to swelling
  - Large circumferential crack noted in overall jacket of one cable exposing insulated conductors

ANACONDA CABLES AGED TO 20 YEARS: *POST-LOCA CONDITION*



ANACONDA CABLES AGED TO 40 YEARS: *POST-LOCA CONDITION*



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OKONITE CABLES: *POST-LOCA VISUAL INSPECTION*

- Group 1 (no aging):
  - Good condition; no cracking
  - Numerous small water-filled bubbles on jacket surface
- Group 2 (aged to 20 yr.):
  - Longitudinal cracks along jacket
  - 10-cm section on one cable opened exposing conductor
- Group 3 (aged to 40 yr.):
  - Longitudinal cracks along jacket on all cables
  - Jacket opened on all cables exposing bare conductor

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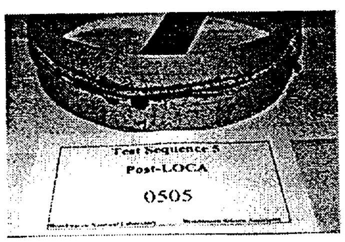
OKONITE CABLES AGED TO 20 YEARS: *POST-LOCA CONDITION*



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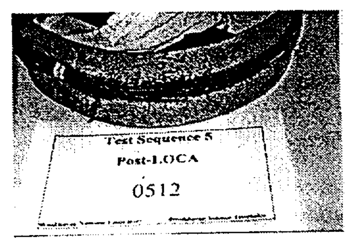
OKONITE CABLES AGED TO 40 YEARS: *POST-LOCA CONDITION*



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LOCA TEST 5: *RESULTS OF VOLTAGE WITHSTAND TEST*

SPECIMENS	TEST VOLTAGE	RESULT
Samuel Moore	2400 VOLTS	5 OF 5 PASSED
Anaconda	2400 VOLTS	5 OF 5 PASSED
Okonite	2400 VOLTS	4 OF 6 FAILED

1 of 2 in Group 2 (aged to 20 years) Failed
3 of 3 in Group 3 (aged to 40 years) Failed

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RESULTS OF TEST 5

- Both the Samuel Moore and Anaconda cables artificially aged to 40 years performed acceptably in this test program
- The Okonite cables artificially aged to 40 years failed catastrophically by splitting open and exposing the bare conductor
- The Okonite failures appear to be due to exposure to the LOCA steam/chemical spray environment after being aged, during which moisture absorption caused swelling and splitting of the insulation

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PRELIMINARY CONCLUSIONS FROM TEST 5

- These test results confirm the original qualification basis of the Samuel Moore and Anaconda cables
- The use of bonded CSPE jackets on top of EPR insulation appears to problematic for some material formulations and thicknesses; potential for failure of the insulation system under accident conditions
- The qualification basis for Okonite/Okolon cables in configurations other than the 1/C #6 AWG 2kV configuration tested in NQRN-1A should be reevaluated

PLANS FOR TEST 6

- Objective:
  - Determine performance of cables aged to the equivalent of 60 years of qualified life during accident conditions
- Approach:
  - Preage and Accident Test Cables with the equivalent of 60 years of qualified life per original qualification
  - Cables to be tested
    - Rockbestos: XLPE/Neoprene (same as LOCAs 1 and 3)
    - AIW: EPR/Unbonded EPR (same as LOCA 2)
    - Samuel Moore: EPR/Bonded CSPE (same as LOCAs 4 and 5)
    - Okonite: EPR/Bonded CSPE (same as LOCA 5)