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Equipment Qualification Research Test of Electric Cable With Factory Splices and Insulation Rework Test No. 2 Report No. 1

E. E. Minor, D. T. Furgal

This report records the results of tests performed by Sandia National Laboratories to provide the NRC with data for assessing the methods and procedures for environmental qualification tests of electric cable repairs and splices as outlined in IEEE 383-1974

Prepared by
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for the United States Department of Energy
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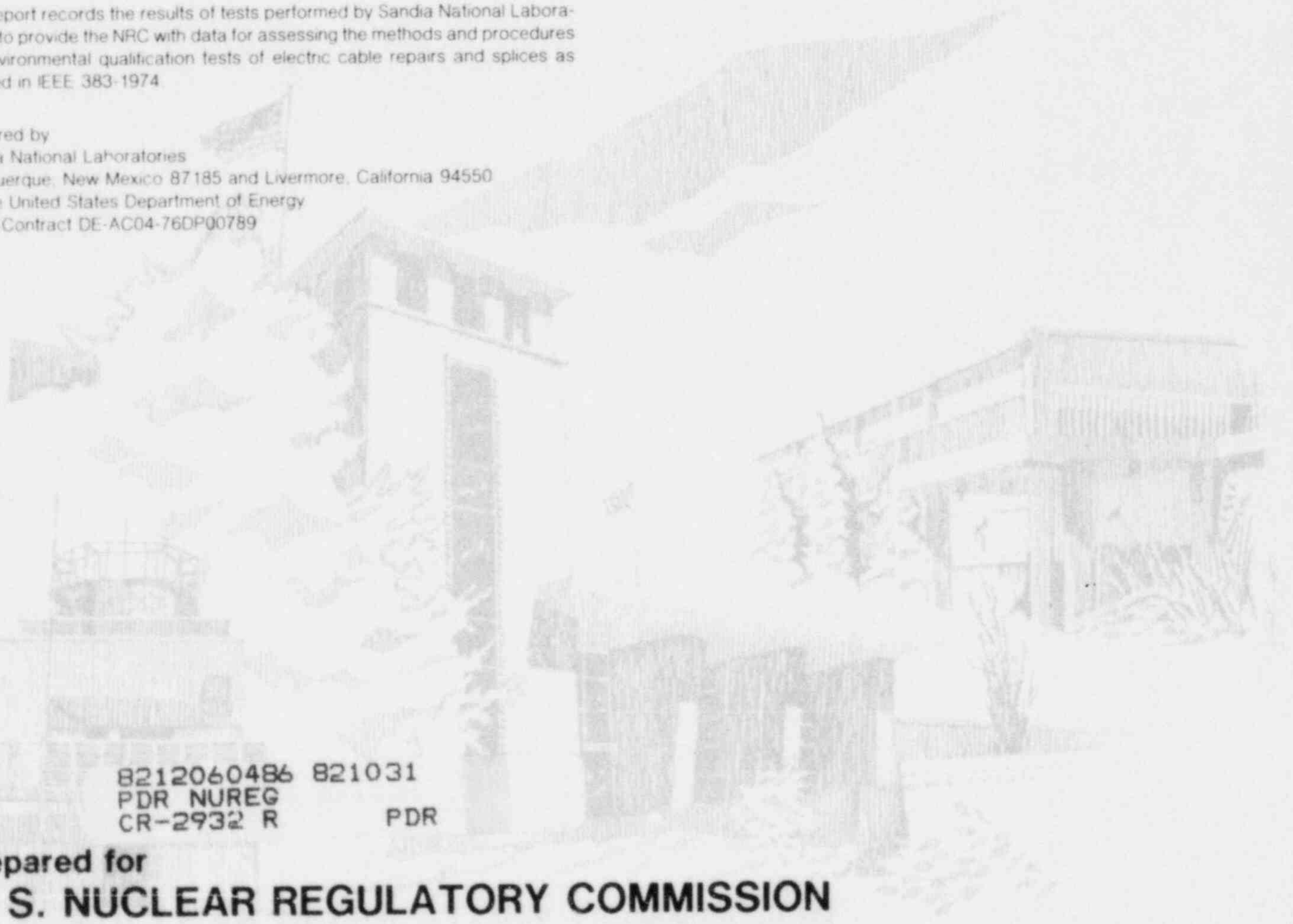

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EQUIPMENT QUALIFICATION RESEARCH TEST OF ELECTRICAL CABLE WITH FACTORY SPLICES AND INSULATION REWORK
TEST NO. 2, REPORT NO. 1

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for the
U. S. Department of Energy

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ABSTRACT

Electric cables with flame-retardant chemically crosslinked polyolefin extruded insulation containing factory-made center-conductor splices and insulation repairs manufactured by The Rockbestos Company were used in a methodology test of the IEEE Standard 383-1974. This standard is concerned with the ability of cables to function during and following exposure to aging and LOCA/MSLB environments. Cable specimens were radiation aged at a low-dose rate and then thermally aged to simulate a 40-year containment exposure. After aging, the specimens were subjected to LOCA radiation and a 33-day steam and chemical spray exposure. The cables were electrically loaded and functioned without failure during and after LOCA steam and chemical spray exposure. Insulation resistance measurements were taken during the exposure sequence. Subsequent to the exposures, hipot and mandrel bend tests were conducted. Test results indicate that the methods given in IEEE 383-1974 are adequate to show that cables can function and support power and control operations during and after a LOCA/MSLB of the severity simulated by the test. Further, the presence of center-conductor splices and insulation repairs did not appear to degrade cable performance.

To determine the most severe cable aging sequence, cable insulation material samples were subjected to varied aging exposures to observe sequence-related and dose-rate-related material degradation. A dose-rate effect was observed. Radiation aging at a low dose-rate, on the average, produced lower insulation material elongation and tensile force* measurements when compared with measurements of the same material after high dose-rate-aging. In other words, low dose-rate radiation aging was more harmful than high dose-rate aging.· When comparing measurements of high dose-rate-aged samples, a sequence-related degradation effect was also apparent. The sequence of high dose-rate radiation aging followed by thermal aging produced, on the average, lower tensile force and elongation measurements when compared with exposure in the reverse sequence. High data variability, however, made it impossible to positively differentiate between the two high dose-rate sequences.

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*Tensile force is used rather than tensile strength--readings were not normalized to sample cross-sectional area. Readings indicate relative degradation.

ACKNOWLEDGMENTS

Sincere appreciation is extended to the Rockbestos Company for supplying cable and insulation sample test specimens. The untiring efforts of F. V. Thome in preparing the facility and equipment are greatly appreciated, as well as his many invaluable suggestions to help achieve successful test completion. Special thanks are also due to J. A. Lewin, for his aid in hardware design, and to T. W. Gilmore, J. C. Bartberger, V. J. Dandini, D. M. Jeppesen, E. A. Salazar, R. B. Padilla, and J. J. Benson, for their contributions to successful test execution. Also, the efforts of J. A. Letz, LWR Safety Department 4440 Quality Assurance Chief, are greatly appreciated.

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1.0 EXECUTIVE SUMMARY

1.1 Introduction

Nine seven-strand No. 6 AWG and nine seven-strand No. 12 AWG electric cables manufactured by The Rockbestos Company with chemically crosslinked polyolefin insulation containing factory-made center conductor splices and insulation repairs were subjected to a methodology test of IEEE Standard 383-1974.[1] This standard is concerned with demonstrating the ability of electric cable to function during and following LOCA/MSLB exposure. Testing was performed in accordance with guidelines in IEEE Standard 323-1974, IEEE Standard 383-1974[2] and NUREG-0588.[3]

Two series of tests are described in this report: (1) Tests of cable specimens exposed to aging and LOCA/MSLB environments to evaluate the methods for measuring cable performance and degradation given by IEEE 383-1974, and (2) tests of cable insulation samples to determine the most severe aging environment and exposure sequence.

1.2 Cable Specimen Tests

Test measurements performed on cable specimens encompassed x-ray, visual inspection, electrical continuity, and insulation resistance measurements prior to and during the test sequence. Hipot and mandrel bend tests were conducted after the exposures. The cables were exposed in the following sequence conforming to IEEE 383-1974:

1. Low dose-rate radiation aging (62 krd/hr* for 50.3 Mrd)
2. Thermal aging [~ 846 hrs at 302°F (150°C)]
3. LOCA radiation (0.77 Mrd/hr* for 146 Mrd)
4. Steam and chemical spray exposure [33 day LOCA/MSLB profile (cables energized-480 VAC, 11 amperes)].

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*Air equivalent dose

The cables maintained their current-carrying capability during and following the LOCA steam and chemical spray exposure. Insulation resistance measurements taken to evaluate insulation material degradation dropped from greater than 10^{12} ohms for virgin materials to approximately 5.5×10^5 ohms for No. 6 AWG cable and 1.5×10^6 ohms for No. 12 AWG cable (see Figure 2-6) during the initial accident profile pressure and temperature peaks. After one week into the accident profile, the insulation resistance increased to approximately 4.0×10^7 ohms and 1.0×10^8 ohms, respectively, and remained fairly constant through the remainder of the exposure.

Indentations in the cable insulation material were observed during post-exposure visual inspection (see Section 2.3.3 and Figure 2-7). The indentations occurred at cable pressure points and were assumed to be the result of insulation material thermal softening. The cables were snug but not tightly wound on the mandrels. However, we believe that expansion of the mandrel and insulation material during thermal aging caused the cable to tighten-up around the mandrel posts, thus causing pressure points.

A build-up of residue was observed where the steam and chemical spray came into direct contact with the cables (see Section 2.3.5 and Figures 2-8 and 2-9). Chemical analysis of this residue showed that there was a reaction between the chemical spray and the insulation material causing the residue to form. Physical analysis of the insulation material showed a four percent reduction in weight from virgin material values when the residue was scraped off.

1.3 Insulation Sample Tests

To determine the most severe aging exposure, insulation samples were subjected to varied sequences of radiation and thermal aging. High and low radiation dose-rates were applied during the aging exposures to determine the dose-rate influence on insulation degradation. Tensile force and elongation measurements were used to determine insulation material degradation.

Insulation samples were divided into groups for tensile force and elongation tests and given different aging and LOCA exposures. Group numbers from Table 3-1 are shown bracketed.

- Virgin material--unaged [Group 3B].
- Aged similar to common industry practice--thermal aging followed by high dose-rate radiation aging (860.5 hrs at 302°F (150°C) and 865 krd/hr* for 50.0 Mrd) [Group 1B].
- Aged in the reverse sequence to Group 1B samples--high dose-rate radiation aging followed by thermal aging [Group 2B].
- Low dose-rate radiation aging followed by thermal aging (47.7 krd/hr* for 50.2 Mrd and 860.5 hrs at 302°F (150°C)) [Group 4B].
- Samples from Groups 1B, 2B, and 4B exposed to high dose-rate LOCA radiation (dry) for approximately an additional 50 Mrd [Groups 1B, 2B, and 4B Supp. #1].
- Samples from Groups 1B, 2b, and 4B exposed to high dose-rate LOCA radiation (dry) for approximately an additional 150 Mrd [Groups 1B, 2B, and 4B Supp. #2].

Measurements of tensile force** and elongation were made on all samples. These measurements were the basis for determining insulation material degradation.

The insulation material showed a dose-rate effect (see Table 3-2 and Figures 3-1 and 3-2). Samples aged by exposure to low dose-rate radiation followed by thermal aging (Group 4B), on the average, showed the most severe degradation. All groups had very little material life remaining and appeared to be at nearly the same level of mechanical degradation as radiation exposure approached 200 Mrd (TID). Group 1B samples showed the least degradation. Based on these test results, the sequence of low dose-rate radiation aging followed by thermal aging was the exposure sequence used for cable specimen aging. It should be noted that these research tests produced material degradation that was more severe than observed when cables were exposed to the same environments; however, these results should not be taken as part of the cable test results.

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*Air equivalent dose.

**Tensile force used--data not normalized to cross-sectional area.

2.0 CABLE SPECIMEN TESTS

2.1 Description of Cable Test Specimens

Eighteen Firewall III insulated cables, approximately 25 feet (7.6 m) in length, were tested. They consisted of nine power cables with seven-strand No. 6 AWG center conductors covered with 0.045 inch (0.11 cm) thick, flame-retardant, chemically crosslinked polyolefin insulation and nine control cables with seven-strand, No. 12 AWG tin-coated soft copper center conductors covered with 0.030 inch (0.08 cm) thick insulation of the same material. The cables were rated at 600 VAC and were previously qualified for a 194°F (90°C), 40-year life, nuclear power plant application. One power cable, Specimen No. 19, contained a center conductor splice. One power cable, Specimen No. 24, contained an insulation repair. Three control and two power cables, Specimens 13, 14, 15, 22 and 23, contained both center conductor splices and insulation repairs.

2.2 Test Procedure

2.2.1 Radiography of Splices and Insulation Repairs

a. High-Intensity X-Ray

The seven cables with center conductor splices and insulation repairs were x-rayed at approximately 150 kV in two orientations differing by a 90 degree radial rotation to assess the condition of each splice and the condition of the conductor under each insulation repair. No anomalies were observed.

b. Low-Intensity X-Ray

The six cables with insulation repairs were x-rayed at approximately 75 kV in two orientations differing by a 90 degree radial rotation to assess the condition of the insulation patches. No anomalies were observed.

2.2.2 Pre-Exposure Visual Inspection

All cables were visually inspected (without magnification) prior to radiation exposure to observe for obvious insulation material defects. No defects were observed.

2.2.3 Electrical Continuity Test

The center conductor of each cable was checked for electrical continuity with a multimeter before the cable was readied for testing. All cables passed this test.

2.2.4 Winding Cables on Mandrel

Approximately the middle six feet (1.8 m) of each cable was wound around a stainless steel mandrel having a length of 44.75 inches (114 cm) and a 12 inch (30 cm) diameter (see Figures 2-1 and 2-2). Thus, the splices and insulation repairs were located in the segment of the cable wrapped around the mandrel. The 18 cables tested and reported on herein were simultaneously exposed with nine cables of another type; thus, the purpose for cable numbering beginning with Cable No. 10 in this report.

2.2.5 Pre-Exposure Water Immersion Insulation Resistance Measurements

After the cables were wound around the mandrel, but prior to radiation and temperature exposure, the mandrel was immersed in room temperature tap water for approximately one hour. Cable insulation resistance measurements at a potential of 500 VDC were made. The instrument was held on each cable until the instrument meter stabilized. Test data are shown in Table 2-1, Column 2.

2.2.6 Accelerated Radiation Aging

The mandrel-wound cables were exposed to a Cobalt-60 source in the Sandia National Laboratories High Intensity Adjustable Cobalt Array (HIACA) radiation facility at a dose-rate of approximately 62 krd per hour for 11 hours, 35 minutes, giving a total integrated dose (TID) through aging of 50.3 Mrd.*

After radiation aging, insulation resistance measurements were made. During these measurements, cables were gradually submerged in water. Therefore, the locations where leakage occurred could be isolated and hence, damage to Cables No. 10 and 19 was found. Cables 10 and 19, therefore, were not considered when evaluating test results.

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*Air equivalent dose.

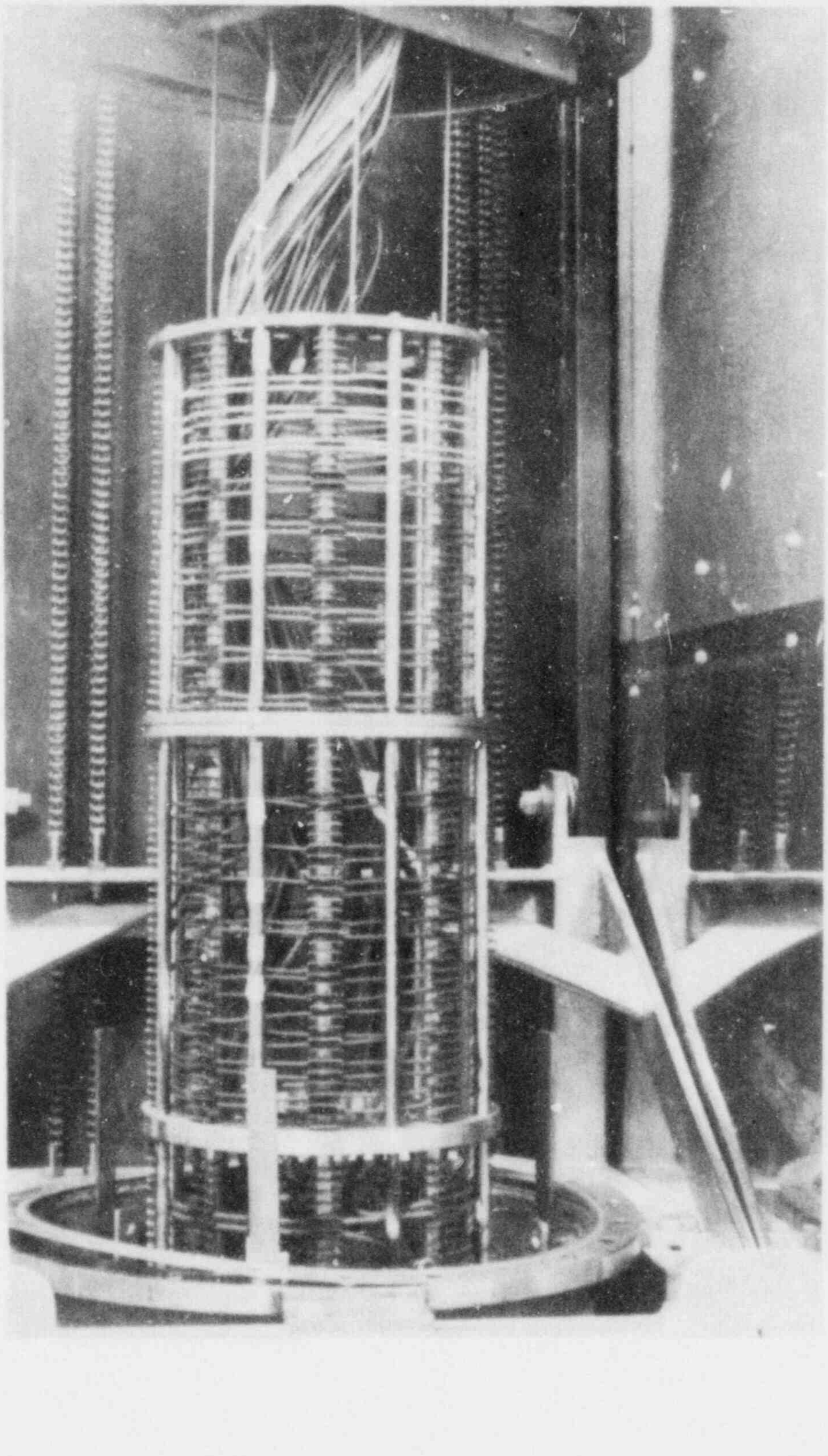

Figure 2-1. View of Cables on Mandrel

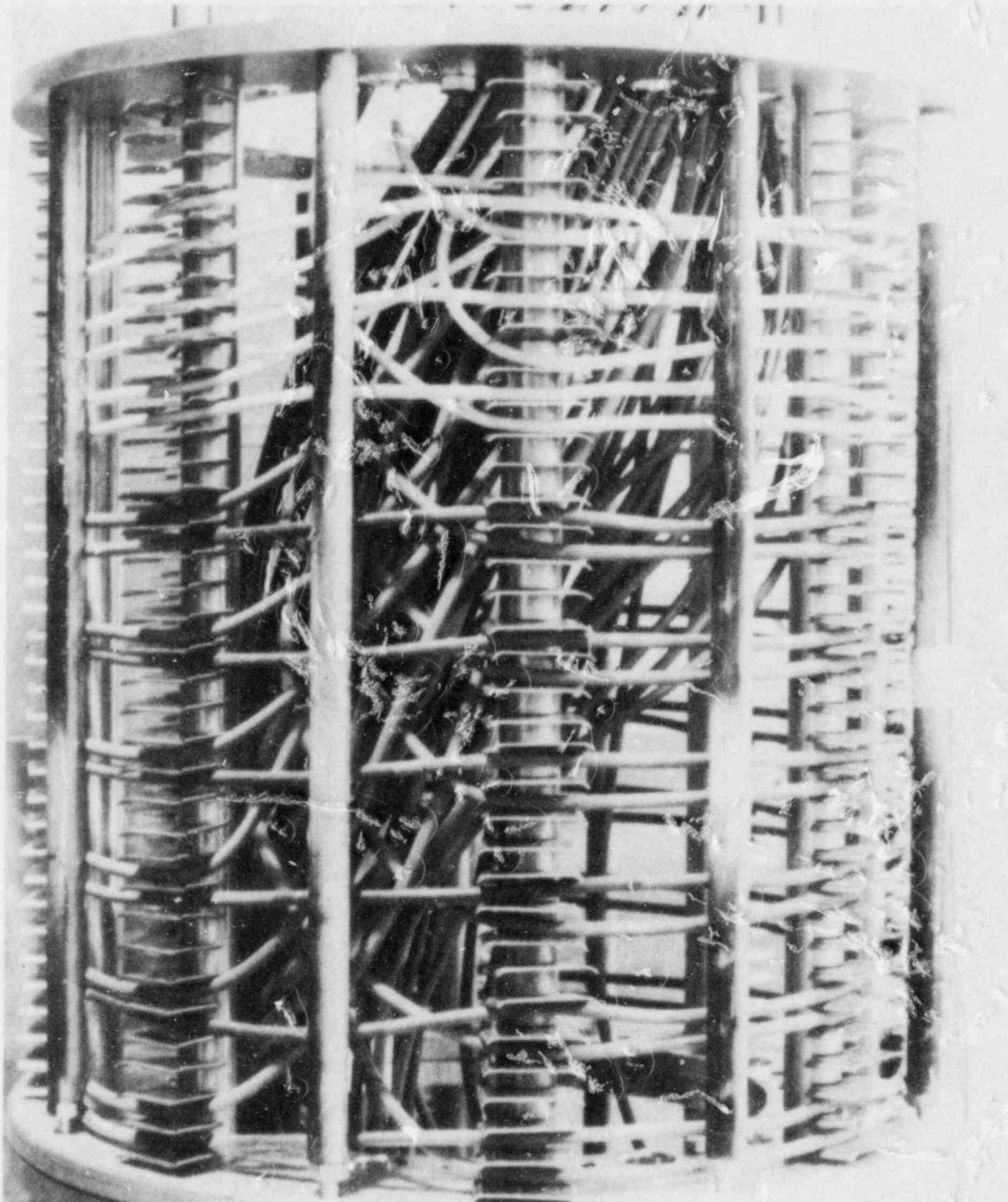

Figure 2-2. Close-up View of Cables on Mandrel

Table 2-1

Results of IR Tests Prior to
Steam/Chemical Spray Environment Exposure
(Ohms)

Cable No.	Pre-Radiation Aging (Wet)	Post-Radiation Aging (Wet)	Post-Thermal Aging (Wet)	Post-Accident Rad. (Dry)	Post-Accident Rad. (Wet)
10	$>10^{12}$	$>10^{12}$	$<.5\times10^{6}$(1)(a)	$.68\times10^{10}$	$<.5\times10^{6}$(2)(a)
11	$>10^{12}$	$>10^{12}$	$.95\times10^{10}$	$.67\times10^{10}$	$.34\times10^{10}$
12	$>10^{12}$	$>10^{12}$	$.93\times10^{10}$	$.62\times10^{10}$	$.31\times10^{10}$
13	$>10^{12}$	$>10^{12}$	$.90\times10^{10}$	$.60\times10^{10}$	$.31\times10^{10}$
14	$>10^{12}$	$>10^{12}$	$.92\times10^{10}$	$.67\times10^{10}$	$.32\times10^{10}$
15	$>10^{12}$	$>10^{12}$	$.90\times10^{10}$	$.52\times10^{10}$	$.28\times10^{10}$
16	$>10^{12}$	$>10^{12}$	$.90\times10^{10}$	$.57\times10^{10}$	$.29\times10^{10}$
17	$>10^{12}$	$>10^{12}$	$.88\times10^{10}$	$.54\times10^{10}$	$.28\times10^{10}$
18	$>10^{12}$	$>10^{12}$	$.85\times10^{10}$	$.59\times10^{10}$	1.1×10^{7}(b)
19	7.0×10^{12}	2.0×10^{12}	$.6-.9\times10^{6}$(a)	$.49\times10^{10}$	$<.5\times10^{6}$(3)(a)
20	9.0×10^{12}	2.0×10^{12}	$.56\times10^{10}$	$.56\times10^{10}$	2.6×10^{9}
21	1.0×10^{13}	2.0×10^{12}	$.56\times10^{10}$	$.49\times10^{10}$	8.0×10^{9}
22	5.0×10^{12}	1.4×10^{12}	$.53\times10^{10}$	$.54\times10^{10}$	4.7×10^{9}
23	9.0×10^{12}	1.5×10^{12}	$.52\times10^{10}$	$.52\times10^{10}$	4.5×10^{9}
24	1.4×10^{13}	2.0×10^{12}	$.53\times10^{10}$	$.52\times10^{10}$	2.6×10^{9}
25	1.3×10^{13}	2.0×10^{12}	$.54\times10^{10}$	$.52\times10^{10}$	4.0×10^{9}
26	1.6×10^{13}	2.0×10^{12}	$.54\times10^{10}$	$.57\times10^{10}$	4.5×10^{9}
27	5.0×10^{13}	2.0×10^{12}	$.54\times10^{10}$	$.53\times10^{10}$	4.0×10^{9}

(a) Tested at 10 V Potential

(b) Tested at 100 V Potential

(1) While immersed, using a Fluke 8100-A Multimeter, a reading of approximately 3.8×10^{5} ohms was obtained. After water was drained, while still very wet, the IR reading was 2.5×10^{5} ohms at 500 V using a Hipotronics Megohmmeter.

(2) While immersed, using a Fluke 8100-A Multimeter, a reading of approximately 4.7×10^{5} ohms was obtained.

(3) While immersed, using a Fluke 8100-A Multimeter, a reading of approximately 1.0×10^{5} ohms was obtained.

NOTE: Readings recorded in this table were obtained using a Hewlett-Packard Model 4329A High Resistance Meter.

2.2.7 Post-Radiation Aging Insulation Resistance Measurements

After radiation aging, water-immersion insulation resistance measurements as described in Section 2.3.5 were made while the cables (on the mandrel) were suspended in the HIACA radiation facility. Test data are shown in Table 2-1, Column 3.

2.2.8 Accelerated Thermal Aging

Cables were then thermally aged for 863 hours, 55 minutes, at 302°F (150°C). This is the thermal aging sequence used by the cable manufacturer and is based on Arrhenius methodology.

2.2.9 Post-Thermal Aging Insulation Resistance Measurements

After thermal aging, water-immersion insulation resistance measurements as described in Section 2.3.5 were made while the cables (on the mandrel) were suspended in the HIACA radiation facility. Test data are shown in Table 2-1, Column 4.

2.2.10 Accident Radiation Exposure

All cable specimens were exposed, in the HIACA radiation facility, to an additional 146 Mrd (196.3 Mrd TID) gamma radiation at a dose rate of 0.77 Mrd* per hour to simulate LOCA exposure.

2.2.11 Post-Accident Radiation Insulation Resistance Measurements

After LOCA radiation exposure, dry and water-immersion insulation resistance measurements were made with the cables on the mandrel. Test data are shown in Table 2-1, Columns 5 and 6.

2.2.12 Steam and Chemical Spray Environment Exposure

The cable specimens were exposed to a steam and chemical spray environment which followed the profile shown in Figure 2.4.** This profile is similar to that used by cable manufacturers in performing cable qualification tests to IEEE 383-1974. The cables (wrapped

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*Air equivalent dose.

**See Reference 1, p. 18.

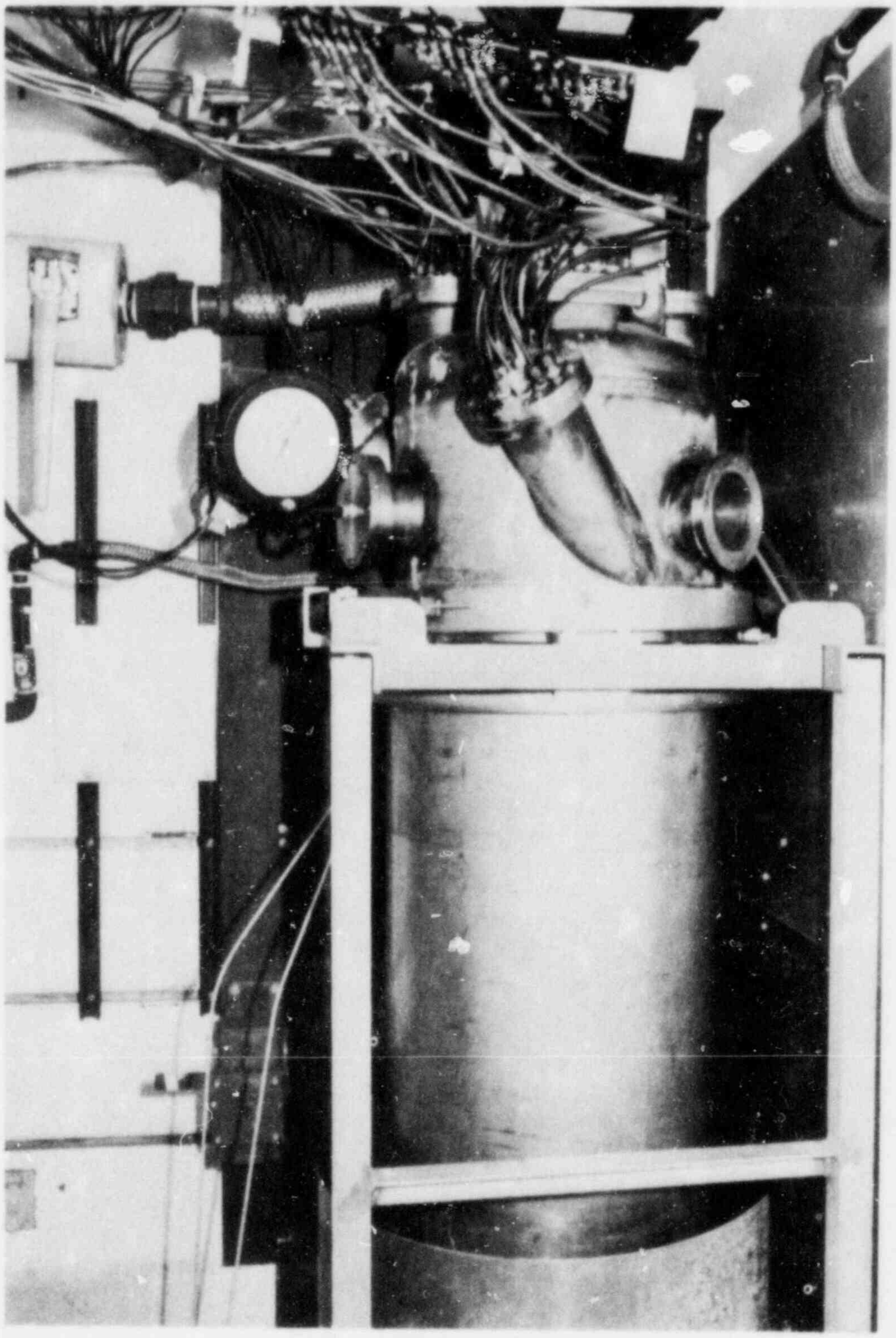
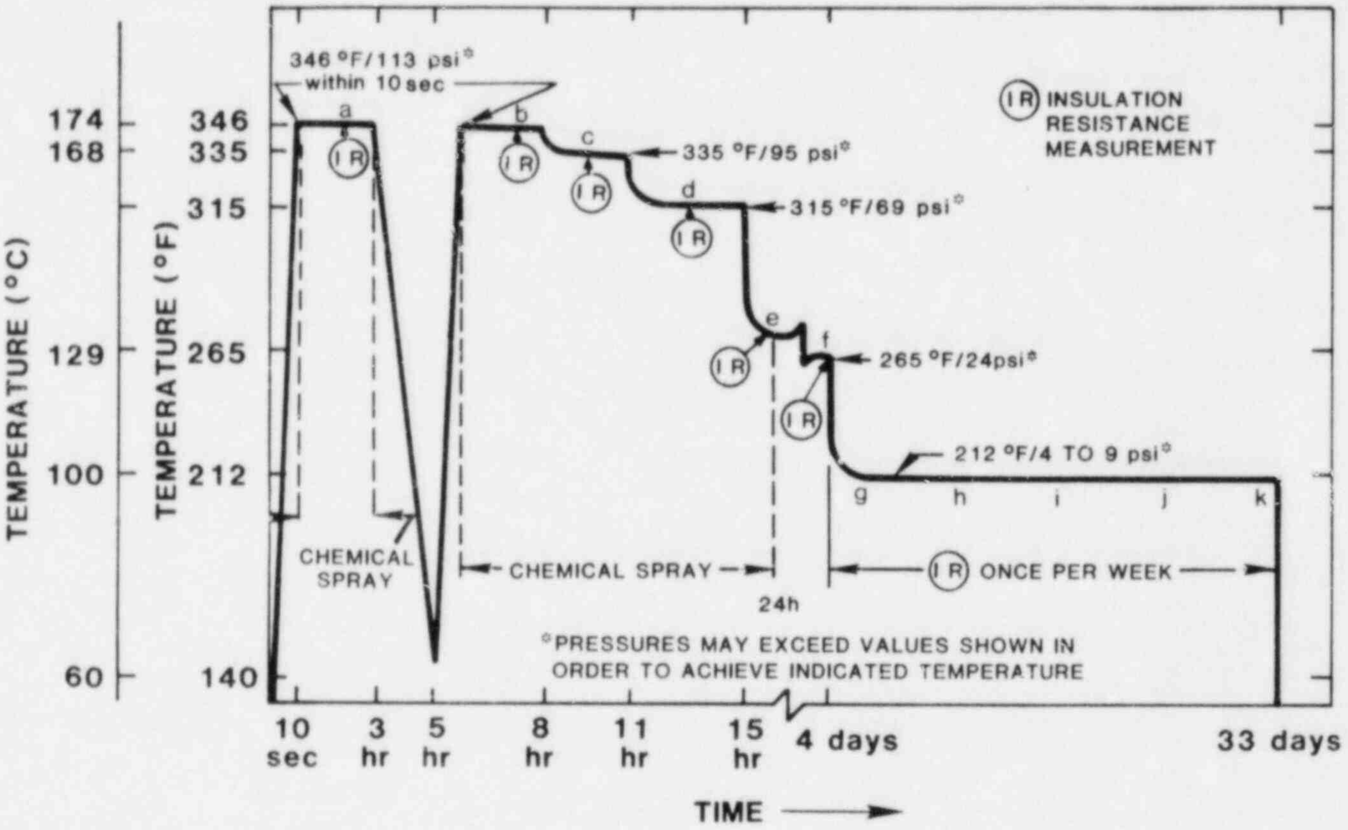


Figure 2-3. View of Test Chamber with Cable Installed



NOTE: TEMPERATURES TO BE WITHIN 5°F OF VALUES SHOWN

Figure 2-4. Specified Temperature/Pressure Profile For Steam/Chemical Spray Exposure around the mandrel) were exposed to this environment while inside an environmental test chamber (see Figure 2-3).

2.2.13 Steam and Chemical Spray Environment Insulation Resistance Measurements

Insulation resistance measurements were taken during the steam and chemical spray exposure at intervals indicated in Figure 2-5. Test data are shown in Tables 2-2 and 2-3 and are plotted in Figure 2-6 along with data contained in Table 2-1.

2.2.14 Post-Exposure Hipot Test

While wrapped around the mandrel, cables were gradually immersed in room temperature tap water. Hipot leakage current measurements were taken after a one-minute energization. The mandrels were gradually immersed during the hipot test so that the exact location of any insulation breakdowns could be observed. Cables with 0.030 inch (0.08 cm) insulation were tested at 2400 VAC and cables with 0.045 inch (0.11 cm) insulation were tested at 3600 VAC to produce an insulation stress of 80 volts per mil. The cables were immersed in water for one hour. Measurements were again taken after a five-minute energization. Test data are included in Appendix F.

2.2.15 Post-Exposure Visual Inspection

The cables were visually inspected while wrapped around the mandrel and again after straightening. They were checked for insulation cracks or other physical defects and also to determine, if possible, the physical cause for the electrical test anomalies which we suspected were caused by handling damage. Observations are noted in Appendix F.

2.2.16 Post-Exposure Cable Bend Test

Cables were removed from the mandrels and bent in the direction of the cable's set around a mandrel having 40 times the cable diameter. While wrapped around the bend-test mandrel, the cables were visually inspected for insulation cracks. Additionally, a representative sample of cables were wrapped around the bend-test mandrel in a direction opposite to their set and once again visually inspected. Observations are also included in Appendix F.

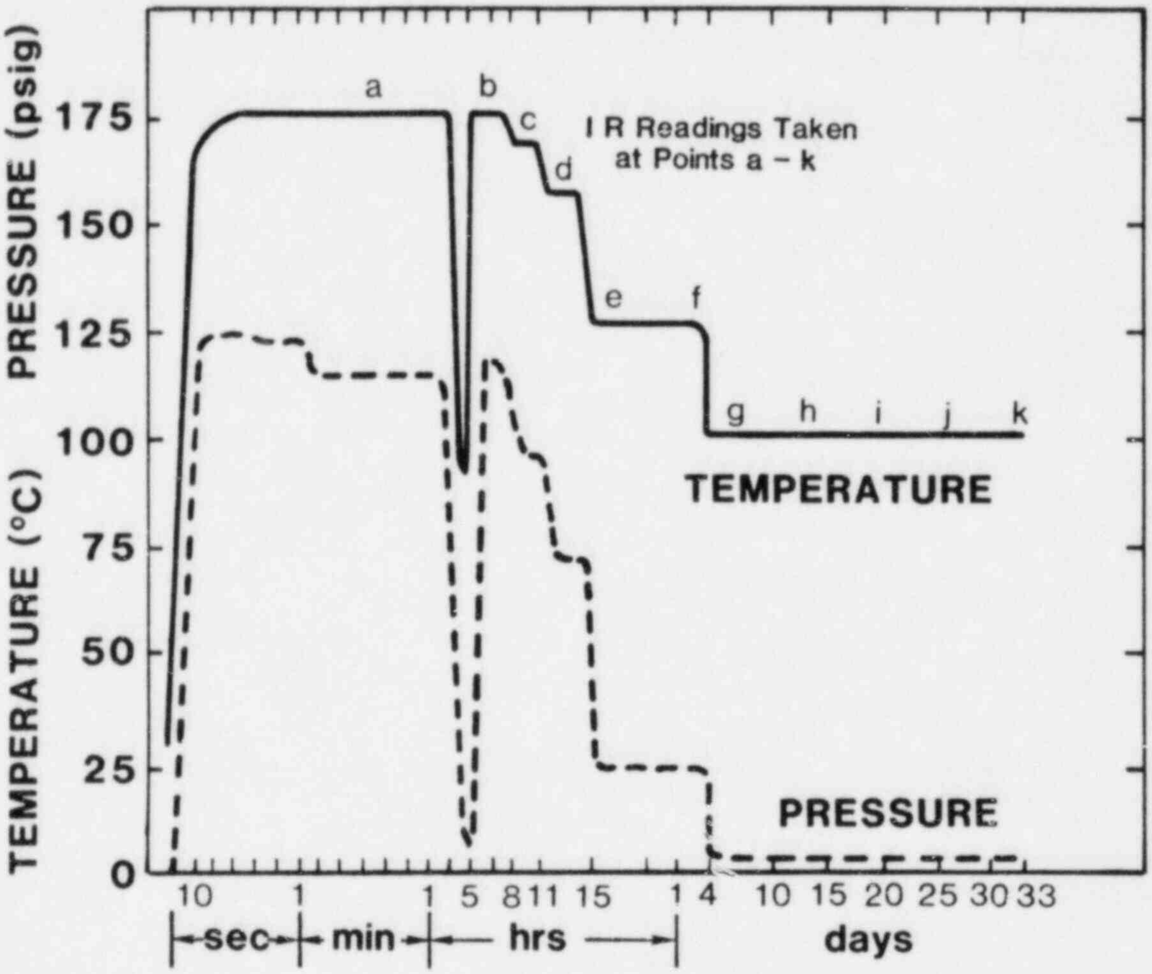


Figure 2-5. Actual Temperature and Pressure Profiles for Steam/Chemical Spray Exposure

Table 2-2

Results of IR Tests During Steam/Chemical Spray Environment Exposure -- Control Cables

	a	b	c	d	e	f	g	h	i	j	k[1]
Cable No.	1st Peak 8/6/81	2nd Peak 8/6/81	169°C 8/6/81	158°C 8/6/81	131°C 8/7/81	130°C 8/10/81	102°C 8/11/81	102°C 8/18/81	102°C 8/25/81	102°C 9/1/81	102°C 9/8/81
10	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(25V) .16x10^{7}	(50V) .32x10^{7}	(50V) .37x10^{7}	(50V) .37x10^{7} (2)
11	(25V) .148x10^{7}	(25V) .31x10^{7}	(25V) .158x10^{7}	(50V) .355x10^{7}	(250V) .19x10^{8}	(250V) .18x10^{8}	(500V) 1.2x10^{8}	(500V) 1.4x10^{8}	(500V) 1.4x10^{8}	(500V) 1.35x10^{8}	(500V) 1.3x10^{8}
12	(25V) .15x10^{7}	(25V) .151x10^{7}	(25V) .158x10^{7}	(50V) .355x10^{7}	(10V) <.5x10^{6}	(100V) 1.7x10^{7}	(500V) .30x10^{8}	(500V) .75x10^{8}	(500V) .50x10^{8}	(500V) .60x10^{8}	(500V) .75x10^{8}
13	(25V) .15x10^{7}	(25V) .16x10^{7}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(100V) 1.25x10^{7}	(250V) .15x10^{8}	(250V) .18x10^{8}	(250V) .19x10^{8}	(250V) .22x10^{8}	(250V) .22x10^{8}
14	(25V) .15x10^{7}	(25V) .155x10^{7}	(25V) .158x10^{7}	(10V) .9-1.0x10^{6}	(10V) <.5x10^{6}	(250V) .15x10^{8}	(500V) .5-.6x10^{8}	(500V) .55x10^{8}	(500V) .55x10^{8}	(500V) .80x10^{8}	(500V) .80x10^{8}
15	(25V) .16x10^{7}	(25V) .152x10^{7}	(25V) .158x10^{7}	(50V) .355x10^{7}	(250V) .19x10^{8}	(250V) .175x10^{8}	(500V) 1.2x10^{8}	(500V) 1.25x10^{8}	(500V) 1.2x10^{8}	(500V) 1.1x10^{8}	(500V) 1.2x10^{8}
16	(25V) .16x10^{7}	(25V) .17x10^{7}	(25V) .21x10^{7}	(50V) .39x10^{7}	(250V) .21x10^{8}	(250V) .19x10^{8}	(500V) 1.3x10^{8}	(500V) 1.4x10^{8}	(500V) 1.4x10^{8}	(500V) 1.6x10^{8}	(500V) 1.5x10^{8}
17	(25V) .165x10^{7}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(250V) .15x10^{8}	(500V) 1.1x10^{8}	(500V) 1.3x10^{8}	(500V) 1.6x10^{8}	(500V) 1.6x10^{8}	(500V) 1.6x10^{8}
18	(25V) .163x10^{7}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(10V) <.5x10^{6}	(250V) .185x10^{8}	(500V) .95x10^{8}	(500V) 1.35x10^{8}	(500V) 1.4x10^{8}	(500V) 1.6x10^{8}	(500V) 1.5x10^{8}

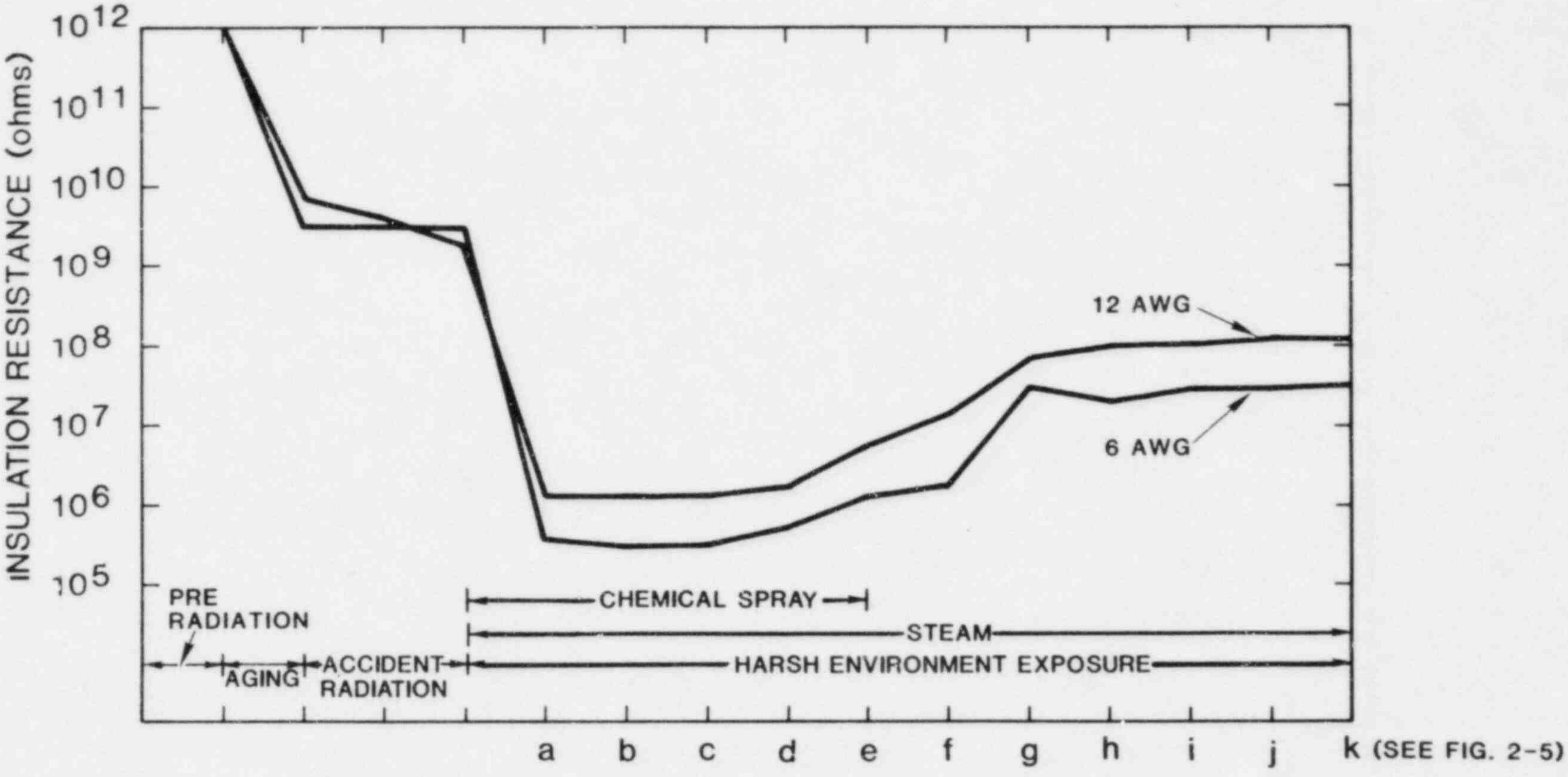
Notes: 1. See Figure 2-5 for LOCA steam sequence relationship.
2. Cable No. 10 sustained handling damage and is considered a "no test".

Table 2-3

Results of IR Tests During Steam/Chemical Spray Environment Exposure -- Power Cables

	a	b	c	d	e	f	g	h	i	j	k(1)
Cable No.	1st Peak 8/6/81	2nd Peak 8/6/81	169°C 8/6/81	158°C 8/6/81	131°C 8/7/81	130°C 8/10/81	102°C 8/11/81	102°C 8/18/81	102°C 8/25/81	102°C 9/1/81	102°C 9/8/81
19	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$ (2)
20	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(25V) $.23x10^7$	(500V) $.40x10^8$	(250V) $.125x10^8$	(250V) $.20x10^8$	(250V) $.21x10^8$	(250V) $.23x10^8$
21	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(25V) $.23x10^7$	(500V) $.46x10^8$	(500V) $.57x10^8$	(500V) $.62x10^8$	(500V) $.65x10^8$	(500V) $.63x10^8$
22	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(25V) $.17x10^7$	(50V) $.275x10^7$	(50V) $.27x10^7$
23	(10V) $.65x10^6$	(10V) $.54x10^6$	(10V) $.57x10^6$	(10V) $.90x10^6$	(10V) $.62x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(500V) $.31x10^8$	(500V) $.62x10^8$	(500V) $.63x10^8$	(500V) $.62x10^8$
24	(10V) $.64x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$
25	(10V) $.64x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(25V) $.19x10^7$	(500V) $.4-.5x10^8$	(50V) $.50x10^7$	(50V) $.50x10^7$	(50V) $.35x10^7$	(100V) $.6-.8x10^7$
26	(10V) $.64x10^6$	(10V) $.53x10^6$	(10V) $.58x10^6$	(10V) $1.0x10^6$	(100V) $.57x10^7$	(100V) $.57x10^7$	(500V) $.48x10^8$	(500V) $.55x10^8$	(500V) $.65x10^8$	(500V) $.65x10^8$	(500V) $.63x10^8$
27	(10V) $.64x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$	(10V) $<.5x10^6$)	(10V) $<.5x10^6$	(10V) $<.5x10^6$

Note: (1) See Figure 2-5 for LOCA steam sequence relationship.
(2) Cable No. 19 sustained handling damage and is considered a "no test".



NOTE: PLOTS OF DATA SHOWN IN TABLES 2-1 AND 2-2

Figure 2-6. Insulation Resistance Profile

2.2.17 Measurement Data Precaution

As stated in Section 2.1, cable test specimens were 25 feet (7.6 m) in length. However, due to the physical construction of the mandrel and test chamber, only 18-20 feet (5.5-6.1 m) of cable was physically inside the chamber and exposed to the steam and chemical spray environment. In addition, approximately 32 feet (9.8 m) of cable not similar to the test specimens connected the cables to a terminal strip to facilitate cable access for making electrical measurements. Insulation resistance measurement data reflect the values for the entire length of cable connected to the terminal strip. The reader is cautioned regarding the extraplation of these data to the much longer cable lengths found in nuclear power plants. The data show relative change in insulation resistance for the cables during the test sequence and are not absolute values of resistivity.

Insulation resistance measurements were taken in an electrically unguarded mode. Therefore, values represent the gross resistance between the conductors and ground. The effect of surface conductivity (skin effect) which comprises a very small portion of these values was not separated from the insulation resistance values recorded.

2.3 Test Results and Conclusions

2.3.1 Cable Performance

The insulation resistance measurements were originally included in the test plan to provide a figure of merit or index of relative insulation material degradation. Subsequently, a pass/fail threshold was assigned to the insulation resistance measurements to increase the significance of the measurements. A conservative value of 1.0×10^7 ohms was arbitrarily selected and in retrospect, should not have been imposed as a failure criterion. The following evidence supports this position:

1. At all times, the cables performed their intended function, i.e., in this test to carry an imposed load of 11 amperes at 480 VAC; even though some insulation resistance measurements were less than 5.0×10^5 ohms.

2. IEEE Standard 383-1974, the current standard for qualification testing of cables with splices and insulation repairs, does not specify that insulation resistance measurements be used as a failure criterion.

Therefore, we now feel that the use of insulation resistance measurements against a pass/fail criterion was inappropriate. However, the insulation resistance measurements have provided significant information as to the relative performance of the cable insulation material throughout the testing sequence.

2.3.2 Insulation Resistance

Insulation resistance values for all cables during the steam and chemical spray exposure generally followed the profile shown in Figure 2-6. Pre-exposure insulation resistance measurements of water-immersed cable specimens showed insulation resistances to be greater than 10^{12} ohms as shown in Table 2-1, Column 2. Measurements taken after thermal aging showed that Cables No. 10 and 19 had insulation resistances of less than 5.0×10^5 and $6.0\text{-}9.0 \times 10^5$ ohms, respectively, on the 10 volt scale as measured with a Hewlett-Packard 4329A High Resistance Meter. Cables 10 and 19 read 3.8×10^5 and 6.0×10^5 ohms, respectively, using a Fluke 8100A multimeter. After the water was drained from the test chamber (cables still wet), the insulation resistances were again measured using a Hipotronics Megohmmeter. Cable No. 10 read 2.5×10^5 ohms on the 500 volt scale while Cable 19 did not provide a stable reading.

Dry and water-immersion measurements were taken subsequent to the accident exposure. Values obtained during the dry measurements were in the range of 5.0×10^9 ohms. Cables 10 and 19 read 6.8×10^9 and 5.9×10^9 ohms, respectively. Nominal values for water immersion measurements were in the range of 4.0×10^9 ohms while Cables 10 and 19 read 4.7×10^5 and 1.0×10^5 ohms, respectively, using the Fluke multimeter. At this point, Cable 18 also indicated severely degraded insulation resistance values.

Prior to steam and chemical spray exposure, a careful inspection of Cables 10 and 19 was made. It was determined that the low insulation resistance values for Cable 10 were a result of handling damage when the mandrel was loaded into the test chamber after thermal aging. Damage was observed at two locations on Cable 10 at the same circumferential orientation. Cable 19 had a short at a location where it passed over a support tab on the mandrel. This is assumed to have been caused by insulation softening during thermal aging.

Insulation resistance measurements taken during the initial accident profile steam pressure peak (see Figures 2-5 and 2-6, point a) showed significantly degraded readings in the range of 6.0×10^5 and 1.5×10^6 ohms for the No. 6 and No. 12 AWG cables, respectively. Cables 10, 19, 20, 21 and 22 had readings below 5.0×10^5 ohms. At the second pressure peak (Figure 2-5, point b), Cables 17, 18, 24, 25, and 27 had also measured below 5.0×10^5 ohms. Also, during both peaks, eight of the nine No. 6 AWG cables (Cables 19 and 21 through 27) began weeping at the ends of the cables extending from the chamber. This was due to the pressure differential between the chamber and atmospheric pressures. The subsequent visual inspection showed that the weepage occurred both on cables where insulation material handling damage was observed and on cables where no visible damage damage was apparent. We therefore conclude that some of the weepage may be attributable to thermal softening and expansion of the insulation material or to insulation damage not readily visible to the naked eye. At nine hours into the profile (Figure 2-5, point c), Cable 13 also measured below 5.0×10^5 ohms. At four days into the profile (Figure 2-5, point f), Cables 10, 19, 22, 23, 24, and 27 still measured below 5.0×10^5 ohms. As the exposure continued, insulation resistance readings improved. At the end of the exposure profile, Cables 19, 24, and 27 had readings below 5.0×10^5 ohms.

2.3.3 Hipot

Hipot measurements taken after the steam and chemical spray exposure indicated an average of 4.2 and 3.3 ma leakage for No. 6 and No. 12 AWG cables, respectively, after water immersion for one hour. Cables 10, 14, 19, 22, 24, and 27 indicated breakdown. As stated in Section 2.3.2 above, handling damage was observed on Cables 10 and 19. In addition, a post-test visual inspection showed that the hipot breakdowns which could be visually confirmed occurred outside the mandrel test area. The observable cable fault locations around the mandrel area are listed in Appendix F. By observing the bubbling which occurs at the point of hipot breakdown, it was determined that conductor splices and insulation repairs were not a contributing factor to the breakdowns.

As previously discussed, the portion of the cables above the mandrel was subject to flexing during movement between the thermal and radiation aging facilities and also during installation into the LOCA chamber. We believe that this test-induced degradation further aggravated the aging related material degradation. The degradation was increased even further during LOCA exposure leading to the inordinate number of hipot breakdowns. We suspect, in some instances, that the breakdowns occurred at locations where moisture entered the cable through insulation damage locations not visible to the naked eye.

It was noted that where cables crossed mandrel pressure points, such as rods and supports, insulation material indentations occurred (see Figure 2-7). It is assumed that this condition occurred because of insulation material thermal softening. Cables in these tests were snugly wrapped around the mandrel. In future tests, more space will be allowed between the cables and the mandrel to reduce the probability of these test-induced failures. Since we do not know the pressure at the cable-mandrel interface, we cannot relate this information to loads that may occur on cables at the bottom of cable trays or on cables that cross end point supports in power plant installations.

2.3.4 Bend Test

Bend tests conducted after accident exposure did not produce any observable insulation cracks or damage.

2.3.5 Post-Test Observations

Above the mandrels, where the steam and chemical spray came in direct contact with the cables, a build-up of residue was observed (see Figures 2-8 and 2-9). The residue was analyzed using a Perkin-Elmer B 240 Elemental Analyzer. The analysis showed the presence of carbon and hydrogen in proportions similar to those found in virgin insulation material. Therefore, it was evident that there was a reaction between the chemical spray and the insulation material and that the residue was not simply a deposit of condensed chemical spray. To determine the extent of degradation, virgin and exposed insulation material samples were analyzed. The weight of each sample was measured. The residue was carefully scraped from the insulation and the remaining insulation sample reweighed. Comparing the weights of the scraped and virgin samples, the measurements showed that four percent of the weight was removed. Although the quantity of residue build-up gives the appearance of severe insulation degradation,

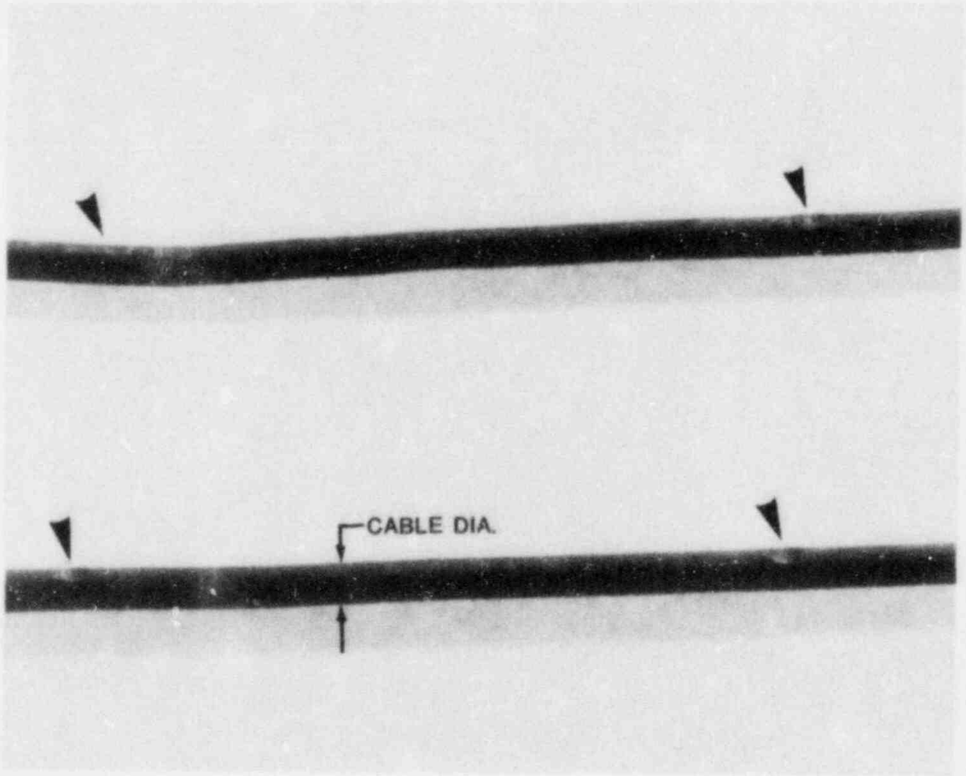


Figure 2-7. View of Cable Showing Insulation Material Deformation

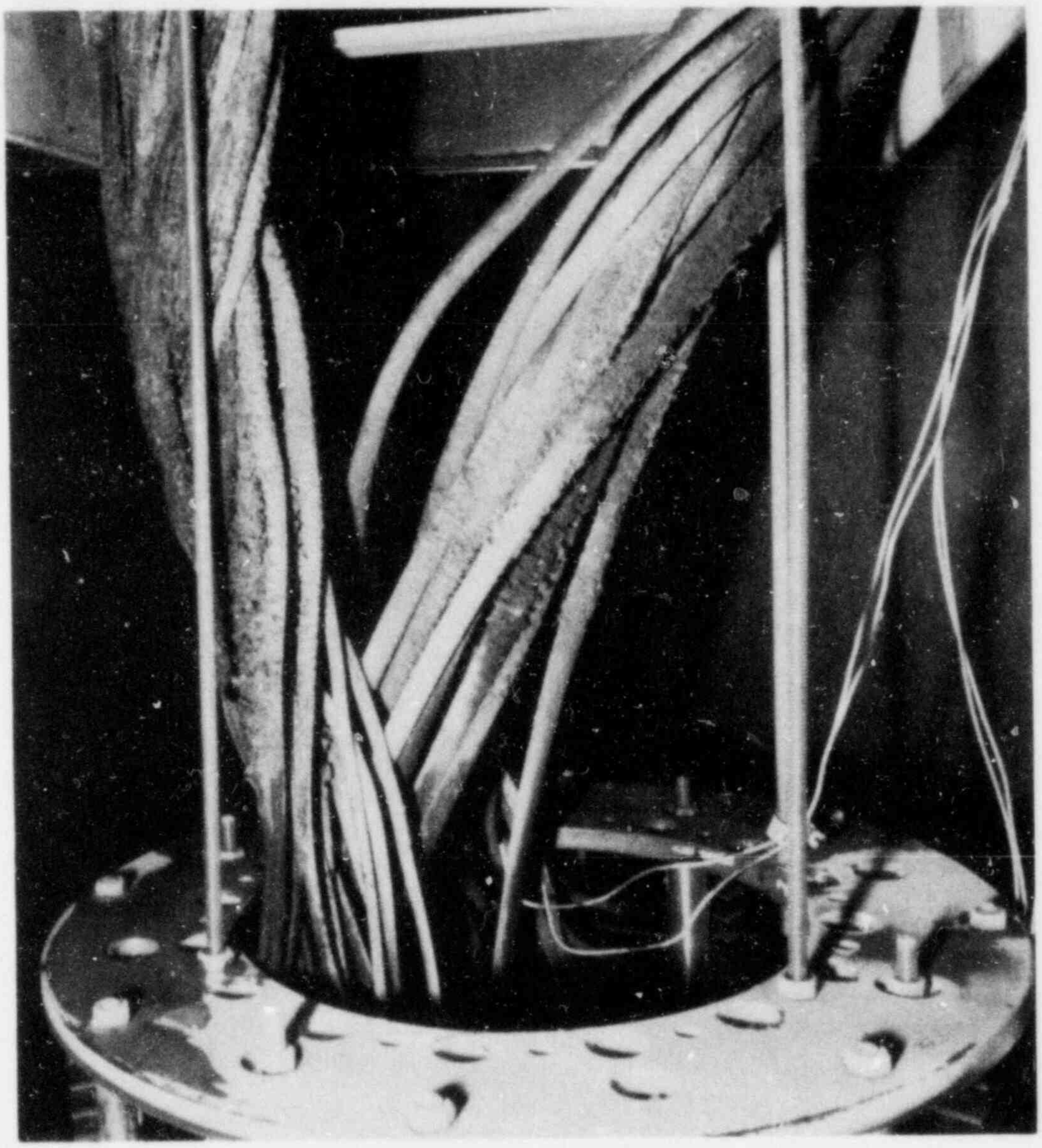


Figure 2-8. View of Residue Build-up Above Mandrels

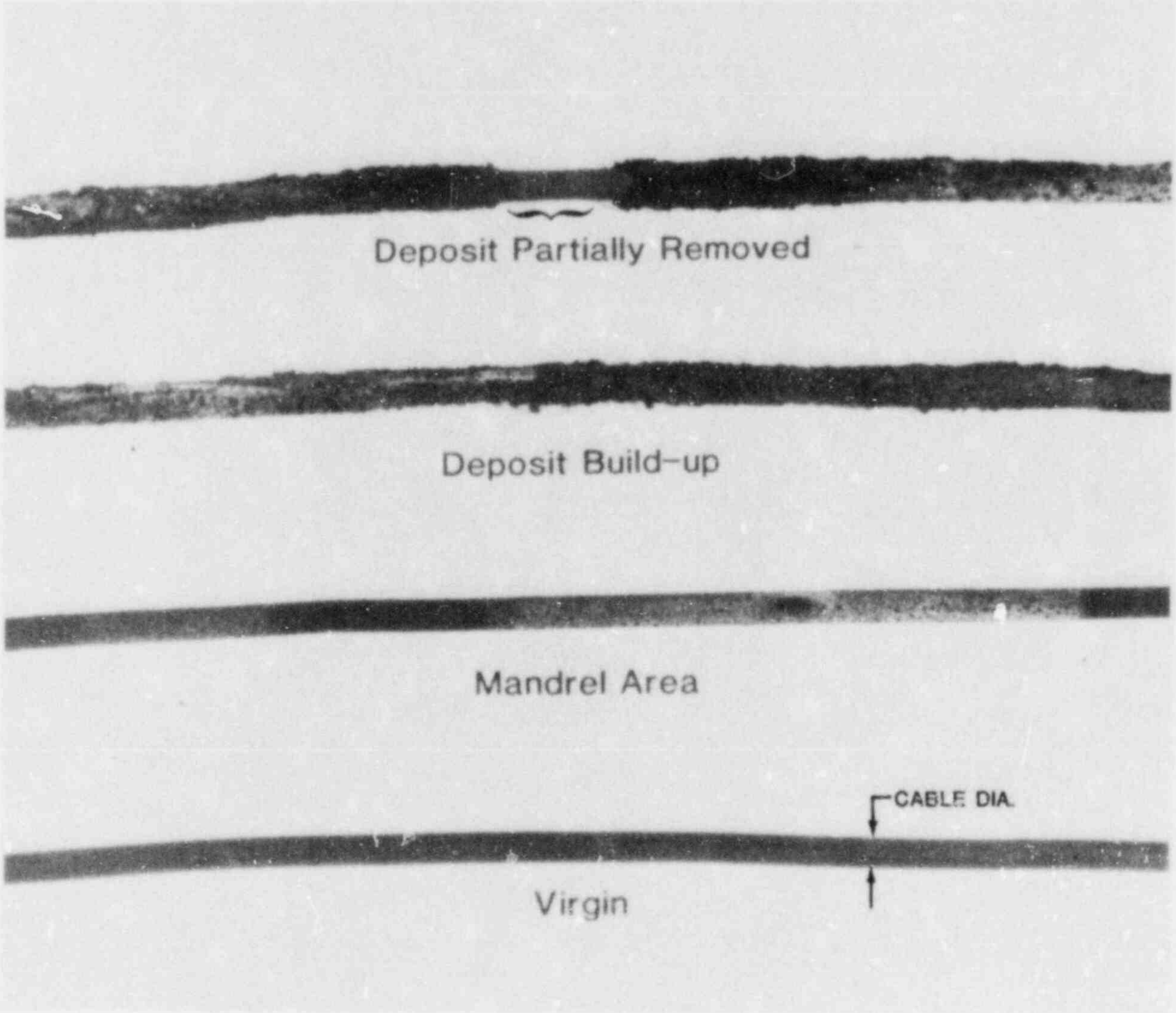


Figure 2-9. Photograph of Cable Showing Material Build-up

the measurements indicate that the insulation material loss was not significant when evaluating its effect on cable function during a LOCA/MSLB.

Based on our analysis, test data indicate that the cables could function and support power and control operations during and after a LOCA/MSLB of the severity simulated by the test. Further, the presence of center-conductor splices and insulation repairs did not appear to degrade cable performance.

3.0 INSULATION SAMPLE TESTS

3.1 Description of Insulation Samples

Insulation material samples were flame-retardant, chemically crosslinked polyolefin. Test samples were in the form of 6 to 8 inch (15 to 20 cm) long, 0.030 inch (0.08 cm) thick, hollow cylindrical pieces from No. 12 AWG cables with a nominal outer diameter of 0.155 inch (0.39 cm). The samples were furnished by the cable manufacturer and were stripped from cable made during the same run as the cables tested.

3.2 Test Procedure

Insulation samples were divided into groups as indicated in Table 3-1. Group 3B provided virgin material baseline data.

Group 1B was high dose-rate radiation aged at 865 krd* per hour for an integrated dose of 50.0 Mrd. This group was then thermally aged for 860.5 hours at 302°F (150°C).

Group 2B was exposed in the reverse sequence of Group 1B--thermal aging followed by high dose-rate radiation aging.

Group 4B was low dose-rate radiation aged at 47.7 krd* per hour for an integrated dose of 50.2 Mrd. This group was then thermally aged for 860.5 hours at 302°F (150°C).

Groups 1B, 2B and 4B, "Supplemental Test No. 1", were samples aged per the sequences described above (1B, 2B and 4B) followed by an additional radiation exposure of approximately 50 Mrd at 865 krd* per hour for a total integrated dose (TID) of approximately 100 Mrd.

Groups 1B, 2B and 4B, "Supplemental Test No. 2", were samples aged per the sequences described above followed by an additional radiation exposure of approximately 150.0 Mrd at 865 krd* per hour for a TID of approximately 200 Mrd.

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*Air equivalent dose.

Table 3-1

Insulation Sample Exposure Sequence

Group	Exposure Sequence	Sample Size
3B	Virgin Material	16
1B	High-Rate Radiation (50 Mrd)/* Thermal Aging	5/5 (1)
2B	Thermal/High-Rate Radiation (50 Mrd) Aging	5/5 (1)
4B	Low-Rate Radiation (50 Mrd)/ Thermal Aging	5/5 (1)
1B Supp.** #1	High-Rate Rad./Thermal plus 50 Mrd LOCA	5
2B Supp. #1	Thermal/High-Rate Rad. plus 50 Mrd LOCA	5
4B Supp. #1	Low-Rate Rad./Thermal plus 50 Mrd LOCA	5
1B Supp. #2 2B Supp. #2 4B Supp. #2	Group aging plus 150 Mrd LOCA	69 (2)

* In this table "/" means "followed by".

** Supplemental tests were conducted on aged samples to evaluate the effects on material tensile force and elongation produced by subsequent LOCA radiation doses.

(1) Indicated sample quantities were tested for elongation and tensile force exposure; e.g., Group 1B, five samples tested after radiation aging and an additional five samples tested after radiation and thermal aging.

(2) Samples from the three populations tested as a single group. (Separate group sample identities were lost--see Section 3.2.)

It was intended to pull five samples from each group at the end of each 50 Mrd exposure increment until a 200 Mrd TID exposure was reached. At the end of the first 50 Mrd increment (100 Mrd TID) five samples from each group were tested (Supplemental Test #1). Due to a power outage, it was necessary to interrupt the next exposure cycle at 19 Mrd and temporarily store the samples. Unfortunately, an equipment problem caused the containers to be spilled during storage and the samples were mixed. Therefore, the group identity of the individual samples was lost.

Because it was impossible to separate the samples into their respective groups, all untested samples were subsequently exposed to additional radiation to obtain a total integrated dose of 200 Mrd. They were then subjected to tensile/elongation tests as a single population (Supplemental Test #2).

The insulation samples were exposed to thermal and radiation aging in air. While stored, samples were maintained in a nitrogen environment. Radiation aging was performed in the Sandia National Laboratories' North Gamma Irradiation Facility (NGIF). Thermal aging was performed in large thermal ovens at Sandia. The ovens provide for air exchange during thermal aging to prevent oxygen depletion. Tensile measurements were obtained using an Instron model 1130 Tensile-Elongation tester. Recorded data is contained in Appendix B.

3.3 Test Results and Conclusions

Test results are presented in tabular form in Table 3-2 and shown graphically in Figures 3-1 and 3-2.

Insulation material degradation, on the average, was more affected by dose-rate than by sequence of exposure. The aging sequence of low dose-rate radiation followed by thermal aging, on the average, produced a reduction in elongation and in tensile force when compared with high dose-rate aging sequences. The sequence of thermal aging followed by high dose-rate radiation aging was, on the average, the least severe. The sequence of high dose-rate radiation aging followed by thermal aging, on the average, produced degradation in both elongation and tensile force that was between the most and least severe exposure sequences. However, high data variability, as shown by the error bars shown on Figures 3-1 and 3-2, makes it impossible to positively differentiate between the degradation effects caused by any of the high dose-rate exposures.

Table 3-2

Comparison of Aging Sequence and Dose Rates

Group	Exposure Sequence	Elongation (%)		Tensile Force (lb)	
		Mean	σ	Mean	σ
3B	Virgin Material	400.8	42.4	31.3	4.7
1B (1)	High-Rate Radiation (50 Mrd)/Thermal Aging	128.0	36.2	28.1	5.3
1B		50.0	9.1	16.8	1.1
2B (1)	Thermal/High-Rate Radiation (50 Mrd) Aging	261.0	22.2	22.8	1.8
2B		69.0	13.9	23.1	2.4
4B (1)	Low-Rate Radiation (50 Mrd)/Thermal Aging	119.6	44.7	23.1	2.7
4B		29.2	4.6	14.7	0.6
1B Supp. #1	High-Rate Rad./Thermal plus 50 Mrd LOCA	15.0	5.0	14.5	2.0
2B Supp. #1	Thermal/High-Rate Rad. plus 50 Mrd LOCA	26.2	10.6	19.5	0.6
4B Supp. #1	Low-Rate Rad./Thermal plus 50 Mrd LOCA	10%	----	10.7	1.9
1B, 2B, 4B Supp. #2	Group aging plus 150 Mrd LOCA	10%	----	11.3	4.6

(1) Data taken after the first aging process of two exposure sequence to observe the effect produced by each exposure.

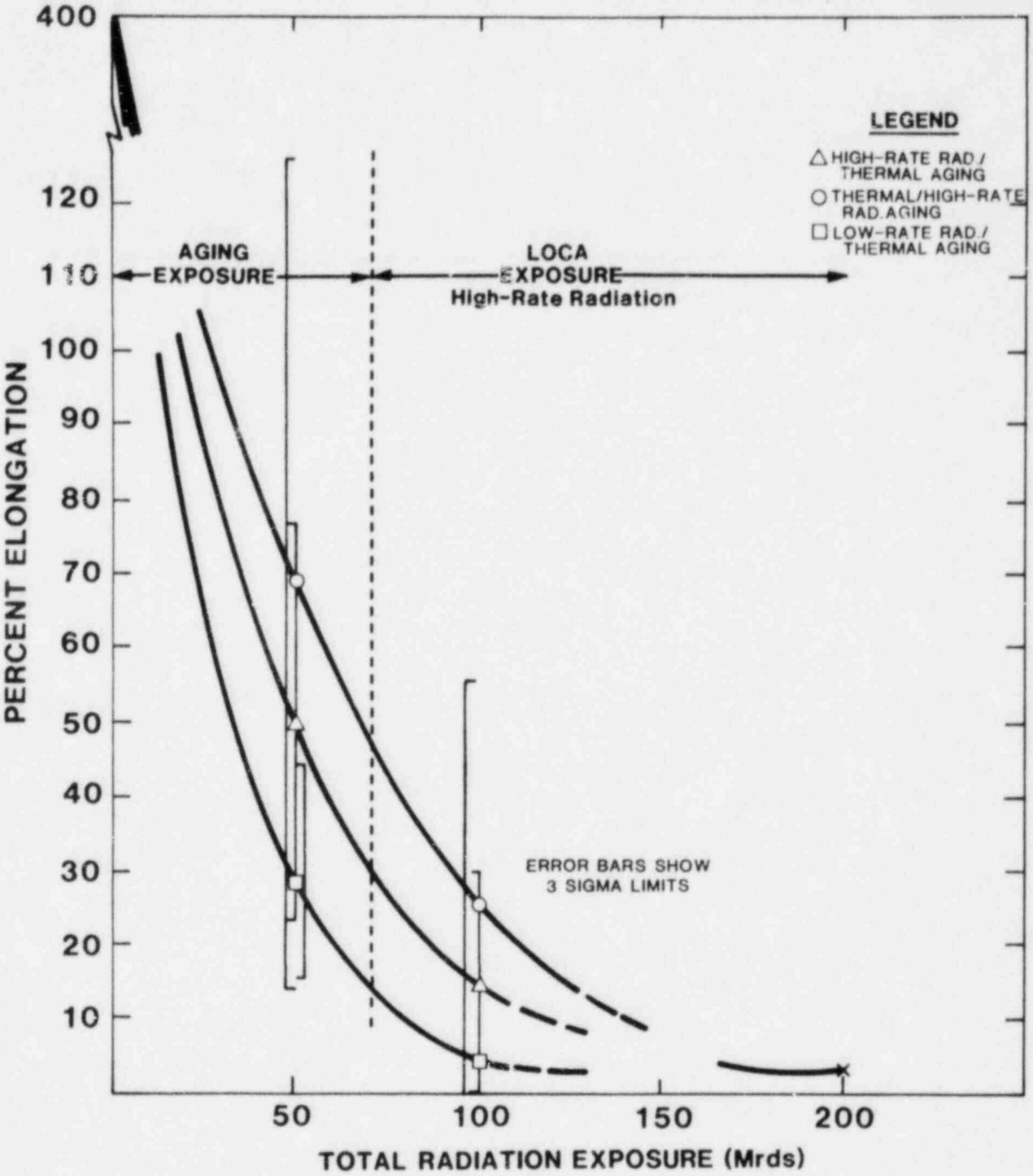

Figure 3-1. Percent Elongation vs Radiation Exposure

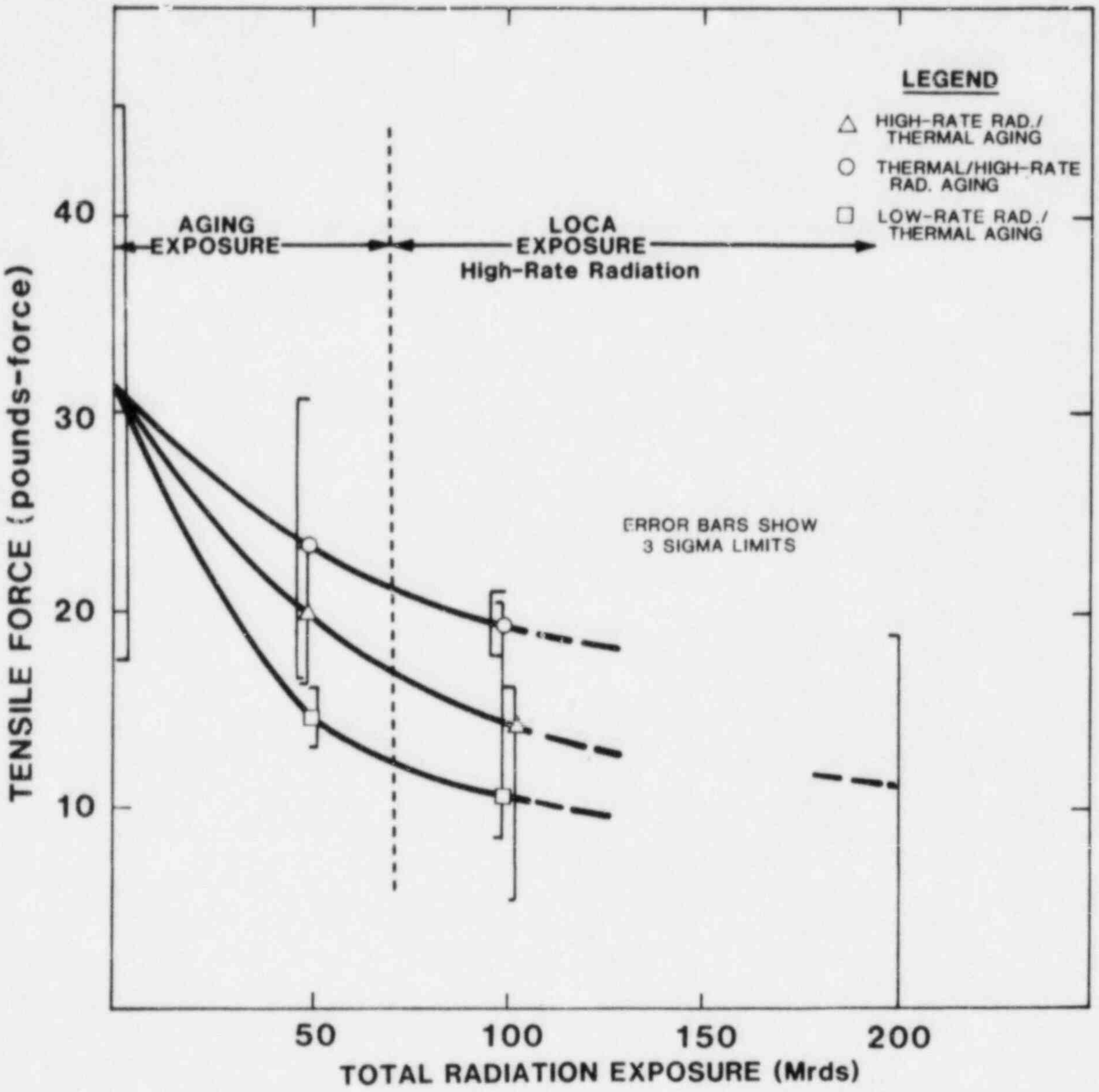

Figure 3-2. Tensile Force vs Radiation Exposure

After approximately 200 Mrd TID, the test results show that there was very little material life remaining. On the average, the samples had little or no elongation (<10%) remaining and the tensile force required to break them was about one-third of that required originally. Based on the results of the insulation sample tests, it was decided that the cables described in Section 2.0 would be subjected to an aging sequence of low dose-rate radiation aging followed by thermal aging.

REFERENCES

1. IEEE Std. 323-1974 "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations."

2. IEEE Std. 383-1974 "IEEE Standard for Type Test of Class 1E Electric Cable, Field Splices and Connections for Nuclear Power Generating Stations."

3. NUREG-0588 "Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment" U.S. NRC, Washington, DC, December 1979.

4. K. T. Gillen, R. L. Clough, Occurrence and Implications of Radiation Dose-Rate Effects for Material Aging Studies, Sandia National Laboratories, U.S. NRC Report NUREG/CR-2157, SAND80-1976, June 1981.

5. R. L. Clough, K. T. Gillen, Radiation Thermal Degradation of PE and PVS: Mechanism of Synergistic and Dose-Rate Effects, Sandia National Laboratories, U.S. NRC Report NUREG/CR-2156, SAND80-2149, June 1981.

APPENDIX A

TEST PLAN FOR IEEE 383-1974 TEST OF ELECTRIC CABLE WITH FACTORY SPLICES AND INSULATION REWORK

TEST PLAN FOR

IEEE 383-1974 TEST OF

ELECTRIC CABLE WITH FACTORY SPLICES AND INSULATION REWORK

QUALIFICATION RESEARCH TEST NO. 2

Earl E. Minor

Revision 3: March 1981

Sandia National Laboratories
Albuquerque, New Mexico 87185
operated by
Sandia Corporation
for the
U. S. Department of Energy

Prepared for

Office of Inspection and Enforcement
Reactor Construction Inspection
U. S. Nuclear Regulatory Commission

1. Background and Objectives

The purpose of this test plan to to verify the methodology for environmental qualification of electrical cable specimens by performance of aging and hazardous environment testing. This test plan conforms to IEEE 323-1974,[1] IEEE 383-1974,[2] and NUREG-0588.[3] In addition to the cable tests, cable insulation samples will be exposed to variations in radiation and thermal aging sequence and radiation exposure rates prior to thermal aging to determine the effects of (1) radiation aging prior to thermal aging versus thermal aging prior to radiation aging and (2) radiating aging at two difference dose rates prior to thermal aging. Insulation samples from test specimens No. 1 have been exposed, with results indicating both a sequence a dose-rate effect on degradation.[4,5]

2. Description of Test Items

2.1 Test Specimens No. 1

These cables consist of single-conductor, stranded copper, No. 12 AWG center conductors covered with mineral-filled, non-chlorinated, flame-resistant, chemically cross-linked polyethyiene extruded insulation. The center conductor contains seven strands. These cables are rated at 600 VAC and qualified for a 40-year life at 90°C. A total of nine samples, each 25 feet long, (7.6 m) have been provided, three of which have been spliced (welded) in the factory, and three of which have both center-conductor welds and insulation patches. The rework area is at approximately the midpoint of each specimen. The three samples with only center-conductor welds are covered with a nominal 0.030-inch (0.08 cm)-thick insulation. The other six samples, all of which contain insulation repairs, have a nominal insulation thickness of 0.045-inch (.11 cm). The nominal size, therefore, of the three samples with center conductor welds is 0.150-inch (.38 cm) and of the remaining six samples 0.180-inch (.46 cm).

2.2 Test Specimens No. 2

These specimens consist of nine control cables with seven-strand, No. 12 AWG, tin-coated, soft copper center conductors covered with 0.030-inch thick, flame-retardant, chemically cross-linked polyolefin insulation and nine power cables with seven-strand, No. 6 AWG, center conductors covered with 0.045-inch thick insulation of the same material. The diameter of the control cables is 0.152-inch minimum (0.155 nominal, 0.158 maximum) and of the power cables, 0.275-inch minimum (0.283 nominal, 0.290 maximum). These cables are qualified for a 40-year life at 90°C. Five of the specimens (two power and three control cables) contain spliced center conductors with insulation repairs; one power cable specimen contains an insulation repair without a center-conductor splice. There are no repairs in the center sections of the other 12 specimens.

3. Preparation of Insulation Test Samples

3.1 Samples from Supplier No. 1

Two feet were removed from each 25-foot cable, one foot from each end. The insulation was removed from these pieces of cable in four-inch lengths. These four-inch lengths of 0.045-inch thick insulation were used as samples in the test sequence described in paragraph 5. (See references 4 and 5.)

3.2 Samples from Supplier No. 2

Insulation samples were furnished by the supplier in six-inch lengths to be used in the test sequence described in paragraph 5. These samples are certified by the supplier as being from the same insulating run as the cables which were furnished for testing. The insulation samples were stripped in approximately six-inch lengths from No. 12 AWG wire and are 0.030-inch thick. The supplier's letter certifying the samples to be from the same run as the cables will be retained in SNL files as part of the quality data for these tests. These samples are currently being tested as described in section 5 of this test plan.

4. Description of Test

NOTE: The test described in this section applies only to the cables and not to the insulation test samples.

4.1 Radiography of Splices and Insulation Repairs

4.1.1 High-Intensity X-Ray

Those cables which contain either splices or insulation repairs shall be x-rayed at approximately 150 kV in two orientations, the second rotated 90 degrees from the first, to assess the condition of each splice and the condition of the conductor under the insulation repair.

4.1.2 Low-Intensity X-Ray

Those cables which contain insulation repairs shall be radiographed at approximately 75 kV in two orientations: (1) perpendicular to (directly into) the patched area and (2) rotated approximately 90 degrees from the first exposure.

4.2 Pre-Exposure Tests

4.2.1 Original "Specimen 1" Test

Pretest inspection and measurements consisted of (1) visual inspection and identification and (2) immersion in room temperature tap water for one hour with ends exposed, at the end of which exposure the cables were subjected to insulation resistance measurements at a DC potential of 500 V held for one minute.

4.2.2 Original "Specimen 2" Test

No pretest inspections were reported.

4.2.3 Proposed Sandia Tests

All specimens shall be subjected to preliminary tests and inspections as follows to determine the condition of specimens prior to exposure.

4.2.3.1 Visual Inspection

Visual inspection without magnification shall be performed to look for cracks, splits, crazing, or other obvious defects in the outer insulation. If defectiveness is found, magnification may be used to determine the extent and nature of the defect. Pictures shall be taken of serious defects.

4.2.3.2 Continuity

Continuity of each cable shall be checked prior to winding specimens on the mandrel.

4.2.3.3 Water Immersion/IR Test

After winding on the mandrel, the cables shall be immersed in room temperature tap water for one hour with ends exposed, then subjected to insulation resistance measurements at a potential of 500 VDC held for one minute. Voltage tolerance shall be ± 5% and reading accuracy ± 10%. Readings at the end of one minute shall be recorded. All readings shall be in excess of 10 megohms.

4.3 Physical Configuration for Test

All specimens shall be wound around a stainless steel mandrel having a diameter of approximately 12 inches. Approximately the middle six or seven feet of each cable shall be wound around the mandrel. This configuration shall be exposed to radiation exposure, thermal aging, and steam-and-chemical-spray exposure.

4.4 Radiation Aging

4.4.1 Original Tests

Radiation aging of both types of cables was added to LOCA radiation exposure.

4.4.2 Proposed Sandia Radiation Aging

All cables shall be exposed at a dose rate of approximately 60 krad/hr in air for a total dose of 50 Mrad ± 10% to simulate the effects of 40 years of low-level radiation exposure.

4.5 Thermal Aging

4.5.1 Original "Specimen 1" Test

These cables were subjected to 10 days (240 hours) at 150°C (302°F).

4.5.2 Original "Specimen 2" Test

These cables were subjected to 1300 hours (approximately 55 days) at 150°C (302°F). Arrhenius data were provided which dictated 850 hours at 150°C to simulate the 40-year, 90-degree life. This was adjusted to 1300 hours to add margin.

4.5.3 Proposed Sandia Test

Specimens No. 1 shall be exposed to 150°C (302°F) for 240 hours (10 days). Specimens no. 2 shall be exposed to 150°C for 864 hours (36 days). These tests will duplicate the exposure to which samples were submitted during original verification tests except that very little margin is added for specimen 2 tests. The specimens no. 2 shall be aged for 624 hours and then the specimens no. 1 shall be exposed during the last 240 hours of specimen 2 exposure, in separate ovens, so that the aging for both specimen groups will be completed at approximately the same time.

4.6 Post-Aging Test

4.6.1 Original "Specimen 1" Test

Post-thermal-aging tests were performed consisting of insulation resistance measurements. No accept/fail criteria were given. However, data were tabulated in the report of this work.

4.6.2

No post-aging tests were reported for original specimen 2 tests.

4.6.3 Proposed Sandia Test

All cables shall be subjected to an insulation resistance test at a potential of 500 VDC held for one minute. This test will be done in the HIACA exposure chamber. To perform this test, the cables, wound on the mandrel, shall be submerged in room temperature tap water with the cable ends out of the chamber. The 500-volt potential shall be impressed between each cable and the chamber. Readings at the end of one minute shall be recorded. Readings shall be in excess of 10 megohms. Voltage tolerance shall be ± 5% and reading accuracy ± 10%.

4.7 Radiation Exposure (LOCA)

4.7.1 Original "Specimen 1" Test

These cables were exposed to gamma radiation using a cobalt-60 source at an average rate of 0.76 Mrad/hr for a cumulative minimum dose of 220 Mrad. This exposure combined radiation aging and LOCA exposures.

4.7.2 Original "Specimen 2" Test

These cables were exposed to gamma radiation using a cobalt-60 source at an average rate of 0.54 Mrad/hr for a cumulative dose of 201 Mrad.

4.7.3 Proposed Sandia Exposure

All cables will be exposed to a uniform radiation dose of 150 Mrad ± 10% at an average dose rate of about 0.75 Mrad/hr in air, using a cobalt-60 simulator. This exposure and the radiation aging (paragraph 4.4.2) will give a total radiation exposure to the test specimens of 200 Mrad, ± 10%.

4.8 Post-Radiation Test

4.8.1 Original Tests

No post-radiation tests were recorded.

4.8.2 Proposed Sandia Test

After radiation all cables shall be subjected to an insulation resistance test at a potential of 500 VDC held for one minute. This test will be done in the HIACA exposure chamber. To perform this test, the cables, wound on the mandrel, shall be submerged in room temperature tap water with the cable ends out of the container. The 500-volt potential shall be impressed between each cable and the chamber. Readings at the end of one minute shall be recorded. Readings shall be in excess of 10 megohm. Voltage tolerance shall be ± 5% and reading accuracy ± 10%.

4.9 Hazardous Environment Test

4.9.1 Original "Specimen 1" Test

The steam and chemical spray profile shown in Figure 1 was used for exposure of these cables. They were energized throughout the test with 660 VAC, 11 A, except when insulation resistance tests were being performed. Insulation resistance tests were performed at each temperature level and once each week during the last 29 days of the 33-day exposure. (See Figure 1.) The chemical solution was sprayed at a rate of at least 0.15 gal/min per square foot; this rate was based on a total solution flow rate of 2.5 gal/min divided by the area of an imaginary cylinder located midway between the inner and outer mandrels. Composition of the spray was:

0.28 molar H_3BO_3 (3,000 ppm boron)

0.064 molar $Na_2S_2O_3$

NaOH to make a pH of 10.5 at 77°F (25°C)

4.9.2 Original "Specimen 2" Test

The steam and chemical spray profile of Figure 1 was also used for the exposure of these cables. Insulation resistance tests were not performed, but the cables were energized throughout exposure with 600 VAC. Current was not reported. The spray composition was the same as described above for Specimen 1 tests. The profile and spray composition used in both of these tests is that which is suggested in IEEE 323-1974.

4.9.3 Proposed Sandia Test

The test specimens shall be installed in a chamber and exposed to the temperature/pressure/chemical spray profiles shown in Figure 1. Temperatures shall be achieved within 5 degrees. Pressures shall be those achieved by saturated steam. Each cable shall be fed through access ports to the outside of the chamber. Three sets of cables connected in series shall be formed as follows: (1) cables from supplier No. 1, (2) No. 12 AWG cables from supplier No. 2, (3) No. 6 AWG cables from supplier No. 2. The capability exists to remove from the circuit any cable which might fail and to continue the test with circuits energized. Each circuit shall be energized with a potential of 480 VAC ± 5%, 11 A ± 1A, during the exposure period except when insulation resistance measurements are being performed. Insulation resistance tests will be performed on each cable at each temperature level and once each week during the last 29 days of the 33-day exposure (see Figure 1). The chemical solution will be sprayed at a rate of 0.15 gal/min per square foot (6.1 liter/min per square meter) of specimen surface area projected perpendicular to the spray direction. Composition of the chemical spray shall be as follows:

0.28 molar H_3BO_3 (3,000 ppm boron)

0.064 molar $Na_2S_2O_3$

NaOH to make a pH of 10.5 at 77°F (25°C)

4.10 Post-Exposure Inspection

4.10.1 Water Immersion/High Potential Test

While wrapped around the mandrel, the cables shall be immersed in room temperature tap water for one hour minimum then subjected to a high potential withstand test of 80 VAC/mil (3600 VAC rms for 0.045-inch material and 2400 VAC rms for 0.030-inch material) of insulation held for five minutes. This test will be done in the HIACA exposure chamber. The two ends of the cable shall be connected together to one of the hi-pot tester's output leads. The other tester lead shall be connected to the chamber. At the end of five minutes, leakage/charging current shall be measured for each cable. Leakage current shall be less than 10 mA. Voltage tolerance shall be ± 5% and reading accuracy ± 10%.

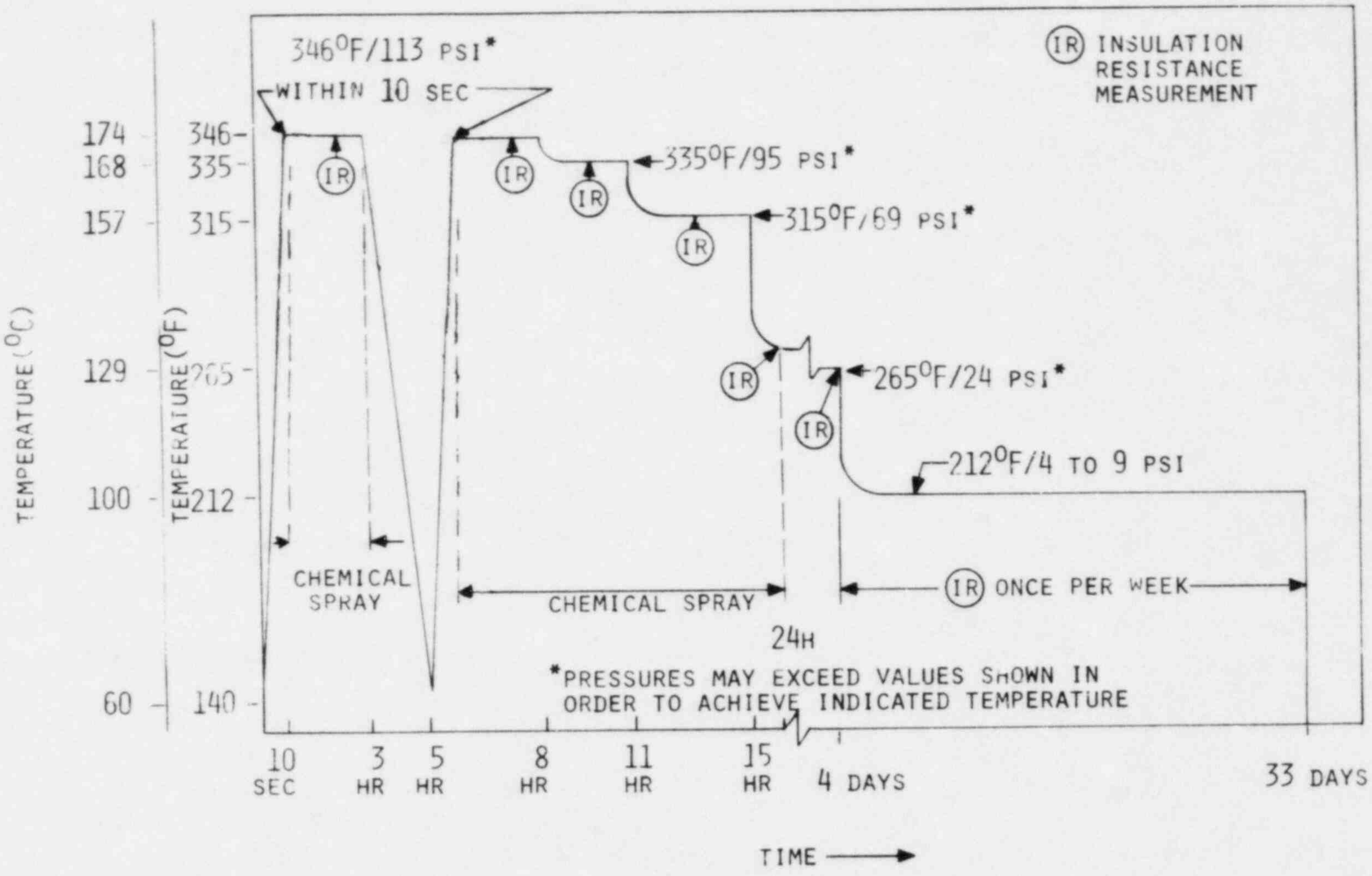

Figure 1. Specified Temperature/Pressure Profile for Steam/Chemical Spray Exposure

4.10.2 Inspection on Mandrel

After removal of the mandrel containing the specimens from the chamber and before removal of the cables from the mandrel, all accessible parts of each cable shall be visually inspected for cracks, tears, crazing, or other defectiveness and the results recorded.

4.10.3 Inspection after Straightening

The cables shall be removed from the mandrel(s) and straightened. They shall then be reinspected visually for defectiveness as above.

4.10.4 Bend Test

Each cable shall be wrapped around a mandrel having a diameter 40 times the diameter of the cable and shall be inspected from cracks, tears, crazing, or other defectiveness. Results shall be recorded.

5. Test of Insulation Samples

NOTE: As of the date of this revised test plan, insulation samples from supplier No. 1 have been subjected to aging and radiation exposures. Tensile/elongation tests have been conducted and the results reported in references 4 and 5. Samples from supplier No. 2 are being tested.

5.1 Supplier No. 1 Insulation Samples

5.1.1

A total of 111 samples were prepared. Three of the samples were 0.030-inch thick; therefore these three were not included in the experiment. Two additional samples were eliminated from the experiment because they were damaged, leaving 106 samples from the experiment. These were separated into four groups designated 1A, 2A, 3A, and 4A.

5.1.2

Group 3A, consisting of 10 samples, was tested with no exposure to provide baseline data.

5.1.3

Group 1A, consisting of 40 samples, was exposed to high-rate (865 krad/hr, air equivalent) radiation aging to a total dose of 42.5 Mrad followed by thermal aging. Additional high-rate radiation was imposed for a total dose of 196.8 Mrad (air equivalent). Tensile/elongation tests were performed on samples, 1) following aging, 2) at approximately 50 Mrad increments in subsequent exposure, and 3) at the end of radiation exposure.

5.1.4

Group 2A, consisting of 40 samples, received the same exposure and tests as Group 1A, except that thermal aging was performed prior to radiation aging.

5.1.5

Group 4A, consisting of 16 samples, was exposed to low-rate (47.7 krad/hr, air equivalent) radiation aging to a total dose of 42.5 Mrad followed by thermal aging. Additional high-rate radiation and testing were performed as for Groups 1A and 2A.

5.1.6

The insulation material was shown to be sensitive both to sequence and to dose-rate. Refer to reference 4 and 5 for details.

5.2 Supplier No. 2 Insulation Samples

5.2.1

A total of 130 insulation samples are available. These samples are a nominal 0.030-inch thick. These have been separated into four groups, 1B, 2B, 3B, and 4B.

5.2.2

Group 3B, consisting of 16 samples, will provide baseline data.

5.2.3

Groups 1B, 2B, and 4B, each consisting of 38 samples, will be exposed and tested in a manner similar to Groups 1A, 2A, and 4A, respectively. These tests are currently under way. Reports will be written upon completion of the insulation sample tests.

References

1. IEEE Std. 323-1974, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations."

2. IEEE Std. 383-1974, "IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations."

3. NUREG-0588 (for comment), "Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment," USNRC, Washington, DC, December 1979.

4. Unclassified report, E. E. Minor, SNL, to W. R. Rutherford, RRRI/OIE, dated 1/15/81, subject: "Preliminary Report of Tensile/Elongation Results Obtained Following Exposure of Insulation Samples Taken from Cable Supplied by Manufacturer No. 1," (SNL/IEHQ, T7, 06).

5. Unclassified report, E. E. Minor, SNL, to W. R. Rutherford, RRRI/OIE, dated 2/23/81, subject: "Supplemental Tensile/Elongation Results Following Additional Exposure of Insulation Samples from Manufacturer No. 1," (SNL/IEHQ, T7, 08).

APPENDIX B

INSULATION MATERIAL SAMPLES TENSILE/ELONGATION TEST DATA

DATA SHEET

Tensile/Elongation Tests

Group 3B - Baseline Data(1)

Sample Number	Elongation (%)	Tensile Force (lb.)	Full Scale on Recorder (lb.)	Jaw Spacing (in.)	Pull Rate	Remarks
1	410	31.2	50	2	5 in./min	
2	290	22.2	50	2	5 in./min	
3	425	37.2	50	2	5 in./min	
4	395	30.0	50	2	5 in./min	
5	420	32.0	50	2	5 in./min	Upper jaw break
6	465	34.0	50	2	5 in./min	
7	380	27.6	50	2	5 in./min	
8	405	31.6	50	2	5 in./min	
9	385	31.2	50	2	5 in./min	
10	350	25.2	50	2	5 in./min	
11	360	24.2	50	2	5 in./min	
12	408	32.8	50	2	5 in./min	
13	435	39.2	50	2	5 in./min	
14	455	36.6	50	2	5 in./min	
15	415	34.4	50	2	5 in./min	
16	415	31.8	50	2	5 in./min	
$\overline{X}$ =	400.8	31.30				
σ =	42.4	4.70				

NOTES: (1) Tests on virgin material.

DATA SHEET

Tensile/Elongation Tests

Group 1B - High Dose-Rate Radiation Aging followed by Thermal Aging(1)

Sample Number	Elongation (%)	Tensile Force (lb.)	Full Scale on Recorder (lb.)	Jaw Spacing (in.)	Pull Rate	Remarks
Data Taken After Radiation Aging						
1	130	27.0	50	2	5 in./min	middle break
2	150	30.6	50	2	5 in./min	
3	150	30.4	50	2	5 in./min	
4	145	33.0	50	2	5 in./min	
5	65	19.4	50	2	5 in./min	
$\overline{X}$ =	128.0	28.10				
σ =	36.2	5.30				
Data Taken After Radiation and Thermal Aging						
1	60	17.0	50	2	5 in./min	
2	55	18.0	50	2	5 in./min	
3	40	15.6	50	2	5 in./min	
4	45	15.8	50	2	5 in./min	
5	(2)	17.8	50	2	5 in./min	Extensiometer malfunction
$\overline{X}$ =	50.0	16.84				
σ =	9.1	1.11				

NOTES: (1) Radiation Aging at 865 krd/hr for 50 Mrd exposure and Thermal Aging at 150°C for 860.5 hours.

(2) Strip pulled loose from upper part of extensiometer, so no "blips" were transmitted to the recorder.

DATA SHEET

Tensile/Elongation Tests

Group 2B - Thermal Aging Followed by High Dose-Rate Radiation Aging(1)

Sample Number	Elongation (%)	Tensile Force (lb.)	Full Scale on Recorder (lb.)	Jaw Spacing (in.)	Pull Rate	Remarks
			Data Taken After Thermal Aging			
1	240	21.2	50	2	5 in./min	
2	235	20.8	50	2	5 in./min	
3	270	25.0	50	2	5 in./min	
4	285	23.4	50	2	5 in./min	
5	275	23.6	50	2	5 in./min	
$\bar{X}$ =	261.0	22.80				
σ =	22.2	1.76				
			Data Taken After Thermal and Radiation Aging			
1	55	21.4	50	2	5 in./min	
2	43	20.0	50	2	5 in./min	
3	85	25.6	50	2	5 in./min	
4	80	23.8	50	2	5 in./min	
5	82	24.8	50	2	5 in./min	
$\bar{X}$ =	69.0	23.12				
σ =	18.8	2.35				

NOTES: (1) Thermal Aging at 150°C for 860.5 hours and Radiation Aging at 865 krd/hr for 50 Mrd exposure.

DATA SHEET

Tensile/Elongation Tests

Group 4B - Low Dose-Rate Radiation Aging Followed by Thermal Aging(1)

Sample Number	Elongation (%)	Tensile Force (lb.)	Full Scale on Recorder (lb.)	Jaw Spacing (in.)	Pull Rate	Remarks
		Data Taken After Radiation Aging				
1	165	24.8	50	2	5 in./min	
2	123	22.2	50	2	5 in./min	
3	45	18.8	50	2	5 in./min	
4	130	25.6	50	2	5 in./min	
5	135	24.2	50	2	5 in./min	
$\bar{X}$ =	119.6	23.10				
σ =	44.7	2.7				
		Data Taken After Radiation and Thermal Aging				
1	25	14.6	50	2	5 in./min	Lower jaw break
2	30	14.4	50	2	5 in./min	Upper jaw break
3	30	14.4	50	2	5 in./min	Lower jaw break
4	25	14.4	50	2	5 in./min	Lower jaw break
5	36	15.8	50	2	5 in./min	Center break
$\bar{X}$ =	29.2	14.72				
σ =	4.6	0.61				

NOTES: (1) Radiation Aging at 47.7 krd/hr for 50.2 Mrd exposure and Thermal Aging at 150°C for 860.5 hours.

DATA SHEET

Tensile/Elongation Tests

Sample Number	Elongation (%)	Tensile Force (lb.)	Full Scale on Recorder (lb.)	Jaw Spacing (in.)	Pull Rate	Remarks
Group 1B - Supplmental Test #1(1)						
1	<10	15.0	50	2	5 in./min	Top jaw break
2	<10	11.4	50	2	5 in./min	Top jaw break
3	20	16.6	50	2	5 in./min	Top jaw break
4	15	15.8	50	2	5 in./min	Bottom jaw break
5	10	14.4	50	2	5 in./min	Top jaw break
$\bar{X}$ =	15.0	14.64				
σ =	5.0	1.99				
Group 2B - Supplemental Test #1(2)						
1	45	20.4	50	2	5 in./min	Bottom jaw break
2	20	19.0	50	2	5 in./min	Bottom jaw break
3	24	19.4	50	2	5 in./min	Bottom jaw break
4	21	19.2	50	2	5 in./min	Bottom jaw break
5	21	19.4	50	2	5 in./min	Top jaw break
$\bar{X}$ =	26.2	19.48				
σ =	10.6	0.54				
Group 4B - Supplemental Test #1(3)						
1	<10	11.6	50	2	5 in./min	Top jaw break
2	<10	7.8	50	2	5 in./min	Bottom jaw break
3	<10	12.8	50	2	5 in./min	Top jaw break
4	<10	11.0	50	2	5 in./min	Top jaw break
5	<10	10.4	50	2	5 in./min	Bottom jaw break
$\bar{X}$ =	<10	10.72				
σ =	--	1.86				

NOTES:

(1) High dose-rate radiation aging, thermal aging and additional 50 Mrd exposure at high dose-rate.

(2) Thermal aging, high dose-rate radiation aging and additional 50 Mrd exposure at high dose-rate.

(3) Low dose-rate radiation aging, thermal aging and additional 50 Mrd exposure at high dose-rate.

DATA SHEET

Tensile/Elongation Tests

Groups 1B, 2B, 4B - Supplemental Test #2(1)

Sample Number	Elongation (%)	Tensile Force (lb.)	Full Scale on Recorder (lb.)	Jaw Spacing (in.)	Pull Rate	Remarks
1	0	0	50	2	5 in./min	Top jaw break
2	0	0	50	2	5 in./min	Bottom jaw break
3	0	0.4	50	2	5 in./min	Top jaw break
4	0	0	50	2	5 in./min	Bottom jaw break
5	< 10	0.4	50	2	5 in./min	Bottom jaw break
6	< 10	8.8	50	2	5 in./min	Bottom jaw break
7	< 10	14.8	50	2	5 in./min	Bottom jaw break
8	< 10	15.0	50	2	5 in./min	Top jaw break
9	10	11.4	50	2	5 in./min	Top jaw break
10	< 10	9.0	50	2	5 in./min	Bottom jaw break
11	< 10	16.8	50	2	5 in./min	Top jaw break
12	< 10	11.4	50	2	5 in./min	Bottom jaw break
13	< 10	16.2	50	2	5 in./min	Top jaw break
14	< 10	16.6	50	2	5 in./min	Top jaw break
15	< 10	11.4	50	2	5 in./min	Bottom jaw break
16	< 10	16.6	50	2	5 in./min	Bottom jaw break
17	0	0	50	2	5 in./min	Bottom jaw break
18	< 10	9.2	50	2	5 in./min	Top jaw break
19	10	18.4	50	2	5 in./min	Bottom jaw break
20	< 10	9.6	50	2	5 in./min	Bottom jaw break
21	< 10	15.4	50	2	5 in./min	Top jaw break
22	11	10.6	50	2	5 in./min	Bottom jaw break
23	< 10	15.2	50	2	5 in./min	Bottom jaw break
24	< 10	13.2	50	2	5 in./min	Bottom jaw break
25	< 10	12.0	50	2	5 in./min	Top jaw break
26	< 10	10.6	50	2	5 in./min	Top jaw break
27	< 10	8.0	50	2	5 in./min	Bottom jaw break
28	< 10	9.6	50	2	5 in./min	Top jaw break
29	< 10	14.2	50	2	5 in./min	Top jaw break
30	< 10	14.8	50	2	5 in./min	Top jaw break
31	10	12.0	50	2	5 in./min	Top jaw break
32	< 10	11.2	50	2	5 in./min	Top jaw break
33	< 10	14.6	50	2	5 in./min	Top jaw break
34	< 10	11.8	50	2	5 in./min	Bottom jaw break
35	< 10	11.0	50	2	5 in./min	Bottom jaw break
36	< 10	8.6	50	2	5 in./min	Top jaw break

NOTES: (1) Group aging and additional 150 Mrd exposure at high dose-rate.

DATA SHEET

Tensile/Elongation Tests

Groups 1B, 2B, 4B - Supplemental Test #2 (cont.)

Sample Number	Elongation (%)	Tensile Force (lb.)	Full Scale on Recorder (lb.)	Jaw Spacing (in.)	Pull Rate	Remarks
37	<10	6.8	50	2	5 in./min	Bottom jaw break
38	<10	10.2	50	2	5 in./min	Top jaw break
39	<10	12.0	50	2	5 in./min	Bottom jaw break
40	<10	11.4	50	2	5 in./min	Top jaw break
41	<10	11.0	50	2	5 in./min	Top jaw break
42	10	15.8	50	2	5 in./min	Middle
43	10	19.0	50	2	5 in./min	Bottom jaw break
44	<10	12.4	50	2	5 in./min	Top jaw break
45	<10	13.2	50	2	5 in./min	Bottom jaw break
46	0	0	50	2	5 in./min	Bottom jaw break
47	<10	15.4	50	2	5 in./min	Top jaw break
48	<10	11.6	50	2	5 in./min	Bottom jaw bre
49	<10	9.0	50	2	5 in./min	Bottom jaw break
50	<10	10.4	50	2	5 in./min	Bottom jaw break
51	<10	9.2	50	2	5 in./min	Bottom jaw break
52	<10	12.0	50	2	5 in./min	Top jaw break
53	<10	10.6	50	2	5 in./min	Bottom jaw break
54	<10	13.8	50	2	5 in./min	Top jaw break
55	<10	9.4	50	2	5 in./min	Top jaw break
56	<10	13.8	50	2	5 in./min	Top jaw break
57	<10	12.8	50	2	5 in./min	Top jaw break
58	<10	13.8	50	2	5 in./min	Bottom jaw break
59	<10	16.8	50	2	5 in./min	Top jaw break
60	<10	15.0	50	2	5 in./min	Top jaw break
61	<10	13.8	50	2	5 in./min	Bottom jaw break
62	<10	11.4	50	2	5 in./min	Bottom jaw break
63	<10	14.6	50	2	5 in./min	Top jaw break
64	<10	10.8	50	2	5 in./min	Bottom jaw break
65	<10	18.6	50	2	5 in./min	Bottom jaw break
66	<10	10.4	50	2	5 in./min	Bottom jaw break
67	<10	12.6	50	2	5 in./min	Bottom jaw break
68	<10	10.8	50	2	5 in./min	Top jaw break
69	<10	10.2	50	2	5 in./min	Bottom jaw break
$\bar{X}$ =	<10	11.27				
σ =	--	4.62				

APPENDIX C

DATA FROM INSULATION RESISTANCE TESTS
PRIOR TO
STEAM/CHEMICAL SPRAY ENVIRONMENT EXPOSURE

DATA SHEET

Insulation Resistance Tests Prior to Steam/Chemical Spray Environment Exposure

	Pre-Radiation Aging Dry 3/13/81		Pre-Radiation Aging Water Immersion 3/13/81		Post-Radiation Aging Water Immersion 4/16/81	
Cable No.	Resistance H-P	Amer.	Resistance H-P	Amer.	Resistance H-P	Amer.
10	>10^{12}	>2.5x10^{9}	>10^{12}	>2.5x10^{9}	>10^{12}	>5x10^{9}
11	>10^{12}					
12	>10^{12}					
13	>10^{12}					
14	>10^{12}					
15	>10^{12}					
16	>10^{12}					
17	>10^{12}					
18	>10^{12}		↓		↓	
19	5.0x10^{13}		7.0x10^{12}		2.0x10^{12}	
20	6.0x10^{13}		9.0x10^{12}		2.0x10^{12}	
21	5.0x10^{13}		1.0x10^{13}		2.0x10^{12}	
22	4.0x10^{13}		5.0x10^{12}		1.4x10^{12}	
23	4.0x10^{13}		9.0x10^{12}		1.5x10^{12}	
24	4.0x10^{13}		1.4x10^{13}		2.0x10^{12}	
25	5.0x10^{13}		1.3x10^{13}		2.0x10^{12}	
26	6.0x10^{13}		1.6x10^{13}		2.0x10^{12}	
27	6.0x10^{13}	↓	5.0x10^{13}	↓	2.0x10^{12}	↓

DATA SHEET

Insulation Resistance Tests Prior to Harsh Environment Exposure

Cable No.	Post-Thermal Aging Water Immersion 6/30/81 (6)		Post-LOCA Radiation Dry 7/10/81		Post-LOCA Radiation Water Immersion 7/10/81 (7)	
	Resistance		Resistance		Resistance	
	H-P	Hipotronics	H-P	Hipotronics	H-P	Hipotronics
10	(1)	(1)	$.68\times10^{10}$	9.0×10^{9}	(3)	(3)
11	$.95\times10^{10}$	1.9×10^{11}	$.67\times10^{10}$	9.5×10^{9}	$.34\times10^{10}$	7.6×10^{9}
12	$.93\times10^{10}$	1.9×10^{11}	$.62\times10^{10}$	8.3×10^{9}	$.31\times10^{10}$	6.5×10^{9}
13	$.90\times10^{10}$	2.0×10^{11}	$.60\times10^{10}$	8.0×10^{9}	$.31\times10^{10}$	6.0×10^{9}
14	$.92\times10^{10}$	2.7×10^{11}	$.67\times10^{10}$	9.5×10^{9}	$.32\times10^{10}$	7.0×10^{9}
15	$.90\times10^{10}$	3.0×10^{11}	$.52\times10^{10}$	6.5×10^{9}	$.28\times10^{10}$	5.5×10^{9}
16	$.90\times10^{10}$	2.5×10^{11}	$.57\times10^{10}$	7.5×10^{9}	$.29\times10^{10}$	6.0×10^{9}
17	$.88\times10^{10}$	2.9×10^{11}	$.54\times10^{10}$	7.0×10^{9}	$.28\times10^{10}$	5.5×10^{9}
18	$.85\times10^{10}$	2.2×10^{11}	$.59\times10^{10}$	7.5×10^{9}	(4)	(4)
19	(2)	(2)	$.49\times10^{10}$	6.5×10^{9}	(5)	(5)
20	$.56\times10^{10}$	2.5×10^{10}	$.55\times10^{10}$	7.5×10^{9}	2.6×10^{9}	4.5×10^{9}
21	$.56\times10^{10}$	3.5×10^{10}	$.49\times10^{10}$	6.5×10^{9}	8.0×10^{9}	4.0×10^{9}
22	$.53\times10^{10}$	2.3×10^{10}	$.54\times10^{10}$	7.1×10^{9}	4.7×10^{9}	4.3×10^{9}
23	$.52\times10^{10}$	3.5×10^{10}	$.52\times10^{10}$	7.25×10^{9}	4.5×10^{9}	4.5×10^{9}
24	$.53\times10^{10}$	4.9×10^{10}	$.52\times10^{10}$	7.25×10^{9}	2.6×10^{9}	5.0×10^{9}
25	$.54\times10^{10}$	3.9×10^{10}	$.52\times10^{10}$	7.0×10^{9}	4.0×10^{9}	4.5×10^{9}
26	$.54\times10^{10}$	6.0×10^{10}	$.57\times10^{10}$	8.0×10^{9}	4.5×10^{9}	5.0×10^{9}
27	$.54\times10^{10}$	7.3×10^{10}	$.53\times10^{10}$	7.0×10^{9}	4.0×10^{9}	4.3×10^{9}

Remarks:

(1) Cable #10 -- read $<.5\times10^{6}\,\Omega$ (10V scale) on H-P tester and $<.1\times10^{6}\,\Omega$ (50V scale) on Hipotronics tester. Measured ~380kΩ on Fluke 8100-A multimeter. After water drained, cables still wet, measured 250kΩ (500V scale) on Hipotronics tester.

(2) Cable #19 -- read $.6$-$.9\times10^{6}\,\Omega$ (10V scale) on H-P tester and 6-$7\times10^{5}\,\Omega$ (100V scale) on Hipotronics tester. Measured ~600 kΩ on Fluke 8100-A multimeter. After water drained, cables still wet, unable to obtain stable reading on Hipotronics tester.

(3) Cable #10 -- read $<.5\times10^{6}\,\Omega$ (10V scale) on H-P tester and $<.1\times10^{6}\,\Omega$ (50V scale) on Hipotronics tester. Measured 473kΩ on Fluke 8100-A multimeter.

(4) Cable #18 -- read $1.1\times10^{7}\,\Omega$ (100V scale) on H-P tester and 800kΩ (500V scale) on Hipotronics tester. Measured ~72MΩ on Fluke 8100-A multimeter.

(5) Cable #19 -- read $<.5\times10^{6}\,\Omega$ (10Vscale) on H-P tester and $<.1\times10^{6}\,\Omega$ (50V scale) on Hipotronics tester. Measured 100 kΩ on Fluke 8100-A multimeter.

(6) Water approximately 10 inches above top of mandrel.

(7) Water approximately 11 inches above top of mandrel.

APPENDIX D

DATA FROM INSULATION RESISTANCE TESTS DURING STEAM/CHEMICAL SPRAY ENVIRONMENT EXPOSURE

DATA SHEET

Insulation Resistance Tests

IR Test in Steam -
During First Peak
Temp. 175°C, Press. 116.5 psig
Start: 11:00 a.m.
End: 11:20 a.m.
8/6/81

IR Test in Steam -
During Second Peak
Temp. 175°C, Press. 115 psig
Start: 4:35 p.m.
End: 5:00 p.m.
8/6/81

IR Test in Steam -
1st Ramp Down from 2nd peak
Temp. 169°C, Press. 98.5 psig
Start: 7:30 p.m.
End: 7:55 p.m.
8/6/81

Cable No.	Resistance		Resistance		Resistance	
	H-P	Hipotronics	H-P	Hipotronics	H-P	Hipotronics
10	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$
11	(25V) $.148x10^7$	(500V) $1.54x10^6$	(25V) $.31x10^7$	(500V) $1.48x10^6$	(25V) $.158x10^7$	(500V) $1.83x10^6$
12	(25V) $.15x10^7$	(500V) $1.54x10^6$	(25V) $.151x10^7$	(500V) $1.5x10^6$	(25V) $.158x10^7$	(500V) $1.83x10^6$
13	(25V) $.15x10^7$	(500V) $1.54x10^6$	(25V) $.16x10^7$	(500V) $1.12x10^6$	(10V) $<.5x10^6$	(500V) $1.4x10^6$
14	(25V) $.15x10^7$	(500V) $1.56x10^6$	(25V) $.155x10^7$	(500V) $1.47x10^6$	(25V) $.158x10^7$	(500V) $1.84x10^6$
15	(25V) $.16x10^7$	(500V) $1.55x10^6$	(25V) $.152x10^7$	(500V) $1.45x10^6$	(25V) $.158x10^7$	(500V) $1.82x10^6$
16	(25V) $.16x10^7$	(500V) $1.7x10^6$	(25V) $.17x10^7$	(500V) $1.62x10^6$	(25V) $.21x10^7$	(500V) $2.1x10^6$
17	(25V) $.165x10^7$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(500V) $1.2x10^6$
18	(25V) $.163x10^7$	(500V) $1.62x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(500V) $1.4x10^6$
19	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$
20	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$
21	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $.13x10^6$	(10V) $<.5x10^6$	(50V) $.16x10^6$
22	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$
23	(10V) $.65x10^6$	(100V) $.70x10^6$	(10V) $.54x10^6$	(100V) $.54x10^6$	(10V) $.57x10^6$	(100V) $.58x10^6$
24	(10V) $.64x10^6$	(100V) $.68x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$
25	(10V) $.64x10^6$	(100V) $.68x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$
26	(10V) $.64x10^6$	(100V) $.68x10^6$	(10V) $.53x10^6$	(100V) $.52x10^6$	(10V) $.58x10^6$	(100V) $.60x10^6$
27	(10V) $.64x10^6$	(100V) $.68x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$	(10V) $<.5x10^6$	(50V) $<.1x10^6$

DATA SHEET
Insulation Resistance Tests

	IR Test in Steam - 2nd Ramp Down from 2nd Peak Temp. 158°C, Press. 71.2 psig Start: 11:00 p.m. End: 11:35 p.m. 8/6/81		IR Test in Steam - 3rd Ramp Down from 2nd Peak #1 Temp. 131^{O}C, Press. 26.6 psig Start: 2:40 a.m. End: 3:05 a.m. 8/7/81		IR Test in Steam- 3rd Ramp Down from 2nd Peak #2 Temp. 130C^{o}, Press. 26.2 psig Start: 9:20 a.m. End: 9:40 a.m. 8/10/81	
Cable No.	Resistance		Resistance		Resistance	
	H-P	Hipotronics	H-P	Hipotronics	H-P	Hipotronics
10	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$
11	(50V) $.355\mathrm{x}10^{7}$	(500V) $3.4\mathrm{x}10^{6}$	(250V) $.19\mathrm{x}10^{8}$	(500V) $1.9\mathrm{x}10^{7}$	(250V) $.18\mathrm{x}10^{8}$	(500V) $1.7\mathrm{x}10^{7}$
12	(50V) $.355\mathrm{x}10^{7}$	(500V) $1.55\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(500V) $2.0\mathrm{x}10^{6}$	(100V) $1.7\mathrm{x}10^{7}$	(500V) $1.6\mathrm{x}10^{7}$
13	(10V) $< .5\mathrm{x}10^{6}$	(500V) $2.2\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(500V) $3.5\mathrm{x}10^{6}$	(100V) $1.25\mathrm{x}10^{7}$	(500V) $6.5\mathrm{x}10^{6}$
14	(10V) $.9\text{-}1.0\mathrm{x}10^{6}$	(500V) $1.65\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(500V) $3.5\mathrm{x}10^{6}$	(250V) $.15\mathrm{x}10^{8}$	(500V) $1.6\mathrm{x}10^{7}$
15	(50V) $.355\mathrm{x}10^{7}$	(500V) $3.3\mathrm{x}10^{6}$	(250V) $.19\mathrm{x}10^{8}$	(500V) $1.9\mathrm{x}10^{7}$	(250V) $.175\mathrm{x}10^{8}$	(500V) $1.7\mathrm{x}10^{7}$
16	(50V) $.39\mathrm{x}10^{7}$	(500V) $3.7\mathrm{x}10^{6}$	(250V) $.21\mathrm{x}10^{8}$	(500V) $2.2\mathrm{x}10^{7}$	(250V) $.19\mathrm{x}10^{8}$	(500V) $1.8\mathrm{x}10^{7}$
17	(10V) $<.5\mathrm{x}10^{6}$	(500V) $1.65\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(500V) $2.0\mathrm{x}10^{6}$	(250V) $.15\mathrm{x}10^{8}$	(500V) $1.45\mathrm{x}10^{7}$
18	(10V) $<.5\mathrm{x}10^{6}$	(500V) $1.8\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(250V) $.185\mathrm{x}10^{8}$	(500V) $1.6\mathrm{x}10^{7}$
19	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$
20	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(25V) $.23\mathrm{x}10^{7}$	(500V) $1.85\mathrm{x}10^{6}$
21	(10V) $<.5\mathrm{x}10^{6}$	(50V) $.15\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $.16\mathrm{x}10^{6}$	(25V) $.23\mathrm{x}10^{7}$	(500V) $2.2\mathrm{x}10^{6}$
22	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$
23	(10V) $.90\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $.62\mathrm{x}10^{6}$	(50V) $.45\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$
24	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $.5\mathrm{x}10^{6}$	(50V) $.1\mathrm{x}10^{6}$
25	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(25V) $.19\mathrm{x}10^{7}$	(100V) $1.5\mathrm{x}10^{6}$
26	(10V) $1.0\mathrm{x}10^{6}$	(500V) $1.0\mathrm{x}10^{6}$	(100V) $.57\mathrm{x}10^{7}$	(500V) $6.0\mathrm{x}10^{6}$	(100V) $.57\mathrm{x}10^{7}$	(500V) $5.2\mathrm{x}10$
27	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$	(10V) $<.5\mathrm{x}10^{6}$	(50V) $<.1\mathrm{x}10^{6}$

DATA SHEET
Insulation Resistance Tests

Cable No.	IR Test in Steam - After Final Ramp Down 1st Week Test Temp. 102.3°C, Press. 3.9 psig Start: 8:05 a.m. End: 8:35 a.m. 8/11/81		IR Test in Steam - After Final Ramp Down 2nd Week Test Temp. 102°C, Press. 4.1 psig Start: 8:00 a.m. End: 8:30 a.m. 8/18/81		IR Test in Steam - After Final Ramp Down 3rd Week Test Temp. 102°C, Press. 4.1 psig Start: 8:10 a.m. End: 8:40 a.m. 8/25/81	
	Resistance		Resistance		Resistance	
	H-P	Hipotronics	H-P	Hipotronics	H-P	Hipotronics
10	(10V) $<.5\times10^{6}$	(50V) $.14\times10^{6}$ (1)	(25V) $.16\times10^{7}$	(500V) 1.6×10^{6}	(50V) $.32\times10^{7}$	(500V) 2.9×10^{6}
11	(500V) 1.2×10^{8}	(500V) 1.25×10^{8}	(500V) 1.4×10^{8}	(500V) 1.4×10^{8}	(500V) 1.4×10^{8}	(500V) 1.42×10^{8}
12	(500V) $.30\times10^{8}$	(500V) 5.5×10^{7}	(500V) $.75\times10^{8}$	(500V) 9.0×10^{7}	(500V) $.50\times10^{8}$	(500V) 7.5×10^{7}
13	(250V) $.15\times10^{8}$	(500V) 1.6×10^{7}	(250V) $.18\times10^{8}$	(500V) 1.6×10^{7}	(250V) $.19\times10^{8}$	(500V) 2.0×10^{7}
14	(500V) $.5-.6\times10^{8}$	(500V) 8.0×10^{7}	(500V) $.55\times10^{8}$	(500V) 6.5×10^{7}	(500V) $.55\times10^{8}$	(500V) 9.0×10^{7}
15	(500V) 1.2×10^{8}	(500V) 1.22×10^{8}	(500V) 1.25×10^{8}	(500V) 1.25×10^{8}	(500V) 1.2×10^{8}	(500V) 1.25×10^{8}
16	(500V) 1.3×10^{8}	(500V) 1.3×10^{8}	(500V) 1.4×10^{8}	(500V) 1.45×10^{8}	(500V) 1.4×10^{8}	(500V) 1.4×10^{8}
17	(500V) 1.1×10^{8}	(500V) $.95\times10^{8}$	(500V) 1.3×10^{8}	(500V) 6.5×10^{7}	(500V) 1.6×10^{8}	(500V) 1.55×10^{8}
18	(500V) $.95\times10^{8}$	(500V) 5.5×10^{6}	(500V) 1.35×10^{8}	(500V) 1.15×10^{8}	(500V) 1.4×10^{8}	(500V) 1.35×10^{8}
19	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$ (1)	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$
20	(500V) $.40\times10^{8}$	(500V) 4.5×10^{7}	(250V) $.125\times10^{8}$	(500V) 1.85×10^{7}	(250V) $.2\times10^{8}$	(500V) 1.9×10^{7}
21	(500V) $.46\times10^{8}$	(500V) 4.7×10^{7}	(500V) $.57\times10^{8}$	(500V) 6.0×10^{7}	(500V) $.62\times10^{8}$	(500V) 6.5×10^{7}
22	(10V) $<.5\times10^{6}$	(50V) $.11\times10^{6}$ (1)	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$	(25V) $.17\times10^{7}$	(100V) $.5\times10^{6}$
23	(10V) $<.5\times10^{6}$	(50V) $.125\times10^{6}$ (1)	(500V) $.31\times10^{8}$	(500V) 3.2×10^{7}	(500V) $.62\times10^{8}$	(500V) 6.5×10^{7}
24	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$ (1)	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$
25	(500V) $.4-.5\times10^{8}$	(500V) 4.8×10^{7}	(50V) $.50\times10^{7}$	(500V) 3.2×10^{6}	(50V) $.5\times10^{7}$	(500V) 4.5×10^{6}
26	(500V) $.48\times10^{8}$	(500V) 4.8×10^{7}	(500V) $.55\times10^{8}$	(500V) 5.7×10^{7}	(500V) $.65\times10^{8}$	(500V) 6.2×10^{7}
27	(10V) $<.5\times10^{8}$	(50V) $<.1\times10^{6}$ (1)	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$	(10V) $<.5\times10^{6}$	(50V) $<.1\times10^{6}$ (2)

Remarks:

	Fluke 8100 A Multimeter:		Simpson 630-PL Multimeter
(1) Cable #10	1.05 MΩ	Cable #10	200 KΩ(Handling damage)
#19	Dead short	#19	Short (Suspected Handling Damage
#22	~ 30 KΩ	#22	175 KΩ(Contained damage which
#23	~ 300 KΩ	#23	250 KΩ occured early during
#24	150Ω	#24	120 Ω steam/chemical spray
#27	540 KΩ	#27	500 KΩ exposure. Specific cause unknown).

Note: These readings taken approximately 21 hours after stabilization at 102°C, 4 psig. The readings generally are somewhat better than results at higher temperatures and pressures.

(2) Cable #27	No stable reading	Cable #27	60 KΩ(See above)

DATA SHEET
Insulation Resistance Tests

IR Test in Steam -
After Final Ramp Down
4th Week Test
Temp. 102°C, Press. 4.1 psig
Start: 8:30 a.m.
End: 8:50 a.m.
9/1/81

IR Test in Steam -
After Final Ramp Down
5th Week Test
Temp. 102°C, Press. 4.1 psig
Start: 8:00 a.m.
End: 8:25 a.m.
9/8/81

Cable No.	Resistance (9/1/81) H-P	Resistance (9/1/81) Hipotronics	Resistance (9/8/81) H-P	Resistance (9/8/81) Hipotronics
10	(50V) .37x10^{7}	(500V) 3.3x10^{6}	(50V) .37x10^{7}	(500V) 3.4x10^{6} (2)
11	(500V) 1.35x10^{8}	(500V) 1.35x10^{8}	(500V) 1.3x10^{8}	(500V) 1.32x10^{8}
12	(500V) .60x10^{8}	(500V) 9.0x10^{7}	(500V) .75x10^{8}	(500V) 1.0x10^{8}
13	(250V) .22x10^{8}	(500V) 2.2x10^{7}	(250V) .22x10^{8}	(500V) 2.9x10^{7}
14	(500V) .80x10^{8}	(500V) 1.15x10^{8}	(500V) .80x10^{8}	(500V) 1.05x10^{8}
15	(500V) 1.1x10^{8}	(500V) 1.3x10^{8}	(500V) 1.2x10^{8}	(500V) 1.2x10^{8}
16	(500V) 1.6x10^{8}	(500V) 1.5x10^{8}	(500V) 1.5x10^{8}	(500V) 1.45x10^{8}
17	(500V) 1.6x10^{8}	(500V) 1.65x10^{8}	(500V) 1.6x10^{8}	(500V) 1.6x10^{8}
18	(500V) 1.6x10^{8}	(500V) 1.53x10^{8}	(500V) 1.5x10^{8}	(500V) 1.45x10^{8}
19	(10V) $<$.5x10^{6}	(50V) $<$.1x10^{6} (1)	(10V) $<$.5x10^{6}	(50V) $<$.1x10^{6} (2)
20	(250V) .21x10^{8}	(500V) 1.9x10^{7}	(250V) .23x10^{8}	(500V) 2.2x10^{7}
21	(500V) .65x10^{8}	(500V) 7.5x10^{7}	(500V) .63x10^{8}	(500V) 7.0x10^{7}
22	(50V) .275x10^{7}	(100V) 1.0x10^{6}	(50V) .27x10^{7}	(500V) 4.0x10^{6}
23	(500V) .63x10^{8}	(500V) 7.7x10^{7}	(500V) .62x10^{8}	(500V) 7.0x10^{7}
24	(10V) $<$.5x10^{6}	(50V) $<$.1x10^{6} (1)	(10V) $<$.5x10^{6}	(50V) $<$.1x10^{6} (2)
25	(50V) .35x10^{7}	(500V) 4.8x10^{6}	(100V) .6-.8x10^{7}	(500V) 1.5x10^{7}
26	(500V) .65x10^{8}	(500V) 7.2x10^{7}	(500V) .63x10^{8}	(500V) 7.5x10^{7}
27	(10V) $<$.5x10^{6}	(50V) $<$.1x10^{6} (1)	(10V) $<$.5x10^{6}	(50V) $<$.1x10^{6} (2)

Remarks:

	Fluke 8100A Multimeter		Triplett 630-PL Multimeter		
(1)	Cable #19	Short	Cable #19	Short	(Suspected handling damage)
	Cable #24	2.6KΩ	Cable #24	1.2KΩ	(Contained damage which occurred early during steam/chemical spray exposure. Specific causes unknown)
	Cable #27	Erratic	Cable #27	30KΩ	
(2)	Cable #10	Unstable	Cable #10	450KΩ	(Handling damage)
	Cable #19	Short	Cable #19	Short	(Suspected handling damage)
	Cable #24	~800Ω	Cable #24	800Ω	(See Above)
	Cable #27	Unstable	Cable #27	35KΩ	

APPENDIX E

DATA FROM HIGH POTENTIAL TESTS FOLLOWING STEAM/CHEMICAL SPRAY ENVIRONMENT EXPOSURE

DATA SHEET

Water Immersion Hi-Pot

Gradual Immersion
(1 minute hold-off)

Cable	Leakage(a) (ma)
10	(b)
11	1.8
12	2.0
13	2.0
14	1.8
15	3.5
16	1.8
17	1.8
18	1.8
19	5.0 @ 1.2kV(c)
20	3.1
21	2.4 @ 2.8kV
22	>750(d)
23	3.15
24	4.3(e)
25	5.0 @ 1.7kV(f)
26	3
27	>750(g)

After 1 hour Soak
(5 minute hold-off)

Cable	Leakage(a) (ma)
10	(b)
11	2.3
12	2.4
13	5.1
14	>750 @ 1.05kV(h)
15	3.7
16	2.5
17	4.8
18	2.5
19	>750(i)
20	4.24
21	4.08
22	750(j)
23	4.2
24	--(k)
25	4.3
26	4.2
27	>750(l)

NOTES:

a. 2400 VAC applied to Cables 10-18; 3600 VAC applied to Cables 19-27.
b. Cable #10 -- damaged during installation.
c. Cable #19 -- broke down 5 ma @ 1.2kV.
d. Cable #22 -- broke down above mandrel; point not precisely located.
e. Cable #24 -- broke down at 2 places; at penetration and above mandrel.
f. Cable #25 -- broke down 5 ma @ 1.7 kV at brace above mandrel (installed insulator between cable and brace showed no leakage)
g. Cable #27 -- breaks down immediately (holds no voltage) appears to be above mandrel.
h. Cable #14 -- arcing about 6 inches below top of first mandrel.
i. Cable #19 -- breaks down immediately (holds no voltage) suspect cable is pinched at the mandrel.
j. Cable #22 -- arcing above mandrel.
k. Cable #24 -- arcing at penetration.
l. Cable #27 -- breaks down immediately (holds no voltage) appears to be above mandrel.

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(1)Cable #19 suspected handling damage; all other cables, specific causes unknown.

APPENDIX F

DATA FROM VISUAL AND BEND TESTS
FOLLOWING
STEAM/CHEMICAL SPRAY ENVIRONMENT EXPOSURE

DATA SHEET

Post Exposure Inspection

All Cables -- Considerable build-up of deposit at top (above mandrel) where steam and chemical spray impinged. Insulation appeared to separate into layers in the area of steam and chemical impingement. The insulation appears to have swelled (or have had a material deposited) to some extent all the way up and down the mandrel. The observed condition appears like small blisters or tiny bubbles.

DATA SHEET

Inspection After Straightening Cables

Cable	Description
10	OK except for known handling damage
11	OK
12	OK
13	OK
14	Notch through insulation approximately 6 inches above the top of second mandrel. No explanation. Cable passed all IR tests but failed hipot after 1 hour soak.
15	OK
16	OK
17	OK
18	OK
19	OK above mandrel, suspect location identified, additional testing needed to confirm. (Suspected handling damage)
20	OK
21	OK
22	OK above mandrel, bare copper approx 3/16 inch long, area was between supports. (Cause unknown)
23	OK
24	Gash about 3/4 inch long above mandrel, depression in insulation to copper near bar in mandrel. (Probably caused by pressure on bar when insulation was soft).
25	OK
26	OK
27	Approximately 1/8 inch hole through insulation above mandrel. Could not find physical damage in portion around mandrel. (Cause unknown)

DATA SHEET

Bend Test Visual Inspection

Cable	Description
10	No discernable change while bending around mandrel.
11	No discernable change while bending around mandrel.
12	No discernable change while bending around mandrel.
13	No discernable change while bending around mandrel.
14	No discernable change while bending around mandrel.
15	No discernable change while bending around mandrel.
16	No discernable change while bending around mandrel.
17	No discernable change while bending around mandrel.
18	No discernable change while bending around mandrel.
19	No discernable change while bending around mandrel.
20	No discernable change while bending around mandrel.
21	No discernable change while bending around mandrel.
22	No discernable change while bending around mandrel.
23	No discernable change while bending around mandrel.
24	No discernable change while bending around mandrel.
25	No discernable change while bending around mandrel.
26	No discernable change while bending around mandrel.
27	No discernable change while bending around mandrel.

NOTES:

a. Cables 10-18 were wrapped around a 5.75 inch diameter mandrel. Cables 19-27 were wrapped around a 9.50 inch diameter mandrel.

b. Cables 10-18 had nominal cable diameter of .155 inch. Mandrel diameter required per IEEE 383-1974 is 40x.155 = 6.2 inches. Cables 19-27 had nominal cable diameter of .238 inch. Mandrel diameter required per IEEE 383-1974 is 40x.238 = 9.52 inches.

APPENDIX G

LIST OF MEASUREMENT EQUIPMENT

MEASUREMENT EQUIPMENT

Measurement	Manufacturer and Model No.	Calibration Date
Load voltage, current, and power	Magtrol Power Analyzer, Model No. 4612, Ser. No. 1A167	Expires 2/19/82
Insulation resistance	Hipotronics Megohmmeter, Model No. HM3A, Ser. No. 1352	Expires 12/11/81
Insulation resistance	Hewlett-Packard High Resistance Meter, Model No. 4329A, Ser. No. 02898	Expires 3/4/82
Insulation resistance	American Hipot Tester Megohmmeter Model No. PM 2500, Ser. No. S-77-12	Expires 11/7/81
Insulation resistance	Triplett Multimeter Model No. 630-PL	Indication Only
Hipot	Hipotronics, Model No. HD140, Ser. No. 1420-1139	Expires 10/2/81
Hipot	Hipotronics, Model No. N5-10, Ser. No. 9275	Expires 12/7/81
Pressure	Heise Pressure Gauge, Ser. No. 29155	Expires 11/30/81
Resistance	John Fluke Digital Multimeter, Model No. 8100A, Ser. No. 3318	Expires 12/2/81
Data Recording	Acurex Datalogger, Model No. A Ten/10, Ser. No. 3-21001	Expires 10/6/81
Data Recording	Acurex Datalogger, Model No. A901, Ser. No. 1694	Expires 4/5/81

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1811	R. L. Clough
1813	K. T. Gillen
9400	A. W. Snyder
9440	D. A. Dahlgren
9445	L. O. Cropp
9445	D. T. Furgal (20)
9446	L. L. Bonzon
9446	J. J. Benson
9446	D. M. Jeppesen (10)
9446	E. E. Minor
9446	E. A. Salazar
9551	J. D. McClure
3141	L. J. Erickson (5)
3151	W. L. Garner (3)
8214	M. A. Pound

Org.	Bldg.	Name	Rec'd by	Org.	Bldg.	Name	Rec'd by

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