Qualification Tests of Electrical Cables in a Simulated Loss-of-Coolant-Accident (LOCA) Environment

FRC Final Report
F-C5115

prepared for

American Insulated Wire Corporation
Pawtucket, Rhode Island

April 1979

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Franklin Research Center
A Division of The Franklin Institute
The Benjamin Franklin Parkway, Phila., Pa. 19103 (215) 448-1000

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CONTENTS

FIGURES

TABLES

1. SUMMARY OF SALIENT FACTS

FRC Project Number: C5115

Test Program Conducted for:

American Insulated Wire Corporation (AIW)
Central Avenue and Freeman Street
Pawtucket, RI 02862

Test Program Conducted and Reported by:

Franklin Research Center
20th & The Parkway
Philadelphia, PA 19103

Dates of Test Program:

January through April 1979

Objective of Test Program:

To demonstrate performance of electrical cables for Class 1E service in a nuclear power generating station in accordance with appropriate test guidelines presented in IEEE Standards 323-1974* and 383-1974,† and specifications provided by the client.

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*IEEE Std 323-1974, "IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations," The Institute of Electrical and Electronics Engineers, Inc., New York, NY, 1974.

†IEEE Std 383-1974, "IEEE Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations," The Institute of Electrical and Electronics Engineers, Inc., New York, NY, 1974.

Equipment Tested:

Six specimens of 2/C #16 AWG and six specimens of 2/C #14 AWG electrical cable insulated with ethylene propylene rubber (EPR) and jacketed with Hypalon over the insulated conductors and over tapes, fillers and shields.

Elements of Test Program:

A thermal aging program was performed by the client in which the specimens were divided into two groups of six cables each. One group was aged for 168 hours (7 days) at 121°C (250°F) and the other group remained unaged. All specimens were then subjected to an air-equivalent dose of 206 Mrad from a cobalt-60 source and subsequently to a steam/chemical-spray (S/C) exposure designed to simulate a loss-of-coolant-accident (LOCA) environment. The S/C exposure included an initial peak temperature/pressure of 306°F (152°C)/84 psig (579 kPa) at 4 seconds of elapsed time (ET) followed by a 2.8-hour dwell at 286°F (141°C)/40 psig (276 kPa),* a 21.2-hour dwell at 219°F (104°C)/~3 psig (21 kPa), and a final dwell at 209°F (98°C)/0 psig (0 kPa) for a total S/C exposure of 83 days. A chemical spray consisting of 1.2% boric acid (pH = 8.5 to 10.0) was applied for the first 24 hours of the S/C exposure. The #16 and #14 AWG cables were electrically energized with 10 Vac/1 A and 230 Vac/10 A, respectively, during the S/C exposure.†

Following the S/C exposure, the cables were subjected to a mandrel-bend test at ~40 times the cable diameter and to a high-potential-withstand test at 80 Vac per mil of insulation while immersed in tap water.

Summary of Test Results:

The specimens remained energized for the duration of the 83-day S/C exposure, during which the minimum measured insulation resistance for any specimen was 5 MΩ at 500 Vdc. The cables withstood final bend/high-potential-withstand tests.

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*Temperature/pressure excursions between a maximum of 312°F (156°C)/85 psig (586 kPa) and a minimum of 250°F (121°C)/32 psig (221 kPa) were experienced in the time interval of 5 to 22 seconds ET before conditions were stabilized at 286°F (141°C)/40 psig (276 kPa).

†Potentials listed were applied between conductors. Potentials were 5 ± 1.4 Vac and 115 ± 5 Vac, respectively, between the conductors and the ground plane (i.e., the test vessel).

2. IDENTIFICATION OF EQUIPMENT TESTED

Descriptions of the cable specimens provided by the client and the specimens' required energizing potentials and currents are presented in Table 1. The length of each cable was approximately 30 ft.

Table 1. Identification of Test Specimens

Cable Number	Cable Description (a)	Thermal Aging (b)	Electrical Energizing (c)
C5115-1	2/C #16 AWG 7 x 0.0192-in Tinned Copper Conductor	Unaged	10 Vac/1 A
C5115-2	0.025-in Ethylene Propylene Rubber (EPR) Insulation (OD = 0.108 in)		
C5115-3	0.015-in Hypalon Jacket Over Insulation (OD = 0.138 in)		
	0.0015-in Aluminum/Mylar Shield		
C5115-4	One #18 AWG 7 x 0.0152-in Tinned Copper Drain Wire	168 hours at 121°C (250°F)	10 Vac/1 A
C5115-5	Flame Barrier Tape(s)		
C5115-6	0.001-in Mylar Separator		
	0.060-in Overall Hypalon Jacket (OD = 0.435 in)		
C5115-7	2/C #14 AWG 7 x 0.0242-in Tinned Copper Conductor	Unaged	230 Vac/10 A
C5115-8	0.03-in EPR Insulation (OD = 0.133 in)		
C5115-9	0.018-in Hypalon Jacket Over Insulation (OD = 0.169 in)		
	Neoprene Fillers		
C5115-10	0.001-in Mylar Separator	168 hours at 121°C (250°F)	230 Vac/10 A
C5115-11	Flame Barrier Tape(s)		
C5115-12	0.005-in Corrugated, Bronze Shield (helically wrapped around conductor assembly)		
	0.06-in Overall Hypalon Jacket (OD = 0.6 in)		

Notes: (a) Cable descriptions and nominal dimensions were provided by the client. Actual FRC measurements of cable dimensions may be somewhat different. The nominal dimensions were used when calculating test voltages and bend-test mandrel diameters.

(b) The specimens were thermally aged by the client.

(c) The electrical potentials were provided between conductors. The potentials between the conductors and the ground (vessel) plane were 50% of the listed potentials (i.e., the potentials of cables 1 through 6 and cables 7 through 12 were 5 ± 1.4 Vac and 115 ± 5 Vac above the ground plane, respectively.

3. DESCRIPTION OF TEST FACILITY

The primary test facility used in the test program consisted of a 24-in (0.61-m)-diam by 48-in (1.2-m)-long stainless-steel vessel with a carbon-steel head, as shown in Figures 1 and 2. The test specimens were assembled on two concentric, stainless-steel test mandrels (see Figure 3), which measured 16 and 20 in (0.41 and 0.51 m) in diameter by 33 in (0.84 m) in length. The test mandrels were supported by the vessel head.

Steam was admitted to the test vessel through a central 1-1/2-in NPT perforated section of pipe, which extended approximately 6 in (0.15 m) into the test vessel (see Figure 1). The perforated pipe was surrounded by a concentric section of a 6-in (0.15-m)-diam pipe designed to baffle the incoming steam, thus preventing direct impingement onto the cables.

An array of eight centrally-located spray nozzles* consisting of two nozzle blocks with 4 nozzles each was provided as shown in Figure 1 such that the cables were sprayed with chemical solution at an average rate of at least 0.15 gpm/ft^2 [$(0.1\ \ell/s)/m^2$]; this rate was based on a total solution flow rate of 2.2 gpm (0.14 ℓ/s) divided by the area of an imaginary cylinder located midway between the inner and outer mandrels. Provision was made to collect the spray solution in the bottom of the vessel and to recirculate the solution back through the spray nozzles.

The vessel was equipped with several thermocouples to measure and record the temperatures of the gas in the vicinity of the cables and of the fluids which collected in the bottom of the vessel. The vessel

*Nozzle No. G2.8W, Spraying Systems Company, Wheaton, IL.

pressure was indicated on a dial gage and recorded on a strip chart. A list of data acquisition instruments used in the test program is provided as Appendix A.

Electrical apparatus was prepared to supply potentials and currents to the test specimens as described in Table 1 and Figure 4. The circuits included current-limiting breakers for disconnecting the applied potentials if the leakage/charging current exceeded approximately 1.0 A.

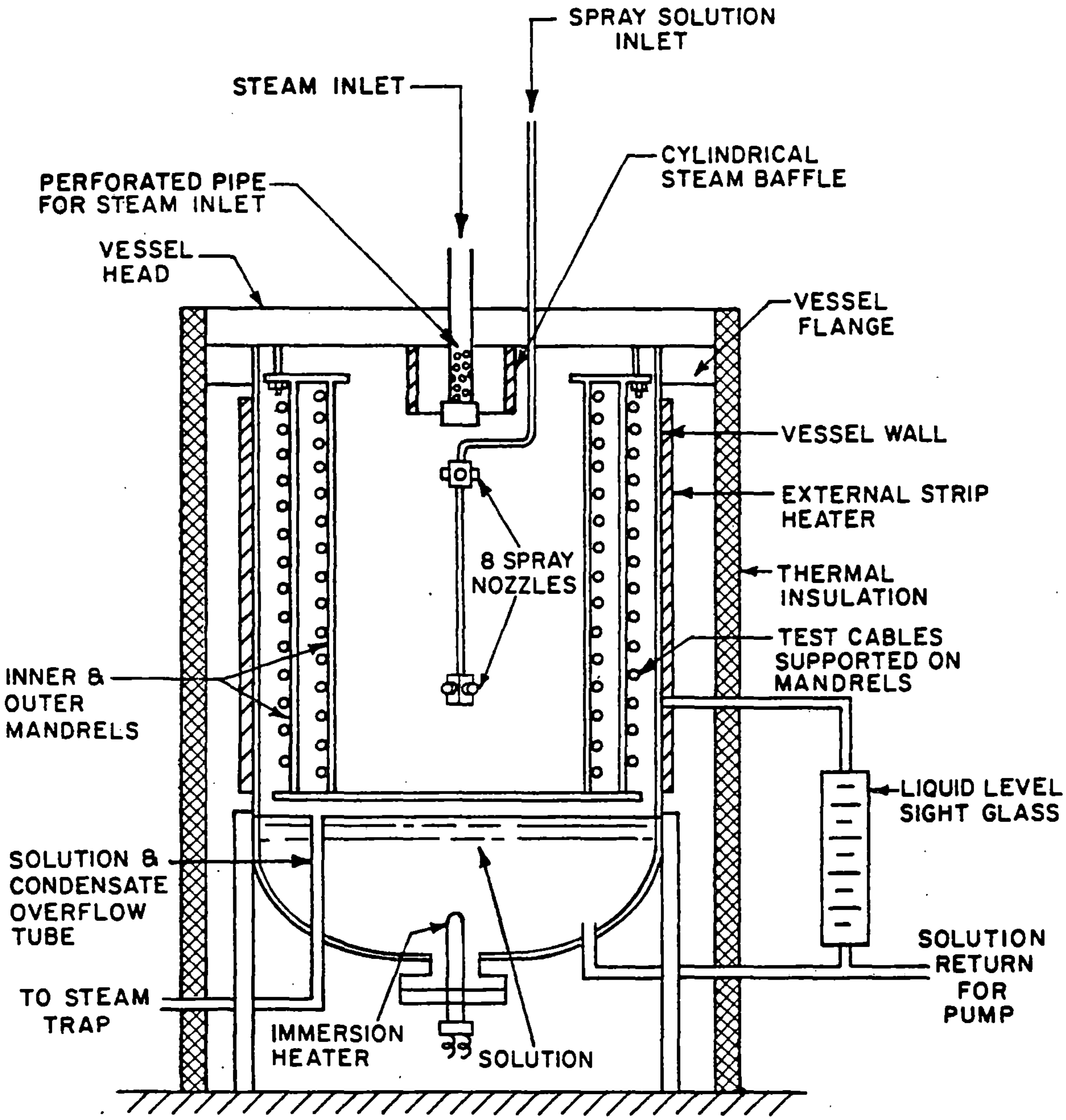


Figure 1. Salient Features of Steam/Chemical-Spray Test Vessel

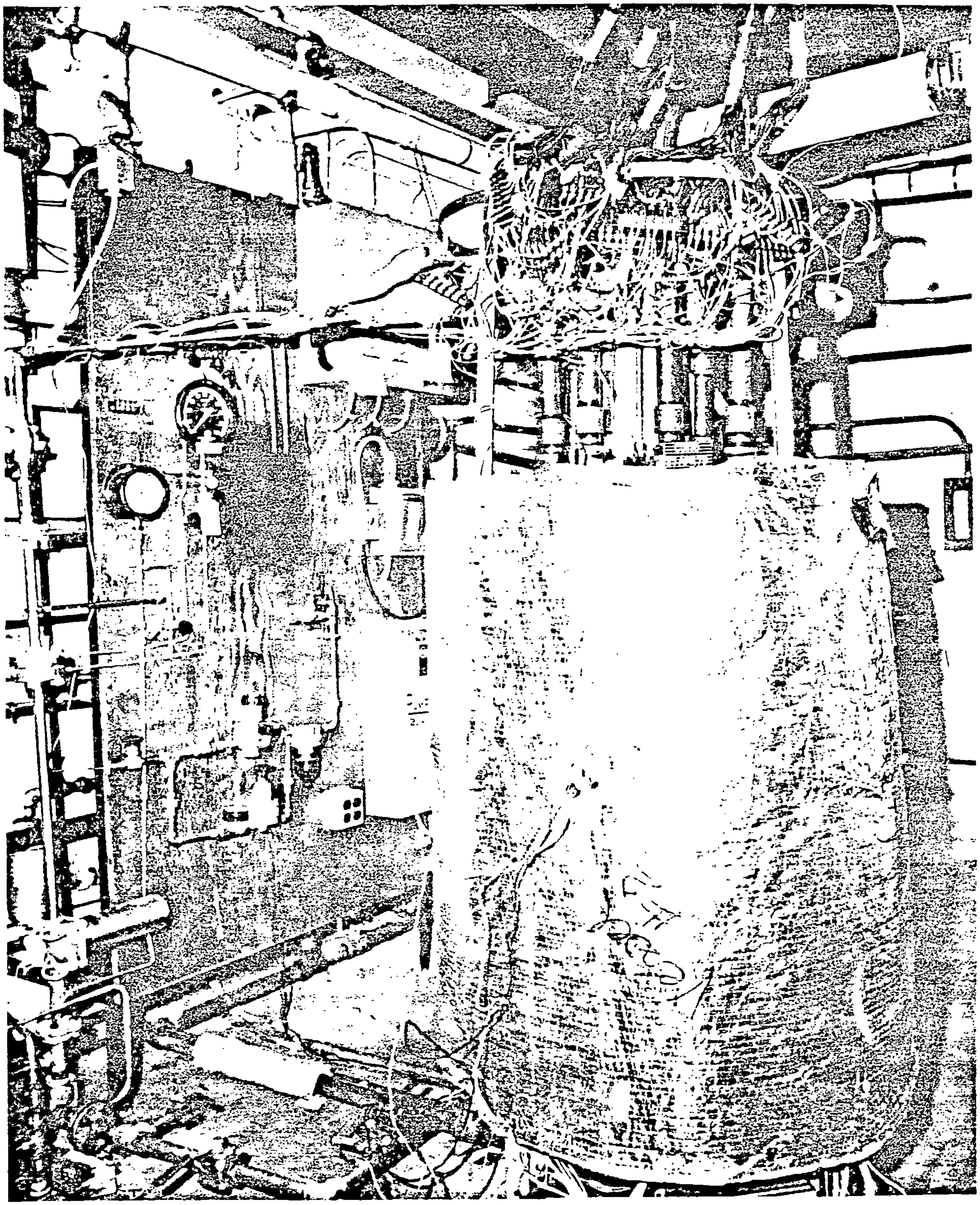


Figure 2. View of Test Vessel and Auxiliary Apparatus

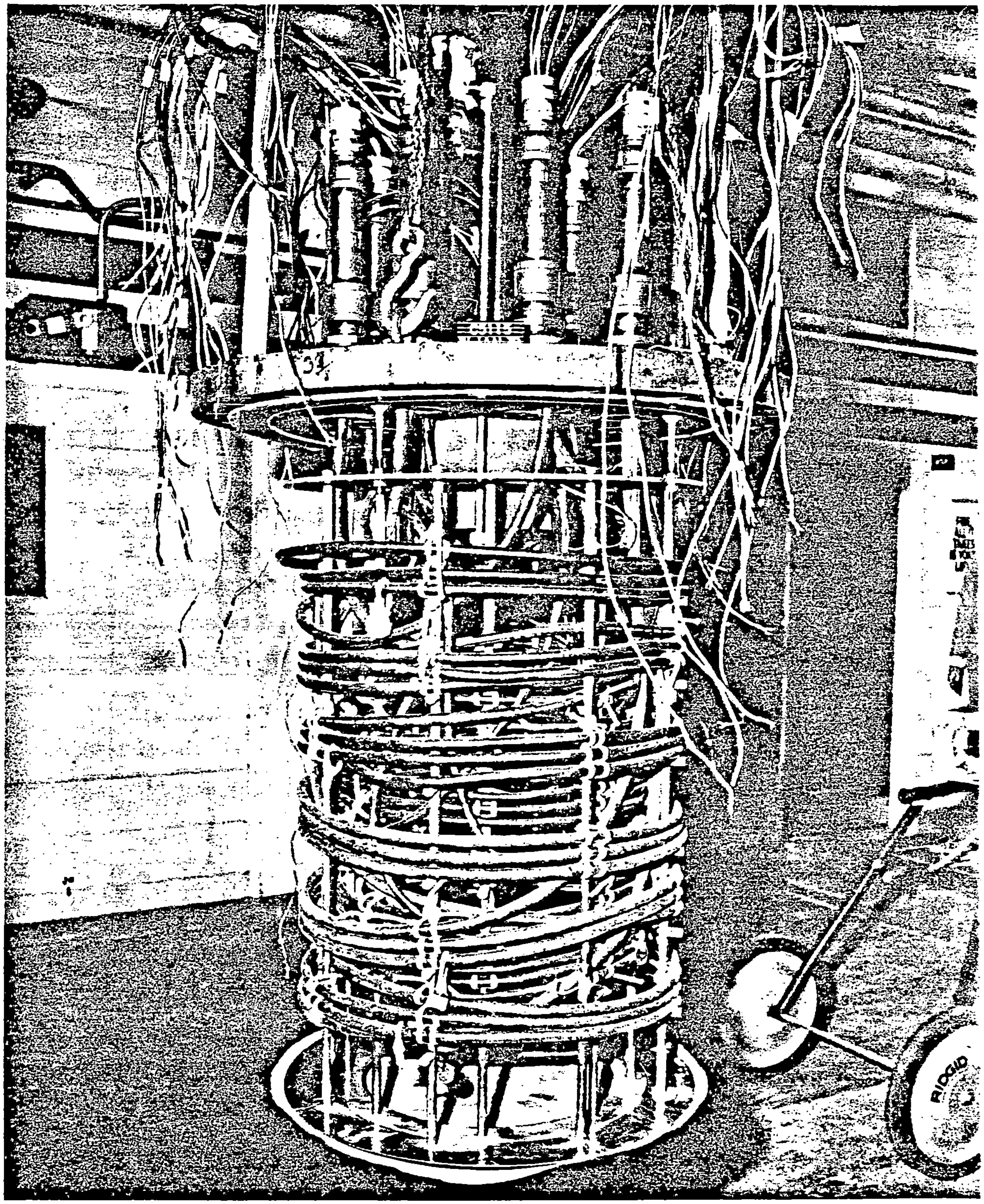
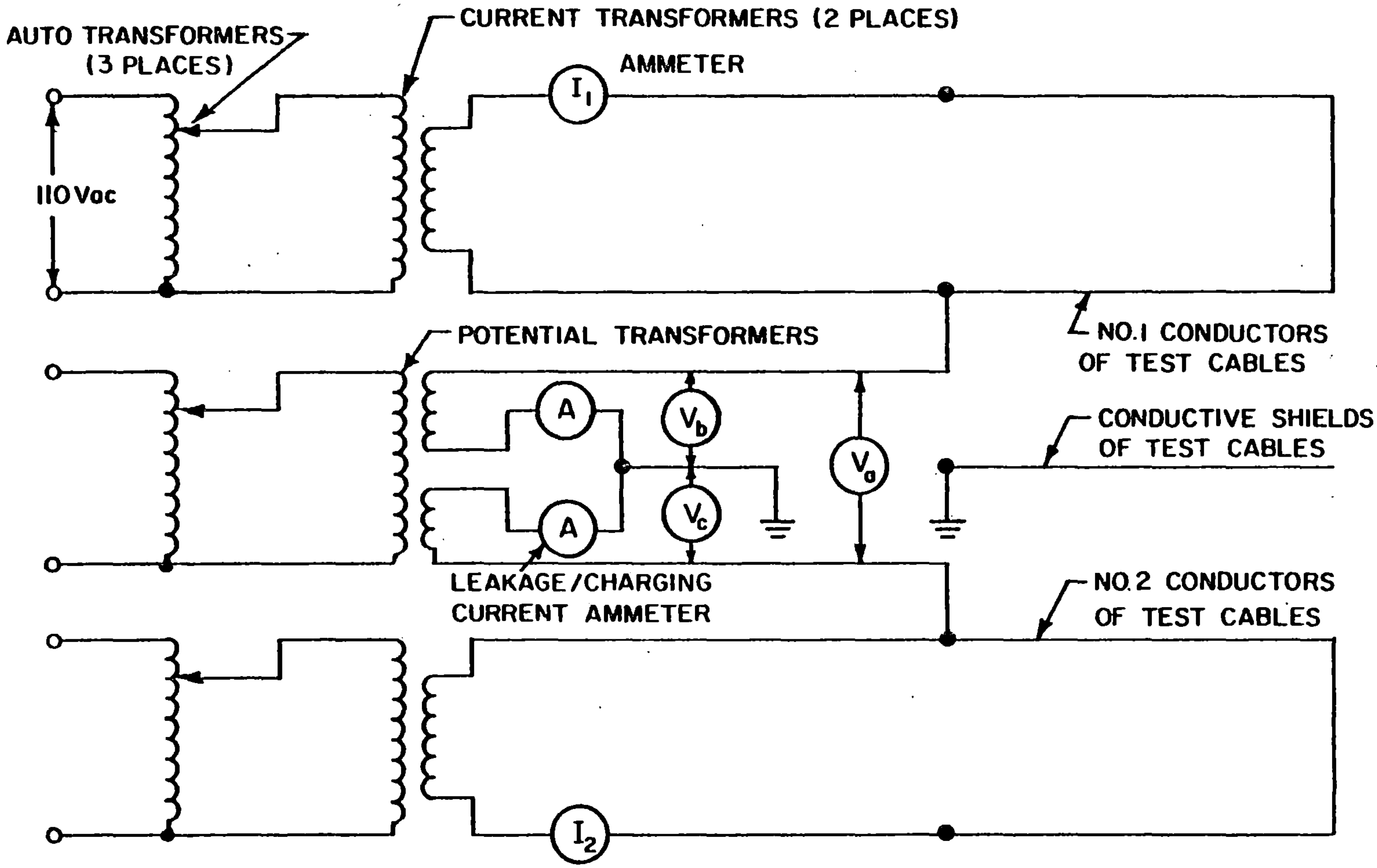


Figure 3. Pre-S/C Exposure View of Cables on Stainless-Steel Mandrel



	V_a	V_b	V_c	I_1	I_2
	(Vac)	(Vac)	(Vac)	(A)	(A)
#14 AWG CABLES	230	115	115	10	10
#16 AWG CABLES	10	5	5	1	1

Figure 4. Schematic of Electrical Energizing Circuits

F-C5115

4. TEST SEQUENCE AND PROCEDURES

The test program was designed to simulate a loss-of-coolant accident (LOCA) and the cooldown period following the accident. The program included thermal aging (conducted by the client), gamma irradiation, an 83-day steam/chemical-spray (S/C) exposure, and final bend/high-potential-withstand tests.

4.1 PRETEST PREPARATION AND INSULATION RESISTANCE MEASUREMENTS

Three turns of each cable were wrapped around the outer, 20-in (0.41-m)-diam (#14 AWG cables) and the inner, 16-in (0.51-m)-diam (#16 AWG cables) portions of the stainless-steel mandrel set (see Figure 3). The cable turns were supported on the mandrels by 0.5-in (13-mm)-diam ceramic bushings and loosely tied in place using fiberglass sleeving.

The mandrel set wrapped with cables was immersed in a tank of tap water at room temperature for a minimum of 1 hour. The insulation resistance (IR) of the cables was then measured at 500 Vdc held for 1 minute between each cable conductor and the other conductor connected to the cable sheath and a bare copper rod placed in a tank of tap water.

4.2 GAMMA IRRADIATION

The cables on the mandrel set were exposed to an air-equivalent dose of 206 Mrad of gamma radiation from a cobalt-60 source at an average dose rate of 0.66 Mrad/hour.

4.3 PREPARATIONS FOR STEAM/CHEMICAL-SPRAY EXPOSURE

The cable ends were routed between the inner and outer mandrels and up through the vessel head. The cable ends were pressure sealed in the vessel head with epoxy-potting compound.

Figure 4. Schematic of Electrical Energizing Circuits

The mandrel set with cables was installed into the test vessel, and the cable ends were connected to electrical circuits (see Section 3) through terminal strips, extension cables and knife switches.

4.4 STEAM/CHEMICAL-SPRAY EXPOSURE

The cables were electrically energized (see Section 3) and then subjected to a steam/chemical-spray (S/C) exposure in accordance with the specified temperature/pressure profile shown in Figure 5 (see Section 4.7). After 5 minutes of elapsed time (ET),* a chemical spray (see Section 3) was applied which consisted of 2100 ppm boron as boric acid† buffered with sodium hydroxide to a pH of 10.0 at room temperature.

After approximately 2 hours ET, a pool of spray solution and condensed steam was allowed to accumulate in the bottom of the vessel; the solution was subsequently recirculated through the spray nozzles. The chemical spray was terminated after 24 hours ET, and the pool of solution was left in the bottom of the vessel. The pH of the solution was measured at least twice per week during the S/C exposure; when the measured pH dropped below 8.5, the pool of liquid was replaced with fresh solution.

The IR of the cables was measured before initiation of the S/C exposure, during the dwell at 286°F (141°C)/40 psig (276 kPa) starting at 1.0 hour ET, at 219°F (104°C)/3 psig (21 kPa), at 208°F (98°C)/0 psig (0 kPa), once per week thereafter, and after the 83-day S/C exposure while the vessel was flooded with water.Δ The measurements included the IR of the extension cables used to connect the specimens to the electrical energizing circuits.

*An elapsed time clock was started upon initiation of the S/C exposure.
†2100 ppm boron is equivalent to a 1.2% (by weight) boric acid solution.
ΔThe vessel was flooded with water for 1 hour prior to IR measurements.

4.5 FINAL TESTS

After the S/C exposure, the cables were severed from the vessel head and removed from the test mandrel set. The specimens were straightened and then wound with six turns around bend-test mandrels with diameters 40 times those of the outside cable diameters (see Section 5.4 for actual mandrel diameters). The cables were visually inspected for defects, tears and cracks in the insulation. The coiled cables were then immersed in tap water at room temperature for a minimum of 1 hour and subjected to a high-potential-withstand test at 80 Vac per mil (3150 Vac per mm) of insulation. The #16 AWG cable with 25 mil (0.64 mm) of EPR insulation was tested at 2000 Vac, and the #14 AWG cable with 30 mil (0.76 mm) of insulation was tested at 2400 Vac. At the end of 5 minutes, the leakage/charging current was measured. The potential was applied to one conductor with the other conductor connected to the ground connection and a bare copper rod immersed in tap water. More than one specimen was tested simultaneously to reduce the time required for the test. A view of post-test arrangements is shown in Figure 6.

4.6 FAILURE CRITERION

The test cables were to be checked for failure during the S/C exposure if the leakage/charging current across the insulation of all cables under test exceeded 1.0 A. Insulation resistance measurements were to be used to identify any test cables responsible for the high leakage/charging current, and these specimens were to be disconnected before the remaining test cables were re-energized.

4.7 DISCUSSION OF STEAM/CHEMICAL-SPRAY EXPOSURE PROFILE

The client's original test specification required a final dwell at 152°F (66.7°C) for the balance of a one-year exposure. This was subsequently reduced to 89 days at 204°F (95.5°C) in accordance with a temperature/time compression analysis conducted by the client and FRC (see Appendix B), and further reduced to 209°F (98.3°C) for 82 days (83 days was the actual total exposure) for reasons of test convenience (i.e., the temperature of 209°F was easier to maintain than 204°F).

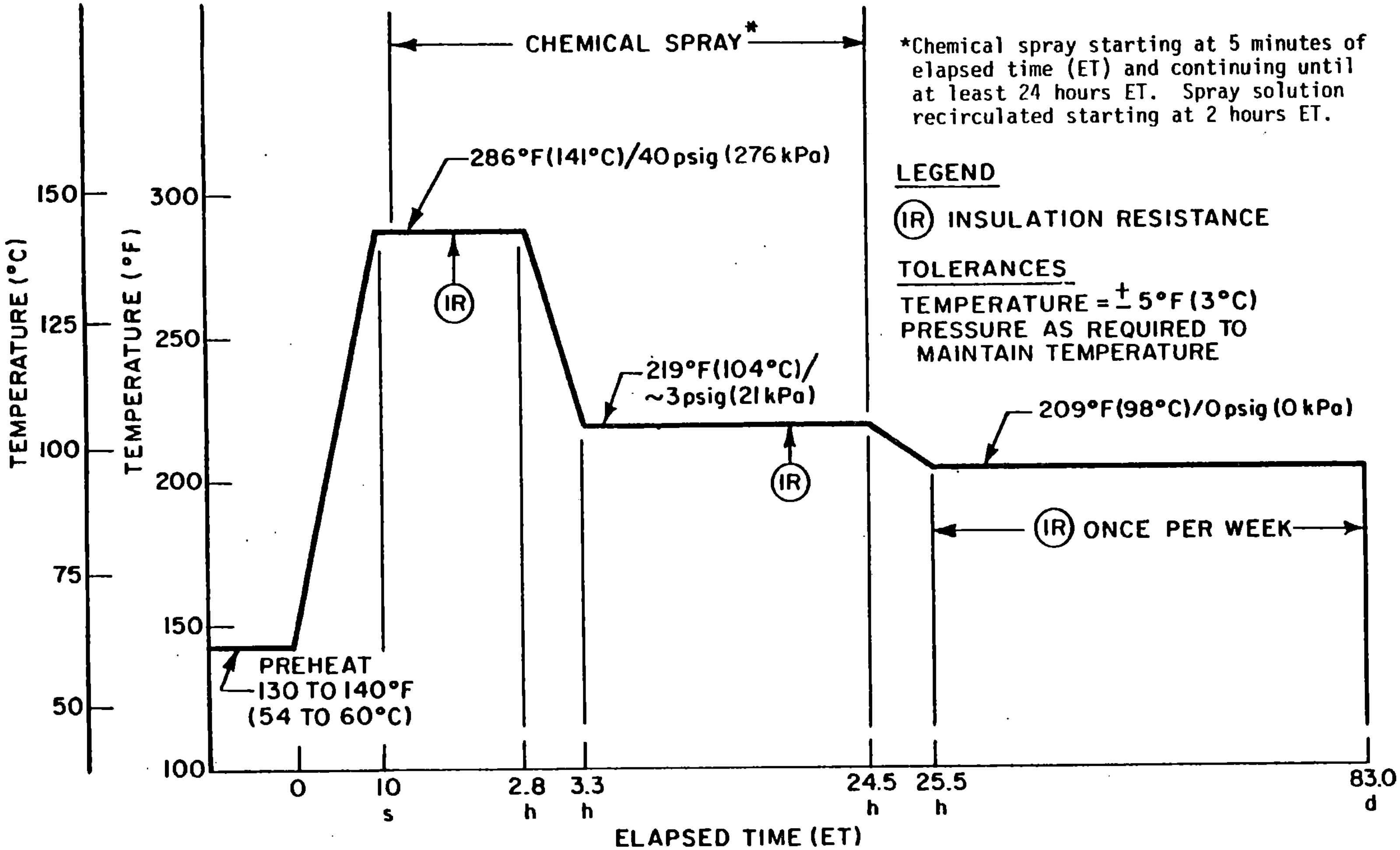


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Figure 5. Specified Temperature/Pressure Profile for Steam/Chemical-Spray Exposure

Figure 5. Specified Temperature/Pressure Profile for Steam/Chemical-Spray Exposure

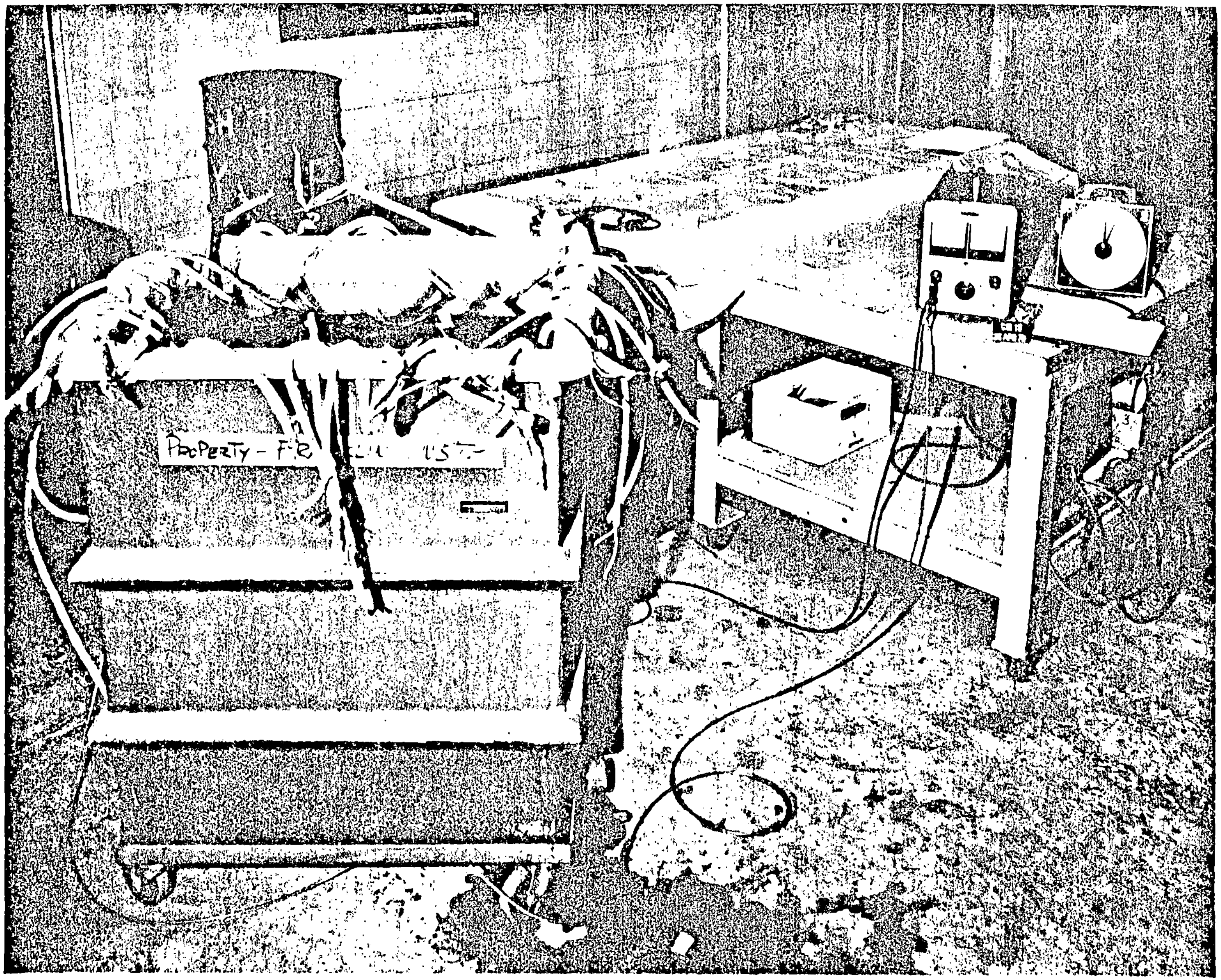

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Figure 6. View of Arrangement for High-Potential-Withstand Test

5. TEST RESULTS

5.1 INITIAL INSPECTION AND INSULATION RESISTANCE MEASUREMENTS

The results of insulation resistance (IR) measurements obtained upon receipt of the cables are presented in Table 2. An initial inspection revealed that the six aged specimens (see Table 1) were apparently in the same good condition as the six unaged specimens. However, the color of the flame barrier tapes in aged specimens 10, 11 and 12 was beige rather than white as in unaged specimens 7, 8 and 9.

It was also noted that specimens 4, 5, 6 and 11 had oily deposits on the outermost jacket and slight indentations in the jacket caused by the cord which held the specimens in coils during transit from the client to FRC.

In addition, specimen 8 had a cut through the jacket about 3-1/2 ft from one end of the cable which extended almost completely around the circumference of the cable. Therefore, this section of the cable was not included in the test vessel for the S/C exposure.

5.2 GAMMA IRRADIATION

After receiving 206 Mrad of gamma irradiation from a cobalt-60 source, all cables were found to be flexible; no visible damage was observed except some impressions where the fiberglass sleeving held the cables in position on the mandrel. A certification of irradiation is provided as Appendix C.

The results of post-irradiation IR measurements are presented in Table 2.

5.3 STEAM/CHEMICAL-SPRAY EXPOSURE

The steam/chemical-spray (S/C) exposure was provided in accordance with the specified temperature/pressure profile illustrated in Figure 5, with the following comments and deviations:

1) Maximum and minimum levels of temperatures and pressures occurred as follows during the initiation of the S/C exposure:

   - 306°F (152°C)/84 psig (579 kPa) at ~4 seconds ET
   - 287°F (142°C)/56 psig (386 kPa) at ~5 seconds ET
   - 310°F (154°C)/86 psig (593 kPa) at ~7 seconds ET
   - 250°F (121°C)/32 psig (221 kPa) at ~15 seconds ET
   - 312°F (156°C)/85 psig (586 kPa) at ~22 seconds ET
   - 295°F (146°C)/60 psig (414 kPa) at ~25 seconds ET
   - 286°F (141°C)/40 psig (276 kPa) thereafter (within tolerance) for the remainder of the 2.8-hour dwell.

2) A temperature of approximately 225°F (107°C) was recorded for a 2-hour period on the eleventh day of the S/C exposure (209°F (98°C) was the specified temperature). This higher temperature was attributed to an adjustment of electric strip heaters on the test vessel.

All 12 cable specimens maintained their energizing potentials and currents (see Table 1) for the duration of the 83-day S/C exposure, except when the circuit was de-energized to measure IR. The lowest measurement of IR for any specimen during the S/C exposure was 5 MΩ at 500 Vdc. IR measurements are summarized in Table 2.

Based on measurements made during the S/C exposure, the pH of the chemical spray during the first 24 hours was 8.0 to 10.5. During the remaining portion of the exposure, the pH of the solution in the bottom of the vessel was maintained between 7.5 and 10.5, except on one occasion when the measured pH was 7.0. Continued dilution with steam condensate and chemical reactions with wetted surfaces slowly reduced the pH of the solution. The solution in the bottom of the vessel was replaced 12 times during the S/C exposure in order to restore the specified pH level.

A post-test view of the cables wrapped around the test vessel mandrel is provided as Figure 7.

5.4 FINAL INSPECTION AND BEND/HIGH-POTENTIAL-WITHSTAND TESTS

Following the S/C exposure, the cables appeared to be in good condition. The #16 AWG cables were limp, and the aged cables appeared to have more whitish chemical deposits on their jackets than the unaged cables. The cables were subjected to a mandrel-bend test around sheet-metal mandrels with diameters of 17 in (0.43 m) for the #16 AWG cables and 22 in (0.56 m) for the #14 AWG cables; the diameter ratios were 39 and 37, respectively. While immersed in tap water, the coiled cables withstood 2000 Vac (#16 AWG) and 2400 Vac (#14 AWG) for 5 minutes. The highest leakage/charging current observed during the high-potential-withstand tests was 3.2 mA.*

on

e

es

rel

*The leakage/charging current was the net result of one or two conductors (each from a separate cable) connected together during the application of 2000 or 2400 Vac (see Section 4.5).

Table 2. Summary of Insulation Resistance Measurements (a,b) (All values are in ohms)

	Measurement Conditions			Cable and Conductor Number							
				1		2		3		4	
Test Program Phase	Temperature (°F)/(°C)	Pressure (psig)/(kPa)	Ground Plane/ Vessel Conditions	1	2	1	2	1	2	1	2
Pre-Irradiation	82/28	0/0	Tap water (c)	1.1×10^{12}	1.1×10^{12}	1.2×10^{12}	1.2×10^{12}	1.2×10^{12}	1.2×10^{12}	6.0×10^{11}	5.2×10^{11}
Post-Irradiation	80/27	0/0	Tap water (c)	1.4×10^{11}	1.2×10^{11}	1.5×10^{11}	1.4×10^{11}	6.2×10^{10}	1.3×10^{11}	9.0×10^{10}	9.5×10^{10}
Pre-S/C Exposure (d)	Room Ambient	0/0	Mandrel and ambient air (e)	5.2×10^{10}	4.5×10^{10}	4.5×10^{10}	6.0×10^{10}	5.0×10^{10}	5.2×10^{10}	3.5×10^{10}	5.4×10^{10}
1.0 h of S/C Exposure (d)	286/141	42/290	Chemical spray on	3.5×10^{7}	4.0×10^{7}	3.0×10^{7}	4.0×10^{7}	3.0×10^{7}	3.5×10^{7}	5.5×10^{6}	6.0×10^{6}
20 h (0.8 d) of S/C Exposure (d)	219/104	4/28	Chemical spray on	2.0×10^{8}	2.0×10^{8}	1.9×10^{8}	1.9×10^{8}	1.9×10^{8}	1.9×10^{8}	1.3×10^{8}	1.4×10^{8}
166 h (6.9 d) of S/C Exposure (d)	210/99	0/0	No spray. Humid air and mandrel (f)	3.8×10^{8}	4.5×10^{8}	4.0×10^{8}	4.0×10^{8}	3.5×10^{8}	4.0×10^{8}	2.2×10^{8}	2.4×10^{8}
1993 h (83 d) of S/C Exposure (d)	212/100	0/0	No spray. Humid air and mandrel (f)	5.0×10^{8}	5.9×10^{8}	5.3×10^{8}	5.7×10^{8}	4.5×10^{8}	5.2×10^{8}	2.9×10^{8}	3.0×10^{8}
Post-S/C Exposure (d)	~86/30	0/0	Vessel flooded with tap water (c)	2.6×10^{10}	2.0×10^{10}	2.2×10^{10}	2.6×10^{10}	1.8×10^{10}	1.9×10^{10}	1.6×10^{10}	2.8×10^{10}

All notes are on page 5-7.

F-C5115

Table 2. Summary of Insulation Resistance Measurements (a,b) (cont.) (All values are in ohms)

Test Program Phase	Measurement Conditions			Cable and Conductor Number							
				5		6		7		8	
	Temperature (°F)/(°C)	Pressure (psig)/(kPa)	Ground Plane/ Vessel Conditions	1	2	1	2	1	2	1	2
Pre-Irradiation	82/28	0/0	Tap water (c)	5.0×10^{11}	5.6×10^{11}	4.0×10^{11}	1.3×10^{11}	1.2×10^{12}	1.1×10^{12}	1.1×10^{12}	1.2×10^{12}
Post-Irradiation	80/27	0/0	Tap water (c)	1.0×10^{11}	1.0×10^{11}	9.0×10^{10}	9.5×10^{10}	4.0×10^{11}	4.0×10^{11}	4.0×10^{11}	4.5×10^{11}
Pre-S/C Exposure (d)	Room Ambient	0/0	Mandrel and ambient air (e)	4.5×10^{10}	5.0×10^{10}	4.0×10^{10}	5.0×10^{10}	5.0×10^{10}	5.4×10^{10}	5.4×10^{10}	5.0×10^{10}
1.0 h of S/C Exposure (d)	286/141	42/290	Chemical spray on	5.3×10^{6}	6.0×10^{6}	5.0×10^{6}	5.2×10^{6}	1.0×10^{7}	1.1×10^{7}	1.0×10^{7}	1.2×10^{7}
20 h (0.8 d) of S/C Exposure (d)	219/104	4/28	Chemical spray on	1.2×10^{8}	1.3×10^{8}	1.1×10^{8}	1.2×10^{8}	1.8×10^{8}	1.8×10^{8}	2.6×10^{8}	2.6×10^{8}
166 h (6.9 d) of S/C Exposure (d)	210/99	0/0	No spray. Humid air and mandrel (f)	2.2×10^{8}	2.3×10^{8}	1.7×10^{8}	1.8×10^{8}	4.5×10^{8}	4.5×10^{8}	5.0×10^{8}	4.5×10^{8}
1993 h (83 d) of S/C Exposure (d)	212/100	0/0	No spray. Humid air and mandrel (f)	3.0×10^{8}	3.5×10^{8}	2.1×10^{8}	2.4×10^{8}	5.0×10^{8}	5.1×10^{8}	5.4×10^{8}	5.3×10^{8}
Post-S/C Exposure (d)	-86/30	0/0	Vessel flooded with tap water (c)	9.0×10^{9}	9.8×10^{9}	1.5×10^{10}	1.7×10^{10}	2.2×10^{10}	2.8×10^{10}	2.4×10^{10}	2.2×10^{10}

All notes are on page 5-7.

F-C5115

Table 2. Summary of Insulation Resistance Measurements (a,b) (cont.)
(All values are in ohms)

Test Program Phase	Measurement Conditions			Cable and Conductor Number							
				9		10		11		12	
	Temperature (°F)/(°C)	Pressure (psig)/(kPa)	Ground Plane/ Vessel Conditions	1	2	1	2	1	2	1	2
Pre-Irradiation	82/28	0/0	Tap water (c)	1.2×10^{12}	1.1×10^{12}	7.0×10^{11}	1.0×10^{12}	7.0×10^{11}	7.7×10^{11}	9.0×10^{11}	1.0×10^{12}
Post-Irradiation	80/27	0/0	Tap water (c)	4.0×10^{11}	4.5×10^{11}	4.0×10^{11}	3.5×10^{11}	4.5×10^{11}	4.0×10^{11}	4.5×10^{11}	4.5×10^{11}
Pre-S/C Exposure (d)	Room Ambient	0/0	Mandrel and ambient air (e)	5.0×10^{10}	5.4×10^{10}	4.0×10^{10}	5.2×10^{10}	4.0×10^{10}	5.2×10^{10}	4.0×10^{10}	5.8×10^{10}
1.0 h of S/C Exposure (d)	286/141	42/290	Chemical spray on	1.0×10^{7}	1.1×10^{7}	8.4×10^{6}	7.8×10^{6}	8.2×10^{6}	7.6×10^{6}	7.0×10^{6}	7.0×10^{6}
20 h (0.8 d) of S/C Exposure (d)	219/104	4/28	Chemical spray on	2.3×10^{8}	2.3×10^{8}	9.8×10^{7}	8.8×10^{7}	9.6×10^{7}	8.5×10^{7}	8.2×10^{7}	7.9×10^{7}
166 h (6.9 d) of S/C Exposure (d)	210/99	0/0	No spray. Humid air and mandrel (f)	5.0×10^{8}	5.0×10^{8}	3.0×10^{8}	4.5×10^{8}	3.0×10^{8}	3.0×10^{8}	2.8×10^{8}	3.0×10^{8}
1993 h (83 d) of S/C Exposure	212/100	0/0	No spray. Humid air and mandrel (f)	5.5×10^{8}	5.5×10^{8}	5.8×10^{8}	5.8×10^{8}	5.8×10^{8}	5.8×10^{8}	4.5×10^{8}	5.0×10^{8}
Post-S/C Exposure (d)	~86/30	0/0	Vessel flooded with tap water (c)	1.7×10^{10}	3.0×10^{10}	2.4×10^{10}	2.0×10^{10}	1.4×10^{10}	1.6×10^{10}	1.8×10^{10}	1.7×10^{10}

All notes are on page 5-7.

Table 2. Summary of Insulation Resistance Measurements (a,b) (cont.)
(All values are in ohms)

Notes:

(a) All IR measurements were made at 500 Vdc held for 1 minute. Measurements were made between each conductor and the other conductor connected to the ground plane, which included the cable mandrel or a copper rod immersed in a tank of tap water, as appropriate.

(b) Additional IR measurements obtained during the S/C exposure and not included in this report were discussed with the client. The resistances were similar to the values listed for 166 hours of the S/C exposure (i.e., between 10^7 and 10^9 Ω). All measurements are on file with the client.

(c) Specimens were immersed in tap water for a minimum of 1 hour prior to IR measurement.

(d) Measurements of IR include the effects of extension cables between the test specimens and the electrical energizing panels.

(e) Mandrel with cables was installed into the test vessel.

(f) Chemical spray terminated; vessel conditions maintained with steam and a pool of heated solution in the bottom of the vessel.

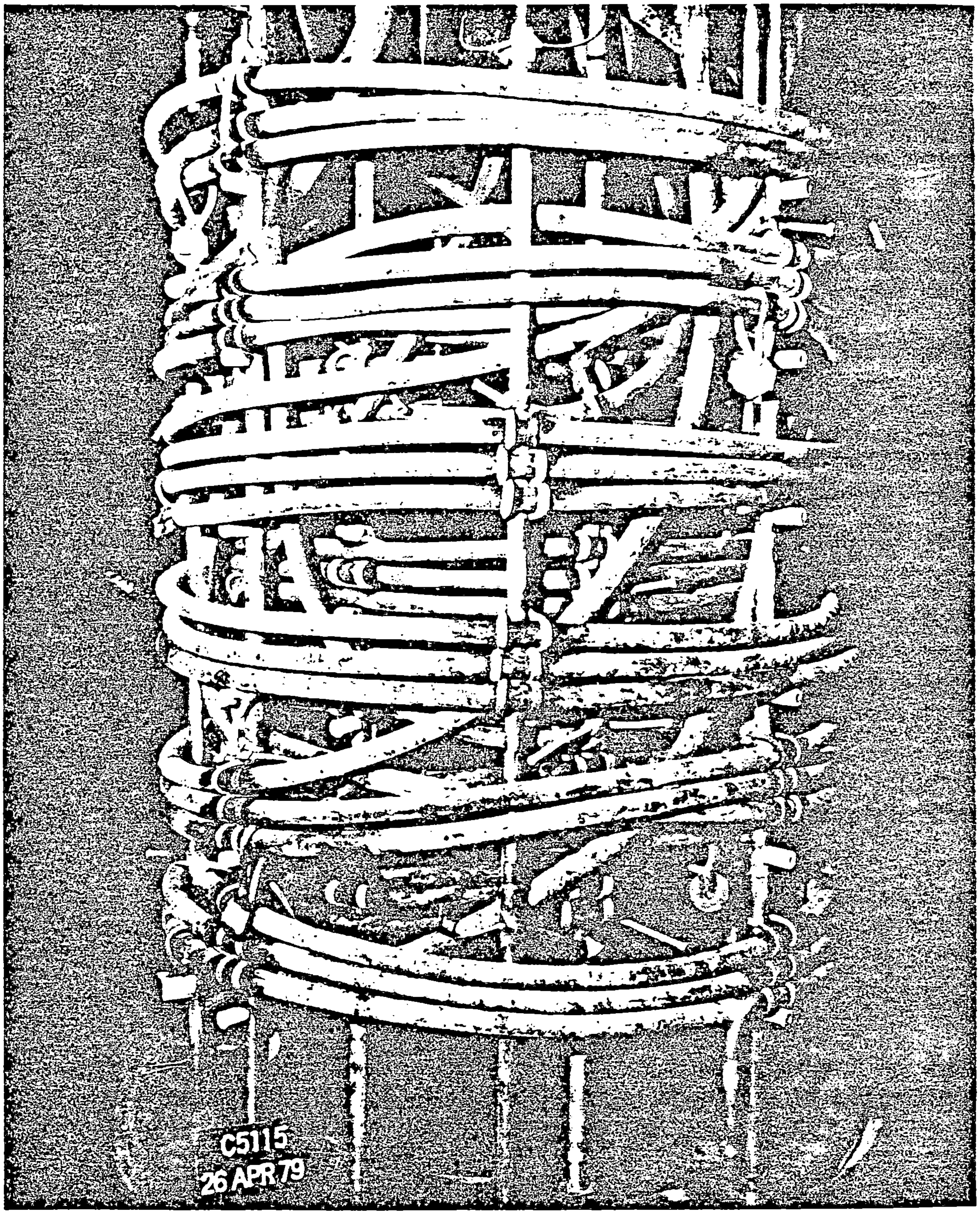


Figure 7. Post-Test View of Cables on Stainless-Steel Mandrel

6. CERTIFICATION

The undersigned certify that this report is a true account of the tests conducted and the results obtained.

G. C. Gambs, Jr.
Project Engineer

D. V. Paulson, Chief
Environmental Testing

APPROVED:

M. M. Reddi, Vice President
Engineering

S. P. Carfagno, Manager
Performance Qualification

List of Data Acquisition Instruments

Appendix A

GENERAL FRC PROCEDURE FOR CALIBRATION OF INSTRUMENTS TO MEASURE TEMPERATURE, ELECTRICAL CURRENT AND LIQUID FLOW RATE

A *List of Data Acquisition Instruments* (hereafter called *Instrument List*) used to measure or record data obtained during this test program is appended. The following remarks are offered to assist the reader in understanding FRC practice for calibrating instruments to measure temperature, electrical current and liquid flow rate.

1. Temperature Measurement

In general, environmental temperatures provided during oven exposures and simulated SLB/LOCA conditions (e.g., steam exposures) are sensed by thermocouples; their signals are displayed and recorded by strip chart recorders with appropriate electronic reference-junction compensation. FRC uses thermocouples and thermocouple wire purchased from vendors who comply with ANSI Standard MC96.1-1975, "Temperature Measurement by Thermocouples," for limits of error (e.g., ± 3/4% over 200°-to-700°F range for ANSI type T). FRC maintains its temperature recorders through a service contract with recorder suppliers who routinely clean, service and calibrate the recorders, traceable to NBS, a minimum of once every four months. The reports of calibration are on file at FRC.

To further substantiate the validity of temperature measurements by thermocouples, FRC maintains special calibrated thermocouples (calibrated at 32°, 212° and 400°F) which are used according to the following procedure:

> On the day a test is started, a calibrated thermocouple is substituted for one of the ANSI-standard-quality thermocouples at the specified oven or test vessel location. (The thermocouples are connected to the recorders with ANSI-standard thermocouple extension wires; Jones-type terminal strips are occasionally included with appropriate thermocouple-metal connecting links.) The calibrated thermocouple is placed in a dewar bath of stirred ice-water for approximately 30 s and then into an insulated flask of actively boiling water for approximately 30 s. If the recorder indicates the temperatures of freezing and boiling water within a tolerance of ± 2°F, the temperature measuring/recording system is considered adequately calibrated for the purposes of the test program. The above *system calibration* procedure is repeated after completion of the oven aging or SLB/LOCA exposure.

2. Electrical Measurement

All electrical measurements are made by instruments with calibrations traceable to NBS. Special circuits are frequently provided to supply current levels requiring *power*-current transformers. In these cases, *instrument*-current transformers are used in conjunction with 5-A movement ammeters to indicate the currents present in the test circuits. These panel-mounted ammeters are calibrated on a program-by-program basis against calibrated ammeters of higher quality.

3. Liquid Flow Rate Measurement

FRC calibrates its liquid flowmeters according to the following procedure:

> The flowmeter is installed in the FRC flow calibration station, which has provisions for adjusting and controlling the flow rate of tap water through the flowmeter. The water is collected in a tank which rests on a beam balance. After steady flow is established, the time for a predetermined mass of water to flow through the flowmeter is measured; time measurements are made with an automatic electric timer.

Most FRC flowmeters are of a concentric orifice-plate type (e.g., Daniel Flow Tube) with a differential-pressure manometer (e.g., Barton Dial Manometer). The orifice and manometer are calibrated *as a system*, although the instruments are identified by separate FRC item numbers. Both the manometer and the orifice are listed in the *Instrument List*.

4. Strip Chart Recorders

As noted in Section 1 above, strip chart recorders are serviced and calibrated a minimum of once every four months. Some recorders respond to voltage inputs other than thermocouple signals and the amount of pen response can be controlled by adjustment of front-panel controls. For these recorders, pen-response calibration is obtained on a program-by-program basis for the specific parameters being recorded. For example, to record pressure the pressure transducer and the recorder are calibrated *as a system* by applying known levels of pressure to the sensor and then recording the amount of recorder pen response. After calibration, the recorder input-amplifier controls remain unchanged, except for occasional minor zero-drift adjustments. The actual calibrations appear on the strip chart. The full-span calibration level (e.g., 0 to 200 psig full scale) is included among the data provided in the *Instrument List*.

INSTRUMENT NUMBER	18018
INSTR AND MFR	SIMPSON VOLTMETER
TYPE/MODEL NUMBER	57 PANEL MOUNTED
SERIAL NUMBER	NONE
RANGE/FEATURES	0 TO 300 VAC
ACCURACY	3.0 PCT. OF F.S.
DATE CALIBRATED	1-29-79
CALIBRATION DUE	7-29-79

INSTRUMENT NUMBER	18079
INSTR AND MFR	AMETEK, PRESSURE TRANSMITTER
TYPE/MODEL NUMBER	50-200-G-B/C
SERIAL NUMBER	10523-1
RANGE/FEATURES	0-200 PSIG
ACCURACY	0.25 PCT. OF F.S.
DATE CALIBRATED	7-25-78 WITH 18187
CALIBRATION DUE	7-25-79

INSTRUMENT NUMBER	18183
INSTR AND MFR	BARTON INSTRUMENT, PRESSURE GAGE
TYPE/MODEL NUMBER	STAINLESS STEEL
SERIAL NUMBER	227-19714
RANGE/FEATURES	0-100 IN. WATER 6000 PSIG STATIC
ACCURACY	0.5 PERCENT OF FULL SCALE DIFF PRESS
DATE CALIBRATED	11-6-78 WITH 18249
CALIBRATION DUE	11-6-79

INSTRUMENT NUMBER	18187
INSTR AND MFR	NORDEN KETAY, PRESSURE GAGE
TYPE/MODEL NUMBER	ACRAGAGE A1S1 316 TUBE
SERIAL NUMBER	1005
RANGE/FEATURES	0-200 PSIG 1 PSI/DIV
ACCURACY	1.0 PERCENT OF FULL SCALE
DATE CALIBRATED	7-25-78
CALIBRATION DUE	7-25-79

INSTRUMENT NUMBER	18221
INSTR AND MFR	ESTERLINE ANGUS SPEED SERVO II
TYPE/MODEL NUMBER	L1102S
SERIAL NUMBER	908001
RANGE/FEATURES	0.5 MILLIVOLT - 100 V.
ACCURACY	0.25 PERCENT OF SPAN
DATE CALIBRATED	1-22-79 5.0 A F.S. BOTH PENS
CALIBRATION DUE	5-22-79

INSTRUMENT NUMBER	18234
INSTR AND MFR	ESTERLINE ANGUS MULTIPOINT RECORDER
TYPE/MODEL NUMBER	E1124E
SERIAL NUMBER	941628
RANGE/FEATURES	24 POINTS 0 - 400 DEGREES F.
ACCURACY	0.25 PERCENT OF FULL SCALE
DATE CALIBRATED	1-22-79 0 TO 400 DEGREES F F.S.
CALIBRATION DUE	5-22-79

INSTRUMENT NUMBER	18241
INSTR AND MFR	HALLTIPLIER CURRENT TRANSDUCER
TYPE/MODEL NUMBER	CT-510 A2
SERIAL NUMBER	NONE
RANGE/FEATURES	0-1 MILLIAMP DC OUTPUT 0-5 A AC INPUT
ACCURACY	0.5 PCT. OF F.S.
DATE CALIBRATED	1-9-79
CALIBRATION DUE	7-9-79

INSTRUMENT NUMBER	18242
INSTR AND MFR	HALLTIPLIER CURRENT TRANSDUCER
TYPE/MODEL NUMBER	CT-510 A2
SERIAL NUMBER	NONE
RANGE/FEATURES	0 TO 1 MILLIAMP DC OUTPUT 0 TO 5 A AC INPUT
ACCURACY	0.5 PERCENT
DATE CALIBRATED	1-9-79
CALIBRATION DUE	7-9-79

INSTRUMENT NUMBER	18249
INSTR AND MFR	DANIEL INDUSTRIES ORIFICE FLOW SECTION
TYPE/MODEL NUMBER	HT-43T
SERIAL NUMBER	NONE
RANGE/FEATURES	0.750 IN DIAM PIPE
ACCURACY	0.75 PCT. OF INDICATION
DATE CALIBRATED	11-6-78 WITH 18183 AND 18361
CALIBRATION DUE	11-6-79 TO 4.98 GPM F.S.

INSTRUMENT NUMBER	18269
INSTR AND MFR	GE AC AMMETER
TYPE/MODEL NUMBER	PANEL MOUNTED WITH CURRENT X
SERIAL NUMBER	NONE
RANGE/FEATURES	0 TO 100 PCT. F.S. 2 PCT./DIV
ACCURACY	2.0 PCT. OF F.S.
DATE CALIBRATED	11-7-78 20 A F.S.
CALIBRATION DUE	5-7-79

INSTRUMENT NUMBER	18287
INSTR AND MFR	ESTERLINE ANGUS TWO PEN RECORDER SERVO II
TYPE/MODEL NUMBER	L1102S
SERIAL NUMBER	908859
RANGE/FEATURES	MV SPAN ADJUST WITH ELECT. T.C. REF. JUNCTS.
ACCURACY	0.25 PCT. OF F.S.
DATE CALIBRATED	1-22-79 0 TO 200 PSIG F.S.
CALIBRATION DUE	5-22-79 0 TO 400 DEGREES F F.S.

INSTRUMENT NUMBER	18292
INSTR AND MFR	GE AMMETER
TYPE/MODEL NUMBER	PANEL MOUNTED WITH CURRENT X
SERIAL NUMBER	NONE
RANGE/FEATURES	0 TO 100 PCT. F.S. 2 PCT./DIV
ACCURACY	2.0 PCT. OF F.S.
DATE CALIBRATED	11-7-78 20 A F.S.
CALIBRATION DUE	5-7-79

INSTRUMENT NUMBER	18353
INSTR AND MFR	SIMPSON AC VOLTMETER
TYPE/MODEL NUMBER	NONE
SERIAL NUMBER	34841
RANGE/FEATURES	0-10 V AC
ACCURACY	3.0 PCT. OF F.S.
DATE CALIBRATED	1-29-79
CALIBRATION DUE	7-29-79

INSTRUMENT NUMBER	18361
INSTR AND MFR	DANIEL ORIFICE PLATE
TYPE/MODEL NUMBER	500
SERIAL NUMBER	NONE
RANGE/FEATURES	0.375 IN DIAM
ACCURACY	0.25 PCT. OF F.S.
DATE CALIBRATED	11-6-78 WITH 18249
CALIBRATION DUE	11-6-79

Acceleration of Post-LOCA Simulation

Appendix B

Acceleration of Post-LOCA Simulation

The initial test plan developed by the client specified that final cable exposure conditions of 152°F (66.7°C)/5 psig (34 kPa), representing post-LOCA conditions, were to be provided for a period of one year. In order to reduce the test duration to a more reasonable value, the Arrhenius model was used to accelerate the post-LOCA exposure.

In accordance with this model, aging of the cable insulation is governed by the following chemical reaction rate equation

$$\frac{dq}{dt} = Ae^{-\frac{\phi}{kT}} = Ae^{-\frac{B}{T}} \qquad (1)$$

where

$\frac{dq}{dt}$ = chemical reaction rate

A = rate constant, usually determined by experiment

B = ϕ/k

ϕ = activitation energy for the chemical reaction, eV, determined by experiment

k = Boltzmann's constant = 0.8617×10^{-4} eV/k

T = absolute temperature, K

By integration and rearranging, Eq. (1) can be rewritten as

$$\ln t_2 = \ln t_1 + B\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \qquad (2)$$

where

t_1 = 1 year = 365-1/4 days = duration at temperature T_1

t_2 = duration of equivalent, accelerated reaction at temperature T_2

T_1 = 340 K (T_1 = 66.7°C + 273.2)

T_2 = absolute temperature (K) of accelerated reaction ($T_2 > T_1$)

The value of B determined by AIW was 6086 K. Using this in Eq. (2) yielded the following sets of values for T_2 and t_2:

T_2	t_2
204°F (95.5°C)	90 days
209°F (98.3°C)	80 days

The value of 80 days at 209°F (98.3°C) was selected. The actual length of the S/C exposure at 209°F (98.3°C) was 82 days, two days longer than the calculated t_2, to account for periods when the vapor temperature in the test vessel was slightly below 209°F (98.3°C).

Certification of Irradiation

Appendix C

ISOMEDIX

January 23, 1979

Mr. David Paulson
Franklin Research Labs
20th & Cherry Streets
Philadelphia, Pa. 19103

Dear Mr. Paulson:

This will summarize parameters pertinent to the irradiation of your mandrel Project #C5115 containing Cables #1 through #12, per your order 42419 dated December 29, 1978.

The mandrel was placed in a Cobalt-60 gamma field and exposed at each of 4 quadrants as marked. By integrating the dose rate at any point on the mandrel during its 4 position exposure an average dose rate was obtained which, when multiplied by the total exposure time yields the total dose.

Mandrel C-5115 was exposed for a period of 311.4 hours at an average dose rate of .66 Megarads per hour, yielding a total dose of 205.5 Megarads.

Dosimetry was performed using an Atomic Energy of Canada, Ltd. (AECL), Red Perspex system with Type BC-2 readout. Calibration of the Perspex is made by AECL using Ceric dosimetry traceable to the U.S.National Bureau of Standards. Isomedix regularly cross-calibrates its AECL system with an in-house Harwell Perspex system, and makes semi-annual calibrations directly with NBS, using the NBS Radiochromic Dye system. A copy of the dosimetry correlation report is available upon request.

Irradiation was conducted in air at ambient temperature and pressure. Radiant heat from the source heated the samples somewhat, but the temperature did not exceed 85^{O}F, as indicated by previous measurements on an oil solution in the same relative position.

Irradiation was started on date of receipt December 30, 1978, and was completed on January 21, 1979.

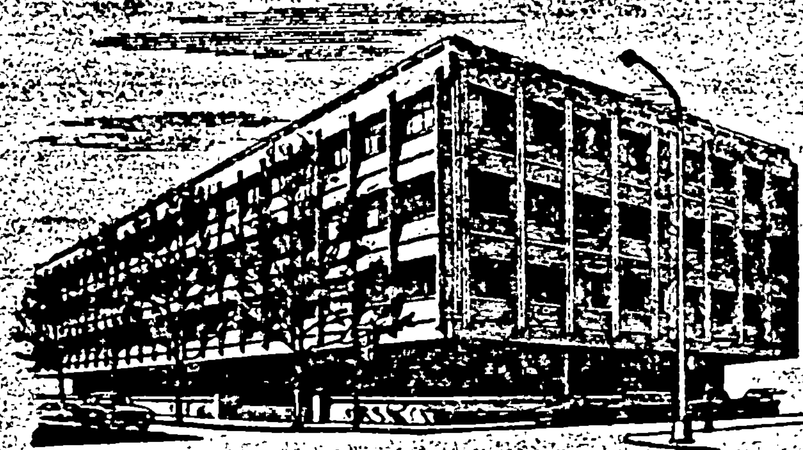
Very truly yours,

Louis Castaldi

Louis Castaldi
Ass't. General Manager

LC:km

Isomedix Inc. • 25 Eastmans Road, Parsippany, New Jersey 07054 • (201) 887-2666



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