

QUALIFICATION OF CABLES TO IEEE STANDARDS

323-1974 and 383-1974

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ABSTRACT

Wire and Cable manufacturers generally qualify products for class IE application by envelope type testing to user specifications and environmental conditions recommended by IEEE Standards 323-1974 and 383-1974. The General Electric Wire and Cable Business Department recently completed two such qualification programs. Cable constructions tested were 600V control cables and 600V, 2KV, and 15KV power cables insulated with flame resistant mineral filled crosslinked polyethylene. The 15KV samples included taped field splices.

To determine the ability of samples to withstand a loss of coolant accident (LOCA) both early in and at the end of design life, both thermally aged and unaged cables were irradiated and subjected to a 100 day plus 10 day margin simulated LOCA test. Samples were heat aged to a time-temperature condition in excess of 40 years of service life. The aging criterion was determined from experimental data fitted to an Arrhenius curve by the Regression Method of IEEE Standard 101-72. All test specimens were irradiated using a Cobalt 60 source to a total integrated dose of 220 Mrad. The simulated LOCA conditions of one test program followed the combined requirements for Boiling Water Reactors and Pressurized Water Reactors. In the second test program, the steam pressure-temperature profile included a simulated main steam line break. Test specimens were wrapped on grounded mandrels and were electrically loaded throughout the simulated LOCA tests. After completion of environmental testing, samples were subjected to the IEEE 383 simulated post-LOCA test. As part of the Class IE qualification program, IEEE 383 vertical tray flame tests at 70,000 Btu/hour were conducted on trays with standard (single layer) cable fill. In addition, more severe vertical tray tests were conducted at 210,000 Btu/hour and 400,000 Btu/hour using both single layer and 40% tray fills.

INTRODUCTION

Wire and cable manufacturers generally attempt to qualify products designed for Class IE use to a set of conditions that encompass industry standards as well as specific requirements of nuclear power generating stations. IEEE Standards 323-74¹ and 383-74², which are guides for Class IE equipment qualification and electrical cable type testing, have been more or less accepted as minimum requirements. Cables are usually qualified by type testing of representative samples. Recommended categories based on cable construction and/or voltage class and samples considered representative are given in IEEE-383. Generic qualification of materials is generally not acceptable, since differences in formulation or processing can alter material properties and aging characteristics.

Due to growing concern for nuclear plant safety and technological advances, user specifications for Class IE products are becoming increasingly more stringent. Changing nuclear plant requirements and industry expectations necessitate continual product development and product re-evaluation by wire and cable manufacturers. The General Electric Wire and Cable Business Department undertakes a qualification program at an independent laboratory approximately every two years in order to test already qualified products to more stringent Class IE requirements and to evaluate new insulations and jackets which incorporate the most recent advances in materials technology.

In ongoing qualification programs, the General Electric Wire and Cable Business Department tests a variety of cables to the requirements of IEEE Standards 323 and 383. In one test program, 600 Volt and 2kV cables were subjected to a combined Design Basis Event (DBE) for Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR). In a second qualification program, 15kV power cable assemblies were subjected to a simulated Steam Line Break (SLB) superimposed on the postulated combined PWR/BWR environmental conditions. The medium voltage 15kV power cable samples included field splices. The cable qualification programs for class IE application and results are presented in this paper.

TESTING TO IEEE 323 AND 383 STANDARDS

Cables for Class IE applications must be qualified for operation under normal service conditions and must meet the criteria of an industry standard such as ICEA, ANSI, or AEIC. In addition, the cable, both in its installed condition and at the end of design life, must be capable of operating through a postulated DBE until safe reactor shutdown is achieved. IEEE Standard 383-74 type tests require cable aging to the end of design life, followed by simulated loss of coolant accident (LOCA) and post-LOCA testing. Aging to the end of design life involves both radiation and thermal exposure and is usually accomplished by accelerated techniques. In simulated LOCA testing, aged and fully energized cable samples are subjected to severe environments of steam pressure, elevated temperature and chemical spray for a prolonged duration. The post-LOCA test requires flexing followed by an electrical high potential test to demonstrate the mechanical and electrical integrity of the cable. Finally, the relative ability of cables to resist fire must be demonstrated by type testing of grouped cables in a vertical tray flame test at 70,000 Btu/hour.

Qualification of field splices for Class IE application requires type testing of cable assemblies, i.e., field splices with cable, to demonstrate electrical, mechanical, and chemical compatibility in a postulated DBE. The pre-conditioning, simulated LOCA, and post-LOCA tests required for Class IE cable qualification are minimum requirements for cable assemblies. Additional preconditioning such as vibration and thermal load cycling are required to simulate stresses on the connector and splice during design life.

Test Sample Description

All cables subjected to the General Electric IEEE 323 and IEEE 383 qualification programs were insulated with nonchlorinated compounds generically classified as mineral filled chemically crosslinked polyethylene (MF-XLPE). The jacket compounds evaluated are generically classified as chlorosulfonated polyethylene and chloroprene. The samples were of the following basic constructions:

Table I - Test Sample Construction

1/C 600V Power Cable 0.76mm (0.030m) Insulation, no jacket
7/C 600V Control Cable 0.76mm (0.030m) Insulation, 1.52mm (0.060m) overall jacket
1/C 2kV Power Cable 1.78mm (0.070m) Insulation, no jacket
1/C 15kV Power Cable with field splice 4.45mm (0.175m) Insulation, copper tape shield, 2.03mm (0.080m) jacket

Prior to submittal for qualification, 600V power and control cables had been fully tested to ICEA S-66-524³, and 15 kV power cables had been tested to the requirements of ICEA S-66-524 and AEIC-5-75.⁴

The field splices of the 15kV medium voltage power cable consisted of a Burndy Corporation compression connector and a 3M nuclear design taped splice. The Burndy connector was a tin-plated, high conductivity conductor joint designed for high voltage cable splices and Class IE application. The taped splice provided continuity between cable layers of conductor shield, insulation, insulation shield, cable tape shield, and jacket. Before submittal for qualification for class IE applications, tests were conducted to determine the power factor and ionization level characteristics of the 15kV cable assemblies.

Cable Assembly Preconditioning

The 15kV cable assemblies were subjected to a preconditioning sequence that included vibration and load cycle testing. The preconditioning was conducted to simulate the electrical and mechanical stresses on the splice during normal life. This phase of the program was developed and carried out by Burndy Corporation.

Each cable assembly was subjected to vibrations in the frequency range of 5 hz to 60 hz in two mutually perpendicular planes. After vibrational testing, the 15 kV samples were subjected to current load cycle tests. The load current produced a conductor temperature of 125°C. Approximately 55 load cycles were performed on each sample. During the preconditioning sequence, the conductor resistance was measured periodically.

Thermal Aging to End of Normal Design Life

The design life of cable insulation under normal 90°C service conditions was determined by accelerated thermal aging and the Arrhenius technique. Per IEEE-383-74, accelerated aging was conducted at three temperatures; one aging temperature was 136°C, and the others were 150°C and 160°C which meet the IEEE 383 requirement that the test temperatures be at least 10°C apart. Since oxidation is the primary degradation process for cable insulation, samples were aged in circulating air ovens. The degree of insulation degradation due to aging was determined by measurements of elongation. This parameter was selected since embrittlement or loss of elongation is well correlated to cable failure, and results are quite reproducible.

The thermal aging of cable insulation is a complex phenomenon involving an initiation period, and probably more than one reaction and activation energy. A typical aging profile of MF-XLPE insulation is shown in Figure 1. The elongation as a function of increasing

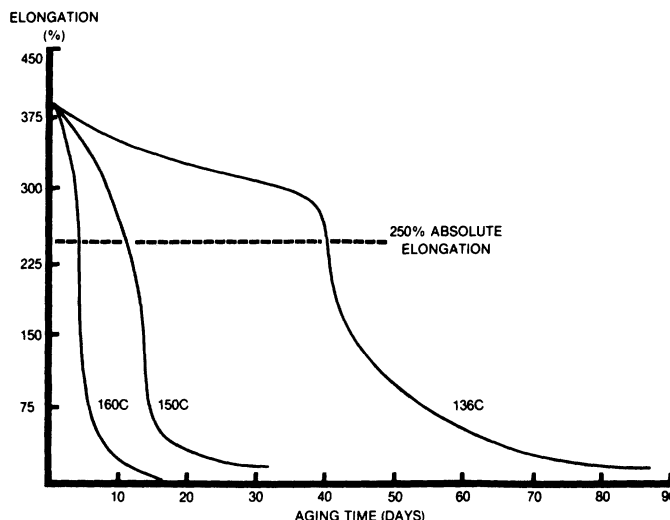


Figure 1. Aging Characteristics of MF-XLPE Insulation

aging time shows an initially slow decrease, followed by a relatively fast degradation, after which the elongation approaches a low, constant value. No procedure has been established for selecting an end of life criterion from aging data. However, the Arrhenius technique is only strictly valid for first order chemical reactions, which imposes a constraint on end point selection. Analysis of the aging profiles showed that the decrease of absolute elongation with time in the range of 250% - 10% elongation was described by a first order chemical reaction. The end of life criterion selected was an absolute elongation of 250%, which corresponds to 65% retention of initial elongation of unaged material. This value is equal to the absolute elongation required by ICEA Standards for unaged materials. This high end of life criterion provides a margin of safety, and insures that at the end of service life the insulated cable continues to be electrically reliable and maintains a high degree of flexibility.

From the aging curves, the times required to reach 250% elongation at the several aging temperatures were determined and were used to establish the Arrhenius plot shown in Figure 2. The thermal life test

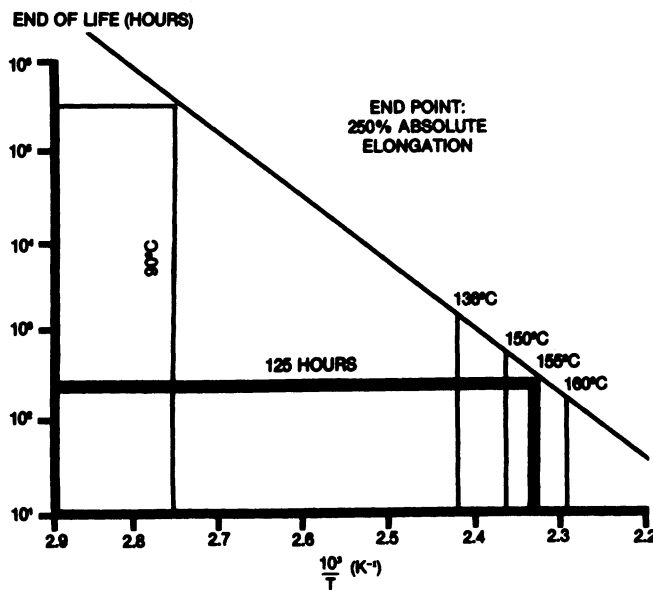


Figure 2. Arrhenius Curve for MF-XLPE Insulation

data were statistically fitted to the Arrhenius curve by linear regression analysis per IEEE Standard 101-1972⁵. Extrapolation of the accelerated aging data shows that the predicted service life of MF—XLPE insulation at 90°C is over 350,000 hours (over 40 years). The importance of using a regression analysis to extrapolate the thermal aging data should be emphasized since extrapolation by eye can result in an error in predicted service life as large as 50%. The use of a less severe end point, i.e. an elongation less than 250%, would have increased the predicted service life. For example, an end point of 10% elongation would have predicted a 90°C service life of almost 60 years; however, at the end of a 60 year life, the insulation would have been highly embrittled and readily subject to electrical failure.

Another parameter sometimes used in the industry to measure degree of insulation degradation due to thermal aging is dielectric strength of the cable wrapped around a 2X mandrel. The selected dielectric strength end point of 3.2kV/mm (80v/mil) is extremely low and probably corresponds to highly embrittled insulation with an absolute elongation less than 10%.

Insulated cables were subjected to accelerated aging simulating an excess of 40 years service at 90°C. Aging temperatures and times were established from Arrhenius curves. For the insulation shown in Figure 2, an aging period of 125 hours at 165°C was selected. In all cases, the aging time exceeded 100 hours, which is the minimum specified by IEEE Standard 323.

The 15kV cable assemblies were aged to the end of design life of the cable insulation.

Radiation Exposure

Radiation exposure degrades cable insulation materials, and high dosages could adversely affect cable Class IE functions. In accord with IEEE Standard 323-1974, insulated cables are required to undergo radiation exposure which simulates the radiation exposure expected to occur during both normal service and postulated accidents. The in-containment DBE integrated radiation dosages for Pressurized Water Reactors and Boiling Water Reactors are given in IEEE-323-1974. Compared to the BWR, the expected DBE radiation dosage in the PWR is considerably higher. The severe PWR radiation exposure of 150 M rad was selected as the DBE cumulative radiation dose for the General Electric cable type tests. The total integrated radiation dose simulating 40 years normal service is 50 M rad, as specified by IEEE-383-1974. The radiation dosage for normal service aging is usually combined with the DBE radiation for a PWR, for a total integrated radiation dose of 200 M rad. IEEE-323-1974 recommends a 10% higher radiation dose (220 M rad) as a provision for adequate margin. The total dosage of 220 M rad approaches the maximum that can be endured by most organic insulation materials without severe degradation.

After thermal aging, cable samples mounted on mandrels were irradiated to a total integrated dose of 220 M rad, which simulated 50 M rad normal life, 150 M rad predicted DBE exposure, and 20 M rad margin. The samples were irradiated by a Cobalt 60 gamma source at an average dose rate of 0.5 M rad/hour. During the exposure time, the samples were rotated 90 degrees approximately every 100 hours. Dosimetry was performed using a Victoreen Model 555 Integrating Dose Meter and Probe.

Loss of Coolant Accident

Type testing to IEEE 323 and 383 requires subjecting nonaged and aged cables to environmental extremes which simulate the postulated conditions of a LOCA. These environmental conditions include prolonged exposure to extreme temperature, pressure, and moisture. Representative profiles of the conditions expected within BWR and PWR containment areas are given in IEEE Standard 323-1974. Cables can be simultaneously qualified for PWR and BWR Class IE application by testing to a set of conditions which encompasses

the postulated DBE environments of both reactor types. An example of such an envelope DBE profile is shown in Figure 3. This profile includes both the PWR chemical spray and the BWR severe temperature/pressure conditions. A postulated LOCA is expected to include only one initial environmental transient. However, cables are generally type tested to two severe steam/chemical transients to demonstrate adequate margin between postulated service and simulated test conditions.

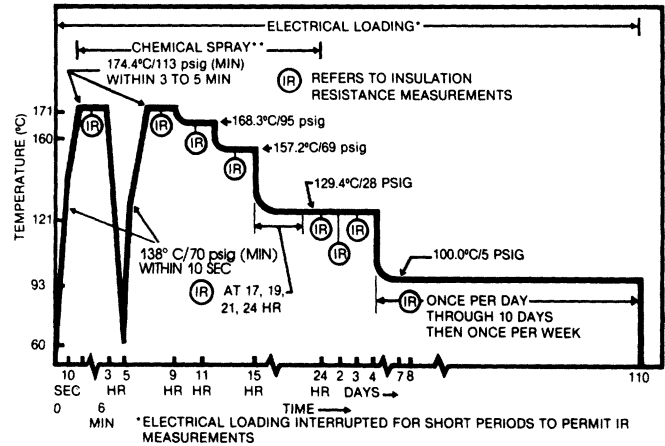


Figure 3. Postulated DBE Environment for Combined PWR/BWR

The postulated DBE environments of nuclear generating stations under design are, in some instances, more severe than the IEEE profiles. User specifications sometimes require type testing to conditions which include a postulated main steam line break (SLB). A postulated LOCA profile with a superimposed SLB is more severe than the combined PWR/BWR profile in terms of required temperature/pressure conditions and duration of chemical spray. Postulated environmental conditions of a combined BWR/PWR LOCA profile with a superimposed main steam line break are shown in Figure 4.

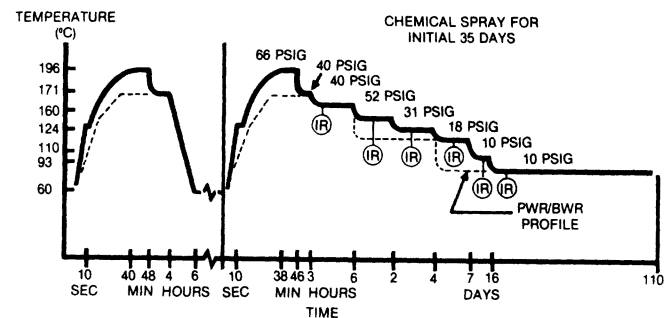


Figure 4. Postulated DBE Environment for Combined PWR/BWR with Superimposed SLB

Test samples of 600 volt and 2 kV constructions were subjected to the simulated DBE conditions of Figure 3. The test duration was 110 days which corresponds to the 100 day BWR test duration plus a 10 day margin. During the first 24 hours of the test period, a sodium

hydroxide-boric acid chemical solution having a pH between 8.5 and 10.5 was applied. Medium voltage 15 kV power cables containing splices were subjected to the temperature/pressure/chemical spray conditions of Figure 4. This 110 day test profile incorporates the simulated SLB, and requires longer dwells at higher temperatures and a longer duration of chemical spray than the combined PWR/BWR profile.

The 15 kV cable assemblies after thermal and radiation aging and prior to LOCA testing are shown in Figure 5. The samples mounted on grounded mandrels were installed in pressure test vessels. The 600 volt power and control cable installation is shown in Figure 6. Throughout both simulated LOCA tests, the samples were energized at 110% rated voltage and normal load current. The load currents were determined from ICEA ampacity tables, and are the levels corresponding to a 90°C conductor temperature for cables in trays. At each temperature/pressure plateau, the electrical load was interrupted, and the insulation resistance was measured.

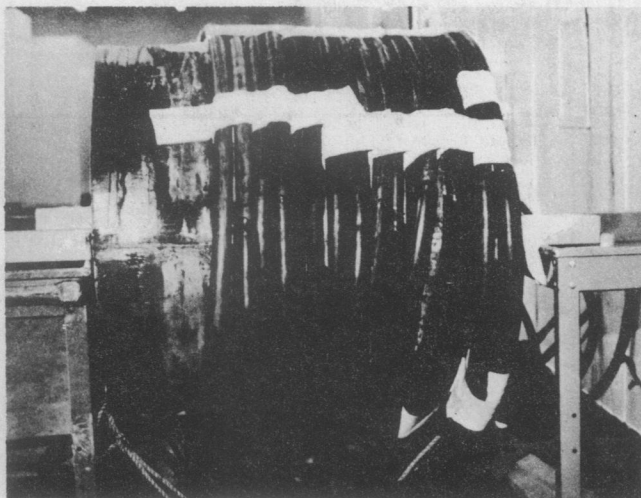


Figure 5. 15 kV Cable Assemblies after Thermal and Radiation Aging

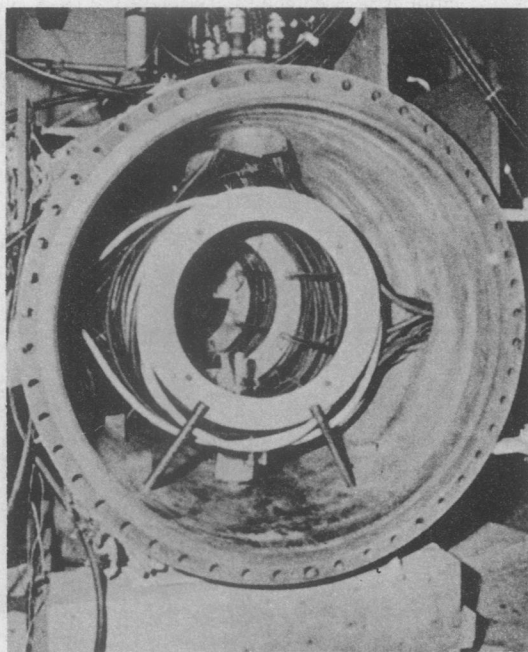


Figure 6. Installation of 600 V Power and Control Cables

At the completion of the 110 day simulated DBE test, the 600V and 2 kV samples were subjected to the IEEE-383 post-LOCA simulation test. The samples were removed from the test mandrel, straightened, and reverse wrapped around a metal mandrel having a diameter 40 times the overall cable diameter. The coiled samples were immersed in room temperature tap water, conditioned for one hour, and subjected to a 5 minute dielectric withstand test at 3.2 kV/mm (80V/mil). The test samples, which had been thermally and radiation aged to a simulated 40 year end of life condition and subjected to a DBE radiation dosage and postulated DBE pressure/temperature/chemical spray environment, successfully passed the dielectric withstand test. The 600 volt power and control cables and 2 kV power cables insulated with MF-XLPE met the requirements of the Class IE test program to IEEE 323 and 383 standards.

The 15 kV medium voltage cable assemblies recently completed the 110 day simulated DBE with superimposed main steam line break. Post-LOCA simulation tests have not yet been performed.

Flame Resistance

To demonstrate that grouped cables do not propagate flame, IEEE-383-74 requires a vertical tray flame test on representative cable constructions. The apparatus consists of a vertical metal ladder tray 2.4m (eight feet) high, 30.50 cm (12 inches) wide, and 7.6 cm (3 inches) deep. The center 14.4 cm (6 inches) of the tray is filled with a single layer of cables spaced approximately one half cable diameter apart. The flame source is a 25.4 cm (10 inch) wide ribbon type gas burner placed 0.6 m (two feet) above the bottom of the tray and 7.6 cm (three inches) from the test specimens. The test procedure specifies a flame temperature of 1500°F in the vicinity of the test samples, which corresponds to a heat input of 70,000 Btu/hr. The flame is allowed to burn for 20 minutes, after which duration of after burn and distances of jacket char and insulation damage are measured. Cables which propagate flame and burn the total height of the tray fail the test. The IEEE-383 flame test arrangement is shown in Figure 7. The 70,000 Btu/hr vertical tray flame test was conducted on 600V 7/C control cables with nonchlorinated MF-XLPE insulation and various jacket materials. To qualify 2 kV - 15 kV power cable, type tests were conducted on #2 AWG 2 Kv and #4/0 AWG 15 Kv power cables insulated with MF-XLPE.

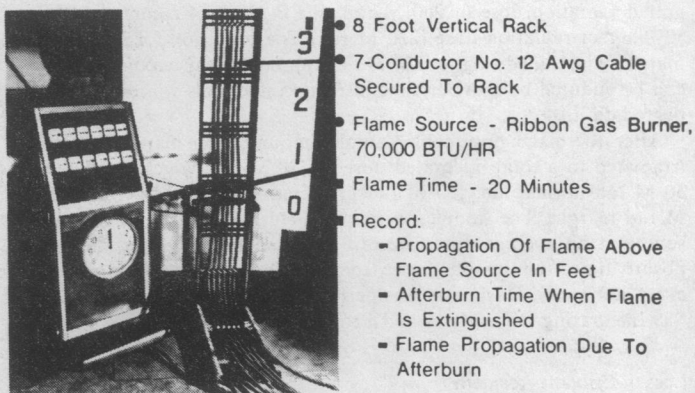


Figure 7. IEEE 383 Vertical Tray Flame Test

Due to concern for ample safety margins in nuclear power generating stations, there is a growing trend to require flame tests more severe than the minimum required by industry standards. User specifications increasingly require cables to pass vertical tray flame tests at higher heat inputs of 210,000 Btu/hr and 400,000 Btu/hr, often

using tray fills of 40%. The 210,000 Btu/hr and 400,000 Btu/hr tests are more severe than the 70,000 Btu/hr test provided that the burner-to-tray spacing is increased to maximize impingement of the flame on the samples. The most severe test conditions are burner-to-tray spacings of 34 cm (13.5 inches) for 210,000 Btu/hr and 51 cm (20 inches) for 400,000 Btu/hr. The tray fill of 40% often specified is more representative of actual tray loading than the single layer fill. This higher tray fill contains more fuel for combustion and is more severe than the single layer test provided the fire is not oxygen limited. To maximize the severity of the 40% fill vertical tray test, the fill must be random, allowing air gaps between the numerous lengths of cables.

Flame tests at higher heat inputs were also conducted on 600V 7/C control cable and #4/0 AWG 15 kV power cable with nonchlorinated MF-XLPE insulations. Tests on 7/C control cables were performed using both single layer and 40% fills. Table II compares data obtained under different flame test conditions. The General Electric cables tested to Class IE requirements far exceed the minimum industry standard for flame resistance.

**TABLE II.
RESULTS OF VERTICAL TRAY FLAME TEST
ON QUALIFICATION CONSTRUCTIONS**

CABLE DESCRIPTION	TRAY FILL	FLAME SOURCE (BTU/HR.)	BURNER-TRAY SPACING		AVERAGE PROPAGATION DISTANCE*			
			CM	IN	JACKET		INSULATION	
					METERS	FEET	METERS	FEET
7/C #12 AWG 600V CONTROL CABLE	IEEE 6 CABLES	70,000	7½	3	0.8	2.8	0.8	2.5
	IEEE 6 CABLES	210,000	7½	3	1.1	3.6	0.6	2.0
	IEEE 6 CABLES	210,000	34	13½	1.4	4.7	1.1	3.7
	40% 52 CABLES	210,000	34	13½	1.3	4.2	—	—
	40% 52 CABLES	400,000	51	20	1.8	5.8	—	—
1/C #2 AWG 2kV POWER CABLE	IEEE 9 CABLES	210,000	7½	3	1.1	3.5	0.7	2.3
1/C #4/0 AWG 15 kV POWER CABLE	IEEE 4 CABLES	70,000	7½	3	1.4	4.8	0.9	3.1
	IEEE 4 CABLES	210,000	7½	3	1.7	5.7	1.2	4.0

*MEASURED FROM BURNER. PASS-FAIL CRITERION FOR 70,000 BTU/HR. IEEE-383 TEST IS 1.8M (6 FT.)

In response to user concern regarding the long term stability of flame retarded cables, flame resistant control cables and medium voltage power cables were thermally aged to 40 years as indicated by the Arrhenius plot. The aged cables successfully passed the IEEE-383 vertical tray flame test at 70,000 Btu/hr. Distances of jacket char and insulation damage were approximately the same for unaged and aged cables, demonstrating that the flame retardant system is stable and provides protection throughout normal service life.

Power cables and single conductors of control cables rated 2 kV or less are also required to pass the vertical flame test of ICEA S-19-81,⁶ Section 6.19.6 (ASTM D2220-68). All 600V and 2 kV power cables included in the test program had successfully passed this test as part of the ICEA-66-524 qualification.

CONCLUSIONS

The General Electric qualification programs illustrate the method of envelope type testing cable products to IEEE Standards and user specifications. Qualification for Class IE application requires severe and extensive conditioning and testing, and includes:

- Thermal aging to end of design life
- Radiation aging to end of design life
- Simulated LOCA

- Post-LOCA mechanical and electrical testing
- Grouped cable flame tests

The General Electric Wire and Cable Business Department successfully completed a comprehensive test program to environmental conditions well in excess of industry requirements. Samples were aged to a condition in excess of 40 years normal service life, and ten per cent safety margins were added to radiation aging and postulated LOCA dosage, simulated LOCA test duration and electrical loading during LOCA. In addition, medium voltage 15 kV power cable assemblies were tested to an environmental profile more severe than IEEE 323 requirements. Representative cable constructions passed not only the minimum flame requirements of IEEE 383, but also the more severe flame test requirements often specified by users, which are vertical tray flame tests at 210,000 Btu/hr and 400,000 Btu/hr with a random tray fill of 40%. The tray fill of 40% more closely simulates actual installation. In addition, cables thermally aged to 40 years passed the IEEE 383 flame test, demonstrating that the flame retardant chemistry of the cable is stable and provides protection throughout the expected service life. The results of these qualification programs demonstrate the electrical, mechanical and flame resistant stability of MF-XLPE insulated cables.

The qualification testing performed was well in excess of current minimum industry requirements, and provides the user with a safety margin that may anticipate possible future increases in environmental and flame resistance requirements.

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