INVESTIGATION OF RAYCHEM CABLE INSTALLED IN THE BRUNSWICK PLANT

PHASE 2—EVALUATION AND TEST RECOMMENDATION

NRC CONTRACT NO. NRC-05-81-247

TASK ASSIGNMENT NO. EL-114

FRC REPORT NO. F-C5569-3002

FRC PROJECT NO. C5569

FRC TASK NO. 3002

Prepared by

K. E. Weise

Prepared for

Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

June 30, 1982

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

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TABLES

1. INTRODUCTION

This report details the Phase 2 investigation of certain electrical cable used in Class 1E service at Carolina Power and Light Company's Brunswick plant. The cable under investigation is unshielded multiconductor Flamtrol cable manufactured by the Raychem Corportion, rated at 1000 V with combined conductor and jacket insulation thickness of 0.12 in or greater.

The conductor insulation in multiconductor 1000-V Flamtrol cable having a combined insulation thickness of 0.12 in or greater (e.g., 0.045-in conductor and 0.08-in jacket cross-linked polyethylene insulations*) was observed in several tests to have different insulation properties than other Flamtrol cables [1, 2, 3]. Of particular concern was a tendency of conductor insulation to experience dielectric breakdowns in water at voltage levels considerably below those expected for polyethylene cable.

Flamtrol cable is a fire-retardant, radiation cross-linked cable. It was theorized that the use of an electron beam of insufficient energy resulted in inadequate penetration of the assembled cable and, as a direct consequence, caused a space charge buildup in the conductor insulation [3]. Subsequent relief of the accumulated space charge resulted in changes in the characteristics of the conductor insulation.

In the Phase 1 evaluation, a review was conducted of available information in NRC files on Flamtrol cable, with emphasis on cable installed in Carolina Power and Light Company's Brunswick plant [5]. A recommendation of this evaluation was that functional testing under simulated loss-of-coolant-accident (LOCA) and submergence conditions be performed on Flamtrol cable with combined jacket and conductor insulation thicknesses of 0.12 in or greater. Testing was recommended because it is the most direct method for resolving the technical issue (especially in view of difficulties and uncertainties in making analytical predictions of cable performance under long-term accident

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*It is common practice to refer to this cable by its aggregate jacket and conductor insulation thickness as 0.125-in insulated cable.

conditions) and because it would provide the greatest assurance of the functional capability of Flamtrol cable.

The Phase 1 technical evaluation report and NRC file documentation revealed that review of space charge phenomenonological considerations was important for assessing cable functional capability and could affect possible cable testing requirements. Furthermore, it was observed that cable jackets on other Raychem Flamtrol cables had exhibited unusual durability when tested under simulated LOCA conditions. Therefore, the Phase 2 investigation of Flamtrol cable included a review of the space charge phenomenon as related to possible cable damage mechanisms resulting from the jacket cross-linking process. The Phase 2 investigation also included a determination of whether analytical considerations of space charge and jacket integrity based in part on existing LOCA test data on other Flamtrol cable [6] could be employed to confirm the capability of Flamtrol cable with insulation thicknesses 0.12 in and greater under accident conditions.

The space charge phenomenon and possible damage mechanism occurring in radiation cross-linked cable are discussed briefly in Section 2 of this report; an expanded discussion appears in Appendix A. Section 3 includes an engineering opinion that insulated Flamtrol cable having combined insulation thicknesses of 0.12-in or greater can perform adequately under normal service conditions, provided that certain conditions are met. Section 3 also discusses the possibility of analytically predicting cable performance, especially under design basis accident conditions; however, it is concluded that an analytical solution is not possible. Section 4 reviews testing considerations for confirmation of functional capability of Flamtrol cable in design basis accident environments. A listing of operating reactor plants with Raychem cable installed in harsh environmental areas is furnished in Section 5. Appendix B provides additional information on qualification documentation cited by plant licensees.

2. SPACE CHARGE EFFECTS IN INSULATION RESULTING FROM ELECTRON IRRADIATION

This section reviews the physical model of space charge buildup in cables irradiated with an electron beam. A brief discussion is provided here, and a more detailed description of the theoretical background and effects of space charge formation is provided in Appendix A of this report.

When a dielectric is exposed to a beam of electrons, some of the electrons will be captured in the dielectric. If the maximum range of the electron beam is smaller than the thickness of the dielectric, a negative space charge is introduced and an internal electric field is produced. If the charge density continues to build up indefinitely, the internal field will eventually exceed the dielectric breakdown strength and cause an arc discharge.

Recently, certain cables with polymer insulations have been subjected to electron beam irradiation during manufacture for the purpose of cross-linking the polymer molecular chains, thereby improving the physical characteristics of the insulation. However, as stated above, under an intense electron beam, a space charge can build up in the cable.

The formation of a space charge region and the subsequent creation of an electric field within the cable can lead to a spontaneous discharge in the insulator as the buildup of space charge reaches a threshold. This threshold for breakdown in dielectrics corresponds to an electric field intensity on the order of 0.3 to 2 million V/cm. In unshielded cable, where it is common practice to ground the conductor(s) during irradiation, discharge occurs from the region of trapped space charge, through the dielectric, to the conductor. The discharge can also be caused by touching the dielectric with a pointed metallic object.

The spontaneous or induced discharge can result in localized decomposition of the insulation, often in the form of small tree-like patterns. Conducting paths can be formed along these "trees" due to the carbonization of the dielectric. If spontaneous discharge occurs at numerous places, degradation and eventual breakdown of the cable insulation can be expected.

Quantification of such damage, however, is difficult. In addition to the uncertainties of the breakdown threshold, which depends on the properties of the insulators, other factors relating to the space charge buildup have to be accurately assessed. These factors include the electron beam energy, the beam intensity, and the irradiation time. Above all, it is not certain how the degradation in cable is quantitatively correlated to the formation of the carbonized treeing paths, nor is it clear how the density of the trees can be quantified in any accurate fashion.

3. FUNCTIONAL CAPABILITY OF FLAMTROL CABLE

3.1 ASSESSMENT OF FLAMTROL CABLE ADEQUACY IN NORMAL SERVICE CONDITIONS

Review of the space charge phenomenon in cable indicates that electron penetration of the jacket with minimal space charge buildup in the jacket is possible. Space charge buildup due to trapping of free electrons, with subsequent discharge to grounded conductors, appears to be limited to the interior regions of the cable (i.e., individual conductor insulation). Although predictions of the spatial electron density in multiconductor cable geometry is not possible with the limited data available, several conditions exist which strongly suggest that damage is limited to the conductor region:

1. An irradiation beam of 2 MeV electrons was reportedly used during cable fabrication. The predominant range for space charge buildup is between 0.20 and 0.30 in for a beam of this energy. This range places the space charge well into the conductor insulation region of multiconductor cables.
2. Dissipation of the space charge can occur at any time from seconds to weeks after formation. Since conductors are at ground potential during jacket cross-linking, an immediate avalanche discharge toward the conductors is expected.
3. Immediate discharge results in greater electron currents than does gradual discharge. The electron currents, if great enough, can produce tree-like figures, in which the paths are carbonized.
4. Discharge paths from the conductor insulation region through the jacket would require traversing of a much greater insulation thickness. The time for gradual charge dissipation for "ungrounded" jackets would be much greater than that for insulation surrounding grounded conductors, i.e., the discharge paths would be expected to be in the conductor insulation, terminating at the conductor.

Numerous tests, including the LOCA test described in Reference 6, provide some assurance that the electron beam irradiation process used by Raychem does result in adequate cross-linking of polyethylene cable jackets for cables smaller than 0.12 in. For example, simultaneous exposure to steam, chemical spray, and radiation resulted in negligible jacket damage during simulated LOCA testing. Polyethylene that was inadequately cross-linked would probably be unable to withstand the combined radiation and temperature conditions, and would have been severely damaged in this test. Similarly, routine production tests of all Flamtrol cable performed by Raychem under IPCEA S-66-524 guidelines would tend to identify jacket physical properties substantially different from those expected of cross-linked polyethylene. Although detailed fabrication information has not been provided on beam current density, irradiation time, or polymer material composition including flame-retardant and cross-linking aid additives, there is no existing information that implies the basic process was different for unshielded, multiconductor cables with various insulation thicknesses. It therefore seems reasonable that the jackets of Flamtrol cable with a combined insulation thickness greater than 0.12 in are cross-linked.

Cross-linked polyethylene jacket and conductor insulation can maintain mechanical properties at higher temperatures than can uncross-linked polyethylene. Changes in mechanical properties (e.g., tensile strength, percent elongation), commonly used as a basis for evaluating thermal and radiation aging characteristics in cable insulations, indicate that cross-linked polyethylene typically demonstrates better resistance to aging than uncross-linked polyethylene. Also, proper cross-linking does not affect overall moisture vapor permeability relative to that of uncross-linked polyethylene. With the exception of polyvinylidene chloride, the moisture permeability of polyethylene is significantly less than that of any other plastic-type material commonly used in cable insulation [8]. For normal service conditions in which the cable is not exposed to significant moisture or prolonged high humidity, the cross-linked polyethylene jacket can be expected to provide adequate protection for internal conductor insulation, including insulation that may be damaged due to space charge mechanisms. However, in view of possible induced space charge effects, no opinion can be provided on the expected capability of this same cable under design basis accident service conditions.* From this assessment, it is clear that cable

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*See discussion in Section 3.2.

with a combined insulation thickness of 0.12 in or greater can be expected to perform acceptably in normal service conditions provided (1) jacket integrity is maintained (i.e., cable jackets have not been split, severely abraided, or otherwise damaged during installation) and (2) all terminations and splices are adequately sealed to preclude moisture reaching conductors at cable jacket ends.

Determination of the actual amount of moisture resulting in possible cable failure under normal service conditions is beyond the scope of this evaluation. Additional testing would be required to develop and establish the validity of any model used for predicting moisture exposure thresholds resulting in damage to the cable. Infrequent or unplanned, limited-duration exposure of the jacketed cable to moisture (not submergence), for example, in concrete cable troughs, is not considered significant. However, the long-term effects possibly resulting from water treeing (see Section 3.2) could be significant, and therefore any exposure to wetness (excluding air-ambient humidity) should be avoided.

Some empirical evidence of the ability of the jacket of Flamtrol cable to protect conductors from deleterious effects of moisture exists. Carolina Power and Light has reported no operational failures in Flamtrol cable with insulation thicknesses greater than 0.12 in, although occasionally some cables may be exposed to some moisture, such as cable runs to the station switchyard. Reference 2 describes a 140-day, long-term jacket water immersion test that was successfully performed on Flamtrol cable specimens. These specimens were taken from reels in which conductor insulation failures to IPCEA moisture resistance tests had previously been demonstrated. Few details on the test conditions were provided in Reference 3; however, the cable was continuously energized with 1 kV ac applied to the conductors.* In additional tests on 0.125-in cables [9], unenergized cables were immersed with jacket ends out of

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*A similar test performed on specimens from the same cable reels with jacket ends submerged resulted in some failures of conductor insulation exposed to the water test environment. Raychem attributed these failures to damage associated with jacket removal.

water for 24 hours, after which voltage tests (at 5.5 kV ac and 16.5 kV dc) and insulation resistance measurements were performed without failure.

3.2 FEASIBILITY OF ANALYTICAL PREDICTIONS OF LOCA ENDURANCE CAPABILITY

For insulated multiconductor Flamtrol cable with combined insulation thicknesses of 0.12 in and greater, reasonable arguments can be made for the ability of the cable to function adequately in normal service conditions based on consideration of jacket integrity and absence of moisture from the conductor region of the cable. Design basis accident conditions, however, result in unusual and significant stresses on cable insulation systems. Prediction of cable performance is difficult at best, even in cable that can demonstrate ability to meet industry moisture resistance criteria; for this reason, qualification testing of materially similar cables in simulated design basis accident environments is routinely performed.

Extrapolation of simulated LOCA test results from 0.09-in insulated multiconductor Flamtrol cable [6] to cable with combined insulation thicknesses of 0.12 in and greater is not technically feasible, especially in view of differences existing in the moisture-resistance capability of the conductor insulation [5]. An attempt to qualify cable on the basis of analytical considerations of jacket adequacy would require quantification of the permeability of the cross-linked jacket to steam-water-spray mixtures under accident conditions. The moisture transport mechanisms are not well defined and, in fact, may be voltage dependent [7, 8, 10, 11]. Since all insulations are permeable to some extent, a second complementary analysis would be required to determine a threshold of conductor insulation failure given that moisture permeated and accumulated inside the jacket. Most likely, testing under conditions similar to the design basis accident would be required to generate the data necessary for evaluating cable adequacy.

Breakdown mechanisms resulting from rapid discharge of accumulated space charge in polyethylene are acknowledged to cause tree-like channels in which significant decomposition of the polymer occurs, often resulting in carbonization. In the presence of an electric field and moisture, electrical or water tree-like phenomena can occur and/or propagate in these electrically stressed or mechanically weakened channels. The low electric field conditions associated with control cable applications would preclude electrical tree development although water treeing can occur and, in some cases, electrochemical treeing can occur if impurities are present.*

The reviews in References 7, 8, and 12 indicate that little is understood of treeing phenomena, with no unifying explanation established. It appears that multiple competing degradation mechanisms typically exist. Water treeing research results have been so variable that standardized methods have been proposed in an effort to establish an experimental reference frame [8]. Water-borne contaminants (e.g, cross-linking aids, polymer additives, chemical spray in nuclear plants), temperature, temperature gradients, applied electric field magnitude and frequency, and (to a lesser extent) pressure can all affect tree inception and propagation [7, 8, 10-15]. Environmental stress levels associated with LOCA conditions are not covered in the range of existing research, which predominantly involves power cable application in near-ambient temperature conditions; the radiation environment is not considered at all. In essence, a data void exists for cross-linked polyethylene treeing phenomena under design basis accident conditions. Finally, the actual mechanisms associated with tree-like phenomena for space charge-induced damage may be substantially different from those encountered in current research. For example, dielectric breakdown of insulated conductor specimens removed from 0.125-in Flamtrol cable has occurred when immersed in water for less than 24 hours at ac voltage stresses as low as 30 to 100 V/mil.** However, laboratory water tree growth research programs on cross-linked polyethylene insulation report failures at higher ac voltage stresses ranging from 250 to 800 V/mil after typical immersion periods of 50 to 5000 hours [8, 9, 10-15].

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*A water soluble cross-linking aid is used in the polethylene formulation for Flamtrol cables.

**Not all conductor insulation experienced breakdowns under test conditions. Conductor insulation should be capable of passing 1 minute ac withstand and ac breakdown tests at approximately 100 V/mil and 450 V/mil, respectively.

It does not appear possible at this time to develop a valid analytical model, using in part the results from previous LOCA testing [9], in order to establish the functional capability under accident conditons of Flamtrol cable with combined (jacket and conductor) insulation thicknesses of 0.12 in or greater. This technical position is based on the high degree of variability and uncertainty associated with phenomenological mechanisms, failure propagation parameters (e.g., temperature, pressure, voltage), and experimental results from industry investigation of polyethylene cable degradation.

4. QUALIFICATION TESTING OF FLAMTROL CABLE INSTALLED IN BRUNSWICK PLANT

4.1 QUALIFICATION TESTING RECOMMENDATION

As discussed in Section 3, it is not possible to reach a reasonably firm conclusion on the capability of the cable under design basis accident conditions. Furthermore, it is doubtful that an analysis could be performed which verifies that the interior of the cable jacket could remain moisture-free, especially under stresses associated with design basis accidents. Although previous LOCA testing has been performed successfully on multiconductor Flamtrol cables with combined insulation thickness less than 0.12 in [9], there is no reliable method of analytically extrapolating these results to determine if the jacket can maintain adequate mechanical integrity or if sufficient quantities of moisture can permeate the jacket on 0.12-in and greater insulated cable.

Recently, x-ray diffraction and electron microscopy techniques have been used to determine the degree of cross-linking in polyethylene. The same techniques can be used to detect the presence of carbonized paths resulting from space charge relief mechanisms. These analytical methods are straightforward and inexpensive to perform.

The performance of a series of tests on Brunswick cable conductor insulation samples may confirm damage associated with space charge buildup, and thereby enable an estimate of the probability of a cable having experienced some space charge-related event. However, for cable already installed in the plant, it remains necessary to correlate evidence of observed damage with ability to function adequately under required service conditions. Therefore, use of diffraction and microscopy techniques can determine the presence of space charge-caused damage; however, the significant question of functional capability of the cable is unresolved.

It is recommended that the functional capability of 0.12-in Flamtrol cable be established by qualification testing of representative specimens removed from the Brunswick plant.

4.2 CABLE TEST PROGRAM RECOMMENDATIONS

A program for evaluating the functional capability of Flamtrol cable under design basis accident conditions should follow the guidance provided in IEEE Std 383-1974 [16]; Raychem qualification tests [6, 17] generally followed the recommendations of this standard. Additional test program considerations and recommendations are presented in the following subsections.

4.2.1 Sample Selection

There is little evidence to suggest that in-use cable would have properties significantly different from those of spare cable for LOCA testing; therefore, the impact on plant operations can be minimized by using samples taken from installed cable spares or reel samples. If possible, the sample selection should include removed spare cable that has been exposed to moist environments. Cable damage during installation should be considered in test sample selection if conductor insulation is not directly exposed to the LOCA test environment (see Section 4.2.2).

Reference 18 indicates that Flamtrol cables with total insulation thicknesses of 0.09, 0.105, 0.120, 0.125, 0.135, and 0.140 in have been installed at the Brunswick plant. Although a detailed review has not been performed, it appears that few spare cables are available with insulation thicknesses of 0.120, 0.135, and 0.140 in.

Raychem Corporation performed a jacket irradiation study on multiconductor cables with conductor insulation and jacket thicknesses of 0.045 and 0.08 in, respectively [3]. Based on the results of this study, in which certain specimens experienced dielectric failures, Raychem concluded that space charge effects could occur during jacket irradiation of 0.125-in unshielded multiconductor Flamtrol cable. Other Raychem tests [2] and those described by F. A. Slautterback in his letter to the NRC [1] demonstrated dielectric failure or reduced breakdown strength in this size cable. Of particular interest are the Raychem "Phase III" tests on 487 stock cables in which "Virtually all such examples [of overall reduction in dielectric breakdown strength] were confined to construction in which component wires had insulation walls of 0.045 inch and jacket walls were 0.08 inch [2]."

It is recommended that the majority of the test specimens be selected from cable with a combined insulation thickness of 0.125 in.; however, at least one specimen from each of the other insulation thicknesses should be tested to confirm that pertinent characteristics are independent of insulation thickness.

4.2.2 Cable Test Configuration and Electrical Interfaces

In Raychem's qualification program for Flamtrol cable, jacketed cable specimens extended through the test chamber head assembly [6]. Current cable testing practice opens the jacket inside the chamber, enabling insulated conductors to be brought out through individual penetrations. Testing of the cable with opened jacket ends exposes conductor insulation to the LOCA environment, and addresses the moisture-resisting capability of the jacket due to permeation through the jacket wall and inleakage at the ends.

An alternate approach to the above testing would be to bring out the entire jacketed cable specimen through the test chamber head in order to provide additional protection to the conductor insulation from LOCA effects. If these (entirely) jacketed specimens demonstrate adequate functional capability throughout the LOCA, then consideration must be given to inplant terminations and splices. It is recommended that representative junction boxes and penetration assembly boxes be included in the test program because cable jacket ends are opened in order for conductor connections to be made to terminal blocks, penetrations, etc. Cable splices and heat-shrink splice sleeves used in the plant should be included in the testing program. Typically, these items are qualified on various conductor insulations that have previously demonstrated acceptable qualification test performance. The combined conductor and cable splice insulation system functional performance must be demonstrated, especially since marginal Flamtrol conductor insulation or splice performance could result in dielectric failure.

4.2.3 Sequential Testing

The Raychem Flamtrol qualification test had simultaneous radiation exposure and LOCA simulation; however, IEEE Std 383-1974 does permit sequential testing consisting of radiation exposure followed by LOCA steam and spray. Whether simultaneous exposure is necessary for the proposed test program cannot be determined at this time. However, it has been industry experience that sequential testing does not yield results that are significantly different from results of simultaneous testing when cable is tested under LOCA conditions. Furthermore, sequential testing is the currently accepted industry practice for cable qualification tests. Therefore, a sequential testing program should be adequate unless a definite technical preference for simultaneous testing is determined.

4.2.4 Age Conditioning

Raychem's thermal and radiation age conditioning procedure and rationale [17] should be reviewed as part of the test program. If the approach is considered acceptable, then age conditioning should be performed in accordance with the Raychem procedure to produce specimens aged to the equivalent of 40 years. Since the installed cable spares are approximately 8 to 10 years old, the actual accelerated thermal aging time (for aging temperatures identical to Raychem's) will be less than that in Reference 17. Similarily, prior in-service radiation exposure must be taken into account to determine the required aging irradiation dose. In the event that Raychem's aging procedure is considered nonconservative, the pre-test aging times or radiation exposure should not exceed the values used in Reference 17. This approach will result in age conditioning of the cable specimens to a simulated age of less than 40 years; however, by limiting accelerated aging conditions to Raychem's aging bases, the introduction of additional test program considerations due to different aging bases is avoided.

Exposure to elevated temperatures and irradiation during accelerated aging actually improves the physical and dielectric properties of some cable insulations and could thus improve their ability to withstand environmental testing-induced stresses. This improvement in cable characteristics can take place if the age conditioning causes a curing-like process instead of degradation process in the cable; curing may dominate for a period followed by subsequent degradation. Whether age conditioning results in net degradation or improvement of Flamtrol cable is unknown. Therefore, testing should be performed on the naturally aged (8- to 10-year-old) specimens as well as on the age-conditioned specimens.

There is an additional reason for testing unaged cables (i.e., cables not conditioned beyond their natural age) under LOCA conditions. Accelerated thermal aging combined with LOCA testing could result in degradation of the specimens to the extent that cable insulation failures would occur during testing. In the event that the predominant failures occurred in the age-conditioned specimens, it might be possible to estimate the time frame in which age degradation becomes critical with respect to the ability of the cable to function adequately.

4.2.5 Radiation Exposure

Prior to LOCA testing, all specimens should receive a gamma irradiation dose of 160 Mrd. Approximately 50 Mrd is considered as the radiation aging dose, and the remaining 110 Mrd as the accident dose [19]. The dose rate used in the Raychem tests was approximately 0.2 Mrd/h; however, if sequential testing is performed, a higher dose rate (e.g., 0.5 Mrd/h) could be used without jeopardizing cable performance.

4.2.6 LOCA Simulation

The Brunswick plant-specific containment design temperature/pressure profile plus margin can be used to establish the LOCA test environment conditions [19]. This test environment is less severe than the temperature/pressure environment used by Raychem in its qualification testing [17]. Such an approach is acceptable because the objective of the test program is to determine the functional adequacy of the Flamtrol cable installed in the Brunswick plant; use of plant-specific environments is permitted by IEEE Std

383-1974, Part 2.4.3.* The use of plant-specific spray instead of the boric acid test spray used in Reference 17 is permitted in IEEE Std 323-1974. The Brunswick plant has a demineralized water spray system.

Throughout the LOCA simulation, cables should be loaded at rated current and voltage, except when periodic IR measurements are made.

4.2.7 Submergence and Functional Duration

In response to the equipment qualification information requested by IE Bulletin 79-01B, "Environmental Qualification of Class 1E Equipment," Carolina Power and Light has stated that Flamtrol cable at the Brunswick plant cannot be submerged in a post-accident period and that all cables are above containment and reactor building flood levels [19]. Post-accident functional operating requirements have been stated as "Long" with no specific value defined. Carolina Power and Light does, however, state that the 30-day LOCA test described in Reference 17 exceeds functional duration requirements. It should be noted that this test included a 30-day spray exposure, which, in the case of the Brunswick plant, may not be entirely required (see also Section 4.2.6). Based on available information and the presumed accuracy of Carolina Power and Light's response to IE Bulletin 79-01B, the post-LOCA test duration would not have to extend beyond 30 days, nor would submergence testing of the cable be required.

[Other licensees (see Section 5) have stated, in their IE Bulletin 79-01B responses, that certain Flamtrol cable is subject to flooding or post-accident submergence. They have also stated long-term functional requirements of greater than 30 days. The requirements of these plants should be included in any qualification tests of Flamtrol cable sponsored by utility groups.]

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*IEEE Std 383-1974 references IEEE Std 323-1974, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations," which provides guidance on establishing simulated service condition test profiles.

4.2.8 Post-LOCA Simulation

After the LOCA exposure, the cables should be removed from the test chamber and given a post-LOCA simulation test as described in IEEE Std 383-1974, Part 2.4. Specimens should be straightened, recoiled around a mandrel, soaked in tap water, and subjected to IR and voltage withstand tests.

4.2.9 Electrical Tests

The cables should be electrically loaded at rated current and voltage throughout the LOCA test, except when periodic IR measurements are made.

The LOCA simulation should then be continued to the end of the LOCA period, at which time the mandrel wrap test, final IR measurements, and 5-minute voltage withstand tests should be performed using an ac potential of 80 V/mil with insulation thickness taken as the conductor wall thickness.

5. OPERATING REACTOR PLANTS WITH RAYCHEM FLAMTROL CABLES

Operating reactor plants with Raychem cable used in Class 1E or safety-related circuits were identified by performing a computer-aided search of the NRC's Plant Qualification File [20], which includes Licensee System Component Evaluation Work (SCEW) sheet responses to IE Bulletin 79-01B, "Environmental Qualification of Class 1E Equipment."*

A supplemental source of information included the Licensee 90-day responses to the NRC's Safety Evaluation Report for Environmental Qualification of Safety Related Electrical Equipment. The 90-day Licensee SER responses are considered more accurate and detailed than the IE Bulletin 79-01B SCEW sheet data; however, Plant Qualification File updating with this information has not been completed. Therefore, it was possible to perform only manual reviews of 90-day response information for those plants in which Raychem cable had been identified by computer searches of Plant Qualification File IE Bulletin 79-01 information.

Identified operating reactor plants with Raychem or Raychem Flamtrol cable installed in safety-related circuits in environmentally harsh areas include:

Arkansas Nuclear One Unit 2
Big Rock Point
Brunswick Units 1 and 2
Calvert Cliffs Units 1 and 2
D. C. Cook Unit 2
Nine Mile Point
Oconee Units 1, 2 and 3
St. Lucie Unit 1
Surry Units 1 and 2

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*Systematic Evaluation Program (SEP) plants were not required to respond to IE Bulletin 79-01B. The Plant Qualification File does contain information similar to that requested by IE Bulletin 79-01B which was developed as part of a SEP review of equipment qualification.

All plants, with the exception of the Oconee plant, appear to use cables identifiable as "Flamtrol." Additional information on cable identification, environment, application, and cited qualification references is summarized in Table 5-1 for each of the above plants identified as having installed Raychem cable. Bibliographic identification of Licensee-cited qualification references appears in Appendix B.

With the exception of the Brunswick plant, complete cable insulation thickness and voltage rating information is unknown for the plants listed in Table 5-1. This information was not required by IE Bulletin 79-01B or as part of the Licensee's SER response. Therefore, Table 5-1 should be considered for preliminary identification purposes only because the cable actually installed in these plants could have combined insulation thicknesses of less than 0.12-in.

Table 5-1

Summary of Raychem Cable Identification, Environment, Application, and Qualification References by Plant

Summary Information	Plant
	Arkansas Nuclear One Unit 2 Docket No. 50-368
1. Cable Identification	
a. Identified Cable	Raychem
b. Cable Description	Special and instrument cable
c. P.O. Number (if provided)	--
d. Other Identifying Information	ID No. 2GEN1006
2. Environment	
a. Location	Inside containment
b. Steam Conditions (Peak Temperature/Pressure)	289°F/48 psig
c. Specified Operating Time	30 days
d. Humidity	100% RH
e. Submergence	No
f. Spray Exposure	15,000 ppm boric acid; pH 10.5
3. Application	
a. Service	Instrument
b. System	Various
4. Qualification References	FIRL Report No. F-C4033-1

Table 5-1 (Cont.)

Summary Information	Plant
	Big Rock Point Docket No. 50-155
1. Cable Identification	
a. Identified Cable	Flamtrol
b. Cable Description	Multiconductor Cable*
c. P.O. Number (if provided)	34490-1601-71
d. Other Identifying Information	--
2. Environment	
a. Location	Inside containment
b. Steam Conditions (Peak Temperature/Pressure)	289°F/27 psig
c. Specified Operating Time	30 days
d. Humidity	100% RH
e. Submergence	Yes
f. Spray Exposure	Lake water
3. Application	
a. Service	Control
b. System	Various
4. Qualification References	FIRL Report No. F-C4033-1

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*The Licensee has stated multiconductor cables are rated at 600V or 1000V.

Table 5-1 (Cont.)

Summary Information	Plant
	Brunswick Units 1 and 2 Docket Nos. 50-324, -325
1. Cable Identification	
a. Identified Cable	Flamtrol
b. Cable Description	Multiconductor, coaxial, and triaxial cable
c. P.O. Number (if provided)	--
d. Other Identifying Information	--
2. Environment	
a. Location	Inside/outside containment
b. Steam Conditions (Peak Temperature/Pressure)	280°F/49 psig
c. Specified Operating Time	Long
d. Humidity	100% RH
e. Submergence	No
f. Spray Exposure	Demineralized water
3. Application	
a. Service	Control and instrument
b. System	Various
4. Qualification References	FIRL Report No. F-C4033-1

Table 5-1 (Cont.)

Summary Information	Plant
	Calvert Cliffs Units 1 and 2 Docket No. 50-317
1. Cable Identification	
a. Identified Cable	Flamtrol 60
b. Cable Description	Cable, coaxial, and triaxial cable
c. P.O. Number (if provided)	--
d. Other Identifying Information	Spec. No. E-123, 99A
2. Environment	
a. Location	Inside containment
b. Steam Conditions (Peak Temperature/Pressure)	269°F/50 psig
c. Specified Operating Time	Not stated
d. Humidity	100% RH
e. Submergence	Not stated
f. Spray Exposure	1.1% Boric acid (1700 ppm boron)
3. Application	
a. Service	*
b. System	Various
4. Qualification References	Raychem Report Nos. EM 517A, EM 523E, EM 644, EM 688, EM 691**

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*Licensee stated cables must be functional for LOCA, HELB, hot standby, and cold shutdown.

**Report Nos. EM 644, 688, and 691 are for coaxial and triaxial cables; EM 517A and 523E are for Flamtrol 60 cables.

Table 5-1 (Cont.)

Summary Information	Plant
	D. C. Cook Unit 2 Docket No. 50-316
1. Cable Identification	
a. Identified Cable	Raychem
b. Cable Description	Instrument cable
c. P.O. Number (if provided)	--
d. Other Identifying Information	Item Nos. 3111, 3112
2. Environment	
a Location	Inside/outside containment
b Steam Conditions (Peak Temperature/Pressure)	328°F/10 psig
c Specified Operating Time	1 year
d. Humidity	100% RH
e. Submergence	Yes
f. Spray Exposure	1.14% boric acid (2000 ppm boron); pH 9-11
3. Application	
a. Service	Various
b. System	Various
4. Qualification References	FIRL Report No. F-C4033-1

Table 5-1 (Cont.)

Summary Information	Plant
	Nine Mile Point Docket No. 50-220
1. Cable Identification	
a. Identified Cable	Raychem
b. Cable Description	Coaxial instrument cable
c. P.O. Number (if provided)	--
d. Other Identifying Information	RG 59B/U
2. Environment	
a. Location	Inside containment
b. Steam Conditions (Peak Temperature/Pressure)	301°F/35 psig
c. Specified Operating Time	28 hours
d. Humidity	100% RH
e. Submergence	No
f. Spray Exposure	Demineralized water
3. Application	
a. Service	Instrument
b. System	Various
4. Qualification References	Rockbestos Qualification of Firewall III, 01-Feb-77

Table 5-1 (Cont.)

Summary Information	Plant
	Oconee Units 1, 2 and 3 Docket Nos. 50-269, -270, -287
1. Cable Identification	
a. Identified Cable	Raychem
b. Cable Description	Multiconductor cable
c. P.O. Number (if provided)	--
d. Other Identifying Information	--
2. Environment	
a. Location	Auxiliary building*
b. Steam Conditions (Peak Temperature/Pressure)	330°F/28 psig
c. Specified Operating Time	30 minutes, 10 days
d. Humidity	100% RH
e. Submergence	No
f. Spray Exposure	No
3. Application	
a. Service	Control
b. System	High Pressure Injection Coolant Storage (quench tank)
4. Qualification References	Duke Power Report No. Tr-012 Raychem Spec. No. 44 Mil Spec-W-81044B

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*Cable is not used in containment; however, cable may be used on other systems. Cable in Unit 3 appears to be located in non-harsh environmental areas.

Table 5-1 (Cont.)

Summary Information	Plant
	St. Lucie Unit 1 Docket No. 50-335
1. Cable Identification	
a. Identified Cable	Flamtrol
b. Cable Description	Cable
c. P.O. Number (if provided)	422358
d. Other Identifying Information	Spec. No. FLO-8770-2923
2. Environment	
a. Location	Inside containment
b. Steam Conditions (Peak Temperature/Pressure)	290°F/42 psig
c. Specified Operating Time	1 year
d. Humidity	100% RH
e. Submergence	Yes
f. Spray Exposure	Boric acid (1720-2450 ppm boron); pH 8.5-10
3. Application	
a. Service	Control, low energy, communication
b. System	Various
4. Qualification References	Raychem Report No. 517A Raychem Report No. 1010

Table 5-1 (Cont.)

Summary Information	Plant
	Surry Units 1 and 2 Docket Nos. 50-280, -281
1. Cable Identification	
a. Identified Cable	Flamtrol
b. Cable Description	300 V instrument cable
c. P.O. Number (if provided)	--
d. Other Identifying Information	Spec. No. NAS-3190
2. Environment	
a. Location	Inside containment
b. Steam Conditions (Peak Temperature/Pressure)	280°F/44 psig
c. Specified Operating Time	120 days
d. Humidity	100% RH
e. Submergence	No
f. Spray Exposure	Boric acid (2000-2200 ppm boron); pH 8.5-11
3. Application	
a. Service	Power to safety systems
b. System	Various
4. Qualification References	Raychem Report-Flamtrol, Qualification to IEEE-Std-383 Raychem Report No. 1403 NUS-VEPCO QDR Packages 5437-54-01, -122-01 Letter J. M. Kuster (Raychem)

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*HELB steam conditions of 430°F/42 psig may also exist for this cable.

6. CONCLUSIONS

The Phase 2 investigation consisted of an examination of technical considerations important to the possible resolution of the functional capability of certain Flamtrol cable installed in the Brunswick plant. These considerations resulted from discussions between NRC and FRC regarding an earlier Phase 1 review.

Phase 2 efforts have been directed toward an examination of the space charge phenomenon, including resultant deleterious effects on cable insulation caused by the charge relief mechanisms. Consideration of jacket integrity as a means of establishing cable functional capability has also been reviewed.

Major conclusions of this Phase 2 investigation with respect to unshielded, multiconductor Flamtrol cable manufactured for and installed in the Brunswick plant with a combined (jacket and conductor) wall insulation thickness of 0.12 in or greater are as follows:

1. A review of the space charge phenomenon in dielectrics indicates that degradation of insulation properties can occur if the maximum range of the electron beam used to achieve cross-linking is less than the thickness of the target-insulating material. Quantification or prediction of the extent of degradation is difficult.
2. For normal service conditions in which the cable is not exposed to significant moisture or prolonged high humidity, it can be expected that the cross-linked polyethylene jacket can provide adequate protection for internal conductor insulation, including insulation that may be damaged by space charge mechanism. Jacket integrity, however, must be maintained for all such cables. It should be determined that cable jackets are intact and adequately sealed at terminations and splices.
3. It is not possible to reach a firm conclusion on the capability of the cable under design basis accident conditions; similarly, it is doubtful that an analytical model that uses data from previous LOCA testing of other Flamtrol cable can be developed in order to establish the functional capability of Flamtrol cable under design basis accident conditions.
4. Functional capability of the Flamtrol cable should be established by qualification testing of representative specimens removed from the Brunswick plant.

Eleven other plants with radiation cross-linked cable manufactured by Raychem have been identified in Section 5 of this report. This identification should be considered as preliminary. In addition, no information is available on insulation thicknesses for those plants.

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October 8, 1976

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31-Oct-80

20. Report: User's Guide for Plant Qualification File (PQF) Data Base
FRC Report M-C5417-2
28-Oct-81

APPENDIX A

SPACE CHARGE EFFECTS IN DIELECTRICS

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APPENDIX A

SPACE CHARGE EFFECTS IN DIELECTRICS

A.1 INTRODUCTION

In the early 1950s, dielectric materials such as borosilicate glass were found useful for beta-ray dosimetry studies because they displayed a coloration center after exposure to a high-intensity electron beam [1, 2]. More extensive studies [3-19] have since been carried out to explain the irradiation effects in dielectrics. These effects were found to be attributable to the accumulation of space charges in the dielectrics.

It is the purpose of this report to review the previous studies and to summarize both the theoretical background and the effects of space charge phenomena on dielectrics. An attempt is also made to relate the effects to the possible physical degradation of cables.

A.2 THEORETICAL BACKGROUND

A.2.1 Electron Interaction with Matter

When an energetic electron enters a medium, it will lose its kinetic energy via various modes of interactions:

a. radiative collisions with atomic nuclei, accompanied by the emission of electromagnetic radiation (bremsstrahlung)

b. collisions with bound electrons, by which incident energy is lost in exciting the atomic electrons

c. collisions with bound electrons, by which enough energy is transferred to ionize the atom.

In the case of ionization, secondary electrons (δ rays) will be produced during the electron thermalization process. If the collision is hard enough, the δ rays will carry sufficient energy to form separate branches along the track of the incident electrons (see Figure A-1). The thermalized electrons and δ rays will either recombine with ions or become trapped in the medium. The electron-trapping effect, as will be discussed later, can occur only in non-conductors and is most manifest in insulators.

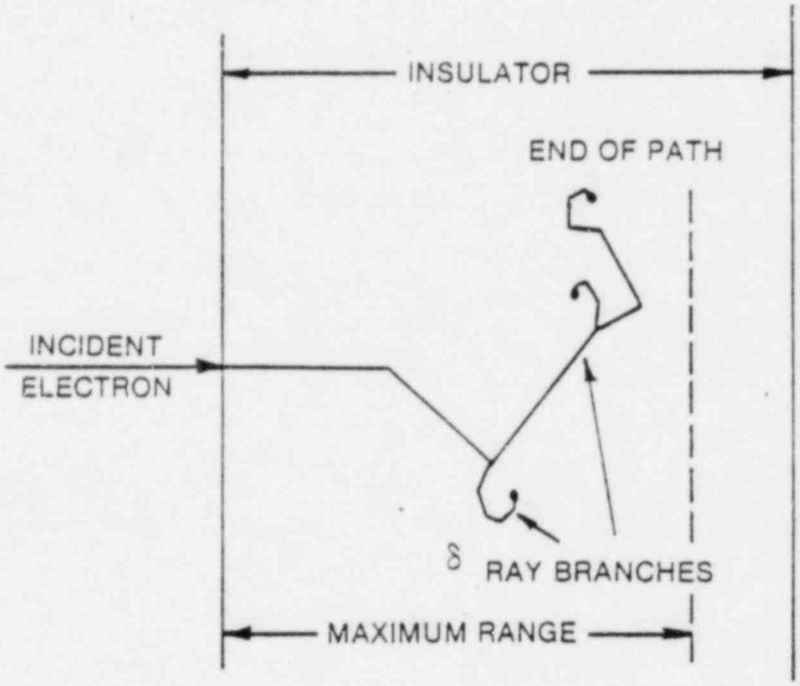


Figure A-1. Passage of Electron Through Matter

As seen in Figure A-1, the deepest penetration of the electron defines its maximum range in the medium. The electron range depends primarily on the incident energy of the electron and the density of the medium. An empirical range-energy relationship is [20]:

$$R = \frac{(0.530E - 0.106)}{\rho}$$

where R is the range in cm, E is the electron energy in MeV (between 1 and 20), and ρ is the density of the medium in g/cm^3.

The amount of energy lost via the various collision modes is also dependent on the incident electron energy and the physical properties of the medium. For instance, at lower energies, most of the collisions are soft and limited to electron excitation, whereas radiative collision and ionization become more frequent at higher energies. Also, materials made up of elements with high atomic numbers tend to enhance the radiative collision.

Not all the energy lost at the site of interaction will dissipate locally in the medium. Bremsstrahlung from radiative collision, for instance, can traverse the medium before it is completely absorbed or escapes. The actual depth-dose distribution is like that shown in Figure A-2 for polyethylene [21]. The curve peaks sharply at lower electron energies, whereas the energy lost by high-energy electrons is more evenly distributed throughout the range.

A.2.2 Theoretical Interpretation of Electrical Conductivity in Materials

Electrical conductivity of various materials can best be explained by a simple quantum-mechanical model as depicted in Figure A-3. The valence band consists of energy states that are normally filled by atomic electrons. The conduction band, on the other hand, has energy levels which are normally unoccupied; conduction is possible when some of the levels are occupied by electrons.

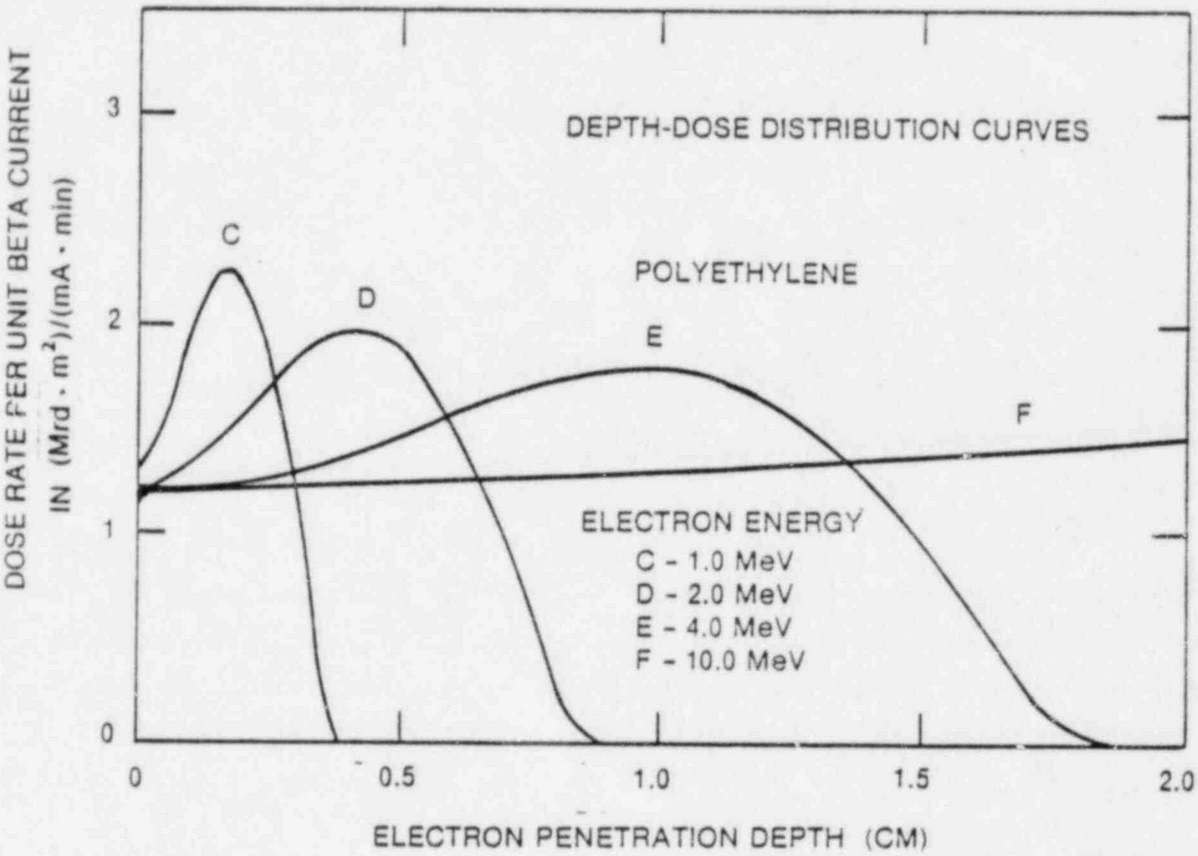


Figure A-2. Electron Depth-Dose Distribution in Polyethylene [21]

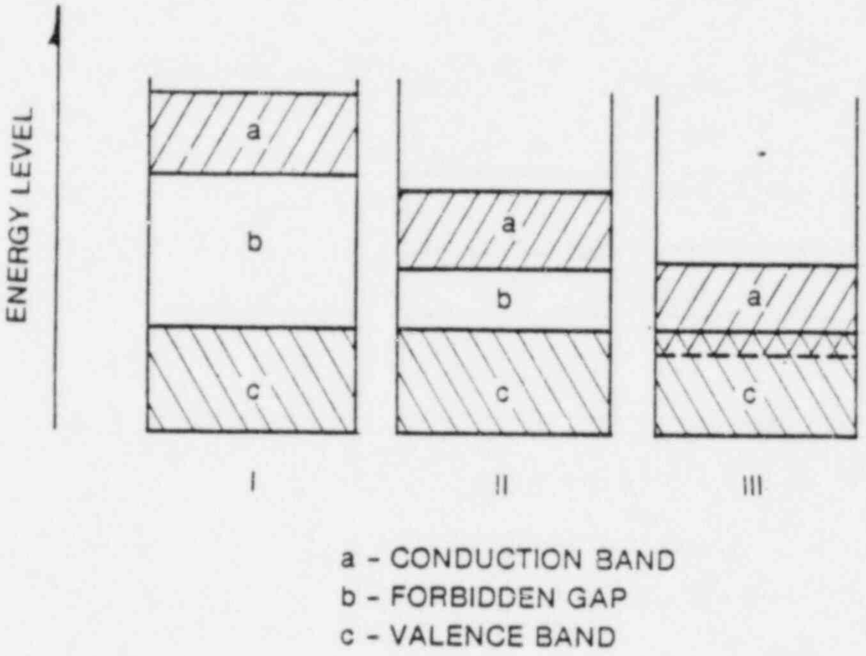


Figure A-3. Schematic Energy Levels in (I) Dielectrics, (II) Semiconductors, and (III) Conductors (Conduction and Valence Bands Overlap)

For conductors, the conduction and valence bands have overlapping energy levels so that, under ordinary conditions, electrons can occupy energy states in the conduction band. In such a case, the conductivity of the material is very high. For semiconductors, or for non-conductors such as dielectrics, the conduction and valence bands are separated by an energy gap, called the "forbidden gap," which disallows occupation by any electrons. Hence, a certain amount of energy is needed to excite electrons from the valence to the conduction band in order to conduct electricity. The forbidden gap is highest in dielectrics for which occupation of conduction levels by valence electrons is normally almost impossible. Dielectrics exhibit a very high resistivity.

A.2.3 Trapping of Free Electrons in Dielectrics

Theoretically, the forbidden gap is free of electron states so that occupation by electrons is not possible. Practically, however, energy states are formed in the gap by the presence of chemical impurities, interstitials, structural defects, and other departures from the ideal lattice structure of the dielectric. Since these additional energy levels do not belong to the conduction band, they will become trapping sites capable of locking up free electrons. Thus, when a dielectric is exposed to an electron beam, most of the thermalized electrons (or δ rays) will be immobilized at these trapping sites. Space charges of such free electrons will then accumulate in the dielectric. Figure A-4 illustrates such a space charge accumulation and the resulting electric field.

Due to the transport phenomenon of incident electrons, the depth-dose curve and the space charge distribution are different from each other. On the one hand, at the incident boundary, dose deposition is relatively large, but there is virtually no space charge buildup. On the other hand, the space charge distribution peaks at a deeper penetration than does the depth-dose curve, as illustrated in Figure A-5. Therefore, free electrons tend to concentrate within a narrow region near a particular depth.

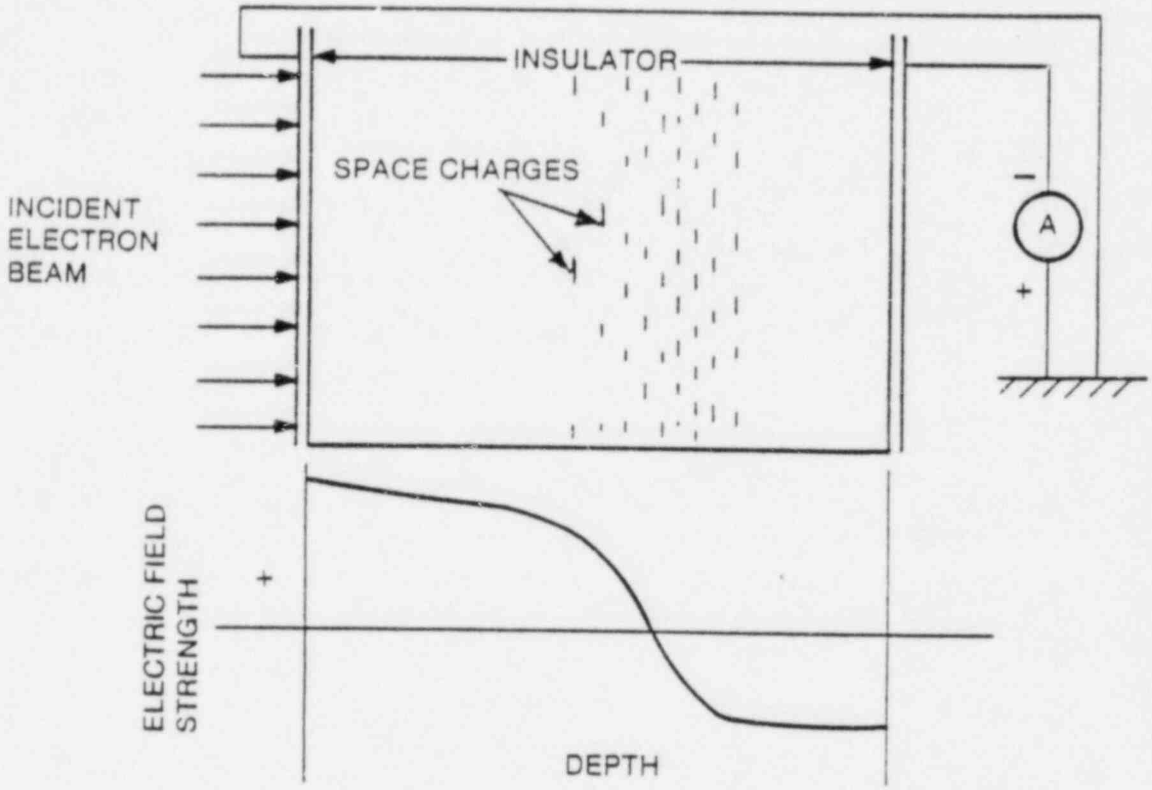
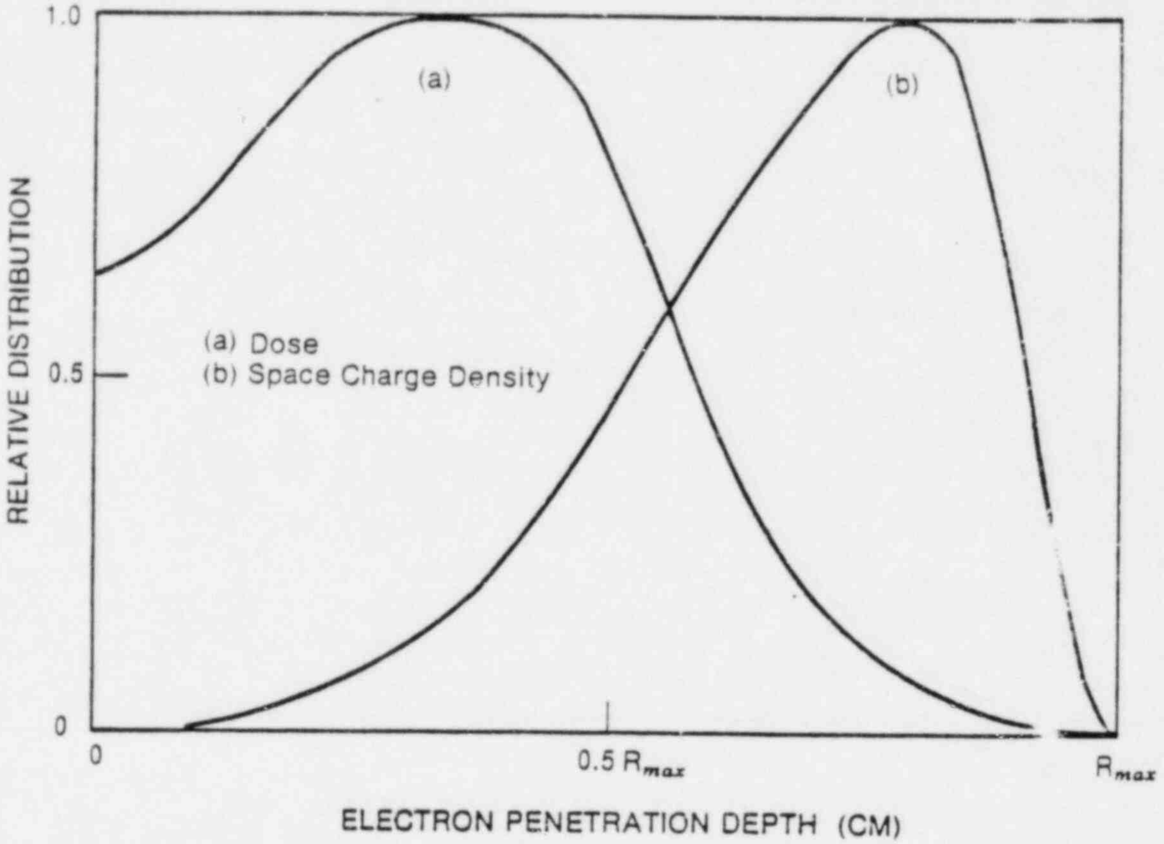


Figure A-4. Field Strength Due to Electron Space Charges



NOTE: The relative distribution for dose and space charge density throughout the dielectric is obtained by normalizing each distribution by the maximum value of that distribution. R_{max} is the maximum range of an electron in the dielectric material.

Figure A-5. Comparison of Electron Depth-Dose and Charge Deposition Profile in Dielectrics [17]

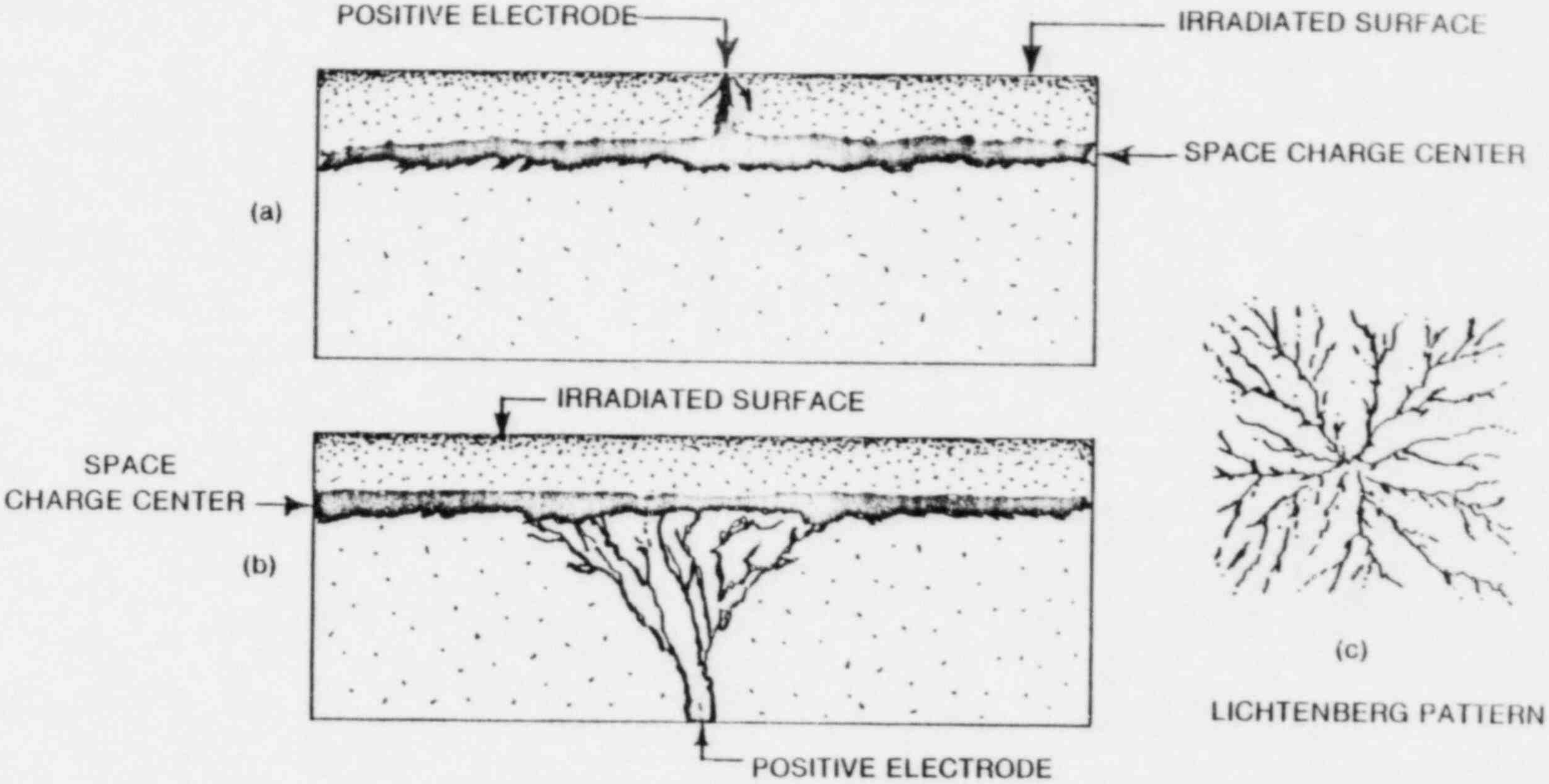
A.3 POSSIBLE EFFECTS DUE TO THE FORMATION OF SPACE CHARGES

Breakdown of dielectrics under electron bombardment and the subsequent formation of electrical discharges due to the accumulation of space charge has been the focus of previous studies. In the event of breakdown, a treeing phenomenon is observed that exhibits the well-known Lichtenberg pattern (see Figure A-6). The breakdown can be triggered by an electrode, or it can simply occur spontaneously if the induced electric field is sufficiently strong. A recent study by Matsuoka et al. [17] shows that spontaneous breakdown in polyethylene can occur at an induced field strength of 2 million V/cm. This was created by bombarding a polyethylene slab with a 17.5-MeV beta-ray beam at an intensity of 0.44 $\mu A/cm^2$ for 90 seconds. This is equivalent to a total charge fluence of 4×10^{-5} coulomb/cm^2. Studies of various dielectrics have reported spontaneous breakdown at a charge fluence as low as 6×10^{-6} coulomb/cm^2 [10].

The charge retention period in dielectrics also exhibits a large variation, ranging from a fraction of a second to as long as a month [4]. The retention period is approximately proportional to the amount of space charge accumulated. It is believed that space charge cannot be retained for an indefinite time because either discharge or diffusion will take place to ease the electric potential inside the dielectric.

As a result of dielectric breakdown, discharge tracks ("trees") form a conducting path between the space charge center and the breakdown surface, thus lowering the resistance of the dielectric. If breakdown occurs at numerous places, degradation of the dielectric's insulating properties is expected.

Although the exact degradation mechanism is not well known, Robinson has offered a reasonable explanation [24]. Consider a dielectric made of molecules of the paraffin series, represented by chains of carbon molecules with the extra valences satisfied by hydrogen. The ionization during breakdown causes a rearrangement of molecules, with heavy and lightweight hydrocarbon molecules as end products, and possibly the release of hydrogen gas. It is



NOTE: Sample shown in (a) experienced dielectric breakdown through the irradiated volume; sample in (b) broke down through the unirradiated volume; top view of discharge pattern is shown in (c).

Figure A-6. Treeing Phenomenon of Dielectric Breakdown probable that, when the electron irradiation is sufficiently severe (spark discharge), the dissociation ("knocking-off") continues until only carbon remains. Therefore, the dielectric is "carbonized" along the discharge tracks.

The severity of the carbonization effect is not completely understood. Tests on primitive cables used in the early 1930s [24] revealed that carbonization could produce pinholes in the paper wrappings used as insulation if the spark discharge was severe or had been passing through the carbon core for a considerable period of time. It is not clear, however, whether the same thing would happen to modern dielectrics.

Another breakdown effect is the conductivity induced in dielectrics by irradiation. A formula derived for the conductivity, σ, induced by irradiation of low-density polyethylene is [17]:

$$\sigma = 8.6 \times 10^{-17} D^{0.78} \ \text{ohm}^{-1}\text{cm}^{-1}$$

where D is the dose rate in rad/s.

That is, if the dose rate is 10^6 rad/s, the conductivity induced is about 4×10^{-12} $\text{ohm}^{-1}\text{cm}^{-1}$. This is substantially higher than the value 10^{-16} $\text{ohm}^{-1}\text{cm}^{-1}$ ordinarily measured in polyethylene. The induced conductivity, however, decays with time after irradiation is terminated.

Other possible space-charge-induced effects, such as embrittlement and susceptibility to humidity and other environmental factors, have not been reported, although they may conceivably occur in dielectrics.

A.4 PARAMETERS AFFECTING SPACE CHARGE ACCUMULATION

Since both the depth dose profile and the space charge profile (Figure A-5) are confined to the maximum range of electrons in the dielectric, the formation of the space charge center is likely only if the dielectric is thicker than the maximum range. As discussed earlier, the maximum range of electrons in a particular dielectric is dependent only on the incident electron energy.

Both the beam intensity and irradiation time also influence space charge accumulation. The accumulation, in time, will also increase the induced electric field so that the space charge will become somewhat "compacted" into a narrower band as irradiation continues.

Temperature is also reported to influence the space charge. Space charge profiles tend to become "softened" as the temperature increases. That is, space charge is more dispersed at higher temperatures.

The physical properties of the dielectric are an important factor in the space charge effect. For example, the impurity content will largely determine the electron-trapping sites in the dielectric.

The external environment, such as the mechanical stresses induced by high ac and dc voltages, may also have an effect on space charge. Any external conducting object, even the conductor core inside the cable, can potentially serve as a positive electrode and cause the discharge of the space charge and subsequent dielectric breakdown.

A.5. EVALUATION OF SPACE CHARGE EFFECT IN CABLES

A.5.1 Estimation of Space Charge Buildup

A simplified model is presented here for estimation of space charge buildup in cables. As shown in Figure A-7, the hypothetical cable consists of a conductor core of radius r cm, covered by polyethylene insulation of thickness d cm. If the thickness d of the insulating material is larger than the maximum range of the electrons in the insulation, a space charge region will be formed within the insulation. Assuming that the cable is rotated during irradiation to produce a uniform exposure, the space charge will form a ring-shaped region in the insulator (Figure A-7).

The space charge density within the ring can be calculated by

$$q = IT(r + x) \times 10^{-6}/(r + d)$$

where

q = space charge density* (coulomb/cm^2)

I = electron beam intensity (μA/cm^2)

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*In this model, all space charge is located and uniformly distributed over a surface at the center of the space charge ring.

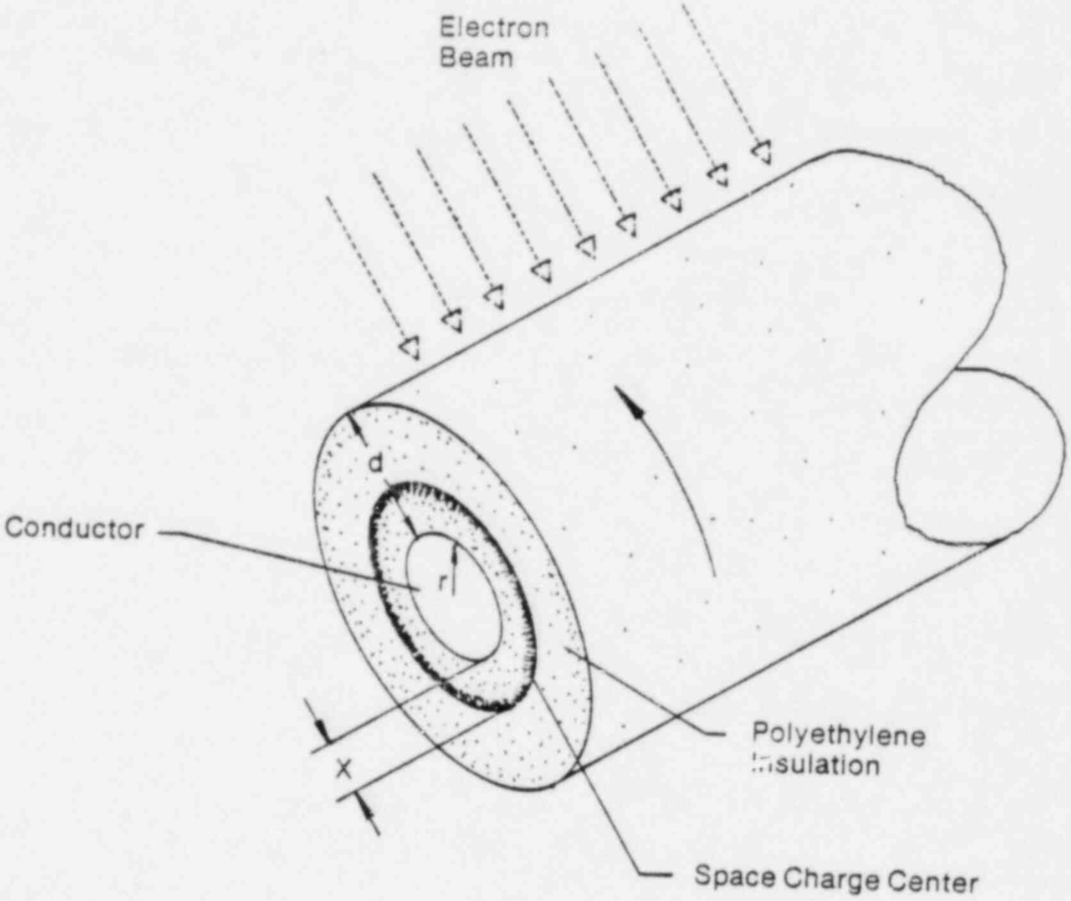

Figure A-7. Schematic Diagram of Possible Space Charge Formation in Raychem Electric Cable by Electron Beam Irradiation

T = exposure time (second)

r = radius of conductor (cm)

d = thickness of insulation (cm)

x = location of space charge from the outer surface of conductor (cm).

The electric field strength induced at the outer surface of the conductor by the space charge in given by

$$E = 2 \pi q(r)/4 \pi E_o(r + x) = 5.7 \times 10^{12} q(r)/(r + x) \text{ V/cm}$$

From the above two equations, it can be estimated that for an electron beam intensity of 0.2 μA/cm^2 and a dielectric breakdown field of 1 million V/cm, it will take less than a second to reach the breakdown threshold.

A.5.2 Uncertainties of Space Charge Predictions

Several key parameters are required for detailed space charge analyses of assembled multiconductor cables. These factors are:

- electron beam energy, E
- beam intensity, I
- irradiation time, T.

Other factors important to any investigation are:

- electron beam apparatus and the equipment setup for cross-linking the insulator
- quantity of fire retardant and cross-linking aids used in cable fabrication and their role in forming the electron-trapping sites
- temperature and other environmental factors during the cross-linking process
- spatial and shielding effects of conductors with respect to the cross-linking irradiation beam.

In view of the above complexities and limitations of the inherently simplified model, an accurate prediction of space charge buildup cannot be made. However, the simplified model does provide insight into some effects of space charges.

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Oxford University Press, London, 1964

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APPENDIX B

BIBLIOGRAPHY OF CITED RAYCHEM QUALIFICATION REFERENCES FOR OPERATING REACTORS

A bibliographic listing of qualification references for identified plants with Raychem cable installed is provided in this appendix. Asterisked references are for cable other than Flamtrol.

B.1 FIRL Report No. F-C4033-1

L. E. Witcher and D. V. Paulson
Technical Report: Tests of Raychem Flamtrol Insulated and Jacketed Electrical Cables under Simultaneous Exposure to Heat, Gamma Radiation, Steam, and Chemical Spray
Franklin Institute Research Laboratories, 00-Jan-75

Qualification reference for Arkansas Nuclear One Unit 2; Big Rock Point; Brunswick Units 1 and 2; D. C. Cook Unit 2.

B.2 Raychem Corp. Report No. EM 517A

E. J. McGowan
The Effects of Radiation and Aging on Flamtrol Insulated Wire
Raychem Corp., 08-Apr-72

Qualification reference for Calvert Cliffs Units 1 and 2; St. Lucie Unit 1.

B.3 Raychem Report No. EM 523E

E. J. McGowan
Memo to P. Warnes. Subject: Flamtrol - UE&C Tests
Raychem Corp., 24-May-72

Qualification reference for Calvert Cliffs Units 1 and 2.

B.4 Raychem Report No. EM 644

E. J. McGowan
Memo to H. M. Robinson. Subject: Insulation Resistance Tests on Cable at Elevated Temperature and Pressure
Raychem Corp., 27-Nov-72

Qualification reference for Calvert Cliffs Units 1 and 2.

B.5 Raychem Report No. EM 668

E. J. McGowan
Memo to H. M. Robinson. Subject: Insulation Resistance Tests on Cable at Elevated Temperature and Pressure
Raychem Corp., 08-Jan-73

Qualification reference for Calvert Cliffs Units 1 and 2.

B.6 Raychem Report No. EM 691

E. J. McGowan
Memo to H. M. Robinson. Subject: Insulation Resistance Test on Cable at Elevated Temperature and Pressure
Raychem Corp., 29-Jan-73

Qualification reference for Calvert Cliffs Unit 1 and 2.

B.7 Raychem Report No. EM 1010

E. J. McGowan
The Effects of Radiation on Flamtrol at Elevated Temperatures
Raychem Corp.,11-Jul-74

Qualification reference for St. Lucie Unit 1.

B.8 Raychem Report No. EM 1403

E. J. McGowan
Continuation of LOCA Simulation Test
Raychem Corp., 09-Dec-77

Qualification reference for Surry Units 1 and 2.

B.9 Rockbestos Report on Firewall III*

G. S. Buettner and J. R. Marth
Qualification of Firewall III Class 1E Electric
Cables
Rockbestos Co., 01-Feb-77

Qualification reference for Nine Mile Point.

B.10 Duke Power Co. Report No. TR-012

No information available

Qualification reference for Oconee Units 1,2, and 3.

B.11 Raychem Specification No 44*

Wire and Cable, Electric, Radiation Crosslinked Polyalkene
Insulated, Copper
Raychem Corp., 12-Apr-68
Spec. #44, Rev.A

Wire and Cable, Electric, Radiation Crosslinked Polyalkene Insulated,
Copper
Raychem, 15-Oct-71
Spec. 44, Rev. A, Amendment 1

Qualification reference for Oconee Units 1, 2, and 3.

B.12 Mil Spec Mil-W-81044B*

Military Specification: Wire, Electric, Crosslinked
Polyalkene, Crosslinked Alkane-Imide Polymer, or Polyarylene
Insulated, Copper or Copper Alloy
USDOD, 31-Dec-73

Qualification reference for Oconee Units 1, 2, and 3.

B.13 Raychem Report - Flamtrol Qualification to IEEE Std 383

Raychem-Flamtrol Qualification to IEEE Standard 383
Raychem Corp., 10-Jun-76:

Qualification reference for Surry Units 1 and 2.
Note: This report includes as appendices FIRL Report No. F-C4033-1;
Raychem Report Nos. EM 517A and EM 1010.

B.14 NUS Vepco QDR Package 5437-54-01, -122-01

Qualification Review Package: Raychem Corp. 300V XLPE
Instrument Cables; Surry Unit 1
NUS Corp., 19-Nov-81
QDR-5437-54-01, Rev. 1

Qualification Review Package: Raychem Corp. 300 XLPE
Instrument Cable; Surry Unit 2
NUS Corp., 19-Nov-81
QDR-5437-122-01

Qualification reference for Surry Units 1 and 2.

B.15 Letter J. M. Kuster (Raychem)

J. Kuster
Letter to J. H. Barnhart, S&W. Subject: Flamtrol Wire & Cable;
North Anna Nuclear Units 3 and 4
Raychem Corp., 17-Nov-80

Qualification reference for Surry Units 1 and 2.