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VIRGINIA ELECTRIC AND POWER COMPANY

RICHMOND, VIRGINIA 23261

July 14, 1978

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
Attn: Albert Schwencer
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Serial No. 401
PO&M/DLB:das
Docket Nos. 50-280
50-281
License Nos. DPR-32
DPR-37

Dear Sir:

This in response to concerns expressed by members of your staff regarding the use of a certain type cable manufactured by the Continental Wire and Cable Company at Surry Power Station Unit Nos. 1 and 2. This letter summarizes our investigation of this matter and presents our conclusions.

Background

On June 29, 1978, Anaconda Cable, who now own Continental Wire and Cable, notified Vepco that their records indicated that certain cable which had failed environmental testing at another utility might also be in use at Surry Power Station.

In response to this notification, an investigation was initiated immediately to determine if this type of cable was in use in safety systems, inside containment, at Surry Power Station. Concurrently, Anaconda Cable was to determine the exact specifications of the cable which had failed as compared to cable purchased for use at Surry Power Station. The utility which had conducted the cable test was also contacted to determine the conditions under which the cable had failed as compared to our LOCA performance criteria. Our findings are summarized below. Throughout this letter the other utilities Continental cable which failed will be referred to as the "failed cable". The Continental cable in use at Surry will be referred to as the "Surry cable".

Cable Specifications

A review of the records of Continental Wire and Cable has determined that the failed cable is different in several respects from the Surry cable. The failed cable is described in test reports which you now have. The Surry cable specifications are briefly as follows (additional information is provided in the attachments):

- conductor: 16 gage, 7 strand, copper
- insulation: 25 mils cross-linked fire-resistant polyethylene, (compound number CC-2210)
- Shield: 100 percent coverage aluminum mylar tape, with 18 gage 7 strand copper drain wire
- jacket: 45 mils hypalon

A001 S 1/40

The major differences between the failed cable and Surry cable are in insulation compound number and in insulation and jacket thicknesses.

Test Results - Failed Cable

The test in which Continental Cable failed was performed recently for another utility. Since you now have the detailed results of this test, only a brief description will be provided here. The test performed was a combination LOCA/steam break test including a prior radiation exposure of 1.5 X 10^8 rads. The test sequence was as follows.

- irradiation of cable sample to 1.5 X 10^8 rads
- increase temperature and pressure to 340° and 110 psia. T_o was established when these conditions were reached
- 1 hour at 340° and 110 psia
- After 1 hour, temperature was dropped to 250° and maintained for a total test duration of 120 hours

This was an extremely conservative test which combined the worst effects of both the LOCA and steam break. This combination of conditions would never occur under any accident conditions. For example, irradiations on the order of 10^8 would occur only during a LOCA during which temperature and pressure would be considerably less than 340° and 110°F. Similarly, the temperature and pressure in this test are characteristic of a steam break wherein irradiation levels of approximately 10^5 rads would occur. This test was apparently intended to emcompass all conceivable test requirements in order to reduce the number of tests required. For this reason, the test did not establish that the cable would perform unsatisfactorily in either a LOCA or a steam break.

Discussions with personnel involved in this testing indicated that the failed cable was replaced with another make of cable following this test. Our impression from these discussions was that the cable was replaced not so much due to any concern over its performance, but because replacement of the small number of circuits affected was easier and faster than the running of additional, less conservative tests.

In summary, these test results indicate that certain instrument cable which is similar to cable in use at Surry, will not perform satisfactorily when exposed to test conditions which were far more severe than would occur in the event of a LOCA. There is no evidence that the Surry cable would not perform satisfactorily under more realistic test conditions or under actual LOCA conditions. However, to resolve concerns over this issue we have conducted a review of the specifications of Surry's cable and of the test data available relative to its performance during a LOCA.

Use of Continental Cable at Surry

A complete review of all cable runs has not been completed. It has been determined that Continental Cable is extensively used in safety related applications at Surry. The cable is used only as instrument cable. The maximum voltage used in these applications is 50 volts. Note that the voltage applied in the failed cable test was 300 volts.

The Surry cable is in the pressurizer pressure and level and the steam generator level instrumentation on Unit 1. Since the exact extent of its use on both units has not been determined, we have assumed for purpose of this evaluation that the cable has been used in every possible instrument application.

Acceptance Criteria and Test Results - Surry Cable

All safety related electrical equipment for Surry Power Station was purchased to meet the LOCA performance requirements specified in Section 8 of the FSAR. Section 8 requires operability in an environment of 280°F and 40 psig for a period of 30 minutes. Purchase specifications for instrument cable require the capability of withstanding a total radiation dose of 10^8 rads without a significant change in physical and electrical properties, a value well in excess of the 2 X 10^7 rads exposure estimated for a Surry LOCA.

All Surry cable purchased from Continental Wire and Cable, was subjected to extensive testing and inspection to ensure quality ahd performance. A representative test report for one cable sample is included in Attachment 1. Test reports for all Continental Cable are available if desired. These tests included the verification of mechanical design parameters and of basic electrical properties of the conductor and insulation. Tests were performed to monitor the performance of the cable and insulation under a variety of severe environmental conditions. These included measurements of the effect on tensile strength and elongation of 7 days in an air oven at 150°C. The cable was tested for heat distortion at 150°C and accelerated water absorption at 75°C. In all cases, cable performance was satisfactory. Additional information including acceptance criteria is shown on the test report form (attachment 1).

The suitability of this cable for operation under high irradiation has been confirmed both in tests performed by the manufacturer and by other test performed independently. The following article, included as attachment 2, provides a concise summary of the effects of radiation on the electrical properties of various insulation materials.

"Insulation and Jackets for Control and Power Cables in Thermal Reactor Nuclear Generating Stations"

by Robert B. Blodgett and Robert G. Fisher

IEEE Transactions on Power Apparatus and Systems, Vol. PAS-88, No. 5 May 1969

This article, in addition to discussing radiation effects on the standard measures of insulation performance, i.e. tensile strength and elongation, also directly addresses the effects of irradiation on other electrical properties. Note that on page 2 of the article, the types of cable coverings tested are listed. Covering type No. 4, CB CLPE is of the same general type as the Continental Cable used at Surry. As shown in Table XI of the article, under column 4 for CB CLPE, elongation begins to show deterioration prior to other parameters and identifies the theshold of irradiation damage. This confirms the validity of the accepted practice of relying on measurement of elongation and tensile strength to check for insulation deterioration for this type of insulation. In reviewing this article, please note the following.

1) In Table XI under column 4, 5 X 10^7 rads is identified as the theshold of damage for the type of cable used at Surry. A dose of 1 X 10^8 rads represents the end of serviceability.

2) Under "conclusions", cross-linked polyethylene is identified as among the most suitable insulation materials for nuclear plant service.

We will now discuss test results for the specific type of Continental cable used at Surry. This test was performed by the manufacturer in 1971, on insulated conductor only, with no jacket. Test information is included as attachment 3. The test sequence and results are listed on page 2 of the attachment. The test sequence was as follows:

- 120 hours, 50 PSIG steam, followed by
- 120 hours immersion in 0.5% Boric acid solution at 160^{o}F
- Sequence repeated at radiation exposures of 0, 1 X 10^7, 5 X 10^7, and 1 X 10^8

The test results are listed below as Table 1 with the addition of estimated tensile and elongation values for an exposure of 2 X 10^7rads. This has been added because 2 X 10^7 rads is the maximum calculated irradiation under LOCA conditions at Surry.

TABLE 1
LOCA TEST RESULTS
CLPE - COMPOUND #2210

CONDITIONING	TENSILE PSI	ELONGATION %
NONE	2440 (100)	550 (100)
STEAM/BORIC ACID	2390 (98)	450 (82)
RADIATION ONLY		
1 X 10^7 RADS (GAMMA)	2640 (106)	425 (77)
*2 X 10^7 RADS (GAMMA)	*2538 (104)	*378 (69)
5 X 10^7 RADS (GAMMA)	2230 (92)	238 (43)
1 x 10^8 RADS (GAMMA)	1710 (70)	100 (18)

RADIATION AFTER STEAM		
BORIC ACID		
1 X 10^7 RADS (GAMMA)	2580 (105)	393 (72)
*2 X 10^7 RADS (GAMMA)	*2385 (98)	*344 (63)
5 X 10^7 RADS (GAMMA)	2200 (90)	200 (36)
1 X 10^8 RADS (GAMMA)	1600 (66)	69 (13)

(% RETENTION VS ORIGINAL VALUE)
*ESTIMATED BY LINEAR INTERPOLATION

Based on IPCEA standards, an acceptable value for tensile strength and elongation following this test is 50 percent of the original value of each. The test sequence which most closely approximates the Surry LOCA condition is the 2 X 10^7 rads exposure following the steam and boric acid exposure. Based on a linear interpolation of actual test data the tensile strength and elongation following a LOCA would be 95% and 63% (results underlined) of the original values. This is acceptable. These test results indicate that, under the highest possible irradiation, and in temperature, moisture and pressure conditions of greater severity and duration than Surry LOCA conditions, the cable will perform satisfactorily.

The results also confirm the theshold of irradiation damage at 5 X 10^7 rads. Note also that irradiation is the major contributor to deterioration of cable properties and is far more significant than the steam and water exposure.

Page 3 of attachment 3 is a graph of tensil strength and elongation versus irradiation for the polyethylene compound number 2210 as used in the Surry cable. This data provides additional confirmation of the onset of deterioration at approximately 5 X 10^7 rads, accelerating rapidly as irradiation approaches 10^8. This graph also demonstrates the validity of linear interpolation between 1 X 10^7 and 5 X 10^7 which was used in Table 1.

Instrument Requirements for LOCA

While we are confident that our Continental instrument cable will perform satisfactorily throughout a LOCA and thereafter, it is pertinent to note that the safety related instrumentation located inside the containment is only needed for a short time following a LOCA. The instrumentation and coincidence logic required for the function of engineered safeguards during a LOCA are discussed in Section 7 of the Surry FSAR.

Pressurizer pressure and level are the only instruments inside containment which are necessary for the initiation of safeguards during a LOCA. Except for very small breaks, i.e. less than 1 inch, the initiating function would be completed within 5 minutes.

The containment pressure transmitters which are the most important instruments for safeguards initiation are located outside the containment.

The following instruments, located in containment, while not required to initiated safeguards, are of value in establishing the nature of the accident and for confirming the proper initiation of safety functions.

- containment sump level
- containment temperature
- safety injection flow
- accumulator levels
- steam line pressure
- steam flow
- wide range reactor coolant temperature
- wide range reactor coolant pressure

In response to a LOCA, these instruments are used by the operator to verify system conditions and safeguards operation. A loss of one or more of these instruments would not affect the operation of safeguards. These instruments are of greatest value for the first half hour following an accident.

In summary, instrumentation located inside containment is needed only for a short time following a LOCA for safeguards initiation and for verification of system conditions. Within 30 minutes following a LOCA, this instrumentation is no longer essential; its failure would pose no problem to safe post accident operation. Thus these instruments have served their function long before significant irradiation has occurred. Thirty minutes after the worst LOCA, irradiation is still less than 10^6 rads, far below the threshold of damage.

Summary and Conclusion

The objective of this evaluation has been to determine if certain instrument cable in use at Surry Power Station is suitable for its intended purpose. This concern developed following the failure by similar cable of a LOCA/steam break environmental test at another utility.

We have reviewed the failed cable test results to determine if any new cable performance information was developed which would cast doubt on the bases upon which our original cable selection was made. We found no such evidence. In fact, in many respects, the failed cable test confirmed the test data developed for our cable in 1971. The failed cable test has demonstrated once again that cross linked polyethylene insulation, when irradiated beyond 10^8 rads, will not perform.

The unrealistic and abusive cable test which initiated this concerned is in no way an indication that such cable would not perform its intended function under accident conditions. Indeed, test results performed by the manufacturer and confirmed by others indicates satisfactory performance under severe accident conditions.

The data presented herein demonstrates that for cross linked polyethylene insulation, irradiation is the major contributor to cable deterioration under LOCA conditions. The data also established 5 x 10^7 rads as the theshold for irradiation damage. This is far above the irradiation which would occur under Surry LOCA conditions.

We are confident that the Surry cable will perform its intended function under LOCA conditions. No further investigation or corrective action is considered necessary.

Very truly yours,

W L Stallings for.

C. M. Stallings
Vice President - Power Supply
Production Operations

cc: Mr. James P. O'Reilly

ATTACHMENT 1

SN285 item # 4
11/28/70

CONTINENTAL WIRE & CABLE CORP.
P.O. BOX 1863
YORK, PA.

TEST REPORT

CUSTOMER Virginia Electric & Power Company
ORDER NO. SN 285-3
REQUISITION NO. 24337
J. O. NO. 11448 Stone & Webster Eng. Corp.

SPEC. NUS-341
ITEM NO. 1
FOOTAGE 25 003

REQUIRED	ACTUAL
1.0 CONDUCTOR - #16 (7) TINNED COPPER	#16 (7) Tinned Copper
2.0 INSULATION - CROSS-LINKED POLY.	Cross-linked Poly.
WALL - 0.025" NOM.	.032
3.0 TWIST - NO. OF CONDS. 6	6 conductors
LAY - 5" ± 1/2	5.0"
4.0 SHIELD - ALUM/MYLAR 100% COVERAGE	Alum Mylar 100% Coverage
DRAIN - #18(7) TINNED COPPER	#18 (7) Tinned Copper
5.0 JACKET - HYPALON (BLACK)	Hypalon (Black)
WALL - 0.045" NOMINAL	.050"
6.0 DIELECTRIC - 3.0 KV-5 MINUTES	3.0 KV - 5 Minutes - Passed
7.0 INSULATION RESISTANCE 118 MEGOHMS PER 1000' MIN.	244 Low 306 High
8.0 CONDUCTOR RESISTANCE 4.61 OHMS/1000' MAX.	4.08 Low 4.17 High
(INSULATION)	
9.0 TENSILE STRENGTH (ORIG.) 1,600 PSI MIN.	1688 PSI Low.
ELONGATION - (ORIG.) 300% MIN.	462% Low.
AIR OVEN 7 DAYS AT 150°C TENSILE STRENGTH MIN.% OF UNAGED 50	86.3 %
ELONGATION MIN.% OF UNAGED 50	60.4 %
10.0 HEAT DISTORTION 150°C MAX.% 30	19.8 %
11.0 ACCELERATED WATER ABSORPTION EM-1000 PER IPCEA @ 75°C 1-14 DAYS MAX.% - 20	14.69 %
7-14 DAYS MAX.% - 5	2.87 %
JACKET (HYPALON)	Hypalon

DH Armstrong

CONTINENTAL WIRE & CABLE CORP.
TEST REPORT

12.0 TENSILE - MIN. PSI-1600	1658 PSI
ELONGATION - MIN.%-250	450%
O.D. .450 MAX. NOM	490
13.0 FLAME RESISTANCE	Passed

ACCEPTED ✓ DATE 11/28/70
REJECTED ______ DATE ______

Vernon David Stayman
INSPECTOR

R. L. Stine
QUALITY CONTROL MANAGER

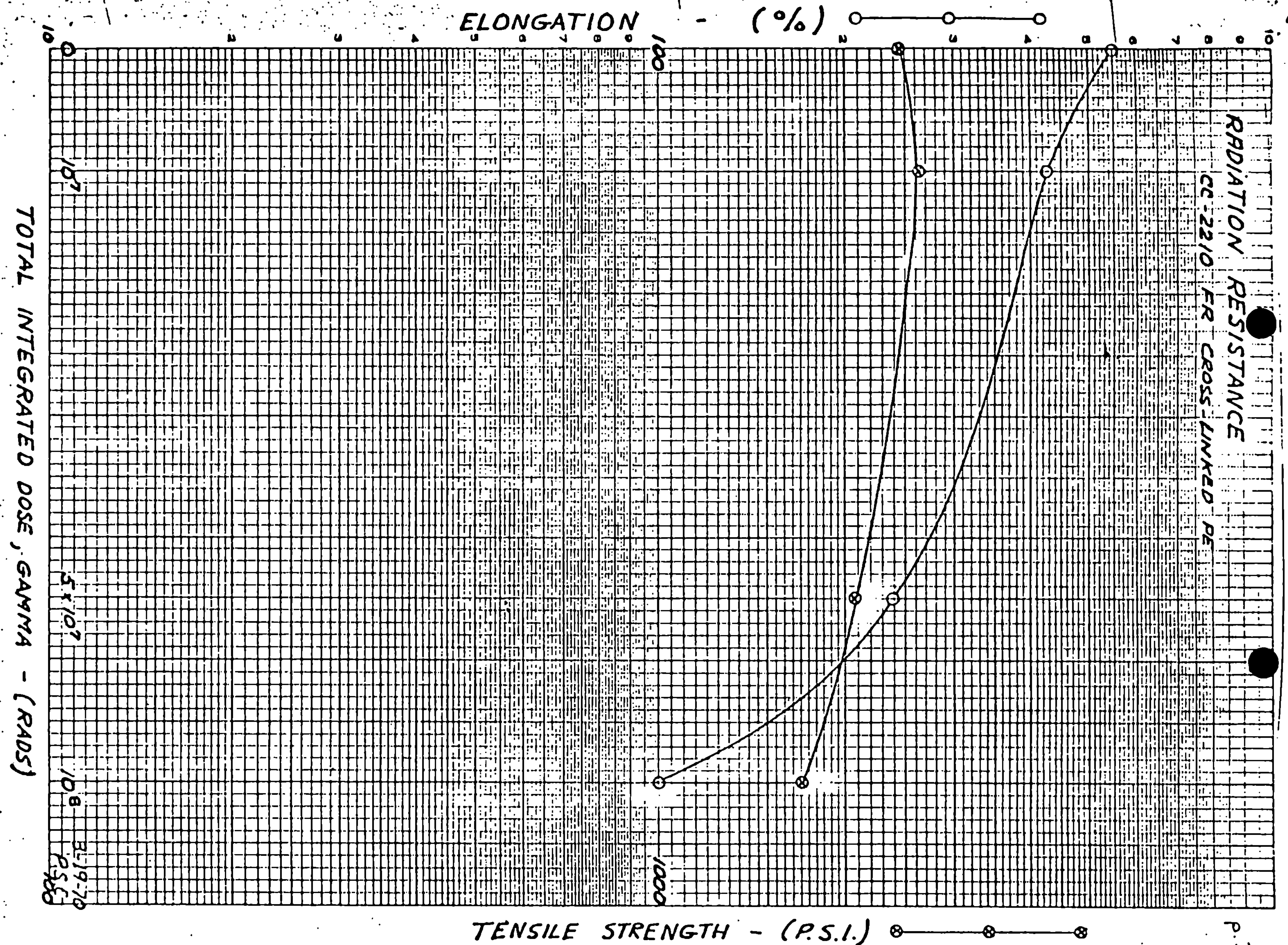
SWORN & SUBSCRIBED TO
BEFORE ME THIS 28th
DAY OF November 1970

NOTARY PUBLIC
My Commission Expires 4-1-74
York, Pa. York County
Sandra J. Willeide

REEL NUMBERS	FOOTAGE
1	12,243
2	12,760

NO. 340-L210 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.



ATTACHMENT 2

Insulations and Jackets for Control and Power Cables in Thermal Reactor Nuclear Generating Stations

ROBERT B. BLODGETT, SENIOR MEMBER, IEEE, AND ROBERT G. FISHER

Abstract—The permanent change in the physical strengths, rate of oxidation, dielectric loss, and electrical stability in 40-psig (142°C) steam and dielectric strength are reported for 13 elastomer-based insulation-jacket combinations after irradiation up to 10^8 rad in air at 5×10^5 rad/h from a cobalt 60 source. Threshold of damage for each property, overall threshold of damage, and highest dose rate still serviceable for the combinations are summarized. On the basis of these data, suggestions are made for IEEE nuclear environment classification of cable coverings rate for continuous 90°C and higher.

Introduction

IN A RECENT survey, Greenwald pointed out that by 1985 new nuclear generating capacity was expected to be twice that for hydro and fossil-fueled additions in the United States [1]. Up to now, thermal reactors have been employed, but high-gain breeder reactors, referred to as "fast breeders," are expected to come into use in the next decade [2]. This rapid increase in the use of nuclear reactors by electrical utilities has focused attention on the need for electrical power and control cables that will withstand gamma and neutron radiation over the projected life of the generating station.

Consider first the situation near the reactor core within the primary shield. Klein and Mannal concluded that only an essentially inorganic insulation structure would function in this area where exposures up to 10^{12} rad/h occur [3]. Elastomer-based insulations and jackets are not suitable for use within the primary reactor shield because the covalent bonds of the organic elastomers are easily disrupted by the high gamma and neutron flux near the reactor cores. Similarly, only essentially inorganic insulations will be suitable within the containment vessel of fast breeder reactors where the normal flux is expected to be as high as 10^5 rad/h.

Next, consider the situation outside the primary shield but within the containment vessel of thermal reactors. In this area gamma dose rates ranging from 0.5 up to 160 rad/h and temperatures up to 70°C are to be expected during normal operation. Should abnormal bursts of energy develop as a result of a nuclear or primary coolant incident, radiation levels may increase to 10^6 rad/h, while the temperature in the area may rise rapidly to 150°C with steam building up to 50 psig.

If we assume a 40-year life for a thermal nuclear generator, the total radiation dose absorbed by a cable within the containment area may approach 5×10^7 rad if there are no abnormal bursts of energy. If such an incident does occur and it is brought back under control within four hours, the additional dose absorbed might be 0.4×10^7 rad.

The exposure of cables to radiation in the auxiliary structures, e.g., the residual-heat-removal compartments, outside the containment vessel is less severe, since the maximum dose rates are expected to be two orders of magnitude lower, i.e., 0.01 times those in the containment vessel. However, cables in this area must operate even during an abnormal burst of energy, because they supply power to pumps, fans, and other safeguard systems needed to prevent a disastrous increase in energy output.

The main question to which this paper is addressed is whether cables insulated and jacketed with elastomer- (polymer-) based material can be expected to perform satisfactorily in the containment and lower radiation areas outside the containment vessel of thermal reactors. Other investigators have established the effect of radiation on the physical properties of various organic materials. In fact, ASTM has held several symposia on radiation effects on materials [4]–[7]. However, the effect of radiation on electrical and heat aging properties of cable coverings has received less attention and is less well established.

Damage Mechanisms

For the most part, radiations of primary interest from the standpoint of damage to elastomer-based insulations and jackets have energies of the order of 1 MeV, gamma photons, and fast neutrons, for example. Most radiation damage to elastomers is caused by internal electron bombardment from the elastic collision between gamma photons and electrons [8], [9].

Since bond energies and ionization potential are as much as six orders of magnitude lower than that for high-energy radiations and the resultant collision-produced energy, both temporary and permanent changes result when elastomer-based insulations and jackets are irradiated. First, consider the temporary changes produced by incident radiation. These are thermoluminescence, increased dc conductivity, and gas evolution [3], [8], [9]. Thermoluminescence is of no concern for cables. An increase in dc conductivity would be of concern only if drastic increases occurred. We will see later that this is not the case. Evolution of gases can be tolerated where adequate ventilation exists, but remains a problem where hermetic enclosures are required. Reed discussed this problem [14].

Now consider permanent damage. Most elastomers ultimately become brittle on prolonged irradiation, depending on their sensitivity. This embrittlement is caused by radiation-induced cross-links between the polymer molecules extending the three-dimensional networks to the degree seen in hard rubber and phenolic resins. A few polymers, e.g., butyl rubber, degrade rather than cross-link when irradiated. In such cases, the scission of the main chain bonds results in the formation of low-molecular-weight chain fragments which resemble soft tar-like substances.

Paper 68 TP 651-PWR, recommended and approved by the Insulated Conductors Committee of the IEEE Power Group for presentation at the IEEE Summer Power Meeting, Chicago, Ill., June 23–28, 1968. Manuscript submitted February 12, 1968; made available for printing April 23, 1968.

R. B. Blodgett is with The Okonite Company, Passaic, N. J.
R. G. Fisher was with The Okonite Company, Passaic, N. J. He is now with Amerace-Esna, Butler, N. J.

It follows that the elemental composition, molecular structure, and volume of material involved are important considerations in radiation environments. Dose rate and kind of radiation are also important factors. Generally, the damage to a polymer by radiation is dependent on the total dose absorbed regardless of the type of radiation. King *et al.* [9] and Collins and Calkins [10] reported reasonable agreement for the changes that occurred in polymers when exposed to alpha, beta, gamma, and neutron radiation fields. The main factor seems to be the total energy to which the material is exposed; this is known as the equal-energy equal-damage concept. It assumes independent action of heat, water, and radiation.

Experimental Gamma Irradiation of Thin-Walled Cable Coverings

The following 13 insulation–jacket combinations on nos. 12 and 14 AWG copper wires were exposed in two configurations to gamma radiation. Both configurations used cobalt 60, gamma = 1.17 to 1.332 MeV, and beta = 0.31 MeV, at a dose rate of 5×10^5 rad/h. Bausch and Lomb cobalt glass chip dosimetry was used to confirm dose rate to less than ± 5 percent. Six sets of the insulation–jacket combinations were exposed to Southwest Research Institute's cobalt 60 source. The wire samples, each 10 feet long, were coiled in a cardboard drum with a diameter of 2 feet. Each coil was one wire thick and several wires tall. The drum rotated at 3 r/min in air. Air temperature ranged from 30–40°C. Total integrated dosages of 5×10^5, 5×10^6, and 5×10^7 were thus obtained. Two additional sets of wires were wrapped around a 5.25- × 11.25-inch long beaker and exposed in Esso Research and Engineering Company's radiation core in air and water at the same dose rate as that above to a total dose of 10^8 rad.

1) *PVC*: Polyvinylchloride per IPCEA S-61-402, section 3.8, and UL types THW and MT. No. 4 AWG (7×) copper, 0.047-inch wall.

2) *HD Poly-PVC*: High-density polyethylene, type III, class B, grade 3 per ASTM D1248-63T and polyvinylchloride per IPCEA S-61-402, section 3.7, and IPCEA S-19-81, section 4.13.5. No. 12 AWG (7×) copper, 0.030-inch insulation, and 0.015-inch jacket.

3) *SBR-Neoprene*: Styrene-butadiene synthetic rubber-based insulation per IPCEA S-19-81, section 3.13, and polychloroprene-based jacket per ASTM D-752 and IPCEA S-19-81, section 3.13.3, and UL type RHW. No. 14 AWG (7×) copper, 0.047-inch insulation, and 0.0156-inch jacket.

4) *CB CLPE*: Low-voltage carbon black-filled chemically cross-linked polyethylene per IPCEA S-66-524, Interim Standard 2, and UL type RHW-RHH. No. 14 AWG (7×) copper, 0.047-inch wall.

5) *CF EPDM-Neoprene*: Ozone-resisting, mineral-filled EPDM-based, low-voltage insulation exceeding the requirements of IPCEA S-19-81, sections 3.15 and 3.16, and polychloroprene-based jacket per ASTM D-752 and IPCEA S-19-81, section 4.13, UL type RHH. No. 14 AWG (7×) copper, 0.047-inch insulation, and 0.0156-inch jacket.

6) *Butyl-Neoprene*: Ozone-resisting butyl-based insulation per IPCEA S-19-81, sections 3.15 and 3.16, and polychloroprene-based jacket per ASTM D-752 and IPCEA S-19-81, section 4.13.3, and UL type RHW-RHH. No. 14 AWG (7×) copper, 0.047-inch insulation, and 0.0156-inch jacket.

7) *Oil-Base CSPE*: Ozone-resisting 90°C oil-base, high-voltage insulation meeting the requirements of IPCEA S-19-81, sections 3.14 and 3.15, UL type RHH, and chlorosulfonated polyethylene-(CSPE) based jacket sic ASTM D-752 and IPCEA S-19-81, section 4.13.3, UL type RHH. No. 14 AWG (7×) copper, 0.047-inch insulation, and 0.0156-inch jacket.

8) *NF CLPE*: High-voltage, nonfilled chemically cross-linked polyethylene (nonstaining antioxidant) per IPCEA S-66-524, Interim Standard 1. No. 14 AWG solid copper, 0.047-inch wall.

9) *CF EPM-CPE*: Ozone-resisting, clay-filled EPM-based, high-voltage insulation per IPCEA S-19-81, section 3.16, and UL type RHW-RHH, and chlorinated polyethylene-based jacket SIC ASTM D-752 and IPCEA S-19-81, section 4.13.3. No. 14 AWG solid copper, 0.047-inch insulation [15], and 0.0156-inch jacket.

10) *Silicone*: Ozone-resisting silicone rubber insulation per IPCEA S-19-81, section 3.17, UL type SA. No. 14 AWG (7×) copper, 0.047-inch insulation, and 0.010-inch glass braid.

11) *Neoprene*: Polychloroprene-based jacket per ASTM D-752 and IPCEA S 19-81, section 4.13.3, UL type RHH. No. 14 AWG solid copper, 0.047-inch wall.

12) *CSPE*: Chlorosulfonated polyethylene-based jacket SIC ASTM D-752 and IPCEA S-19-81, section 4.13.3, UL type RHH. No. 14 AWG solid copper, 0.047-inch wall.

13) *CPE*: Chlorinated polyethylene-based jacket SIC ASTM D-752 and IPCEA S-19-81, section 4.13.3. No. 14 AWG solid copper, 0.047-inch wall.

It should be emphasized that radiation conditions in a nuclear generating station will be less ideal and more complex. Changes in the gamma and neutron flux caused by interactions with surrounding structures may occur. The mass of the cable assembly, cable design, and the number of cables racked in trays may also affect the degree of radiation. Compounding techniques and combinations of ingredients may also influence the resistance to radiation of any polymer-based cable covering. Even so, we feel that the data in the following sections provide a meaningful basis for estimating the useful life of cable insulations and jackets intended for use in nuclear generating stations.

Permanent Changes in Physical and Aging Properties of Cable Coverings

Physical Strength

The data in Table I show that the permanent changes in 23°C tensile strength for cable coverings based on polyethylene, EPDM, polymerized oil, SBR, PVC, neoprene, chlorosulfonated polyethylene, and chlorinated polyethylene were not large enough to affect their useful life when exposed to gamma radiation between 5×10^5 up to 10^8 rad. Silicone became brittle between 10^7 and 10^8 rad, and butyl was degraded to a tar-like liquid between 5×10^6 and 10^7 rad. Stress at 200-percent strain (modulus) followed a similar pattern. For all materials, elongation decreased, undoubtedly due to radiation cross-linking. Elongation data for butyl and silicone were not obtainable after exposure to 5×10^7 rad.

Rate of Oxidation

To assess the permanent effect of gamma radiation and the rate of oxidation for insulating materials, the conductors and jackets were removed from the irradiated samples, and the resulting tubular insulations were aged at 175, 150, 136, 121, 100, and 75°C in forced-air-circulation ovens. For each of the coverings the time to a 40- or 80-percent loss in elongation was determined before and after each radiation dose. For insulations we used time to 40-percent loss in elongations. For jackets we used time to 80-percent loss in elongation, because jacket com-

TABLE I
PERMANENT EFFECT OF GAMMA RADIATION ON PHYSICAL STRENGTHS OF CABLE COVERINGS

	PVC	HD Poly	SBR	CB CLPE	CF EPDM	Butyl	90°C Oil Base	NF CLPE	CF EPM	Silicone	PVC	Neo-prene	CSPE	CPE
							Tensile strength							
Original (psi)	2114	2213	1520	2045	1455	798	804	2272	872	1191	2601	2544	2113	2170
Percent retention after irradiation														
5×10^5	110	96	98	122	104	96	121	102	101	76	80	104	106	112
5×10^6	104	98	100	112	97	58	103	97	106	100	88	98	113	98
5×10^7	79	123	82	101	93	*	98	70	119	100	61	77	124	135
1×10^8	83	118	40	95	79	*	71	59	90	†				
							200-percent modulus							
Original (psi)	2260	2000	588	1767	1033	520	335	1260	730	850	2415	930	884	626
Percent retention after irradiation														
5×10^5	94	95	106	125	100	103	121	96	116	75	81	107	116	108
5×10^6	90	98	121	115	94	69	126	102	127	112	95	103	156	152
5×10^7	‡	‡	150	‡	120	*	121	108	‡	98	‡	160	203	‡
1×10^8	‡	‡	‡	‡	‡	*	103	‡	‡	†				
							Elongation							
Original (percent)	260	640	460	270	470	450	870	480	300	290	250	550	560	670
Percent retention after irradiation														
5×10^5	115	103	93	104	111	93	97	90	96	107	100	96	89	99
5×10^6	115	103	96	96	102	87	90	96	81	90	80	93	86	63
5×10^7	31		70	48	47	*	71	58	41	34	40	46	59	18
1×10^8	19	2	33	37	32	*	53	25	26	†				

* Degraded (scission).
† Brittle.
‡ Elongated <200 percent.

TABLE II

Permanent Effect of Gamma Radiation on Resistance to Oxidation of Cable Coverings

	40-Percent Loss Elongation									80-Percent Loss Elongation			
	PVC	SBR	CB CLPE	CF EPDM	Butyl	90°C Oil Base	NF CLPE	CF EPM	Silicone	PVC	Neoprene	CSPE	CPE
	Estimated years at 70°C												
Nonirradiated (rad)	>115	0.36	>115	>115	25*	64	>115	>115	>115	115	1.9	62	115
Ratio: Irradiated to nonirradiated													
5×10^5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5×10^6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	10^{-4}	1.00	1.00	1.00	1.00
5×10^7	5×10^{-4}	1.00	1.00	1.00	†	1.00	3×10^{-3}	1.00	10^{-6}	10^{-2}	0.50	1.00	10^{-1}
	Activation energy K_E, kcal/mole												
Nonirradiated (rad)	47.5	18.0	35.0	33.0	32.0*	25.4	34.3	34.3	45.5	40.2	20.5	38.3	40.2
Ratio: Irradiated to nonirradiated													
5×10^5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	1.00	1.00
5×10^6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.40	1.00	0.90	1.00	1.00
5×10^7	0.34	1.00	1.00	1.00	†	1.00	0.40	1.00	0.23	0.28	0.90	1.00	0.89

* Based on loss of tensile strength.
† Degraded (scission).

TABLE III

Permanent Effect of Gamma Radiation on Dielectric Constant of Cable Coverings

Dose (rad)	Measured after Two Hours (°C)	PVC	HD Poly	SBR	CB CLPE	CF EPDM	Butyl	90°C Oil Base	NF CLPE	CF EPM	Silicone
		k′(SIC), 40 V/mil, 60 Hz									
None	23	4.90	2.58	3.32	3.58	3.37	4.35	3.44	2.25	3.47	3.11
	75	6.82	2.52	3.84	3.44	3.19	4.21	3.27	2.30	3.49	2.96
	90	7.32	2.51	*	3.04	3.18	4.14	3.09	2.30	3.44	2.98
Percent change											
5×10^5	23	+3	−1	+5	−1	−4	−2	+5	+7	+8	0
	75	−4	−2	+10	−2	−4	−2	0	+3	0	−1
	90	+52	+1	*	+4	+5	−2	+2	−4	+3	−1
5×10^6	23	+4	+39	+5	+3	−9	−20	+10	+3	+8	+29
	75	+6	+42	+6	−7	−6	0	−4	−7	+3	−8
	90	*	+132	*	+4	+5	0	+3	+4	+3	−8
5×10^7	23	+21	+36	+1	+3	−7	−20	+6	+3	+10	+2
	75	+41	+39	−9	−1	−8	†	+1	−1	+6	+1
	90	*	+104	*	+9	+2	†	+10	+9	+9	0
1×10^8	23	+59	−6	+1	+2	+1	†	+7	+2	+7	+6

The high dielectric constants of the neoprene-, CSPE-, and CPE-based jacket materials were not significantly affected.
* Loss higher than limit of bridge.
† No test, sample degraded.

TABLE IV
PERMANENT EFFECT OF GAMMA RADIATION ON TAN δ (POWER FACTOR) OF CABLE INSULATIONS

Dose (rad)	Measured after Two Hours (°C)	PVC	HD Poly	SBR	CB CLPE	CF EPDM	Butyl	90° C Oil Base	NF CLPE	CF EPM	Silicone
		$D = \tan\delta \times 10^4$, ≈100 percent PF, 40 V/mil, 60 Hz									
None	23	540	143	231	65	217	110	118	14	86	110
	75	1424	80	1834	106	254	534	200	24	150	370
	90	2085	140	>3000	380	540	1040	443	27	270	476
Percent change											
5×10^5	23	+7	−20	+1	+11	−41	+6	−14	−33	+2	−17
	75	+21	+375	−14	−14	−16	−12	−34	+350	−2	−3
	90	+34	+750	*	−24	−36	−13	−18	+519	−13	+26
5×10^6	23	+34	−22	+16	+48	−25	+11	−22	+29	+29	−19
	75	+60	+235	−14	+35	−4	−13	−7	+108	+27	−1
	90	*	+593	*	−50	−20	−1	−30	+196	−7	+24
5×10^7	23	+59	−20	−22	+20	−23	+62	−20	+47	+38	+10
	75	+71	+63	−38	−6	−37	†	−5	+67	+39	−19
	90	*	+29	*	−69	−20	†	−48	+419	−20	+6
1×10^8	23	+117	−2	−30	+2	+36	†	−11	+29	+35	+27

Tan δ of the neoprene-, CSPE-, and CPE-based jacket materials were not significantly affected.
* Loss higher than limit of bridge.
† No test, sample degraded.

TABLE V
PERMANENT EFFECT OF GAMMA RADIATION ON DC RESISTIVITY OF CABLE COVERINGS

Dose (rad)	Measured after Two Hours (°C)	PVC	HD Poly	SBR	CB CLPE	CF EPDM	Butyl	90°C Oil Base	NF CLPE	CF EPM	Silicone	Neoprene	CSPE	CPE
		Dc resistivity, 100 teraohm-cm, 500 V dc												
None	23	0.15	240	2.3	70	12	76	15	141	71	0.2	10^{-3}	0.2	10^{-3}
	75	10^{-4}	25	10^{-3}	40	0.3	0.2	1.2	68	1.3	10^{-2}	10^{-4}	10^{-2}	10^{-4}
	90	10^{-4}	20	10^{-4}	37	0.3	0.1	0.1	50	1.0	10^{-3}	10^{-6}	10^{-4}	10^{-3}
Percent change														
5×10^5	23	−28	−43	+50	+33	−20	0	−1	−4	+11	+57	−31	−14	−40
	75	−90	−32	+48	+50	+32	−14	+100	−3	+10	0	−34	−32	−55
	90	+23	−90	−6	−33	−29	−51	+100	−3	0	+52	−85	−54	+198
5×10^6	23	+48	−70	+13	−59	−4	0	−1	−4	+38	0	+15	−5	0
	75	+10	−99	+40	+17	−8	−84	+66	−3	−9	+25	+4	−17	0
	90	−47	−92	0	−43	−51	−98	+90	−3	0	+15	+415	−82	+19
5×10^7	23	−67	−81	+48	−68	+53	−82	−5	−4	+25	+60	0	0	−14
	75	+100	−80	+250	−52	−34	*	+33	−4	−7	+20	+11	−17	−92
	90	+27	−99	+100	−75	−79	*	+25	−3	−40	+64	+390	−75	−85
1×10^8	23	+120	−70	+58	−7	+60	*	+35	−8	0	+60			

* No test, sample degraded.

pounds, in general, are less resistant to oxidation than most insulations in use today. The log of that time was then plotted versus the reciprocal of absolute temperature in degrees Kelvin ($1/T$) to estimate the time to the same change in property at 70°C [11]. The data in Table II show decreases as large as six orders of magnitude for the oxidation resistance of PVC, silicone, and nonfilled, nonstaining CLPE. The oxidation resistance for CPE and PVC decreased by as much as three orders of magnitude after exposure to 5×10^7 rad. The others were not affected. Data on the oxidation resistance of HD polyethylene were not included in Table II because the samples did not yield uniformly after aging. Irradiated samples aged above the melting point of the polyethylene did not flow, indicating that the polymer was cross-linked; the use of radiation to cross-link polyethylene, of course, is well known. We speculate that aging characteristics of irradiated HD polyethylene would be similar to those for chemically cross-linked nonfilled polyethylenes. In regard to the activation energies calculated from the Arrhenius plots of our aging data, the higher the value, the more temperature dependent the aging mechanism. However, different aging mechanisms can have similar activation energies. For example, the 47.5 kcal/mole value for nonirradiated PVC is close to the 45.5 value for silicone. (This level is equivalent to 2 eV.) However, the PVC had a useful life of 200 hours at 136°C, while silicone retained more than 65 percent of its unaged properties after 1440 hours. This difference, we feel, was due to rapid loss of plasticizer in the case of the PVC and normal oxidation for the silicone. The predicted values show that both PVC and silicone should have a long service at 70°C where both plasticizer volatility rate for the PVC and the oxidation of silicone would proceed at a greatly reduced rate.

Changes in Electrical Properties of Cable Coverings

Dielectric Constant (SIC), Tangent of Dielectric Loss Angle (PF), and DC Resistivity

These parameters were monitored during irradiation at 5×10^5 rad/h in 30°C air or 40°C water in the Esso laboratory. Any changes were small and relatively unimportant; they were essentially the same whether the irradiation occurred in air or water. Dielectric constant did not change noticeably. Tan δ increased by factors of 2–4. A tenfold decrease in resistivity was noted for butyl, nonfilled CLPE, EPDM, and EPM while the 90°C oil-base material, carbon black-filled CLPE, and HD polyethylene showed no change. A tenfold increase was seen with PVC.

Permanent changes in these three parameters also were relatively unimportant. Table III shows that, with one exception, the *dielectric constant* was not affected by irradiation. The exception was the high-density polyethylene/PVC covered wire for which k' increased 132 percent after 5×10^5 rad. The room temperature dielectric constants of the neoprene-, CSPE-, and CPE-based materials (23, 6.5, and 10) were not affected significantly by radiation. We were unable to study the effect of radiation in the high-temperature values of dielectric constant; we were unable to balance the Schering bridge when these materials were at 75 and 90°C.

Table IV shows that with two exceptions, *tangent delta* (tan δ) was not permanently affected by irradiation. The exceptions were the high-density and nonfilled cross-linked polyethylene whose tan δ increased as much as 750 percent. The room temperature tan $\delta \times 10^4$ values of neoprene-, CSPE-, and CPE-based materials (1157, 937, 277) were not affected significantly by radiation. Bridge balances were not possible at 75 and 90°C.

The data in Table V show that *dc resistivity* of the crystalline polyethylene-based materials generally decreased while the resistivity of the amorphous rubber-based materials increased. Further, the dc resistivity of HD polyethylene and nonfilled cross-linked polyethylene became more sensitive to temperature with increased irradiation as evidenced by the 2x increase in activation energy K_e from 23 to 90°C shown in Table VI. Carbon black-filled cross-linked polyethylene and clay-filled EPDM were less sensitive to temperature with increased radiation. Others were not affected.

It was not part of our work to establish the cause of the changes in cable coverings after irradiation. However, some speculation on the cause of the marked changes in the product of dielectric constant and tangent delta (dielectric loss index) observed for the nonfilled polyethylene is in order. Consider the case of polyethylene insulations with or without a PVC jacket. Since the changes are about the same, chlorine from the PVC jacket is probably not reacting with the polyethylene. It is more likely that electrons trapped in the crystalline portions of the polyethylene during radiation were released after radiation when temperature was increased during electrical measurements. This will also explain the fact that tangent delta for the nonfilled cross-linked polyethylene (SP = 110°C) wires was at its usual low level when measured at 90°C after conditioning for 24 hours in steam at 40 psig (142°C).

Specific Surface Resistivity

The following data show that this parameter (measured after four weeks' immersion in water) was not significantly affected by radiation. PVC was an exception, since the radiation caused it to deform during water immersion (see Table VII).

Dielectric Strength in Water and Steam

The data in Table VIII show that the dielectric strength (measured immediately after immersion in water) of insulating materials, with two exceptions, was not significantly changed by exposure up to 10^8 rad. PVC retained 73 percent of its breakdown value up to 5×10^7 rad, but retained only 41 percent after 10^8 rad. Dielectric strength for butyl did not change up to 5×10^6 rad, but was 80 percent lower after 5×10^7 rad when it became very soft. The dielectric strength for jackets decreased nearly fivefold for neoprene and twofold for CSPE and CPE.

Similar effects were seen when irradiated samples were subjected to conditions simulating the steam environment expected within the containment vessel during abnormal bursts of energy. Water-filled jars containing the samples (except for the thermoplastic materials) were maintained in a steam autoclave at 40 psig (142°C) for a maximum period of 32 days. Periodically, the samples were removed from the autoclave and placed in 90°C water for two hours, after which electrical measurements at 40 and 80 V/mil were made. The thermoplastic HD polyethylene and PVC wires were kept continually in the 90°C water; they did not go in the autoclave. The data in Table IX show that the ability of the carbon black- and nonfilled cross-linked polyethylene, clay-filled EPDM and EPM, high-temperature oil-base and silicone materials to withstand 80 V/mil was not seriously affected by gamma radiation up to 5×10^7 rad. SBR was less stable after irradiation, but independent of dosage. Butyl was unstable above 5×10^6 rad. Silicone had the poorest resistance to steam; the nonirradiated control lasted only four days. The silicone had hydrolyzed to a powdery residue. HD polyethylene did not fail in 90°C water regardless of dosage; D (tan $\delta \times 10^4$) was higher than expected, near 1000 for irradi-

TABLE VI
ACTIVATION ENERGY K_E KCAL/MOLE FOR 23 TO 90°C DC RESISTIVITY OF INSULATIONS

Dose (rad)	PVC	HD Poly	SBR	CB CLPE	CF EPDM	Butyl	HT Oil Base	NF CLPE	CF EPM	Silicone
None	17.5	10.5	26.6	27.7	10.5	17.6	10.9	1.4	15.1	15.5
5×10^5	17.5	22.4	26.6	27.7	7.9	17.6	10.9	1.4	15.1	15.5
5×10^6	17.5	22.4	26.6	9.0	7.9	17.6	10.9	2.8	15.1	15.5
5×10^7	17.5	22.4	26.6	9.0	7.9	*	10.9	2.8	15.1	15.5

* Not tested, sample degraded.

TABLE VII
SPECIFIC SURFACE RESISTIVITY AFTER FOUR WEEKS IMMERSION IN WATER (MEGOHMS)

	PVC		Neoprene		CSPE		CPE	
	22°C	90°C	22°C	90°C	22°C	90°C	22°C	90°C
None	3.5	3.5	210.0	8.0	21.0	21.0	0.6	21.0
5×10^5	1.1	*	210.0	0.1	21.0	21.0	0.6	21.0
5×10^6	0.3	*	2.1	0.2	21.0	0.6	180.0	10.5
5×10^7	2.5	*	8.4	0.4	4.2	0.6	180.0	21.0

* No reading, badly deformed, and irregular.

TABLE VIII
PERMANENT EFFECTS OF GAMMA RADIATION ON DIELECTRIC STRENGTH OF CABLE COVERINGS

Dose (rad)	PVC	HD Poly	SBR	CB CLPE	CF EPDM	Butyl	90°C Oil Base	NF CLPE	CF EPM	Silicone	Neoprene	CSPE	CPE
					Rapid rise 60 Hz, S_{max} V/mil at 23°C								
None	1000	1176	960	1000	865	564	625	2028	811	1192	1364	1364	1242
5×10^5	862	1130	952	928	653	618	794	1300	871	1130	204	612	850
5×10^6	863	1220	843	1030	915	542	968	1430	870	1560	170	595	715
5×10^7	725	805	925	1060	842	129	817	1300	788	1490	289	510	648
1×10^8	414	670	612	828	838	*	744	1360	788	1045			

* No test, sample degraded.

TABLE IX
PERMANENT EFFECTS OF GAMMA RADIATION ON DIELECTRIC STRENGTH OF CABLE COVERINGS

Dose (rad)	SBR/ Neoprene	CB CLPE	CF EPDM/ Neoprene	Butyl/ Neoprene	90°C Oil Base/ CSPE	NF CLPE	CF EPM/ CPE	Silicone/ Glass	HD Polyethylene/PVC	PVC
	Days in steam 40 psig (142°C) to failure at 80 V/mil at 90°C								Weeks in 90°C water to failure at 80 V/mil	
None	11	>32	>32	11	32	>32	18	4	>9	>9
5×10^5	4	>32	>32	11	32	4	18	3	>9	>9
5×10^6	4	>32	>32	11	32	>32	18	4	>9	2
5×10^7	4	>32	25	1	25	>32	18	3	>9	1

TABLE X
PERMANENT EFFECT OF GAMMA RADIATION ON FLAME RESISTANCE OF THIN WALL WIRES IN UL FLAME TEST

	PVC		HD Poly/ PVC		SBR/ Neoprene		CB CLPE		CF EPDM/ Neoprene		Butyl/ Neoprene		90°C Oil Base CSPE		NF CLPE		CF EPM/ CPE		Silicone/ Glass	
Dose (rad)	0	10^8	0	10^8	0	10^8	0	10^8	0	10^8	0	10^8	0	10^8	0	10^8	0	10^8	0	10^8
Results	P	P	F	P	F	F	F	F	P	P	F	F	P	P	F	F	P	P	P	P
Percent flag destroyed	0	0	100	0	100	100	100	100	0	0	100	20	0	0	100	100	0	0	0	0
After burn (seconds)	0	0	180	0	52	60	180	100	0	0	50	80	0	0	180	180	0	0	0	0

P—pass; F—failure.

TABLE XI
THRESHOLD OF GAMMA RADIATION DAMAGE (RAD) FOR ELASTOMER-BASED CABLE INSULATIONS

Property	PVC	HD Poly	SBR	CB CLPE	CF EPDM	Butyl	90°C Oil Base	NF CLPE	CF EPM	Silicone	PVC
Tensile strength	10^8	10^8	5×10^7	10^8	10^8	5×10^6	10^8	5×10^7	10^8	5×10^7	5×10^7
Elongation	5×10^7	5×10^6	5×10^7	5×10^7	5×10^7	5×10^6	10^8	5×10^7	5×10^7	5×10^7	5×10^7
Rate of oxidation	5×10^6		$>5 \times 10^7$	$>5 \times 10^7$	$>5 \times 10^7$	5×10^6	$>5 \times 10^7$	5×10^6	5×10^7	5×10^5	5×10^6
Dielectric loss	5×10^7	5×10^5	10^8	10^8	10^8	5×10^6	10^8	5×10^5	10^8	10^8	5×10^7
Electrical stability	5×10^5	5×10^7	5×10^5	$>5 \times 10^7$	5×10^7	5×10^5	5×10^7	5×10^7	$>5 \times 10^7$	$>5 \times 10^7$	5×10^5
Dielectric strength	5×10^7	$>5 \times 10^7$	5×10^7	10^8	$>10^8$	5×10^6	10^8	$>10^8$	$>10^9$	$>10^8$	5×10^7
Overall threshold of damage	5×10^5	5×10^6	5×10^6	5×10^7	5×10^7	5×10^6	5×10^7	5×10^6	5×10^7	5×10^5	5×10^5
Highest dose still serviceable	5×10^6	5×10^7	5×10^7	10^8	10^8	5×10^6	10^8	10^8	10^8	5×10^7	5×10^6

TABLE XII
THRESHOLD OF GAMMA RADIATION DAMAGE (RAD) FOR ELASTOMER-BASED CABLE JACKETS

Property	Neoprene	CSPE	CPE
Tensile strength	5×10^7	5×10^7	5×10^7
Elongation	5×10^7	5×10^7	5×10^6
Rate of oxidation	5×10^6	5×10^7	5×10^6
Overall threshold of damage	5×10^6	5×10^7	5×10^6
Highest dose still serviceable	5×10^7	5×10^7	5×10^7

TABLE XIII
SUGGESTED IEEE NUCLEAR ENVIRONMENT CLASSIFICATION FOR ELASTOMER-BASED CABLE INSULATIONS

Radiation Class	Temperature: Class O (90°C)	Class A (105°C)	Class B (130°C)
1	Silicone*	Silicone*	Silicone
2	Butyl	*	None
3	EPDM EPM Oil base NF CLPE CB CLPE	EPDM CB CLPE EPM	None
4	None	None	None
5	None	None	None

* See Conclusions.

ated samples versus 124 for the control. PVC wires were unstable and failed at 80 V/mil in 90°C water after exposure to 5×10^6 rad.

Permanent Changes in Flame Resistance

To assess the flame-resistant properties of the thin wall wires in this study, we used the Underwriters' Laboratories vertical flame test. The data in Table X show that the flame-retardant properties, except for the HD polyethylene/PVC were not changed after exposure to 10^8 rad. The improvement in HD polyethylene/PVC exposed to 10^8 rad was due, we feel, to radiation cross-linking which prevented the polyethylene from melting and flowing into the flame, but one should not depend on radiation effects to make the wire flame resistant. The risks of spreading a fire also appear to be great with the cross-linked polyethylenes, butyl/neoprene, and SBR/neoprene combinations. Of course, the flame resistance of carbon black- and nonfilled cross-linked polyethylenes can be markedly improved by the application of a suitable flame-retardant jacket [12]. PVC, silicone/glass braid, 90°C oil-base/CSPE, EPDM/neoprene, and EPM/CPE combinations should offer greater assurance against the spread of fires.

Threshold of Damage or Radiation Limits for Cable Coverings

From the data in the previous tables, we have selected the maximum total integrated dose that a covering can withstand without a significant change in each of the properties studied in this work. These doses are given in Table XI and XII in terms of a threshold of radiation damage. Table XI covers the insulation and Table XII the jackets. The results are given in two tables because the effect of radiation of electrical properties is not pertinent for jackets.

Next we took the lowest maximum dose which affected a significant property and combined them with the IEEE temperature designations, classes O, A, and B into the following suggested IEEE nuclear environmental classification [13]. Maximum gamma radiation values in Table XIII are those from Table I in [13] converted to radians using the factors 1 roentgen = 87.7 erg g^{-1} (c) and 1 rad = 100 erg g^{-1}. Radiation class 1 is equivalent to 0.9×10^5 rad; class 2—9×10^5 rad; class 3—8800×10^5 rad; class 4—$88\,000 \times 10^5$ rad; class 5—greater than 10^{10} rad.

Conclusions

We believe the data given above justify the following conclusions:

1) Dimethylsilicone-based insulations (IPCEA S-19-81, par. 3.17) are suitable at their usual 130°C temperature rating only in low-radiation environments, because of its sensitivity to steam and its poor resistance to oxidation after radiation. We rate it only in classes O1, A1, and B1.

2) Carbon black-filled (and probably clay-filled) cross-linked polyethylenes and clay-filled EPM or EPDM-based insulations are suitable at 105°C up to class 3 radiation levels, when protected with suitable flame-resistant braids such as the glass construction in this study or flame and water resistant asbestos constructions. We rate these two materials for classes O1, O2, O3 and A1, A2, A3.

3) Butyl and high-density polyethylenes when properly jacketed are suitable at their usual 90°C temperature rating only up to class 2 radiation levels. We rate these systems only for classes O1 and O2.

4) Nonfilled cross-linked polyethylenes and oil-base insulation, when properly jacketed, are suitable at their usual 90°C temperature rating up to class O3. We rate these systems for classes O1, O2, and O3.

5) SBR- and PVC-based coverings are suitable only at relatively low temperatures and radiation levels. In particular, IPCEA S-61-402, par. 3.7 and 3.8 PVCs are sensitive to hot water and steam when exposed to more than 5×10^5 rad.

6) Neoprene, CSPE, or CPE jackets are suitable at their usual 70°C temperature rating up to 10^7 rad. The radiation limit is based on oxidation effects; flame resistance is not affected by radiation.

Finally, we believe that the most attractive combination of materials for thermal nuclear generating plants will be CSPE- or CPE-jacketed insulations based on nonfilled CLPE, CB (or clay-) filled CLPE, 90°C oil-base, EPDM, or EPM. Such class O3 cables should last at least 40 years when exposed to a total radiation dosage up to 5×10^7 rad and will still be serviceable after exposure up to 10^8 rad.

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Discussion

J. B. Gardner (The Kerite Company, Seymour, Conn.): The authors are to be congratulated on the conception and carrying out of a significant program to develop short-time performance data on a wide spectrum of materials that might be considered for use in nuclear power plant cables. The paper is interesting and most certainly timely.

The purpose seems clearly stated in the paper; namely, "The main question to which this paper is addressed is whether cables insulated and jacketed with elastomer-(polymer)-based material can be expected to perform satisfactorily in the containment area and in the lower radiation area outside the containment vessel of thermal reactors." However, the conclusions listed are more concerned with material or systems classifications than they are with the suitability to perform in nuclear power plants. The Kerite Company has been active in nuclear power plant oriented testing for many years. A series of radiation tests were made in 1958, and others more recently, to dosages up to 6×10^7 rad materials being exposed under wet and dry conditions. The objectives of the testing, however, were nowhere near as broad as those in this paper. In our case we wished to evaluate only those materials (mostly proprietary compounds) which had already proven successful or very promising for generating plant application, to determine if they would meet the specific radiation intensities stated as required of cables in the new nuclear plants.

None of the data reported from the authors' investigation contradicts the prior findings of our more limited investigations, but the conclusions we have drawn and would draw from either our or their experimental data are at some variance with those of the authors.

Before addressing several specific questions to the authors, it seems appropriate to comment on two aspects of overall testing which should be kept in mind by all cable users and cable designers. The first point is one which the authors themselves have made strongly in prior published papers, but seems overlooked in the present work; namely, that very significant differences in performance can be expected from various commercial compounds all containing a polymer (or polymer blends) in common. Notwithstanding this fact, the common polymer may tag the materials with identical names. If name classification of materials has to be, then we all should be warned of the pitfalls that may occur when we ignore major differences among materials of a given name. It may be easier to organize one's thinking, tabulate data, or specify materials by reference to polymer name tags, but it also is likely to be completely erroneous in its implications.

Secondly, with regard to radiation level classifications, I believe it is rather unfortunate that the IEEE classes 1, 2, and 3 differ by factors of 100 in radiation exposures. For instance, the total radiation requirements that have been stated for a number of nuclear installations extend over 10^7 rad of class 2 but do not approach the 10^9 rad of class 3. Therefore, materials which would not apparently qualify within the broad range of class 3 might well be applicable in installations requiring only radiation up to the low end of the range. It seems that many of the organic materials considered for wire application show major changes in susceptibility within the 10^7 to 10^8 rad range. Just how useful the IEEE classification system is going to be for determining suitability of materials for cable installation in nuclear plants is, therefore, very questionable.

Specific questions stemming largely from the above considerations are as follows:

1) In the authors' first conclusion, the limitations of classification of silicone appear to be related to the steam sensitivity of this material. Is steam sensitivity a factor properly used in the IEEE classification? Or, is steam sensitivity more properly related to the applicability of a cable in certain circuits which have to operate after a loss of fluid accident within a containment vessel? We also note a typical ambiguity in thoughts in the first conclusion having to do with the whole classification problem; namely, in the first sentence of the conclusion, silicone insulations are referred to, but at the end they are lumped together and unfortunately referred to as "it".

2) Referring to their second conclusion, how can materials never tested by the authors beyond 10^8 rad be properly placed in a classification which implies suitability for up to 10^9 rad?

3) Noting that some materials are being classified by the authors for 105°C operation in nuclear plants, we would ask; "Why pick nuclear plants as an appropriate location for proposing a higher temperature classification of a given cable than has been done elsewhere in industry standards?"

4) The presence of flame resisting coverings appears to be involved in the IEEE classification suggested in the second conclusion. We would question that this is an appropriate consideration in using the IEEE classifications for materials, and would appreciate the authors' comments.

5) In their third conclusion, the authors have progressed from material classifications to systems classifications. In this conclusion flammability is quite evidently not considered. However, it would seem much more appropriate for one to consider fire as a relevant factor of systems than individual materials. We wonder why there is this apparent discrepancy and whether fire resistance should affect IEEE classifications at all.

6) In their fourth conclusion, is it proper to classify a system class 3 for radiation when one of the components of that system (neoprene) is only rated at class 2?

7) Have the tested PVCs been omitted from the classification intentionally or by oversight?

8) The authors' technique of using cable samples in jars of water at 140°C to investigate susceptibility of materials to "steam atmosphere" is very interesting. Knowing the susceptibility of certain materials to the combination of steam and air from past tests in our laboratories, we would ask, "Do the authors have a firm basis for accepting water immersion tests as indicative of resistance to the steam-air atmosphere expected in containments?"

9) Are the specific compounds used throughout the investigation those with a service record and commercially available today, or were they selected to represent typical materials that meet the various cited IPCEA, UL, or ASTM specifications?

Manuscript received July 11, 1968.

E. M. Davis (Gilbert Associates, Inc., Reading, Pa. 19603): This paper presents some very important information for those who are concerned with the selection and application of cable to be installed within the containment vessel for nuclear reactors.

In the design of nuclear generating stations we feel that the cable insulations materials should, if not exposed to conditions outside the limits for which the cable was intended to operate, outlast the life of the station. The installation and operating problems as well as the shutdown time involved, if found that the entire cable system must be replaced, dictate that the cable should certainly have an expected life well beyond the time when the station is finally decommissioned for the usual reasons of economy and operation. The authors have suggested a 40-year life and a total radiation dose of 5×10^7 rad during this time, and these numbers appear to be a reasonable basis for the active life of the present generation of thermal nuclear reactors. In order to allow for a comfortable margin of safety and also for a short-time high-exposure condition during an incident, it appears that the cable in the containment vessel should be capable of at least a total radiation dose of 5×10^8 rad. It is encouraging to note that the authors' findings show that such a requirement does not prohibit the use of elastomer-based compounds, since these compounds are so much easier to handle than inorganic types of insulation systems.

From an application point of view, a valuable aspect of this paper is the consideration given to those other factors of environment which affect the life of the cable. Much of the previously published research was directed at finding out what the effects of radiation were upon certain basic materials used for electrical insulation. In this connection, we would like to know if the test samples used are representative of the actual compounds that would be supplied by the authors' company.

Manuscript received July 8, 1968.

TABLE XIV
THERMAL DECOMPOSITION OF CABLE COVERINGS

	CB CLPE	CF EPDM	Butyl	Oil Base 90°C	NF CLPE	CF EPM	Silicone	PVC	Neoprene	CPE	CSPE
Onset temperature of volatiles not condensable at 25°C	245	200	290	250	250	200	>300	120	200	150	200
Weight loss* (percent)	3	1	11	4	2	1	2	35	20	33	8
cm^3 gas per gram of compound†	5	4	20	3	5	3	<2	40	20	50	6

* After one-minute heating at 330°C.
† Volume of noncondensable (25°C) gases in milliliters at STP after compound was heated for one minute at 330°C.

Anyone who is now involved in the design of a nuclear generating station is acutely aware of the vastly increased concern over the subject of flammability in the cable system. The authors have touched on this subject, but I believe that much more emphasis is needed. Flame-resistance characteristics can no longer be considered as merely desirable, but must now be given top priority as an absolute necessity. It is far better to use materials which will prevent the spread of fire in a cable system than to rely on water spray systems, for example, to control a fire after it has occurred. Will the authors offer further comment on this subject? Also, do the authors feel that the jacket can be relied upon to provide the necessary flame protection where the insulation material is of a type that will contribute to the spread of fire? I am referring to their statement that "The risks of spreading of fire also appear to be great with the cross-linked polyethylenes, butyl-neoprenes, and SBR-neoprene combinations, but the flame resistance of carbon black-filled and nonfilled, cross-linked polyethylenes can be markedly improved by the application of a suitable flame retardant jacket." For example, it appears that the aging characteristics of PVC after radiation exposure would make it a poor candidate to provide flame protection as a jacket, even though Table XIV shows no permanent effect of gamma radiation on flame resistance.

We are pleased to see that attention was given to conditions simulating irradiated cable subjected to a high-humidity high-temperature environment. This kind of data is necessary during the discussions with the AEC licensing authorities.

One final comment is in regard to the short-time ability of an irradiated cable to simultaneously withstand temperatures of 150°C and steam pressures of 50 psig. Certain cables must continue to supply power to vital equipment for many hours after an incident. There are some who believe that only a solid lead sheath or copper tube can adequately protect a cable insulation system against such conditions. Will the authors please comment on this?

The authors are indeed to be commended for their contribution to the available knowledge on this very important aspect of cable coverings. We hope experiments of this type will continue in order to keep abreast of the rapidly changing technology of nuclear designs and applications.

M. G. Noble (General Electric Company, Waterford, N. Y. 12188): would like to make the following comments.

Steam Resistance of Silicone Rubber: While silicones in general have excellent hot water resistance, it is recognized that high-pressure steam can induce degradation of the silicone polymer.

However, it should be pointed out that silicone rubber cables have had an excellent service record in a number of nuclear plant installations (Indian Point, Yankee Atomic Power, etc.).

Specifications involved have called out the need for resistance to 100-percent relative humidity at 100°C, splashing water at boiling temperatures, and similar environmental conditions.

This performance would indicate that the high-pressure steam conditions described in the paper are rarely encountered in actual service. Furthermore, if they should be introduced, the use of proper cable design will prevent a malfunction. By incorporating a resin-saturated glass braid over the insulation, a protective barrier will exist which will preserve circuit integrity even in a case of severe polymer degradation.

Radiation Resistance of Silicone Rubber: The compound selected by Mr. Blodgett and Mr. Fisher is designated as a dimethyl silicone.

In [16] the author reports that "dimethyl silicones are generally less resistant to radiation than the other silicone types. Methylphenyl silicones show in general the best resistance to radiation of all the silicone types."

Whereas the compound used in this evaluation became brittle at 5×10^7 rad, it is predictable that a methylphenyl or methylphenylvinyl silicone compound would be flexible up to 1×10^8 rad. This factor emphasizes the need to consider silicone rubber as a family of compounds rather than a specific composition of matter. Proper compound selection is essential to achieve optimum resistance to radiation and many other environmental conditions.

Resistance to Oxidation After Radiation: We have never seen any indication that the oxidative stability of silicone rubber was influenced by exposure to gamma radiation.

Obviously, the combined effect of radiation and high-temperature exposure will accelerate hardening and ultimate embrittlement. However, our interpretation has been that the radiation exposure merely advanced the point at which the silicone rubber stood on the heat aging curve. Subsequent aging would continue at the same rate as would normally be observed from that specific point with a nonirradiated sample.

It should be further noted that the ratio in Table II indicating relative service life at 70°C for irradiated versus nonirradiated silicone rubber obscures an important point: even after an initial radiation doseage of 5×10^6 rad, the silicone rubber had an estimated exposure time at 70°C, to sustain a 40-percent loss in elongation, of about eight years—an extremely long period of time. We ask whether, particularly in nonflexing application, this silicone rubber compound could not have been given additional nuclear environmental classification ratings of O2 and A2. It would appear that methyl-phenyl silicones could clearly be given these ratings.

Summation: We wish to commend Mr. Blodgett and Mr. Fisher on an excellent paper. However, we believe that:

1) Their concern over steam sensitivity of silicone rubber can be dispelled by proper cable design.

2) Proper compound selection will optimize radiation resistance.

3) The retention of oxidative stability after radiation requires further study.

4) Analysis of the data included in this report shows that, even after a radiation doseage of 5×10^6 rad, silicone rubber has good high-temperature stability. It would appear that classification ratings of O2 and A2 might be justifiable, particularly if a methylphenyl silicone rubber compound is used as the insulation material.

Manuscript received July 15, 1968.

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M. L. Singer (Hatfield Wire and Cable Division, Linden, N. J. 07036): The authors are to be complimented for making available 'a on the electrical and heat aged properties of cable coverings er exposure to radiation. With the imminent advent of the fast breeder reactors, the study should prove to be of much value, combining as it does, this combination of properties for the first time.

As so often happens when first-rate work is performed, almost as many questions are raised as are answered. For instance, would diphenyl-silicone rubber-based insulations have done better than the dimethyl-si icone rubber insulations which were reported? It is true that the dimethylsilicone rubber insulations are the ones most commonly used today, but this need not be a permanent situation. Similarly, I was surprised at the good performance, after radiation exposure, of the oil-based rubber insulation. Is this really a reflection of the properties of oil-base rubber, or does it reflect the properties of the ethylene-propylene rubber in the insulation? Similar studies of the older natural rubber and SB-R rubber oil-base insulations could yield the answer. These two questions suggest the paths of investigation which can be followed. The effects of structure of the polymer, such as the huge polar group in PVC, and the effects of fillers in the polymers can be investigated fruitfully.

The authors set out only to find whether cables which can presently be fabricated can be expected to perform satisfactorily. They have achieved their goals successfully. This is not the final answer, and the authors' data suggest the paths to be followed in future investigations. That the authors achieved this is also to their credit.

Manuscript received July 15, 1968.

L. McKean (Phelps Dodge Copper Products Corporation, Yonkers, N. Y. 10702): This paper on nuclear cable insulations is a very welcome addition to the technical literature and provides a much needed reference on this particular subject. Anyone who has attempted to search the literature recently for this kind of information in connection with insulated cables will appreciate the availability of this up-to-date study in our particular field.

I thought it would be of interest to describe some interesting studies which we pursued a few years ago in connection with air-dielectric or semi-air-spaced coaxial cables such as the Styroflex aluminum sheathed design employing a polystyrene tape open helix insulation over the conductor.

Such coaxial designs were being sought for applications in connection with reactor monitoring systems for use in the high-intensity zones within the containment vessel. Hence for a typical test environment, field strengths developed within a typical reactor core and within a reactor shell were considered pertinent.

There was real concern that the presence of "ionizing radiation" within the dielectric would not only degrade the solid insulation in the course of time, but that it might immediately alter, drastically, the normal high-frequency transmission characteristics, thereby developing a serious impairment in cable efficiency and performance.

Tests were conducted on Styroflex cable samples placed in a test hole of the reactor core and also in a test tunnel at the Brookhaven Laboratories. The field strength in the reactor core was rated at 1.5 megarads per hour-fast neutrons, and 1.0 megarad per hour-gamma photons. The corresponding field strengths in the test tunnel were approximately two orders of magnitude lower.

In the case of the cable placed in the full reactor field, there was no measurable change in impedance, velocity, or attenuation at frequencies from 1 Mc to 200 Mc. In addition, pulse transmission was studied but no discernible noise (ionization) was evident on the wave front of the reflected pulse.

However a decrease in dc resistivity of three decades, from 10^{12} to 10^{9} ohms, was noted immediately upon entering the field, and resistivity remained essentially at a constant level during the 100-hour exposure period. This effect was duplicated on the samples in the more moderate nuclear field in the test tunnel. Thus, it appears that ionizing radiation does contribute a degree of contamination of the air dielectric as measured on direct current.

These test results indicate that RF performance is not measurably affected by ionizing radiation of the air dielectric during its normal operating life. Polystyrene, of course, offers relatively high stability to radiation, affording a practical insulation for applications in the intermediate intensity range. For very high field strengths, however, only inorganic materials will function satisfactorily over any significant operating life.

Manuscript received July 8, 1968.

R. B. Blodgett and R. G. Fisher: We thank the discussers for their stimulating comments and questions about our findings. Before we attempt to answer the specific questions raised, we first point out that we concur with Mr. Gardner's comments about the wide range covered by each of the IEEE radiation classes. We feel that up to 10^9 rad gamma, divisions of one decade rather than the present two decades would be more useful. No doubt changes along these lines will take place as more data and experience become available. In another comment, Mr. Gardner warned of the pitfalls when major differences between insulation and jacket compounds based on the same polymer are ignored. We agree that such differences cannot be ignored. However, we have found where compounding techniques have been used a maximize intrinsic polymer strengths and minimize weaknesses, the differences in the response to nonnuclear environments among compounds based on the same polymer were not significant. Our data for different PVC cross-linked polyethylene and ethylene-propylene compounds in Table XI indicate the same situation will hold true for optimized compounds based on the same polymers in the nuclear environments to which our investigation was addressed.

In regard to Mr. Davis and Mr. Gardner's question about the compounds used throughout our investigation, all wires except nos. 11, 12, and 13 were obtained on a random basis from our factory stock departments. Items 11–13 were fabricated in our laboratory wire line using randomly selected factory mixed compounds. All compounds are available in commercial products made at our company.

We want to reemphasize that our conclusions concerning the silicone compound investigated may not apply to compounds based on different elastomers such as the methylpheuyl and methylphenyl-vinyl silicones referred to by Mr. Noble. For that very reason we specifically named the type gum employed. This should clear up Mr. Gardner's question about our first conclusion. Since we did not include several different silicone-based compounds in our study, we have no data to answer Mr. Singer's question about the relationship of the type and amount of organic groups on the main silicone chain to their resistance to gamma radiation. Mr. Noble's comments and our references above should shed some light on this matter. The important point here is that some designers specify IPCEA S-19-81, par. 3.17 silicone for use in thermal nuclear generating stations. We feel our data are typical for the silicones normally furnished to that IPCEA specification. Information about the response of the other silicones in tests similar to ours should be required by designers before they set standards for nuclear environments.

The balance of properties reported for the 90°C oil-base insulation was primarily due to the elastomer employed as Mr. Singer suggests. Mr. Gardner asked whether we consider steam, hot water, fire, and the other factors discussed above as proper factors to be considered when assigning IEEE classifications to systems or individual materials. Our answer is yes. So far as our autoclave tests are concerned, we feel confident that it simulates the steam-air atmosphere expected in containment for two reasons. First, our test periods were long enough to allow equilibrium conditions between the water and steam. Second, both the water and steam contained oxygen.

The class O3 cables discussed in our final conclusion should continue to operate under the incident conditions that Mr. Davis

Manuscript received August 22, 1968.

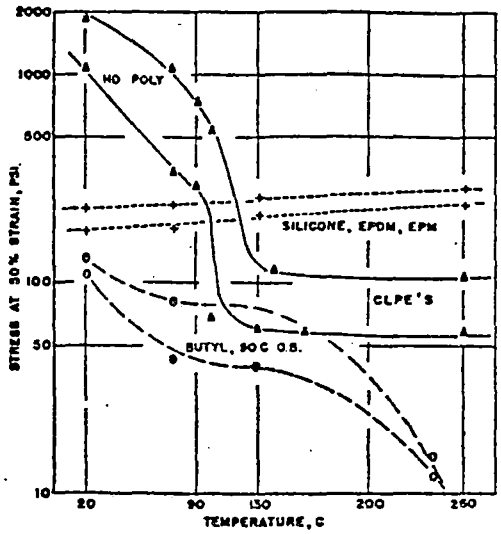

Fig. 1. Effect of temperature on the physical strength of insulations.

described. Of course, the addition of a continuous metal sheath over those class O3 cables would provide maximum assurance of continued service. Mr. Gardner apparently missed the point that our tests, except for air oven agings, were carried out on the insulation–jacket systems described. In addition, the PVC neoprene, CSPE, and CPE coverings were assessed individually. These data on single materials and combinations of materials are the basis for our conclusions. The PVCs in our study were intentionally omitted from the IEEE classifications since they were not suitable for 90°C continuous rating.

We agree with Mr. Davis that the flammability of cable systems require careful attention. The use of fire-resistant jackets in combination with inorganic thermal and fire barrier tapes over the class O3 insulations, for example, should provide the best combination of all-round properties including resistance to and the spread of fires. But cable design is not the only factor in optimizing fire resistant cable systems. The manner in which fire-resistant cables are installed is also important. For example, the practice of using tiers of cables in trays needs to be reexamined. Mixing power and control cables in the same run can be hazardous, if the derating factor for the power cables has not been based on the accurate assessment of the thermal circuit in the trays. Effective protection of the power circuits to avoid "cooking shorts" should also be used. When these and other precautions well known to station design engineers are taken, a water spray system would provide a high degree of assurance against a major conflagration occurring.

In conclusion, we believe the new data in Table XII and Fig. 1 in combination with the data in the original paper should provide designers of containment vessel penetrations with a basis of selecting insulated cables suitable for use within sealed canisters. Insulation and jacket compounds based on halogenated polymers should be avoided because of the corrosive nature of the gases found. All insulations we rated class O3 should be suitable for use within canisters providing the proper derating factor based on the onset temperature, thermal circuit of the canister, and high-temperature physical strengths shown in Fig. 1 are taken into consideration. On the basis of these data, clay-filled EPM and EPDM have the best combination of properties for canister applications.

ATTACHMENT 3

ANACONDA

July 11, 1978

Stone & Webster Engineering Co.
P.O. Box 2325
Boston, MA 02107

Attn: Howard Redgate

Re: VEPCO/Surry Generating Station;
Continental Wire and Cable PO's SN-285 and SN-1458.

Dear Mr. Redgate:

In response to your request for additional information on CC-2210 FR-XLP please find attached our data sheet of August, 1971 entitled "Physical Properties of CC-2210 Cross-linked PE After Various Environmental Conditioning, Simulating a L.O.C.A. Incident in a Nuclear Generating Station". We further state that a FR-XLP insulation material designated CC-2210 was used on the above referenced orders.

Very truly yours,

CONTINENTAL WIRE & CABLE

Paul S. Cardello

Paul S. Cardello
Chief Engineer

PSC:ts
cc: File
Attachments-2

PHYSICAL PROPERTIES OF CC-2210 CROSS-LINKED PE AFTER VARIOUS ENVIRONMENTAL CONDITIONING, SIMULATING A L.O.C.A. INCIDENT IN A NUCLEAR GENERATING STATION.

CONDITIONING	TENSILE (PSI)	ELONGATION (%)
NONE	2440	550
STEAM/BORIC ACID[1]	2390	450
RADIATION ONLY		
1X10^7 RADS (GAMMA)[2]	2540	425
5X10^7 RADS "	2230	238
1X10^8 RADS "	1710	100
RADIATION AFTER STEAM/BORIC ACID[1]		
1X10^7 RADS (GAMMA)[2]	2580	393
5X10^7 RADS (GAMMA)[2]	2200	200
1X10^8 RADS (GAMMA)[2]	1600	69

WIRE SAMPLE #16 (7) AWG, .030" WALL CC-2210

① 120 HOURS, 50 PSI STEAM, FOLLOWED BY 120 HOUR IMMERSION IN 0.5% BORIC ACID SOLUTION @ 160°F.

② COBALT 60 SOURCE (NEUTRON PRODUCTS, MD.).

NO.	CHANGE	DATE	BY

REVISIONS

CONTINENTAL WIRE & CABLE CORP.

DRN. M.Q.Q.	DATE
CKD.	DATE
APP. DSC	DATE 8/71

Form CW-1014