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SPECIFICATIONS, TESTS, AND INSTALLATION OF WIRES AND CABLES FOR THE DIABLO CANYON NUCLEAR POWER PROJECT

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ABSTRACT

This paper describes the process of selecting wires and cables for the Diablo Canyon Nuclear Power Project. The criteria for the fire and environmental tests, the basis for the specifications, and the reasons for the final choice and acceptance are outlined. A short section is dedicated to the installation of cables in raceways with reference to separation and color coding. Also covered are the selection and testing of fire stops and the selection of seismic supports.

INTRODUCTION

Since the early 1960's the nuclear power plants incidents which have occurred around the world, were reported by the media. The results of subsequent investigations were closely scrutinized by utility companies throughout the country.

It became clear that fire was a contributing factor to the losses suffered by the facilities. In many cases power and control cable were involved. Consequently the industry focused its attention particularly on the fire retardancy of wire and cables. Subsequent efforts in research and development produced an impressive variety of wires and cables for nuclear power plants.

Up to 1968 there were few cables which met the fire resistant qualities which should be common to all cables used in power plants. It was at this time that the selection of cables for Diablo Canyon had to be made. However, there were no existing standards which included accepted and satisfactory fire test procedures.

Test procedures adopted by utilities and manufacturers gave markedly different results when performed by Pacific Gas and Electric Company (PGandE). It was this difference in test results that convinced PGandE engineers that there existed enough justification to initiate a program of research and development which would provide PGandE with its own fire test.

CABLE SELECTION

The objective was to select a cable construction that would perform well in a new nuclear plant. The first step in this selection was to obtain from various manufacturers all the information available on their respective products. The next step was to compare the various constructions, materials and tests.

It was during the comparison of published data that some differences, particularly between fire test results, were observed. Furthermore, the discrepancies became even more evident when the published data were compared with results obtained from fire tests performed earlier by PGandE on 12 types of control cable and 21 types of power cable.

Cable Testing

Since doubts were raised by the fire performance characteristics of different cable constructions and materials, it was decided to assign top priority to a fire testing program. The electrical and physical tests were long established and with some minor exceptions or additions the industry standards were considered acceptable. For Loss of Coolant Accident (LOCA) and radiation test, it was decided to accept certified reports on recent tests performed on the same material or cable construction being considered by PGandE. Whenever necessary PGandE would require radiation and LOCA tests performed by independent qualified laboratories.

Because of the fairly large amounts of cable installed inside the containment building, it was decided to expand the scope of the "in house" testing program by adding an environmental test to reproduce some of the conditions that the cable would have to withstand.

Responding to a PGandE invitation, the manufacturers sent a large quantity of cables representing 130 different types. Each type was in quantity sufficient to perform a multitude of tests. The types of cable received, except for a small amount rated 5 kV and 15 kV, were single conductor low voltage power, single and multi-conductor control cables and some instrumentation cable.

With this positive response the program was off to a good start.

FLAME TESTS

The objective of this phase of the program was to investigate different types of ignition sources and different testing procedures for various types of cables.

The purpose was to find acceptable fire tests for each type of cable, construction and/or condition of installation. The selected tests would have to satisfy the following requirements:

1) Be reproducible.

2) Be adequate, with reference to volume of material exposed to the ignition source.

3) Have an ignition source with flame characteristic constant during the length of the test.

4) Be suitable for direct comparative results when absolute values are not required.

The three different burners used as ignition sources for the tests were:

1) Tirill.

2) Fisher.

3) Ransome Company, Model No. S-8-H.

For all the tests performed in this phase the following observations were recorded:

1) Time to ignite.

2) Length of flame application.

3) Time to extinguish after removal of the ignition source.

4) Smouldering time.

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5) Dropping of flaming particles or dripping of melting material.

6) Amount of flame and smoke.

7) Spreading of the flames.

8) Extent of damage to jacket and insulation.

9) Loss of insulation (using a conducting solution).

From the very beginning of the testing it appeared that the procedure described in existing standard on vertical fire test (1) was inadequate. It was observed in most of the tests that the reignition of the burner was "blowing-out" the flame of the burning cable before it reached the indicator. As a result of this observation, it was decided after a few trials to use the same apparatus as in reference (1) except that it was modified to hold the specimen at an angle of 70 degrees with the burner mounted on a 25 degree block. This apparatus was then used for all the tests made with the Tirrill and the Fisher burner.

Test No. 1

One hundred seventy tests on single conductors of various sizes were performed with the Tirrill burner. The time of burner application varied from a minimum of 15 seconds to a maximum of 300 seconds. The results were that a 60 seconds application was chosen for further tests on single conductors smaller than #8 AWG (8.37 mm^2).

Test No. 2

Forty tests on single conductor cables were performed with the Fisher burner. The time of application was the same as for the Test No. 1. As a result, a 60 second application was chosen for further tests on single conductors larger than #8 AWG (8.37 mm^2) but not exceeding 2.50 cm overall diameter.

Test No. 3

A group of twenty samples of multiconductor cable 7c-#12 AWG (3.3 mm^2) was tested as in Test No. 1, but with the burner applied for 15 minutes. During this test the temperature on the insulation in one of the conductors and the insulation resistance were continuously recorded. The test was repeated using the Fisher burner.

A comparison of the results proved that the Fisher burner was more adequate for this test. The insulation failure was recorded at approximately seven minutes for most of the samples.

Test No. 4

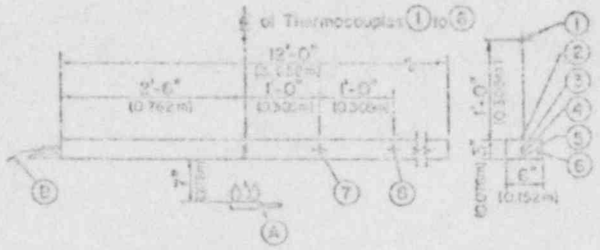
Twenty more samples of multiconductor cable were tested with the Fisher burner applied for three minutes. The purpose was to obtain information on the time required to ignite the 7c-#12 AWG (3.3 mm^2) cables. Observations were made throughout the test. The results were consistent with those obtained in Test No. 3. A 60 seconds application was chosen for further tests on multiconductor cables.

Test No. 5

A small number of samples of medium voltage cable, multiconductor control cable with an overall diameter in excess of 2.54 cm and single conductor low voltage cable larger than #2/0 AWG (67.4 mm^2) were tested using a larger burner (made by Ransome Company, Model No. S-8-H) capable of a much greater output than the Fisher burner. The results of these preliminary tests were inconclusive. It was then decided to limit the scope of the program in time and cost by concentrating the efforts on ignition sources suitable for cables less than one inch in diameter.

Test No. 6

The Ransome burner however was selected for the fire test of cables in tray. The trays used were punched bottom type, 15.2 cm wide and 7.6 cm high, horizontally mounted. Thirty samples of cable selected by previous tests, divided into five groups, compatible as to insulation and jacket material, were laid to a fill equal to 30% of the tray's cross sectional area. The Ransome burner was set 17.8 cm from the bottom of the tray and adjusted for an output of approximately 400,000 Btu/hr, Figure 1. The flame was turned on for 5 minutes. Recordings were made of electrical insulation resistance, cable, tray and ambient temperature at various points, ignition time, amount of flame and smoke, time of after burn, length of flame spread on top and at bottom, and extent of visible damage to samples. Good comparative information was obtained from these tests. Other tests included different types of covers, solid bottom trays and vertical tray arrangements.



LEGEND
① to ⑧ Thermocouples
Ⓐ Ransome Burner
Ⓑ Lead to Insulation Resistance Measuring Devices

FLAME DATA
Free Flame Height = 1'-0" (0.305m)
Flame Width = 9" (0.229m)
Approximate Output = 400,000 Btu/h

Fire test of cables in tray

Figure 1

Fire Testing

During the previous phase of flame selection, a large number of less promising cables were eliminated. The final testing was performed on 31 single conductors #10 AWG (5.2 mm^2) or smaller, 8 single conductors #8 AWG (8.37 mm^2) to 1/0 AWG (53.5 mm... and 18 multiconductors 7-#12 AWG (3.3 mm^2). Each test was repeated three times for each type of cable.

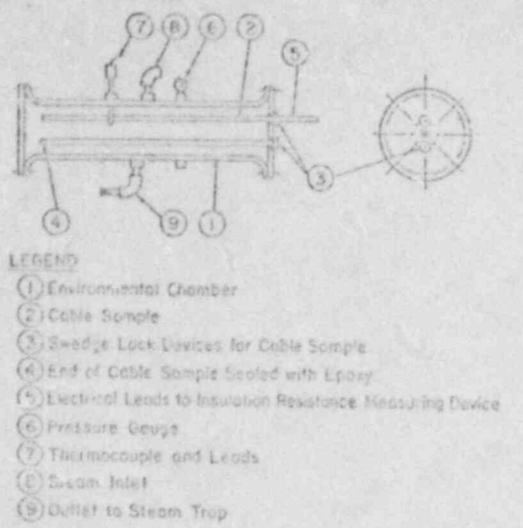
Samples of the small single conductors were tested with the Tirrill burner applied four times for 15 seconds with 15 second off periods between applications. The burner was not reignited if flames were still present at the end of the off periods.

Samples of the multiconductor and larger single conductors were tested with the Fisher burner replacing the Tirrill and using the same procedure.

Four trays, loaded with cables with the four most promising types of insulation, were tested using the Ransome burner as previously described.

ENVIRONMENTAL TESTS

A special environmental chamber was built to reproduce adverse environmental conditions similar to those possible inside the containment building, Figure 2.

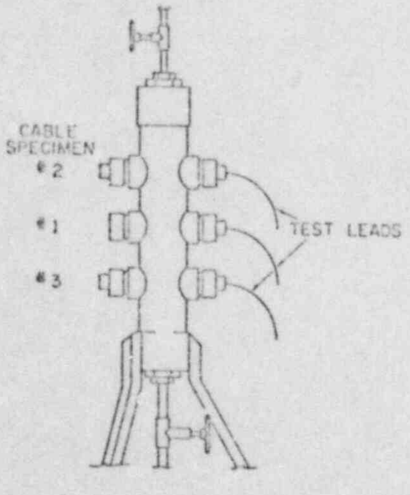


Environmental test apparatus

Figure 2

Steam was utilized as a source of heat, pressure and humidity. With the cable samples inside the chamber, the conditions produced were approximately 150°C, 50 lbf/in^2 and 100% humidity. These were continuously monitored throughout the test.

Six samples of single conductor cables were mounted in the chamber. A source of 120 V ac was applied between the conductor and a braided wire jacket connected to ground. The insulation resistance was recorded periodically throughout the test. At the end of each test the resistance value was checked (hot and cold) with a 500 V megohmmeter. Seven multiconductor cables were tested with four conductors connected to the 120 V ac source and the remaining three connected to ground. The thirteen samples were tested, some for not less than 48 hours, others to a maximum of 103 hours.



Environmental test apparatus for large cables

Figure 3

Fan Cooler Motor Cables

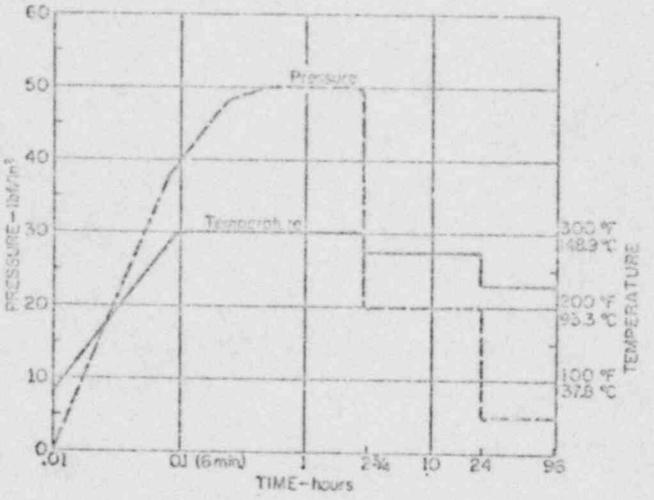
The requirements for a 600 V special type of cable capable of performing during and after a LOCA event, prompted the investigation of new materials and new constructions.

It appeared that a Polyimide insulation with a heavy Chloro sulphonated Polyethylene (CSPE) jacket could have satisfied the requirements without incurring the extremely high cost of special sealed or armored cables. Several manufacturers were approached and after meetings with various engineers a solution was proposed. One manufacturer proposed to supply a sample as required except for the addition of two components that would improve the manufacturing process and possibly add to the overall performance of the cable. The proposal was accepted and a sample prepared for our testing.

Due to the large size of the cable (approximately 1,000 kcmil (507 mm^2) and 4.5 cm overall diameter) our special environmental chamber could not be used. A new chamber built for the sole purpose of testing this cable is shown in Figure 3.

Three samples from 25 to 30 centimeters long were mounted in the chamber. The environmental conditions were monitored as before, with the insulation resistance measured every five minutes with a 500 V megohmmeter. The pressure and temperature profiles for the 96 hour test are shown in Figure 4.

The test was completely satisfactory. The megger reading for two of the samples was at infinite throughout the test. The other sample had readings inversely proportional to the pressure in the chamber, with a low of 70 megohm for the high pressure and a high of 370 megohm for the low pressure.



Pressure and temperature profiles
Figure 4

The three samples were carefully dissected and examined. Sample No. 1, the one with a low megger reading, was too short to extend completely outside the special fittings. The epoxy used to seal the open-end of the cable had not adequately penetrated the strands of the rope lay type of conductor. A very minute path allowed the steam to escape from the chamber, through the strands, thus causing the variable megohm reading.

It is very important to report that samples No. 2 and No. 3 were part of a longer piece of cable previously aged for 240 hours in an oven at 200°C. The cable was aged with a bend in it of approximately 30.5 cm in diameter, and samples No. 2 and No. 3 were purposely cut from the bend portion. The surface of the jacket was somewhat hardened. The samples were carefully straightened, observing the tiny cracks that developed on the inside of the bend. When the samples were straightened cracks were observed to be only on the surface and measured to a maximum of 2 mm depth. There was no change in the depth of cracks after the environmental test.

CABLE SPECIFICATIONS

Safety, performance and economy were the first considerations. Design of the proper installation was the second. The volume of data obtained from the tests was carefully screened and evaluated in the light of existing industry specifications and manufacturers' published data.

Four basic specifications were considered for the bulk of cables installed at the power plant (with exclusion of the 220 kV and 500 kV switchyards). Except for the thermocouple extension wire, the selected conductor material was copper.

Medium Voltage Power Cable Specification

This group included 15 kV rated cable (part of it inside of the containment).

The requirements were for cross-linked polyethylene (XLPE) or ethylene propylene rubber (EPR) insulation with an extruded strand shield, extruded insulation shield, copper shield tape and a flame retardant chlorosulfonated polyethylene or (CSPE) polychloroprene (N) jacket. Insulation thickness was 2.78 mm for the 5 kV class and 5.56 mm for the 15 kV class. Except for the Corona Level Test and the Void and Containment Determination Test (subjects in which the author had substantial direct experience prior to joining the Diablo Canyon Nuclear Power Plant design team), this specification was very similar to a widely used industry standard (2).

The final choice was in favor of the EPR-N. Better thermal stability than XLPE at higher ambient temperature was considered a factor (even if minor). The additions of bedding tape and heat shield proposed by the supplier were considered improvements and accepted.

Low Voltage Power Cable Specification

This group included 600 V rated cable for use inside and outside the containment, and Class I power cable.

The requirements were for:

(a) Single conductors, flame retardant heat and moisture resistant cross-linked polyethylene (XLPE) unjacketed.

(b) Single conductors, heat and moisture resistant vulcanized ethylene-propylene copolymer (EPM) or ethylene-propylene terpolimer (EPDM) with flame retardant, heat and moisture resistant jacket of polychloroprene (N) or chlorosulfonated polyethylene (CSPE).

(c) Single conductors, flame retardant, heat and moisture resistant, methyl-phenyl-vinyl base, radiation resistant silicone rubber (S) with a flame retardant, heat and moisture resistant chlorosulfonated polyethylene (CSPE) jacket or a silicone resin impregnated glass braid jacket.

The cable designated as Class I for installation inside the containment building was requried to withstand for five hours the following environmental conditions: 4.5×10^6 Rads, 150°C, 60 lbf/in^2 and 100% humidity.

The common requirements were:

1) Insulation resistance, ac and dc voltage tests performed with the cables immersed in water. These tests required for 100% of the production.

2) Vertical fire test as previously described in the section of fire testing.

In addition the following design tests were required for each different construction:

1) Horizontal Tray Flame test.

2) A Corrosive Effect test.

3) A Hydrogen Chloride Generation test.

The final choice was in favor of:

(a) A specially compounded, irradiated XLPE with excellent self-extinguishing characteristics and a low corrosive effect.

(b) An EPR with a CSPE jacket with good self-extinguishing characteristics and a favorable cost, particularly in the large size conductors.

(c) A Silicone Rubber compound rated for continuous use at 130°C, radiation and moisture resistant, with a flame retardant CSPE jacket.

A special test was requested for the first two items to determine the possibility of withstanding the exposure for a period of one hour at the temperature of 282°C. The test was meant to simulate the conditions that could develop in case of a steam line break in proximity of a conduit. Samples of the two items were energized at 480 V and exposed to the 282°C temperature for a period of time far exceeding the requirement. Both samples performed without failure and withstood the subsequent 5 kV hipot test.

Control Cable Specification

This group included single and multiconductor, 600 V rated cables for use inside and outside the Containment Building for general application and for Class I service. The requirements were similar to those previously described for the low voltage power cable except for the addition of the overall jackets for multiconductor cables

The tray flame test was changed to a vertical arrangement and a smaller flame. When this specification was drafted, a Working Group of PGC-IEEE was preparing a guide for the installation of wire and cable in Power Plant. The author was a member of that group and at that time the vertical test with a small number of cables seemed adequate and the 70,000 Btu/hr flame was more widely accepted, by the potential cable suppliers, than the larger flame of the PGandE test.

For the single conductor control wire the final choices was:

1) XLPE.

2) Silicone Rubber with CSPE jacket.

For the multiconductor control cable the final choice was:

1) XLPE, as for the singles, and overall XLPE jacket.

2) Silicone Rubber insulation, as for the singles, with a glass braid and and overall jacket of CSPE.

Specifications for Signal and Thermocouple Extension Wires

This group included multiconductors for use inside and outside the containment building, for general application and for Class I service.

These requirements were similar to those for the control cable except for the following:

Signal wire makeup consisting of:

1) Two, three, or four twisted insulated conductors within a common conductive shield, with drain wire and an overall jacket.

2) Two twisted insulated conductors, nonshielded, and an overall jacket.

Thermocouple extension wire makeup consisting of two insulated conductors within a common conductive shield with drain wire and an overall jacket.

The final choice was in favor of XLPE and silicone as for the control cables, with the exception that the silicone cables had a glass braid over the singles and a silicone jacket overall.

CABLES CLASS AND TYPE			OUTSIDE CONTAINMENT AMBIENT TEMP 40 °C	INSIDE CONTAINMENT AMBIENT TEMP. 50 °C					TESTED BY PGBE	TESTED BY OTHERS	COMMENTS
						LOCA X	HIGH TEMP				
			NON-CLASS I	CLASS I			NON-CLASS I				
POWER	15kV. SINGLE COND.	EPR-N(1)	C-T	–	–	–	–	C	F■	IND SPEC	■ Flame retardant jacket
	5kV. SINGLE COND.	EPR-N(1)	C-T	C-T	–	–	–	–	F■	IND SPEC	(1) Polychloroprene rubber
	LOW VOLTAGE SINGLE COND.	EPR-CSPE	C-T	C-T	–	–	–	C-T	E, F	HT●, LOCA IND, SPEC	● Tested capability to withstand exposure to steam jet
		XLPE	C-T	C-T	–	–	–	C-T	E, F	HT●, LOCA IND, SPEC	
		S-CSPE	–	–	C	C	–	–	E, F	IND LOCA SPEC	
	L.V. FAN COOLER CABLE SINGLE COND.	PI(2)-CSPE	–	–	C	C	–	–	E, F△	HT, LOCA△ IND, R△	△ Tests performed on components (2) Polyimide
SPECIAL CABLE ASSEMBLIES	ROD CONTROL SINGLE COND.	EPR-CSPE	C-T	–	–	–	–	T	E, F	IND LOCA SPEC	Groups of six and seven single conductors factory assembled and equipped with connectors
		XLPE	C-T	–	–	–	–	T	E, F	IND LOCA SPEC	
	ROD POSITION INDICATOR MULTI-COND.	EPR-CSPE CSPE JACKET	–	–	–	–	–	T	F	IND SPEC	Multi-conductor with connectors factory installed
CONTROL	LOW VOLTAGE SINGLE COND.	XLPE	C-T	C-T	–	–	–	C-T	E, F	IND LOCA SPEC	
		S-CSPE	–	–	C	C	–	–	E, F	IND LOCA SPEC	
	LOW VOLTAGE MULTI-COND.	XLPE	C-T	C-T	–	–	–	C-T	E, F	IND SPEC	
		S-B(3)-CSPE	–	–	C	C	–	–	F	IND LOCA SPEC	(3) Glass braid
INSTRUMENTATION	L.V. SIGNAL AND THERMOCOUPLE EXTENSION	XLPE	C-T	C-T	–	–	–	C-T	F	IND SPEC	
		S-B(3)-S	–	–	C	C	–	–	–	IND LOCA◆ SPEC	◆ On similar cable (3) Glass braid
		PA(4)	–	–	C	C	C	C-T	–	IND LOCA	(4) Polyarylene rated 250 °C
	COAXIAL AND TRIAXIAL	XLPE	C-T	C-T	C	–	–	C-T	–	IND SPEC	

LEGEND:

C-T	Cable installed in conduit or tray.
CSPL	Chlorosulfonated Polyethylene.
E	Cable successfully tested in environmental chamber, (temperature, pressure, humidity).
EPR	Ethylene Propylene Rubber, rated 90 °C.
F	Cable successfully fire-tested.
HT	Required to perform at temperature higher then 50 °C. Also cable successfully tested at higher temperature.
S	Silicone Rubber (Methyl-Phenyl-Vinylbase) Rated 130 °C.
IND	Cable tested per industry standards, witnessed by P.G.&E. Inspectors.
LOCA	Required to perform also during and after a Loss of Coolant Accident. Also cable or component successfully tested for LOCA.
R	Cable or component successfully tested for radiation resistance.
SPEC	Cable tested per P.G.&E. Co. specification, witnessed by P.G.&E. Inspectors.
XLPE	Cross-linked Polyethylene, rated 90 °C.

Types of cable, use, installation, service and tests
Table 1

Because of delivery problems for part of the silicone cable a new product was taken under consideration. Design tests submitted by the manufacturer indicated that this product, Polyarylene, could in fact meet or exceed the requirements previously set for the silicone.

The Polyarylene insulation and jacket construction was also proposed for thermocouple extension wire installed near the reactor vessel where temperature and radiation might reach a higher level than other locations inside the containment. The documentation presented and the witnessed tests were convincing enough to show that the construction was mechanically superior to the high temperature cable originally specified by the reactor supplier.

Coaxial and Triaxial Cables

These cables were purchased from the supplier of the XLPE control and power cables. The requirements were for XLPE insulation and flame retardant XLPE jacket. Electrical characteristics and dimensions were similar to the applicable industry standards with some restrictions for specific values.

Common Requirements for the Acceptance of Cables

Due to the nature of the project the following requirements were established for all the cables designated for Class I service:

1) Qualification of supplier.

2) Implementation of Quality Assurance Plan with documentation extended to full traceability of materials.

3) Compliance with specification.

4) Evidence of test performance:

   (a) Performed by suppliers and witnessed by Company representatives.

   (b) Performed by independent laboratories.

   (c) Performed by Company.

Table I gives an overall picture of types of cables, where used, how installed, class of service and tests performed.

RACEWAYS

The criteria for the installation of cables in trays and conduits have been established since early 1968 and they are still in line with the present state of the art.

The special instructions to the Nuclear Power Plant design group had particular reference to the following:

1) Definition of the categories of cables with different voltage rating or different service that would not be allowed to occupy the same tray.

2) Limitation of the number of simultaneously loaded medium voltage or low voltage power circuits placed in the same tray.

3) Limitation of the maximum fill, with the total calculated cable area not to exceed 30% of the cross sectional area of the tray and 40% for the conduits.

4) Physical separation of raceways containing redundant circuits by using separate raceways and separate routes.

5) Minimum vertical separation between trays containing power circuit to be not less than 30.5 cm.

6) Limitation of the use of solid bottom trays and solid cover to only when no power cables are involved.

7) Current carrying capacity of cables to be calculated by IPCEA or NEC rules.

8) Interruption of trays at wall penetration and use of concrete encased, square section, metal ducts for a total cross sectional area at least equal to that of the trays.

9) Use of fire stops in all vertical and horizontal trays, particularly at wall and floor penetrations.

10) Use of the color coding of all the cables for Class I service, for the efficient and clear discrimination of redundant vital circuits as well as different channels. For this purpose all the cables were purchased in nine different colors:

    (a) Black for the general use, non Class I cables.

    (b) Orange, Grey and Purple for the three Safeguard Systems.

    (c) Red, White, Blue and Yellow for the different Protection System channels.

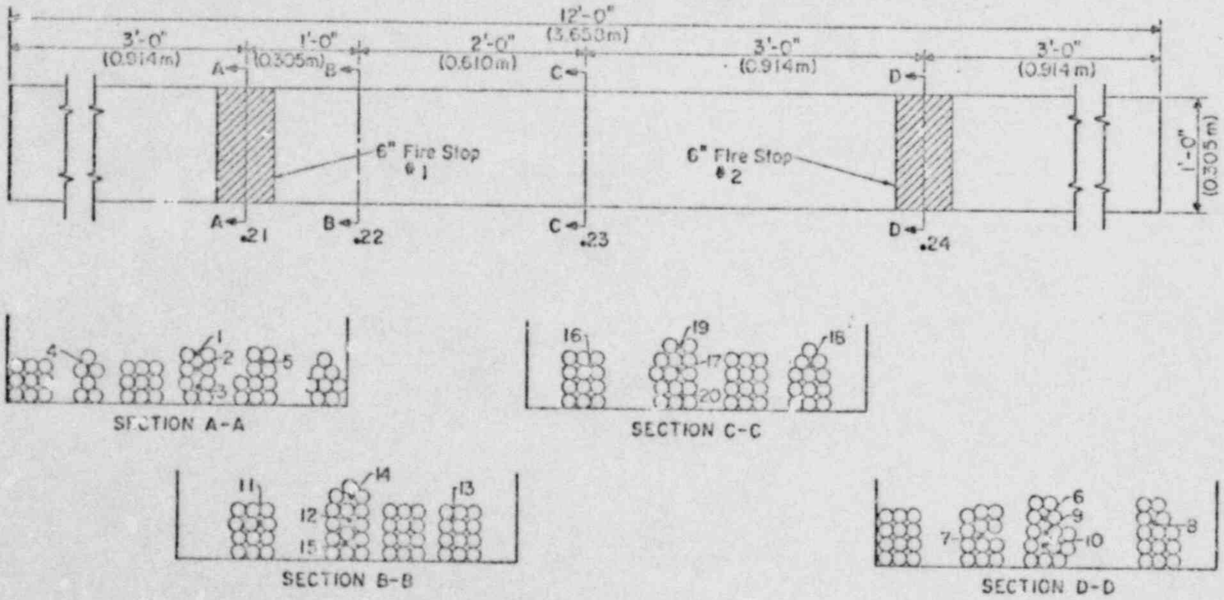
    (d) Brown and Green for Protection Systems trains "A" and "B" outputs actuation circuits.

The coloring of the singles in the multiconductor cable matched that of the jacket. In addition all singles were numbered for identification.

Fire Stops

The use of fire stops was recommended for the following purposes:

(a) To provide a seal impervious to fire at wall and floor penetrations.



Items 1 to 20 Thermocouples installed in conductor bundles
Items 21 to 24 Thermocouples monitoring the ambient temperature

Arrangement of Fire Stops and Location of Thermocouples for the determination of the temperature rise in the conductors

Figure 5

(b) To seal conduits and trays entering equipment enclosures.

(c) To avoid the chimney effect in vertical trays and prevent fire migration in horizontal trays.

Four leading products were investigated with regard to ease of application, curing time and shrinkage, residual flexibility after cure and flame resistance.

Tests were performed on different compounds and inert filler. The product selected was a thixotropic compound used in conjunction with filler made of asbestos fiber (later substituted with a ceramic wool).

The interior fire stop for vertical trays consisted of a 10.2 cm thick barrier of fibers saturated with the compound. The exterior portion of the fire stop consisted of 1.27 cm asbestos-cement panel fastened in a plane perpendicular to the tray and extending for a minimum of 20.4 cm all around it. Prototypes of this fire stop were tested in trays loaded with flammable cables. The fire stop passed the tests and was approved for installation.

Several heat run tests were also performed to determine the amount of temperature rise due to the fire stops and the wire coating. The results were tabulated and used in determining the cable derating.

During the last few years some new products became available and were offered as fire stops. Their installation seemed easier and faster than the fire stops already approved. The new products were evaluated and recently one of them was selected for installation at the Diablo Canyon Nuclear Power Project.

This product is a silicone compound, foamed in place and installed in 15.2 cm thickness. A crash program was developed for the testing of the temperature rise in the cable with the new fire stops. The tests were performed on a 30.5 cm tray loaded with fifty #2/0 AWG (67.4 mm^2) low voltage power conductors, EPR insulated with a CSPE jacket. The tray was mounted inside a chamber at constant, controlled, temperature.

The tests performed were as follows:

1) 40°C ambient with a current of 70 A circulating in each conductor.

2) 40°C ambient and 80 A.

3) 50°C ambient and 70 A.

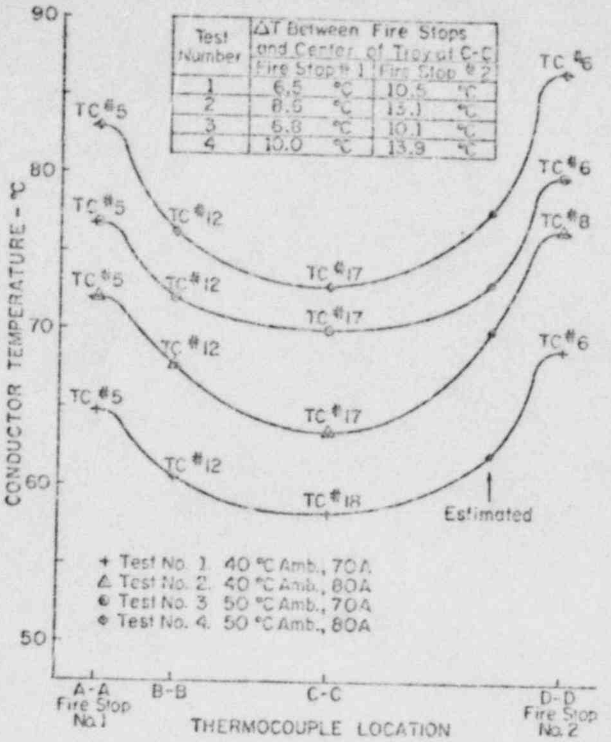
4) 50°C ambient and 80 A.

The tray with the fire stops, conductor arrangement and thermocouple location is shown in Figure 5. The results are represented in Figure 6. For simplicity the curves were plotted using the maximum temperature recorded, with the corresponding thermocouple identified for each value.

The data in Table No. 2 show all the temperatures recorded for all 20 thermocouples installed in the cable bundles shown in Figure 5. Also shown is the total temperature rise over the ambient.

Thermocouples No. 21 to No. 24 were used to monitor the ambient temperature for the tests. For both the 40°C and 50°C ambient, the approximation of the temperature was within one percent.

It is recognized that the number of conductors and the simultaneous current loading used for this test represents a situation rather unlikely to occur in any plant. However the bundle arrangements are quite a common practice and the intent was to test a case limit. Needless to say none of the trays at the Diablo Canyon Project approaches such an extreme limit.



Test Number	ΔT Between Fire Stops and Center of Tray at C-C	
	Fire Stop # 1	Fire Stop # 2
1	6.5 °C	10.5 °C
2	8.6 °C	13.1 °C
3	6.8 °C	10.1 °C
4	10.0 °C	13.9 °C

Maximum temperature measured in cable bundles
Figure 6

POWER CABLE CONNECTORS

Samples of crimp type copper power connectors for wire sizes used at Diablo Canyon were type tested for heat rise, millivolt drop and pullout force. Both 100% and 125% of full rated current, based on Table 310.12 of the 1971 National Electric Code, were circulated through the terminations consisting of the cable and crimped on connector. The temperature rise of the connectors was always less than that of the cable. Voltage drop measurements were obtained in millivolts over a distance from the junction of the tongue and the barrel to approximately 1.5 mm on the wire. In all cases voltage drop values measured on the crimp were less than that measured over an equal length of wire. All samples were subjected to a crimp strength test. Each sample was placed in a Riehle Tensile Test Machine and sufficient force was applied to pull the termination to destruction. All samples passed the minimum requirements of Underwriter Laboratories Standard UL486.

SELECTION AND TESTING OF SEISMIC SUPPORTS FOR RACEWAYS

Seismic design criteria for the supporting structure of the cable tray and conduit system consisted of floor acceleration response spectra provided by a seismic design consultant. Based on a design earthquake with maximum horizontal acceleration of 40%g and vertical acceleration of 27%g, the supports were designed to provide a system with high natural frequencies, to take the predicted maximum floor accelerations without local amplification. The greatest value of floor acceleration used in the design was 165%g for ultimate load conditions (corresponding to DDE or SSE design).

The flexible support concept, which supposedly isolates the supported raceways from movements of the structure, was rejected for the following reasons:

(a) Displacements would be excessive if flexibility were achieved.

(b) Complexity of layout of raceways made it essentially a rigid system.

THERMO-COUPLE LOCATION		THERMO-COUPLE NO.	TEST NO. 1A 70A AMB.=40°C		TEST NO. 1B 70A AMB.=40°C		TEST NO. 1A & TEST NO. 1B AVERAGE TEMP. RISE °C	TEST NO. 2 80A AMB.=40°C		TEST NO. 3 70A AMB.=50°C		TEST NO. 4 80A AMB.=50°C	
			TEMP. °C	TOT. TEMP. RISE °C	TEMP. °C	TOT. TEMP. RISE °C		TEMP. °C	TOT. TEMP. RISE °C	TEMP. °C	TOT. TEMP. RISE °C	TEMP. °C	TOT. TEMP. RISE °C
SECT. A-A	FIRE STOP NO. 1	1	63.2	23.2	63.2	23.2	23.2	70.2	30.2	74.7	24.7	80.1	30.1
		2	64.0	24.0	64.0	24.0	24.0	71.2	31.2	60.9	10.9	79.2	29.2
		3	61.1	21.1	61.3	21.3	21.2	68.0	28.0	72.4	22.4	77.1	27.1
		4	63.1	23.1	63.5	23.5	23.3	69.9	29.9	74.7	24.7	79.9	29.9
		5	64.8	24.8	65.0	25.0	24.9	72.2	32.2	76.9	26.9	82.9	32.9
SECT. D-D	FIRE STOP NO. 2	6	68.8	28.8	69.0	29.0	28.9	75.8	35.8	80.1	30.1	86.8	36.8
		7	61.5	21.5	61.3	21.3	21.4	68.3	28.3	72.3	22.3	77.6	27.6
		8	67.4	27.4	67.8	27.8	27.6	76.7	36.7	79.3	29.3	85.7	35.7
		9	67.8	27.8	68.0	28.0	27.9	75.3	35.3	79.2	29.2	85.9	35.8
		10	65.0	25.0	65.0	25.0	25.0	71.9	31.9	76.2	26.2	82.0	32.0
SECT. B-B		11	54.8	14.8	55.2	15.2	15.0	61.8	21.8	65.6	15.6	68.7	18.7
		12	60.8	20.8	60.8	20.8	20.8	67.9	27.9	72.1	22.1	76.3	26.3
		13	54.1	14.1	54.9	14.9	14.5	58.4	18.4	65.3	15.3	68.2	18.2
		14	56.0	16.0	56.6	16.6	16.3	63.2	23.2	68.1	18.1	71.1	21.1
		15	54.4	14.4	54.8	14.8	14.6	61.9	21.9	66.0	16.0	68.6	18.6
SECT. C-C		16	54.8	14.8	56.6	16.6	15.7	62.2	22.2	68.3	18.3	69.9	19.9
		17	56.3	16.3	56.3	16.3	16.3	63.6	23.6	70.0	20.0	72.9	22.9
		18	58.0	18.0	58.8	18.8	18.4	62.3	22.3	69.3	19.3	71.7	21.7
		19	56.6	16.6	57.4	17.4	17.0	60.7	20.7	69.3	19.3	71.4	21.4
		20	57.1	17.1	57.7	17.7	17.4	61.4	21.4	69.1	19.1	72.2	22.2

Notes: 1) All temperatures are measured at steady state.
2) Tests No. 1A and No. 1B are made at different times to verify the repeatability of the test.
3) The average temperature rise is used to plot the curve of test No. 1 in figure 6.
4) The heavy lines identify the maximum values used in figure 6.

Heat run test on fire stops
Table 2

Adjustable metal framing elements were used as components of the support assemblies, so that on-the-job fabrication could be done with minimal drilling of holes. However some welding was required in the assemblies, and hot-rolled steel angles were used for some of the bracing members.

Embedded sheet metal channels and expansion anchors were the chief means of attachment to ceilings and walls. An engineering standard was developed for the anchors based on review of published test data, published allowable loads, and some in-house testing (static and dynamic).

Support assemblies were designed for either (a) vertical-and-transverse loading or (b) longitudinal loading. Omni-directional supports were utilized as much as possible.

Open-sided trays on single-stem cantilevers were designed to be used whenever possible in order to provide easy access for lift-in placement of cables. Due to the complexity of layout of the tray system, the open sides were in many cases hemmed in by walls and adjacent and intersecting trays so that pulling of cables was the technique actually used. Because the cantilever assembly is inherently weaker in the transverse direction, it probably would have been better to standardize on multiple-stem "trapeze" support assemblies instead of cantilevers.

Standard details were developed with the intention of minimizing the structural design effort. However, due to stringent enforcement of quality assurance rules, over five hundred special designs had to be made to supplement the two dozen "standard" assemblies which constituted the bulk of the support system.

CONCLUSIONS

The Author believes that this paper demonstrates the determination of PGandE Company to design a plant that would minimize all the risks of accidents where cables could be involved. This paper also shows that the cable is not a commodity which can be purchased in millions of meters using only one specification. The variety of requirements in a nuclear power plant demands particular consideration of materials as well as design.

After reviewing the state of the art in fire testing, new tests were developed. The selection of cable listed in Table 1 represents the final results obtained from the evaluation of an impressive amount of data which would be impossible to present in this paper. The fire and the environmental tests combined with the design criteria guided the designer in the selection of cables for the Diablo Canyon Unit. The tests on fire stops gave valuable information on the temperature rise of the cables. This information was then used for the selection of conductor sizes.

The standard details for raceway support were developed to include special designs that would comply with seismic and quality assurance requirements.

It is the conviction of the designers that the cable and raceway system at Diablo Canyon represents the best possible combination of material choice, engineering judgment, economic evaluation and design criteria available today.

FUTURE DEVELOPMENTS

The criteria established for Diablo Canyon could be used as a guide for other power plants, nuclear and conventional.

The amount of information presented in this paper has been limited by the space only. More data are already in our files and more will be collected as the effort to achieve an even safer installation continues. Heat run and fire tests of cables in raceways and fire stops are being performed while this paper is being written.

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REFERENCES

(1) IPCEA S-19-81, NEMA WC 3-1964, Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electric Energy – Part 6.

(2) AEIC No. 5, Specification for Polyethylene and Cross-Linked Polyethylene Insulated Shielded Power Cables Rated 2,001–35,000 volts, 3rd Edition.

ATTACHMENT 2

Environmental Qualification
of
Fan Cooler Power Cables

Samples of electrical cables of the exact construction used in the plant were tested in an environmental chamber under conditions simulating a loss of coolant accident (LOCA). These cables have stranded copper conductors covered with a 22 mil silicone glass braid, two laps of 3 mil polyimide (Kapton) tape, two laps of 6 mil asbestos tape, and a jacket of chlorosufonated polyethylene (Hypalon) with a nominal thickness of 150 mils.

Prior to the LOCA test, two samples each 5 feet long, were aged for 240 hours at 200°C. The center three feet of each cable were then immersed in water at room temperature for 14 days. Dielectric tests at 4000 volts rms were performed daily during this period; the cables passed these tests. Insulation resistance tests were also performed just prior to each dielectric test. These tests show that while the insulation resistance varied from day to day, it never dropped below 850 megohms, and had a final resistance reading of 4500 megohms.

For the LOCA test, a sample 12 inches in length was removed from each of the specimens. First, a woven metal jacket was placed over each cable for measuring insulation resistance with 500 volts DC applied. Then these assemblies were installed in a chamber into which saturated steam was injected. Chamber pressure of 50 ± 2 psig was held for 2 hours and 50 minutes. Readings of insulation resistance were made at 15 minute intervals. The pressure was then reduced to 20 ± 2 psig which was held for 21 hours and 12 minutes; insulation resistance has measured at 30 minute intervals. The pressure was finally reduced to 5 ± 1 psig, which was held for 96 hours; insulation resistance was measured twice daily.

At no time during these tests did the insulation fail. The resistance reading for the two aged samples, remained infinite on the tester. The unaged third sample had a minimum resistance of 70 megohms but, as this sample was slightly too short for the test chamber, these results may have been adversely affected.

Although these cables were not exposed to gamma radiation before these tests were made, the materials used have been qualified in other tests. Radiation resistance of the inorganic materials (asbestos, glass) in the insulation is much beyond that needed for this cable and, therefore, need not be considered here.[1] The organic materials used in the cable are polyimide and chlorosulphonated polyethylene, two high quality plastic compounds very suitable for electrical insulation of cables used in severe environments.

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[1] Kircher and Bowman, "Effects of Radiation on Material and Component."

Polyimide tape was selected for the insulation because of its excellent physical, chemical, and electrical properties, as well as its outstanding resistance to elevated temperatures, gamma radiation and fire. The manufacturer (DuPont) of this material has determined it will withstand more than 10^{10}R of gamma radiation and continuous temperatures exceeding 200°C with no degradation of essential properties. Kapton neither supports combustion nor melts and begins to char above 800°C. There is no known s[illegible]t for polyimide film.

The cable jacket is chlorosufonated polyethylene, also an excellent insulation, and has been used for this purpose in many high quality electrical cables. This material has successfully passed several tests on similar cables after sequential exposure to aging, radiation, and LOCA conditions.[2,3,4] Thus, the Hypalon jacket alone is sufficient to qualify the cable for service under normal and LOCA conditions, and along with the Kapton insulation the cable is fully qualified to perform its safety function.

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[2] Boston Insulated Wire and Cable Company
Test Report 8021, dated November 6, 1970
Test Report 8921, dated May 25, 1972

[3] Battelle Pacific Northwest Laboratories
Final Report 212 BO-1698, dated July 1973 to Boston Insulated Wire and Cable Company.
The Effect of Gamma Radiation on the Insulation Resistance of Boston Insulated Wire and Cable Company's Single and Two Conductor Insulated Wire.

[4] Franklin Institue Research Laboratories
Final Report F-C3016, dated June 1971, for Rome Cable Division of Cyprus Mines Corp.
Qualification Tests of Electrical Cable.
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