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IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations

Sponsor

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of the
IEEE Power Engineering Society

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Foreword

(This Foreword is not a part of IEEE Std 690-1984, IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations.)

This standard is the result of efforts by the working group to accommodate requests for a document, such as IEEE Std 422-1977, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations, for use as a standard in the design, installation of cable systems for Class 1E circuits in Nuclear Power Generating Stations. This document is written as a standard and as such contains more positive statements (utilization of the word *shall*) than IEEE Std 422-1977. Recommendations and related tutorial information have been separated from the text and provided in an Appendix to this standard.

Many sections have been restructured to identify IEEE standards that apply to cable systems for Class 1E circuits and to establish additional requirements deemed essential for the proper design and installation of cable systems for Class 1E circuits. In addition to the sections covered in IEEE Std 422-1977, a new section has been added to this document which addresses documentation of design.

Cable fire protection considerations have been revised substantially to reflect current approaches to the problem resulting from fire tests conducted by various organizations.

At the time this standard was approved the members of the Working Group on Wire and Cable Systems of the Station Design Subcommittee were:

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CLAUSE PAGE

IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations

1. General

1.1 Scope

This standard provides direction for the design and installation of safety related electrical cable systems, including associated circuits, in nuclear power generating stations. Also provided is guidance for the design and installation of those nonsafety related cable systems that may affect the function of safety related systems.

NOTES:

1 — The term *associated circuits* is not repeated throughout the text; however, all requirements for the design and installation of cable systems for Class 1E circuits shall apply equally to associated circuits unless it can be shown by test or analysis that the associated circuits cannot affect the performance of the Class 1E circuits.

2 — Recommendations and related tutorial information regarding cable systems for Class 1E circuits are provided in the Appendix.

1.2 Purpose

The purpose of this standard is to identify existing standards and to establish requirements pertaining to safety related cable systems in nuclear power generating stations. Solutions are recommended for areas of concern such as fire protection, raceways, separation, cable performance requirements, and installation acceptance testing and documentation.

1.3 Definitions

Definitions that apply to only one section are found in that section.

associated circuits: Non Class 1E circuits that share power supplies, signal sources, enclosures, or raceways with Class 1E circuits or are not physically separated or electrically isolated from Class 1E circuits by acceptable separation distance, barriers, or isolation devices.

Class 1E circuits: The safety classification of circuits that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing a significant release of radioactive material to the environment.

design basis events (DBE): Postulated events specified by the safety analysis for the station to establish the acceptable performance requirements of the structures and systems.

2. References

When the following standards are superseded by a revision the revision shall apply.

[1] ANSI/ANS 59.4-1979, Generic Requirements for Light Water Nuclear Power Plant Fire Protection.[1]

[2] ANSI/ASME NQA 1-1979, Quality Assurance Program Requirements for Nuclear Power Plants.

[3] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

[4] ANSI/IEEE Std 336-1980, IEEE Standard Installation, Inspection, and Testing Requirements for Class 1E Instrumentation and Electric Equipment at Nuclear Power Generating Stations.

[5] ANSI/IEEE Std 383-1974 (1980), IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations.

[6] ANSI/IEEE Std 384-1981, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits.

[7] ANSI/IEEE Std 634-1978, Cable Penetration Fire Stop Qualification Test.

[8] ANSI/NFPA 10-1981, Standard for Portable Fire Extinguishers.

[9] ANSI/NFPA 15-1982, Standard for Water Spray Fixed Systems for Fire Protection.

[10] ANSI/NFPA 70-1984, National Electrical Code.

[11] ANSI/NFPA 72D-1979, Installation, Maintenance, and Use of Proprietary Signaling Systems.

[12] ANSI/NFPA 72E-1982, Selection and Placement of Fire Detectors.

[13] ANSI/NFPA 90A-1981, Standard for the Installation of Air Conditioning and Ventilating Systems.

[14] ASTM E119-1983, Standard Methods of Fire Tests of Building Construction and Materials.[2]

[15] IEEE323-1983, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.

[16] IEEE Std 422-1977, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations.

[17] NFPA 13-1983, Standard for Installation of Sprinkler Systems.[3]

[18] NFPA 14-1983, Standard for the Installation of Standpipes and Hose Systems.

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[1] ANSI documents are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[2] ASTM documents are available from Sales Service, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

[3] NFPA documents are available from Publication Sales Division, National Fire Protection Association, Battery-march Park, Quincy, MA 02269.

3. Cable, Field Splice, and Connection Qualification

This section establishes qualification requirements that shall be utilized in specifying cables, field splices, and connections of cable systems for Class 1E circuits.

3.1 Definitions

connection: A cable terminal, splice, or hostile environment boundary seal at the interface of cable and equipment.

field splice: A permanent joining and reinsulating of conductors in the field to meet the service conditions required.

qualified life: The period of time for which satisfactory performance can be demonstrated for a specific set of service conditions.

service conditions: Environmental, power and signal conditions expected as a result of normal operating requirements, extremes in operating requirements, and postulated conditions appropriate for the design basis events of the station.

3.2 Requirements

1) Cables, field splice, and connections shall have a qualified life for all service conditions that are postulated for the areas where they are to be used and shall be qualified in accordance with IEEE Std 323-1983 [15] and ANSI/IEEE Std 383-1974 [5].[4]
2) All cables installed in cable trays shall pass the vertical tray flame test described in ANSI/IEEE Std 383-1974 [5].

4. Conductor Sizing

This section establishes cable conductor sizing requirements for various types of cable installations for Class 1E circuits.

Cables shall be sized to carry load current with the following special considerations:

1) Unless the safety analysis of the plant supports other ambient temperatures, the minimum ambient temperatures used in calculating cable ampacities shall be 20°C for buried installations and 40°C for exposed installations. Conductor size shall be selected to carry required normal, emergency overload, and short-circuit current without exceeding rated temperature of the insulation at the maximum postulated ambient temperature. Temperature extremes under design basis events shall be addressed by the qualification of the cable in accordance with ANSI/IEEE Std 383-1974 [5].
2) Where cable is routed through several types of installation conditions (direct buried, sun exposure, exposed conduit, cable penetration fire stops, covered cable trays, wireways, near hot steam lines, etc) conductor size shall be selected for the limiting condition.
3) Selection of conductor size shall also consider voltage regulation requirements, shield circulating current, and mechanical strength in addition to cable current requirements.

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[4] The numbers in brackets correspond to those of the references in Section 2

5. Electrical Segregation

This section establishes requirements for the electrical segregation of cable systems for Class 1E circuits according to voltage levels, signal levels, and vulnerability to electrical noise pickup.

5.1 Cable Classifications

5.1.1 Medium-Voltage Power Cables

Designed to supply power to utilization devices of plant auxiliary systems rated 601 V to 15,000 V.

5.1.2 Low-Voltage Power Cables

Designed to supply power to utilization devices of the plant auxiliary systems rated 600 V or less.

5.1.3 Control Cables

Applied at relatively low-current levels or used for intermittent operation to change the operating status of a utilization device of the plant auxiliary system.

5.1.4 Instrumentation Cables

Used for transmitting variable current or voltage signals (analog) or those used for transmitting coded information (digital).

5.2 Requirements

1) Medium-voltage power cables shall be installed so that the medium-voltage cannot be impressed on any lower voltage system through a failure of cable insulation. See Appendix, A4.2.
2) Instrumentation cables shall be installed to minimize unacceptable noise pickup from adjacent circuits and equipment. See Appendix, A4.3.

6. Separation and Identification

This section establishes requirements for the separation and identification of cable systems for Class 1E circuits.

6.1 Definition

separation: Physical independence of redundant circuits, components, and equipment. (Physical independence may be achieved by space, barriers, shields, etc.)

6.2 Requirement

Cable systems for Class 1E circuits shall meet the separation and identification requirements of ANSI/IEEE Std 384-1981 [6] (see Section 6 for additional separation requirements).

7. Shielding and Shield Grounding

This section establishes requirements for shielding and shield grounding of medium-voltage power and instrumentation cable systems for Class 1E circuits.

7.1 Medium-Voltage Power Cable

7.1.1 Definition

cable shielding: A nonmagnetic metallic material applied over the insulation of the conductor or conductors to confine the electric field of the cable to the insulation of the conductor or conductors.

7.1.2 Shielding Requirements

Cables rated above 5 kV shall be shielded, except for special applications or cable designs.

7.1.3 Shield Grounding Requirements

Shielded cables shall be terminated with appropriate qualified terminations that do not compromise the integrity or qualification of the cable.

7.1.4 Shield Grounding Requirements

1) Cable shields and metallic sheaths/armor shall be solidly grounded at one or more points so that they operate at or near ground potential at all times.
2) Shields or sheaths that are grounded at more than one point carry induced circulating current. Compensation for the heating effect of the induced circulating current shall be considered when calculating the cable ampacity.

7.2 Instrumentation Cable

7.2.1 Definition

shield: Braid copper, metallic sheath, or metallic coated polyester tape (usually copper or aluminum), applied over the insulation of a conductor or conductors for the purpose of reducing electrostatic coupling between the shielded conductors and others that may be either susceptible to, or generators of, electrostatic fields (noise). When electromagnetic shielding is intended, the term *electromagnetic* is usually included to indicate the difference in shielding requirement and material.

7.2.2 Requirements

1) Cable shields shall be electrically continuous except where specific reasons dictate otherwise. When two lengths of shielded cable are connected at a terminal block, an insulated point of the terminal block shall be used for connecting the shields.
2) The shield of each cable shall be isolated to prevent stray and multiple grounds to the shield.
3) The shield shall not be used as an electrical conductor when only designed to reduce electrostatic or electromagnetic coupling.
4) The shielding criteria (for example, shield effectiveness, grounding techniques, etc) of coaxial, triaxial, and instrumentation cables shall be in accordance with system design requirements and equipment manufacturer's instructions.

8. Cable-Penetration Fire Stops, Fire Breaks, and System Enclosures

This section establishes requirements for the selection and application of cable-penetration fire stops, cable fire breaks, and cable system enclosures (cocoons) for cable systems for Class 1E circuits.

8.1 Definitions

fire-resistive barrier: A wall, floor or, floor-ceiling assembly erected to prevent the spread of fire.

NOTE — To be effective, fire barriers shall have sufficient fire resistance to withstand the effects of the most severe fire that may be expected to occur in the area adjacent to the fire barrier and shall provide a complete barrier to the spread of fire.

fire-resistive barrier rating: This is expressed in time (hours and minutes) and indicates that the wall, floor, or floor-ceiling assembly can withstand, without failure, exposure to a standard fire for that period of time.

NOTE — The test fire procedure and acceptance criteria are defined in ASTM E 119-1981 [14].

cable penetration: An assembly or group of assemblies for electrical conductors to enter and continue through a fire-rated structural wall, floor, or floor-ceiling assembly.

cable-penetration fire stop: Material, devices, or an assembly of parts providing cable penetrations through fire-rated walls, floors, and floor-ceiling assemblies, and maintaining their required fire rating.

cable-fire break: Material, devices, or an assembly of parts installed in a cable system, other than at a cable penetration of a fire-resistive barrier, to prevent the spread of fire along the cable system.

cable-system enclosure (cocoon): An assembly installed around a cable system to maintain circuit integrity, for a specified time, of all circuits within the enclosure when it is exposed to the most severe fire that may be expected to occur in the area.

8.2 General Requirements

The selection of material for use in cable penetration fire stops, cable-fire breaks, and cable-system enclosures (cocoons) is governed by local environmental conditions and design basis events (for example, flood, radiation, seismic, and aging as described in Appendix A2). In addition, the following possibilities shall be considered:

1) Compatibility between the fire-resistive materials and the cable and raceway materials
2) Toxic or corrosive gases or fumes developed during installation
3) Expansion which might crush insulation or jacketing during installation and operation
4) Cable ampacity
5) Ability to withstand pressure differentials (cable-penetration fire stops only)
6) Ability to withstand a hose-stream test that is acceptable for use on an electrical fire (cable-penetration fire stops only)

8.3 Cable-Penetration Fire-Stop Requirements

Cable-penetration fire stops shall be provided wherever the cable system penetrates a rated fire resistive barrier. The cable-penetration fire stop shall have a fire rating equal to, or greater than, the required fire rating of the barrier. The fire rating and installation of the fire stop shall be qualified in accordance with ANSI/IEEE Std 634-1978 [7]. Modifications or additions of cables through the fire stop shall not compromise the integrity of the fire stop.

8.4 Cable-Fire Break Requirements

Cable-tray-fire breaks shall be installed in cable-tray systems as deemed necessary by the fire hazards analyses.

8.5 Cable-System Enclosure (Cocoon) Requirements

Cocoons used to permit separation distances less than those stated in ANSI/IEEE Std 384-1981 [6], 6.1.1.2 shall be in compliance with the requirements of ANSI/IEEE Std 384-1981 [6], 6.1.1.3.

9. Fire-Detection Systems

This section establishes requirements for the selection and application of fire-detection systems for cable systems for Class 1E circuits. The application requirements are as follows:

1) Automatic fire-detection devices shall be installed in accordance with ANSI/NFPA 72D-1979[11], and ANSI/NFPA 72E-1982 [12], in areas of high cable concentration (see Appendix A7).
2) Fire-detection systems shall be electrically supervised to comply with requirements of ANSI/NFPA 70-1984 [10], Article 760 and ANSI/NFPA 72D-1979 [11].

10. Fire-Extinguishing Systems

This section establishes requirements for the selection and application of fire-extinguishing systems protecting cable systems for Class 1E circuits.

10.1 Fixed Fire-Extinguishing System Application Requirements

1) A fire hazard analysis (see ANSI/ANS 59.4-1979 [1]) shall be conducted to determine if fixed automatic fire-extinguishing systems are necessary for areas of high cable concentration and spaces below raised floors or above false ceilings containing exposed cables.
2) When the analysis in 10.1(1) determines that fixed extinguishing systems are required, automatic water-spray systems designed in accordance with NFPA 13-1983 [17], or ANSI/NFPA 15-1982 [9] shall be used. If the activation of fixed automatic water-spray discharge could cause undesirable consequences to sensitive equipment which would negate single failure criteria, such equipment shall be protected from the spray and sealed against potential water damage due to water traveling along the cable system. If the equipment cannot be protected, an extinguishing system utilizing another extinguishing agent shall be provided in accordance with the appropriate NFPA standard.
3) System operational testing shall be in accordance with NFPA standards.
4) Fixed fire-extinguishing systems, whether manual or automatic, shall alert control-room operators of system operation or of any abnormal condition. Fire-extinguishing systems shall be electrically supervised to comply with the requirements of ANSI/NFPA 72D-1979 [11], and Class 1 circuits as defined in ANSI/NFPA 70-1984 [10], Article 725.
5) In areas where forced ventilation would circulate smoke or a gaseous extinguishing agent, or both, to other areas, mechanical ventilation systems shall be shut down prior to system actuation, and fire dampers shall be closed by mechanical or electrical release devices prior to fire-protection system discharge.

10.2 Portable Fire-Extinguishing Requirements

1) Portable fire extinguishers shall be located throughout the plant in accordance with ANSI/NFPA 10-1981 [8] to provide adequate coverage of all cable systems for Class 1E circuits.
2) For personnel safety, water-base or water solution portable fire extinguishers, unless specifically listed and tested for that application, shall not be used on fires involving energized cables.

10.3 Standpipe and Hose-Station Requirements

1) Standpipe and hose stations shall be located throughout the plant in accordance with NFPA 14-1983 [18] to provide adequate coverage of all cable systems for Class 1E circuits.
2) Hose stations shall be provided with nozzles that are approved by a national test laboratory for use near energized electrical equipment.

11. Handling and Installation

This section establishes requirements for the construction methods and materials for the handling and installation of cable systems for Class 1E circuits.

11.1 General Requirements

1) The installation and inspection of cable systems for Class 1E circuits shall meet the requirements of ANSI/IEEE Std 336-1980 [4].
2) Cables shall be installed in raceway systems that are qualified for the design basis events.
3) Cables shall be installed so that the independence of Class 1E equipment and circuits is maintained in accordance with ANSI/IEEE Std 384-1981 [6].
4) The cable raceway system shall be permanently identified prior to installation of cable. Identification of cables and raceways shall meet the requirements of ANSI/IEEE Std 384-1981 [6].
5) Cable field splice types and locations shall be recorded and filed for plant maintenance reference. See Section 13 for documentation procedure requirements.

11.2 Storage Requirements

1) During storage, the ends of cables shall be sealed against moisture and contamination.
2) Reels shall be stored and handled in accordance with manufacturers' recommendations to avoid damage to and deterioration of the cable.

11.3 Cable-Installation Requirements

1) Cables shall be installed in raceway systems that have suitable pull points (boxes, manholes, etc) so that maximum allowable pulling tensions and sidewall pressures are not exceeded (see Appendix A10).
2) Cables shall be installed in raceway systems that have adequately sized bends, boxes, and fittings so that cable manufacturers' minimum allowable bending radii for cable installations are not violated.
3) Where steel conduits or sleeves are used, all phases of three phase ac circuits and both legs of single-phase ac circuits shall be installed in the same conduit or sleeve to minimize induction heating.
4) Cables shall be installed so that the movement of mechanical systems will not affect the integrity of the cable system.
5) Cables shall not be installed in raceways that are utilized to carry or support equipment, piping, instrument tubing, or other facilities unless the raceway system is specifically designed to accommodate the additional loads and unless special precautions are taken to protect the cables against the effects of failure of the supported devices and from their contents.
6) Pulling instructions for all cables shall follow the cable manufacturers' recommendations.
7) Cables shall not be pulled around sharp corners or obstructions.
8) Cables shall not be pulled at temperatures below the cable manufacturers' recommended minimum pulling temperature.
9) Cable pulling lubricants shall be compatible with the cable jackets.
10) Bare wire rope shall not be used to pull cables in conduits.

11) Medium-voltage power cables shall be properly sealed during and after installation. All other cables shall be properly sealed during and after installation in wet locations.
12) The cable end within a pulling device shall be removed from the cable prior to termination.
13) When the cable pull is complete, cable manufacturers' recommendations for minimum bending radius shall be followed for permanent training.
14) Protection of the cables shall be provided on trays at floor levels and at locations where there is likelihood of physical damage.

11.4 Raceway—Cable-Fill Requirements

1) The quantity of cable in any tray shall be limited by cable ampacity requirements. See Section 4, structural capability of the tray and its supports, and the cross-sectional area of the tray.
2) A cable tray filled to the predetermined quantity (design limit) shall not be used for further cable routes unless an inspection or an analysis has been made that indicates additional cables can be installed.
3) An analysis shall be made to determine the range of weight of cable loading and this figure shall be used in the seismic analysis of the cable-tray support system. These loadings shall not be exceeded by placing more cables in the tray than allowed by the seismic design.
4) Conduit fill shall be in accordance with ANSI/NFPA-70-1984 [10], ch 9, Table 1, unless an analysis has been made that indicates that additional cables can be installed.

11.5 Requirements for Supporting Cables in Vertical Runs

1) Cable terminals shall not be subjected to excessive tensions resulting from vertical cable runs.
2) Vertically run cables shall be secured, as required, by support devices installed at intervals in the raceway systems. In vertical trays, cables shall also be secured at intermediate locations as necessary to keep all cables completely within the tray.

12. Acceptance Testing of Installed Cables

This section establishes requirements for testing of cables after installation and includes field splices and connectors of cable systems for Class 1E circuits.

12.1 Purpose

The purpose of the tests is to verify that major cable-insulation damage did not occur during storage and installation. It should be noted, however, that these tests may not detect damage that may eventually lead to cable failure in service; for example, damage to cable jackets or insulation shield on medium-voltage cable or to the insulation on low-voltage cable.

12.2 Requirements

1) Testing of installed cable systems shall meet the requirements of ANSI/IEEE Std 336-1980 [4].
2) Medium-voltage power cables shall be dc high potential tested prior to equipment connection.
3) Low-voltage cables shall be either insulation-resistance tested prior to connecting cables to equipment or functionally tested (at equipment operation voltage) as part of the checkout of the equipment system.
4) Cable test results shall be recorded and filed for future plant reference.

13. Documentation

This section establishes documentation requirements for the design and installation of cable systems for Class 1E circuits.

13.1 Definition

documentation: Any written or pictorial information describing, defining, specifying, reporting or certifying activities, requirements, procedures, or results.

13.2 Requirements

1) Documents, as required, shall be prepared as work is performed to furnish evidence of the quality of items and of activities affecting quality.
2) Documents shall include the results of reviews, inspections, tests, and materials analysis. The documents shall also include, as appropriate, data such as qualifications of procedures, equipment, computer programs, and personnel. Documents shall, as a minimum, identify the date of review, inspection or test, identity of the reviewer, inspector, data recorder, the type of review or observation, the results, the acceptability, and the actions taken in connection with any deficiencies noted.
3) The collection, storage, and maintenance of documents shall meet the requirements of ANSI/ASME NQA-1-1979 [2].
4) Certificates of conformance shall meet the requirements of ANSI/ASME NQA-1-1979 [2].
5) Design installation and protection requirements not included in this standard shall be documented in accordance with the specific documentation requirements of the IEEE standards referenced in Section 2 of this standard.

Annex A

(Informative)

A.1 General

This section applies to Section 1 of this standard.

A.1.1 Scope

This Appendix provides recommendations for achieving the requirements of IEEE Std 690-1984 together with related tutorial information regarding the design and installation cable systems of Class 1E circuits. It is not intended to imply that recommendations given here are the only acceptable methods of achieving the requirements of this standard.

A.1.2 References

[A1] IEEE Std AEIC CS5-82,, Specifications for Thermoplastic and Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 kV through 46 kV (8th Edition).[5]

[A2] AEIC CS6-1982, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 kV through 69 kV (4th Edition).

[A3] ANSI/NFPA 11-1983, Standard for Foam Extinguishing Systems.[6, 7]

[A4] ANSI/NFPA 12-1980, Standard for Carbon Dioxide Extinguishing Systems.

[A5] ANSI/NFPA 12A-1980, Standard for Halogenated Fire-Extinguishing Agent Systems.

[A6] ANSI/NFPA17-1980,, Standard for Dry Chemical Extinguishing Systems.

[A7] IEEE Std ICEA P-32-382-1969, Short-Circuit Characteristics of Insulated Cable.[8]

[A8] IEEE Std 422-1977, Guide for the Design and Installation of Cable Systems in Power Generating Stations.[9]

[A9] IEEE S-135, Power Cable Ampacities, vol 1—Copper Conductors, vol 2—Aluminum Conductors (ICEA P-46-426).

[A10] NEMA WC 3-1980, Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-19-81 Sixth Edition).[10]

[A11] NEMA WC 7-1971 (R 1976), Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-66-524).

[A12] NEMA WC 8-1976, Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-65-516).

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[5] AEIC documents are available from the Publication Department of the Association of Edison Illuminating Companies, 51 East 42nd Street, New York, NY 10017.

[6] ANSI documents are available from the Sales Department, American National Standard Institute, 1430 Broadway, New York, NY 10018.

[7] NFPA documents are available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

[8] ICEA documents are available from Insulated Cable Engineers Association, Inc, PO Box P, South Yarmouth, MA 02664.

[9] IEEE documents are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

[10] NEMA documents are available from The National Electrical Manufacturers Association, 2101 L Street, Suite 300, Washington, DC 20037.

[A13] NEMA WC 51-1975 (R 1980), Ampacities—Cables in Open-Top Cable Trays (ICEA P-54-440 Second Edition).

A.1.3 Applicable Document in Preparation[11]

A.2 Cable, Field Splice, and Connection Qualification

This section applies to Section 3 of this standard.

A.2.1 Service Conditions

Cables may be directly buried, installed in conduit above or below ground, enclosed in wireways above ground, or exposed in cable-tray runs. Cables and field splices should be suitable for operation in their installed environments. Connections should be suitably protected for their installed environments.

A.2.2 Design Considerations

Proper identification of design limits, proper selection of the cable, and proper determination of the required installation design and methods will help ensure the highest quality installation. All cables should meet the requirements of applicable Insulated Cable Engineers Association (ICEA) and Association of Edison Illuminating Companies (AEIC) standards. See A.1.2.

A.2.3 Plant Location by Area

Areas within the nuclear plant site have *normal, abnormal,* and *accident* environmental characteristics.

Normal, abnormal, and accident environments are defined in the Safety Analysis Report (SAR), Section 3.11. Plant areas outside the reactor building such as the control room, relay rooms, and switchgear rooms may be affected by fire, flooding, seismic, or loss of HVAC events but not conditions such as a loss of cooling accident (LOCA).

Equipment located inside containment is subjected to the most extreme environmental conditions for postulated accidents. For equipment located outside containment, the high energy line break (HELB) typically produces the most severe environmental conditions.

A.2.4 Temperature/Pressure

1) The postulated accidents which could produce severe environmental conditions are:
    a) A LOCA which can result in the highest pressure condition
    b) A HELB which can produce high temperatures
2) Cable, field splice, and connector operating temperatures in nuclear generating stations are normally based on 40 °C ambient. Special considerations shall be given to installations in areas where ambient temperatures exceed 40 °C (such as, in reactor containment, near steam valves and equipment enclosures).

A.2.5 Relative Humidity (rh)

For both PWR and BWR, 100% rh is assumed.

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[11] When the following document is completed, approved, and published, it will become a part of this listing.
IEEE Project P628 (in preparation), Standard Criteria for the Design, Installation, and Qualification of Raceway Systems for Class 1E Circuits for Nuclear Power Generating Stations.

A.2.6 Atmosphere/Chemicals

During an accident condition the atmosphere within a PWR containment may consist of saturated steam, air, and hydrogen.[12] In addition, the equipment could simultaneously be exposed to a typical aqueous spray of

Boron	1900–2200 ppm
pH (min—max) of Boric Acid—Sodium Hydroxide Solution	9.0–10.5
Sodium Hydroxide	1.75% by weight

The actual aqueous spray chemical composition for the particular application should be used to specify the equipment.

NOTE — Chemicals, heat, or radiation may cause coatings such as paint or galvanizing, to flake, peel, or otherwise be removed from the surface being protected.

A.2.7 Radiation

Selection of materials for use in radiation environments shall consider the short and long term effects of radiation. It is generally impossible to use only materials that will not be degraded in service. Consideration shall be given to the type and extent of radiation effects which may take the form of hardening, swelling, softening, or degradation. The effects of normal and accident integrated radiation doses on material properties are cumulative. Materials subjected to low level radiation over a long period of time may not retain their desired properties. Materials satisfactory for use in areas of low level radiation may not be suitable for use in areas of continued high level radiation or in the event of a LOCA.

A.2.8 Aging Simulation

Aging simulation is designed to put a test specimen in the end-of-life or the plant design life service condition, whichever is earlier. Aging simulation includes thermal and radiation. Thermal rate of deterioration may be determined by the Arrhenius technique. Radiation simulation is normally accomplished by short-term high dosage rates.

A.2.9 Definitions

duration: The length of time that equipment is required to function. (Duration may be continuous, short-term, or intermittent.)

continuous: Operates during or following design basis event (DBE) or safe shutdown and shall function without interruption for the duration of the event.

short-term: Operates for a time less than the duration of the design basis event (DBE) or safe shutdown.

intermittent: Operates on a cyclic basis during the design basis event (DBE) or safe shutdown.

A.2.10 Fire

1) The concept of defense-in-depth against fire and its consequences includes the use of noncombustible materials. When the use of noncombustible materials is not practical such as in the selection of cables, lubricants, equipment, and other components, their flame retarding properties should be considered.

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[12] Hydrogen accumulations may occur from the corrosion of aluminum and zinc or from a zirconium-water reaction.

2) The flame test parameters outlined in ANSI/IEEE Std 383-1974 [5], 2.5 do not necessarily represent installed conditions in nuclear power generating stations. Therefore, cables qualified with this test may propagate fire depending on installation and loading configurations. The installation of cables that have passed this fire test does not preclude the need for other fire protection measures.

A.3 Conductor Sizing—Recommendations

This section applies to Section 4 of this standard.

A.3.1 Recommendations

1) IEEE S-135 [A9][13] provides cable ampacity tables for various cable constructions and methods of installation. It also covers the selection of the proper conductor size and the application of derating factors. For configurations other than those given in these tables, ampacities should be calculated using accepted industry methods.
2) Ampacities for cables in duct banks will vary considerably from IEEE S-135 [A9] if the number of loaded ducts, duct configuration, buried depths, and concrete dimensions vary from the values assumed in that standard.
3) Cable installed in exposed groups, conduits, or closely spaced in cable trays, require ampacity derating according to the cable configuration. Derating factors are included with the ampacity tables in IEEE S-135 [A9].
4) Ampacities for nonspaced cables in trays should be determined from tables and application data provided in NEMA WC 51-1975 (R 1980) [A13] or calculated using acceptable industry methods.
5) Short-circuit current should be limited as determined by ICEA P-32-382-1969 [A7]. It should be noted that the short-circuit current referenced in ICEA P-32-382-1969 [A7] is the root-mean-square (rms) value of the fault current for the total interval of short-circuit current flow. The transient dc component becomes less significant as the interval of current flow becomes longer.
6) Where fire-stops and fire-breaks are used, additional ampacity derating may be required.

A.4 Electrical Segregation—Recommendations

This section applies to Section 5 of this standard.

A.4.1

Cables installed in stacked cable trays should be arranged by descending voltage levels with the higher voltages at the top.

A.4.2

Recommended methods for achieving requirement 5.2(1) *Medium-voltage power cable shall be installed so that the medium-voltage cannot be impressed on any lower voltage system through failure of cable insulation* are:

1) Installation of medium-voltage cables in raceways that are separated from low-voltage power and control cables and from instrumentation cables. Installation of the different classes of medium-voltage power cables in separate raceways is also recommended.
2) Utilization of interlocked armored shielded cables (separate raceways not required).

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[13] Numbers preceded with A and in brackets correspond to those of the references in A.1.2.

A.4.3

Recommended methods for achieving requirement 5.2(2) *The installation of instrumentation cables shall consider electrical noise pickup from adjacent circuits and equipment* are:

1) Installations that provide physical separation between the instrumentation cables and any electrical noise source. However, physical separation in itself may not suffice.
2) Installations in enclosed metallic raceways. See A.5.2 for additional information.
3) Cable configurations such as twisted conductors and shielding. See A.5.2 for additional information.
4) Specification of equipment that has proper filtering or is otherwise immune to electrical noise.

A.4.4

Guidelines for physical segregation of low-voltage power cable, control cable, and instrumentation cables.

1) Avoid combining cables of widely different sizes in the same raceway system to prevent damage to the smaller cables during installation unless adequate protection is provided.
2) Low-voltage power cables may be mixed with control cables if their respective sizes do not differ greatly and if they have compatible operating temperatures. When this is done in trays, the power cable ampacity should be calculated as if all cables in the tray were power cable, unless position and grouping are controlled. Complete separation of power cable from control cable is also a common practice.
3) Analog signal cables should be run separate from all power and control cables, and from unshielded cables carrying digital or pulse type signals. Separation can be provided by separate raceways or by a barrier in a tray. Separation from other electrical noise sources such as power transformers and motors, should be maintained. Voice communications cable (without power supply conductors), if adequately shielded, may be included in raceways with analog signal cables.

A.5 Shielding and Shield Grounding

This section applies to Section 7 of this standard.

A.5.1 Medium-Voltage Power Cable

A.5.1.1 Shielding Recommendations

Cables rated 5 kV are normally shielded. Shielding can also be used to monitor or test cable installation for additional assurance of insulation integrity. The need for shielding of cables in the operation range of 2 kV to 5 kV should be considered when any of the following conditions exist:

1) Transition from conducting to nonconducting environment
2) Transition from moist to dry earth
3) Dry soil where static discharge drain is inadequate
4) Damp conduits
5) Connections to overhead lines
6) Cable surfaces collect conducting materials, such as soot or salt deposits
7) Electrostatic fields are sufficient in magnitude to interfere with control and instrumentation circuit functions
8) Safety to personnel is involved
9) Long underground cables
10) Single-phase circuits in trays

A.5.1.2 Shield Losses That Affect Ampacity

The magnitude of circulating current flowing in shields grounded at more than one point depends on the mutual inductance between the cable shielding and the cable conductors and the mutual inductance to the conductors in other cables, the current in these conductors, and the impedance of the shield. Circulating current heats the shield and thereby reduces the effective ampacity for the cable. Table A1 gives formulae for calculating the shield loss for single conductor cables.

(Table A1 has been derived from Chapter 10, Table 26, of EEI Underground Systems Reference Book.)

To facilitate calculating the mutual reactance and shield resistance, the following formulae may be used (these formulae neglect proximity loss, but are accurate enough for practical purposes):

$$X_{\mathrm{M}} = 2\Pi f\left(0.1404 \log_{10}\frac{S}{r_{\mathrm{m}}}\right) \mu\Omega/\mathrm{ft}$$

$$a = 2\Pi f(0.1404 \log_{10} 2)\ \mu\Omega/\mathrm{ft}$$

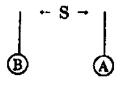
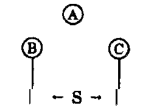
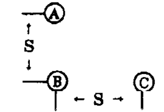
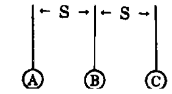
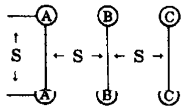
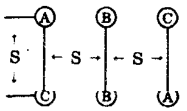
$$b = 2\Pi f(0.1404 \log_{10} 5)\ \mu\Omega/\mathrm{ft}$$

$$R_{\mathrm{s}} = \frac{\rho}{8 r_m t}\ \mu\Omega/\mathrm{ft}$$

where

X_{M} = mutual inductance of shield and conductor ($\mu\Omega$/ft)
a, b = mutual inductance correction factors for various cable arrangements ($\mu\Omega$/ft)
$\mu\Omega$ = micro-ohm = $\Omega \cdot 10^{-6}$
R_{s} = resistance of shield ($\mu\Omega$/ft)
t = thickness of metal tapes used for shielding (inches)
f = frequency (hertz)
S = spacing between center of cables (inches)
r_m = mean radius of shield (inches)
I = conductor current (amperes)

Table A.1—Formulas for Calculating Shield Voltages, Current, and Losses for Single-Conductor Cables*

Cable Arrangement Number and Diagram	I One phase	II Equilateral	III Rectangular	IV Flat	V Two circuit	VI Two circuit
						
Induced Shield Voltage—Shields Open Circuited			Microvolt to Neutral per ft (Multiply by 10^{-6} to Obtain Vp/ft)			
Cable—A Cable—C	IX_M	IX_M	$\frac{I}{2}\sqrt{3Y^2+\left(X_M-\frac{a}{2}\right)^2}$	$\frac{I}{2}\sqrt{3Y^2+(X_M-a)^2}$	$\frac{I}{2}\sqrt{3Y^2+\left(X_M-\frac{b}{2}\right)^2}$	$\frac{I}{2}\sqrt{3Y^2+\left(X_M-\frac{b}{2}\right)^2}$
Cable—B	IX_M	IX_M	IX_M	IX_M	$I\left(X_M+\frac{a}{2}\right)$	$I\left(X_M+\frac{a}{2}\right)$
Shield Loss—Shields Solidly Bonded			Microwatt per ft (Multiply by 10^{-6} to Obtain W/ft)			
Cable—A Cable—C	$I^2R_S\frac{X_M^2}{R_S^2+X_M^2}$	$I^2R_S\frac{X_M^2}{R_S^2+X_M^2}$	$I^2R_S\frac{(P^2+3Q^2)+2\sqrt{3}(P-Q)+4}{4(P^2+1)(Q^2+1)}$			
Cable—B	$I^2R_S\frac{X_M^2}{R_S^2+X_M^2}$	$I^2R_S\frac{X_M^2}{R_S^2+X_M^2}$	$I^2R_S\frac{1}{Q^2+1}$			
Total loss	$2I^2R_S\frac{X_M^2}{R_S^2+X_M^2}$	$3I^2R_S\frac{X_M^2}{R_S^2+X_M^2}$	$3I^2R_S\frac{P^2+Q^2+2}{2(P^2+1)(Q^2+1)}$			
		$P=\frac{R_S}{Y}$ $Y=$	$X_M+\frac{a}{2}$	X_M+a	$X_M+a+\frac{b}{2}$	$X_M+a+\frac{b}{2}$
		$Q=\frac{R_S}{Z}$ $Z=$	$X_M-\frac{a}{6}$	$X_M-\frac{a}{3}$	$X_M+\frac{a}{3}-\frac{b}{6}$	$X_M+\frac{a}{3}-\frac{b}{6}$

* This table has been derived from EEI Underground Systems Reference Book, Ch 10, Table 26. It is reprinted here with permission.

For 60 Hz:

$$X_M = 52.92 \log \frac{S}{r_m} \mu\Omega/\text{ft}$$

a = 15.93 μΩ/ft
b = 36.99 μΩ/ft
ρ = apparent resistivity of shield in Ω/cmil ft at operating temperature (assumed 50 °C). (This includes allowance for the spiraling of the tapes or wires.)

Typical values of ρ:

Overlapped tinned copper tape	30 Ω/cmil ft
Lead sheath	150 Ω/cmil ft
Aluminum sheath	20 Ω/cmil ft

It is assumed that the cables are carrying balanced current.

For cables installed three per conduit, use Arrangement II in Table A1. The spacing S in this case will be equal to the outside diameter of the cable increased by 20% to allow for random spacing in the conduit.

The induced circulating current correction usually is negligible in the following cases for three-phase circuits:

1) Three-conductor cables encased by a common metallic sheath
2) Single-conductor shielded cables 500 kcmil conductor or smaller installed together in a common raceway
3) Triplexed cables
4) Single-conductor lead sheathed cables 250 kcmil conductor or smaller installed together in a common duct.

All three phases of a circuit should be installed in the same conduit. Where it is necessary to run only one phase per conduit, either the conduit should be selected and installed to minimize circulating current in the conduit or conduit heating resulting from circulating current shall also be accounted for in determining the cable ampacity.

When a cable shield is grounded at only one end, the length of cable run will be limited by the acceptable voltage rise of the shield. Similar considerations shall be given to all runs of lead sheathed cables.

Because of the frequent use of window-type or zero-sequence current transformers (for ground overcurrent protection), care shall be taken in the termination of cable shield wires at the source. If the shield wire passes through the window-type current transformer, the ground return path should be brought back through this current transformer before connecting to ground. This is necessary for correct relay operation.

A.5.1.3 Induced Shield Voltages

Shields of single-conductor cable carrying alternating current will have a potential buildup if grounded at only one point. Table A.1 can be used to calculate the induced shield voltage. Table A.2 gives the typical lengths of shield with only one ground for the maximum shield potential to stay within 25 V. If higher potentials are selected, the extrapolation is linear. Induced shield voltages also depend on insulation thickness, cable geometry, and spacing. If greater precision than is given in Table A.2 is required, separate calculations should be made.

These lengths are based on the highest loading conditions of copper conductors likely to be encountered. They apply to cables operating at any 60 Hz voltage. The lengths given are from the grounded point to the shield insulating joint. If the midpoint of the section is grounded, the total length between insulating joints can be twice the length given.

Table A.2—Typical Allowable Shield Length From One Ground Point

Size Conductor	One Cable Per Duct (ft)	Three Cables Per Duct (ft)
AWG No 1/0	1250	4500
AWG No 2/0	1110	3970
AWG No 4/0	865	3000
250 kcmil	815	2730
350 kcmil	710	2260
400 kcmil	655	2110
500 kcmil	580	1870
750 kcmil	510	1500
1000 kcmil	450	—
2000 kcmil	340	—

A.5.2 Instrumentation Cable

A.5.2.1 Noise Voltage Problem Areas

The following noise voltage problem areas should be considered in the design and installation of signal cables for instrumentation systems. See A.5.2.2 for recommendations for noise voltage reduction.

1) *Normal-Mode Noise* (*Transversal or Differential*). The noise voltage which appears differentially between two signal wires and which acts on the signal sensing circuit in the same manner as the desired signal. Normal-mode noise may be caused by one or more of the following situations:
   a) Electrostatic induction and differences in distributed capacitance between the signal wires and the surroundings
   b) Electromagnetic induction caused by varying magnetic fields linking unequally with the signal wires
   c) Junction or thermal potentials due to the use of dissimilar metals in the connection system
   d) Common mode to normal mode noise conversion
2) *Common-Mode Noise* (*Longitudinal*). The noise voltage which appears equally and in phase from each signal conductor to ground. Common-mode noise may be caused by one or more of the following situations:
   a) Electrostatic Induction. With equal capacitance between the signal wires and the surroundings, the noise voltage developed will be the same on both signal wires
   b) Electromagnetic Induction. With the magnetic field linking the signal wires equally, the noise voltage developed will be the same on both signal wires.
3) *Common-Mode to Normal-Mode Conversion*. In addition to the common-mode voltages which are developed in signal conductors by the general environmental sources of electrostatic and electromagnetic fields, differences in voltage exist between different ground points in a facility due to the flow of ground current. These voltage differences are considered common mode when connection is made to them either intentionally or accidentally, and the current they produce is common mode. Common mode-current can develop normal mode noise voltage across unequal circuit impedances.
4) *Crosstalk*. The noise or extraneous signal caused by ac or pulse-type signals in adjacent circuit is termed crosstalk.

A.5.2.2 Recommendations for Noise Reduction

The general recommendations set forth should be tempered by specific manufacturer's recommendations or other accepted industry practices.

1) *Ground Signal Circuit at One Point*. The signal circuit may originate at a source such as a transducer and terminate at a load such as a recorder, either directly or through an intervening amplifier.

   If the recorder is fed directly from a grounded voltage generating transducer such as a thermocouple, the recorder circuits shall be capable of high common-mode rejection, or they should be isolated from ground. Isolating the recorder circuits from ground effectively opens the ground common-mode voltage path through the signal circuit. If an intervening amplifier is a single-ended amplifier, the low side of the signal circuit is not broken and is grounded at the recorder. Therefore, the situation is not changed so the same procedure shall be followed with the recorder as indicated above.

   A guarded isolated differential amplifier provides isolation of both input terminals from the chassis (or ground) and from the output. This amplifier is capable of high common-mode rejection and provides the input-output isolation so that the output ground will not affect the input circuit.

   Typically, the high common-mode rejection ratio of an isolated differential amplifier used in instrumentation systems is approximately 10^6: 1 (120 dB) and is the ratio of common-mode voltage applied to the amount of normal-mode voltage developed in the process.

   When an ungrounded transducer is used, it may be possible to obtain satisfactory results by leaving the transducer circuit ungrounded, connecting the cable shield to the amplifier guard shield, and grounding the shield at either the transducer end, or the amplifier end. However, it is considered that connecting cable shield to amplifier guard shield and grounding both transducer cable shield and circuit at the transducer will result in a less noisy, more stable system. Also see A.5.2.2(6) for additional shield grounding recommendations when transducer circuit is grounded.
2) *Electrostatically Coupled Noise*. Shielding of signal cables will reduce electrostatically coupled noise voltage. A properly grounded shield will greatly reduce the stray capacitance between the signal conductors and external sources of electrostatic noise so that very little noise voltage can be coupled in the signal circuit.
3) *Electromagnetically Induced Noise*. Twisting of signal conductor pairs is the most economically effective method of noise reduction. By alternately presenting each conductor to the same electromagnetic field, equal (and in phase) voltages are induced in each conductor with respect to ground. The common-mode voltage so developed is converted to a small amount of normal-mode noise as determined by the common-mode rejection ratio of the signal amplifier (isolated differential or equivalent). The frequency of twisting (lay) affects noise reduction ability and therefore shall be considered in specifying twisted pair cable.

   The materials normally used for shielding of instrumentation cable are nonferrous and cannot shield against power frequency electromagnetic fields. The steel normally used in conduit or tray is not of high enough permeability to provide very effective shielding at power frequencies. However, some benefit may accrue from the use of rigid steel conduit or steel trays with solid bottoms and tightly fitting solid steel covers.
4) *Crosstalk*. Using cables with twisted pair conductors and individually insulated shields over each pair is the best method to eliminate crosstalk.
5) *Separation*. Physical separation of instrumentation cables can be utilized to reduce noise pickup. However, physical separation in itself, unless carefully analyzed, may not achieve the desired degree of immunity.
6) *Shield Grounding*. Connect the shield to ground at only one point, for example, where the signal is grounded. If the shield is grounded at some point other than where the signal is grounded, charging current may flow in the shield due to differences in potential between the signal and shield ground locations. If the shield is grounded at more than one point differences in ground potential will drive current through the shield. In either case, shield current can induce common-mode noise current into the signal leads, and by conversion to normal-mode noise, voltage, proportional to signal circuit resistance unbalance, can reduce accuracy of signal sensing. Also, in a system with grounded transducer and isolated-input differential amplifier, the cable shield should connect to the amplifier guard shield, but grounding the shield at the amplifier will reduce the amplifier's common-mode rejection capability. Grounding the shield only at the transducer will maintain the shield at the same ground potential as the transducer which will minimize the shield induced common-mode current while permitting the amplifier to operate at maximum common-mode rejection capability. Also see A.5.2.2(1) for recommendations for shield and signal circuit grounding of ungrounded transducer.

A.5.2.3 Shielding Practices

1) The cables for computer or high-speed data logging application using low-level analog signals should be made up of twisted and shielded pairs. For noncomputer-type applications, such as annunciators and events recorders, shielding may not be required.
2) Twisting and shielding requirements for digital input and digital output signals vary between different manufacturers of computerized instrumentation systems. Separation of digital input cables and digital output cables from each other and from power cables may be required. Where digital inputs originate in close proximity to each other, twisted pair multiple conductor cables with overall shield may be permitted, or multiple conductor cable with common return may be permitted, and overall shielding may not be required. Digital output cables of similar constructions may also be permitted. Individual twisted and shielded pairs should be considered for pulse-type circuits. Cables for digital signal circuits in noncomputer applications usually do not require twisting or shielding.

A.5.2.4 Grounding Practices

1) All shields should be grounded in accordance with A.5.2.2(6).
2) Signal circuits, if grounded, should be grounded at only one point.
3) Digital signal circuits should be grounded only at the power supply.
4) The shields of all grounded junction thermocouple circuits and the shields of thermocouple circuits intentionally grounded at the thermocouple should be grounded at or near the thermocouple well.
5) Multipair cables used with thermocouples should have twisted pairs with individually insulated shields so that each shield may be maintained at the particular thermocouple ground potential.
6) Each resistance temperature detector (RTD) system consisting of one power supply and one or more ungrounded RTDs should be grounded only at the power supply.
7) Each RTD should be on a separate ungrounded power supply except as follows:
    a) Groups of RTDs embedded in windings of transformers and rotating machines should be grounded at the frame of the respective equipment for safety.
    b) A separate ungrounded power supply should be furnished for the group of RTDs installed in each piece of equipment.
8) When a signal circuit is grounded, the low or negative potential lead and the shield should be grounded at the same point.

A.6 Cable-Penetration Fire Stops, Fire Breaks, and System Enclosures

This section applies to Section 8 of this standard.

A.6.1 General Recommendations

In addition to the requirements of S 6.2, the following considerations are recommended in the selection of material for use in cable-penetration fire stops, cable fire breaks, and cable-system enclosures (cocoons).

1) Ability to install additional cables
2) Ease of installation

A.6.2 Cable-System Separation Recommendations

Redundant cable systems necessary to achieve and maintain safe shutdown reactor status should be separated by a fire-resistive barrier. Fire-resistive barriers should preferably consist of rooms or areas with walls, floors, and ceilings of three hours fire-resistance rating. A rating of less than 3 h may be acceptable if supported by appropriate data. Where overriding design features prohibit the use of separate fire areas for each cable train, a cable-system enclosure (cocoon) of the necessary fire resistance may be used.

EXCEPTION: Cable systems in the primary containment building may not require a fire barrier enclosure if the redundant cable system is located at least 90° around the circumference of the containment building from the primary cable system or if test and analysis of the cable system demonstrate that a fire barrier enclosure is not required.

A.7 Fire-Detection System

This section applies to Section 9 of this standard.

A.7.1 Area of High Cable Concentration

Automatic fire-detection systems are generally installed in areas of high cable concentration. One method of determining an area of high cable concentration is as follows:

An area of high cable concentration (actual or potential) exists for horizontal cable trays when more than 7.5 ft of total cable tray width exists in the zone of influence. The zone of influence is determined by extending lines from the bottom of the side rails of the lowest cable tray at a 30° angle from vertical (see Fig A.1).

A.7.2 Heat Detectors

Heat detectors may be used to detect cable-system fires. They may be the fixed-temperature, rate compensated, rate of rise, or combination fixed-temperature and rate-of-rise type, with thermally sensitive elements of the spot-pattern or line-pattern design. Typical areas where they are used are cable spreading areas, control rooms, computer rooms, relay rooms, communication equipment rooms, electrical equipment rooms, switchgear rooms, essential motor-control center areas, containment penetration areas, cable tunnels, cable shafts, and open areas.

A.7.2.1 Fixed-Temperature Detectors

The various types of fixed-temperature detectors are:

1) Bimetallic strip thermostat
2) Snap action disk thermostat
3) Thermostatic cable
4) Thermostatic line sensors
5) Fusible metal
6) Quartzoid bulb

Neither bimetallic thermostats nor snap-action thermostats are destroyed or permanently damaged by actuation. The fusible metal, quartzoid bulb, and the sections of thermostatic cable and thermostatic line sensors affected by heat, shall be replaced following actuation.

A.7.2.2 Rate Compensated, Rate-of-Rise, and Combination Fixed-Temperature Rate-of-Rise Temperature Detectors

Rate compensated detectors alarm at a predetermined air temperature, but are designed to compensate for thermal lag. There are several advantages of rate-of-rise devices over fixed point devices. They can be set to operate more rapidly, and are effective across a wide range of ambient temperatures, usually recycle more rapidly, and tolerate slow increases in ambient temperatures without giving an alarm. Combination fixed temperature and rate-of-rise thermal detectors will respond directly to a rapid rise in ambient temperature caused by fire, tolerate slow increases in ambient temperature without registering an alarm, and recycle automatically on drop in ambient temperature. Their disadvantages are that the detector will not respond to a fire that propagates slowly until the fixed temperature is attained, and false alarms may be registered on rapid increase in ambient temperature resulting from conditions other than hostile combustion.

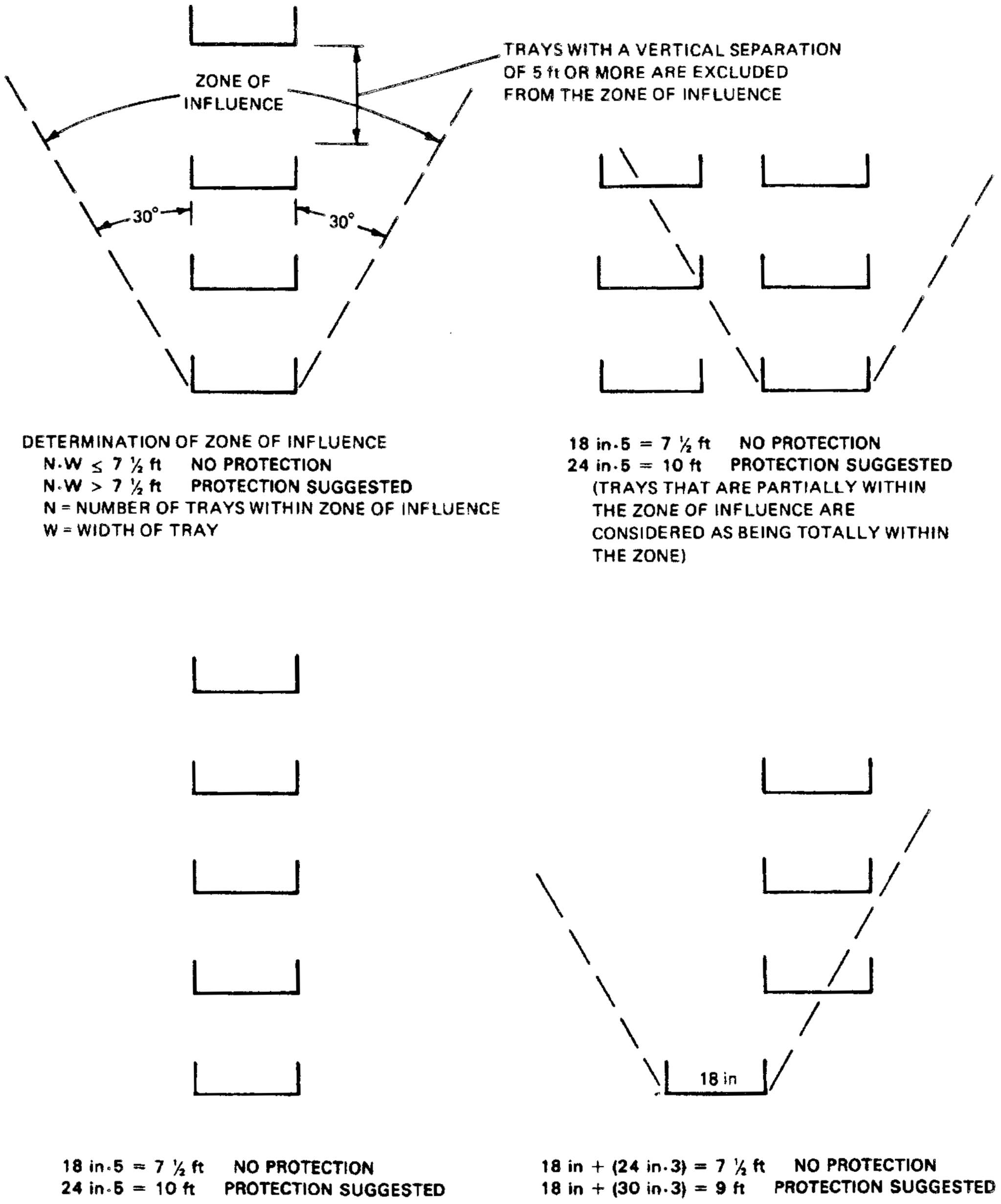


Figure A.1—Determination of Potential High Cable Concentration Cable Tray Fire Zone of Influence

The various types of combination fixed-temperature and rate-of-rise detectors include

1) Thermopneumatic detector (spot pattern)
2) Thermoelectric detector (spot pattern)
3) Thermopneumatic tube detector (line pattern)

A.7.3 Smoke Detectors

Smoke detectors are employed where the type of fire anticipated will generate invisible and visible products of combustion before temperature changes are sufficient to actuate heat detectors. Typical areas are cable spreading areas, control rooms, computer rooms, relay rooms, communications equipment rooms, electrical equipment rooms, switchgear rooms, essential motor-control center areas, containment penetration areas, cable tunnels, cable shafts, and open areas.

1) *Photoelectric Detectors*. Photoelectric detectors are of the spot type or light scattering type. In each, the partial obscuring or reflecting of a photoelectric beam by visible products of combustion between a receiving element and a light source is detected to actuate an alarm.
2) *Combustion Products Detectors*. Ionization detectors and condensation nuclei detectors alarm at the presence of invisible combustion products. Combustion products entering the outer chamber of an ionization detector disturb the balance between ionization chambers and causes alarm actuation. Condensation nuclei detectors operate on the cloud chamber principle which allows invisible particles to be detected by optical techniques.

Ionization detectors should not be installed in areas exposed to a constant radiation level in excess of 20 R/h nor in areas where traces of combustion products may be present under normal conditions such as in diesel-generator rooms.

A.7.4 Flame Detectors

Flame detectors alarm at the presence of light from flames, usually in the ultraviolet or infrared range. Detectors are set to detect the typical flicker of a flame. Detectors may be provided with a time delay to eliminate false alarms from transient flickering light sources.

A.8 Fire-Extinguishing Systems

This section applies to Section 10 of this standard.

A.8.1 Fire-Extinguishing Agents

Various fire-extinguishing agents are utilized to extinguish fires in cable systems. The more common types are as follows:

1) *Water*. Water is the most commonly used extinguishing agent because of its cooling, smothering, dilution, and emulsifying properties. Water should be used with discretion in areas of electrical equipment. Provision should be made to prevent inadvertent operation of water suppression systems. An adequate drainage system should be provided.
2) *Carbon Dioxide*. Carbon dioxide is a non-combustible gas which can penetrate and spread to all parts of a fire. It does not conduct electricity and can be used on energized electrical equipment. Carbon dioxide may produce unconsciousness and death. A dangerous concentration of carbon dioxide is 9% or above, whereas the minimum concentration required for fire extinguishment is 30% and more. For additional guidance, see ANSI/NFPA 12-1980 [A4].
3) *Dry Chemicals*. The dry chemical fire-extinguishing agents currently used are a mixture of powders, primarily sodium bicarbonate (ordinary), potassium bicarbonate (purple K), or monoammonium phosphate (multipurpose). When introduced directly to the fire area, dry chemical agents will rapidly smother the flame. However, these agents reduce visibility, pose a breathing hazard, and tend to clog the filters of ventilating equipment.
   Dry chemicals should not be used where delicate, electrical equipment is located. The insulating properties of dry chemicals might render the contacts inoperative. For additional guidance see ANSI/NFPA 17-1980 [A6].
4) *Halogenated Compounds*. A halogenated compound is one which contains elements from the halogen series, that is, fluorine, chlorine, bromine, and iodine. Halogen atoms form noncombustible gases when they replace the hydrogen atoms in hydrocarbon compounds such as methane (CH_4) or ethane (CH_3 CH_3). Caution is recommended when the use of halogenated compounds are proposed in areas where continuous high-voltage arcs may exist due to their highly corrosive breakdown products.
5) *Foam*. Foam is a homogeneous blanket obtained by mixing water, foam liquid, and air or a gas. Foam fire-suppression systems are classified as high or low expansion. High-expansion foam is an aggregation of

bubbles resulting from the mechanical expansion of a foam solution by air or other gases with a foam-to-solution volume ratio of 100:1 to approximately 1000:1. Foams with expansion ratios significantly less than 100:1 are produced from air foam, protein foam, fluorprotein foam, or synthetic foam concentrates. All foams are electrically conductive and should not be used on fires involving unenclosed energized electrical equipment. For additional guidance see ANSI/NFPA 11-1983 [A3].

A.8.2 Standpipe and Hose-Station Recommendations

The standpipe and hose system should be capable of delivering water to hose stations located within reach of areas containing cable systems for Class 1E circuits following the safe shutdown earthquake.

A.9 Handling and Installation

This section applies to Section 11 of this standard.

A.9.1 General

Criteria for the design, installation, and qualification of raceway systems for Class 1E circuits are given in A.1.3.

A.9.2 Cable Pulling Recommendations

A.9.2.1 Distance Limitations

The maximum distance a cable may be pulled in conduits without subjecting it to damage, depends on the following conditions:

1) Maximum allowable sidewall pressure of the cable construction
2) Tensile strength of conductor or jacket, or both
3) Coefficient of friction between cable jacket and conduit surface
4) Weight of cable
5) Number, location, angle, and radius of bends
6) Slope
7) Lubrication
8) Method of pulling cable (pulling eyes, basket weave grip, etc)
9) Limits of cable pulling and reel handling equipment

A.9.2.2 Reel Position

Pulling tension will be increased when the cable is pulled off of the reel. Turning the reel and feeding slack cable to the duct entrance may change a difficult pull to an easy one.

A.9.2.3 Bend Locations

The direction of pulling has a large influence on the pull if bends are included. Whenever a choice is possible, pull so that the bend or bends are closest to the reel. The worst condition possible is to pull out of a bend at or near the end of the run.

A.9.2.4 Maximum Cable Pulling Length

Conduit and duct system design should consider the maximum pulling lengths of cables to be installed. To determine the maximum pulling length of a cable or cables, it is necessary to determine the maximum allowable values for both pulling tensions and sidewall pressure. The pulling length will be limited by one or both of these factors.

A.9.2.4.1 Maximum Allowable Pulling Tension

The maximum allowable pulling tension should be determined from the manufacturer's cable recommendations or from the following information:

1) Based on pull by conductor

   $T_{\max} = K \cdot N \cdot \text{cmil}$

   where

   $T_{\max}$ = maximum pulling tension, (lb)
   cmil = circular mil area of each conductor
   N = number of conductors
   K = 0.008 lb/cmil for annealed copper and hard aluminum
   = 0.006 lb/cmil for $^3/_4$ hard aluminum

2) Based on pull by basket grip applied over: Nonshielded jacketed cables—2000 lb
   Shielded jacketed cables—1000 lb
   Do not exceed tension limit of A.9.2.4.1 (1)

A.9.2.4.2 Maximum Allowable Sidewall Pressure

Sidewall pressure is the radial force exerted on the insulation and sheath of a cable at a bend point when the cable is under tension. The maximum allowable sidewall pressure is 500 lb/ft of radius[14] for power and control cables. For instrumentation cable use cable manufacturer's recommendations.

A.9.2.4.3 Expected Pulling Tension

The expected pulling tension of one cable in a straight section of duct may be calculated from the following formula which does not consider slope:

$$T = LWK_o$$

where

T = total pulling line tension, (lb)
L = length of conduit runs, (ft)
W = weight of cable(s), (lb/ft)
K_o = basic coefficient of friction

The expected pulling tension of a cable in an inclined section of duct may be calculated from the following formulae:

$$\text{Upward } T = WL(\sin\alpha + \text{K}\cos\alpha) + (\text{prior tension})$$

$$\text{Downward } T = WL(K\cos\alpha - \sin\alpha) + (\text{prior tension})$$

where

α = angle from horizontal

For conduit runs containing horizontal bends, the expected pulling tension around a bend should be determined as follows:

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[14] Sidewall pressures greater than published values should be cleared through the cable manufacturer.

Refer to Fig A.2 and assume pulling from A to D

then,

$T_{\mathrm{C}} = T_{\mathrm{B}}\, eK_{\mathrm{o}}\, \alpha$

where

T_{C} = tension after the bend, (lb)
T_{B} = tension into the bend, (lb)
e = naperian logarithm base (2.72)
K_{o} = basic coefficient of friction
a = angle of the bend (radians), 1 degree = 0.01745 radians

T_{B} is determined for the pull by the straight-length method given above.

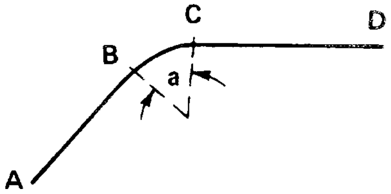

Figure A.2—Expected Pulling Tension Around a Horizontal Bend for Conduit or Duct Runs Containing Horizontal Bends

The basic coefficient of friction, typically, ranges from 0.3 for well lubricated cables pulled into smooth, clean conduits to 0.5 for lubricated cables pulled into rough or dirty conduits. The use of a different coefficient of friction may be substantiated by comparison of the actual versus calculated pulling tension.

When three cables are pulled into a duct, the pulling tension is not simply three times that of a single cable pull. Because of the wedging action between cables and duct, even in a straight pull, the effect is to produce a side pressure which is treated as an increase in the basic coefficient of friction (K_{o}), and is called the weight correction factor (W_{c}). The effective coefficient of friction, K, is:

$K = W_{\mathrm{c}} K_{\mathrm{o}}$

The pulling tension for three cables then becomes:

$T = 3KLW$ for straight pulls

The additional tension imposed by a bend is calculated the same way as for a one-cable pull except that K_{o} is replaced by K.

Figure A.3 can be used to determine W_{c} when the ratio of the duct inside diameter and cable outside diameter (D/d) is known.

Pull points or manholes should be installed wherever calculations show that expected pulling tensions exceed either maximum allowable pulling tension or sidewall pressure.

A.9.2.4.4 Critical Jamming Ratio

When three single-conductor cables are pulled into a conduit it is possible for the center cable to be forced between the two outer cables, while being pulled around a bend, if the *D/d* ratio approaches a value to 3.0. Up to a ratio of 2.5 the cables are constrained into a triangular configuration. However, as the value approaches 3.0, jamming of the cables could occur and the cables would *freeze* in the duct causing serious cable damage. To allow for tolerances in cable and conduit sizes, and for ovality in the conduit at a bend, the *D/d* ratio's between 2.8 and 3.1 should be avoided (see Fig A.3).

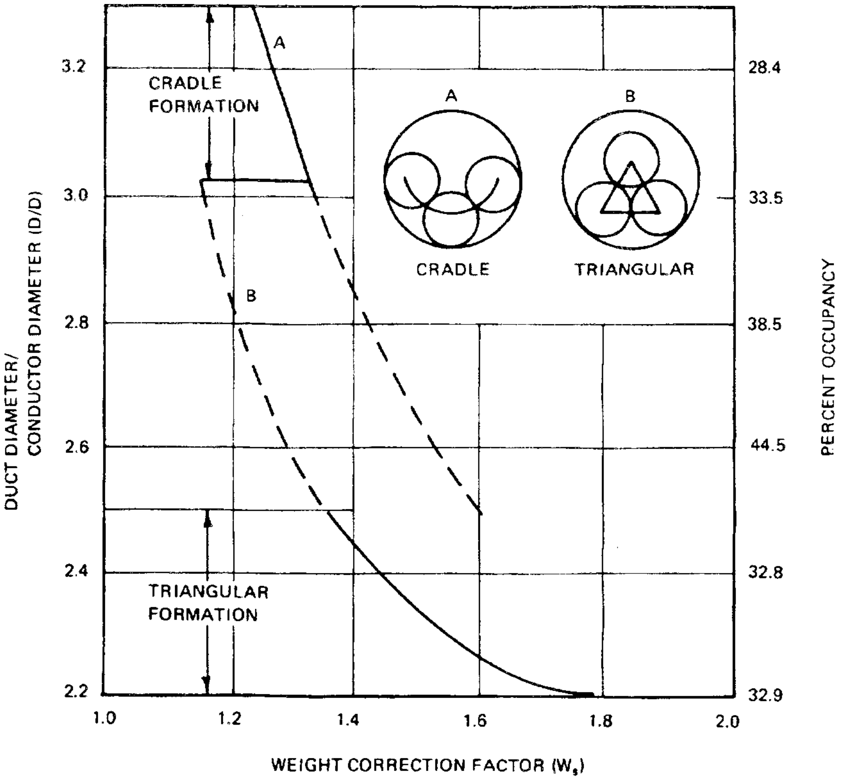

Figure A.3—Tension and Jamming Graph

A.9.2.4.5 Expected Sidewall Pressure

The sidewall pressure acting upon a cable at any bend may be estimated from the following equations:

$$P = \frac{T}{R}$$ for single conductor cable

$$P = \frac{1}{3}(3W_c - 2)\frac{T}{R}$$ for 3 cables in cradle formation where the center cable presses hardest against the duct

$$P = \frac{W_c T}{2R}$$ for cables in triangular formation where the pressure is divided equally between the two bottom cables.

where

P = sidewall pressure on the critical cable(s) (lb/ft)
T = total pulling tension, (lb)

R = radius of bend, (ft)
W_c = weight correction factor (see Fig A.3)

The cable manufacturers' recommendations should be followed for all cable configurations not covered by the formulae in A.9.2.4.5.

A.9.3 Raceway Cable Fill Recommendations

1) The weight of cable in trays should be based on the analysis of the performance of the tray support system in a seismic event.
2) Cable should be installed no higher than the top of the side rails of its cable tray except as necessary at intersections and where cables enter/exit the cable tray over the side rails.
3) The smaller size low-voltage power cables in trays are often mixed with control and digital signal circuits on a nonspaced random fill basis. (When this is done in trays, the power-cable ampacity should be calculated as if all cables in the tray were power cable, unless position and grouping are maintained.)
4) Control cables and instrumentation cables in trays are generally installed on a nonspaced random fill basis.
5) Where single conductors are used in trays for two or three wire power circuits, these conductors should be securely bound in circuit groups to prevent excessive movements due to fault-current magnetic forces and to minimize inductive heating effects in tray sidewalls and bottom.
6) Cable fill, for example, summation of the cable cross-sectional area, in random filled cable trays should be limited in design to a predetermined percentage of cable tray usable cross-sectional area.
   A percentage fill limit is needed for random filled trays because cables are not layed in neat rows and secured in place. This results in cable crossing and void areas which take up much of the tray cross-sectional area. Generally, a 30% to 40% fill for power and control cable and 40% to 50% for instrumentation cables will result in a tray loading so that no cable will be installed above the top of the side rails of the cable tray except as necessary at intersections and where cables enter or exit the cable tray systems.
7) Ampacities for power cables in randomly filled cable trays given in NEMA WC51-1975 (R1980) [A13] are based on the depth of cable in tray.

A.9.4 Cable Installation Recommendations

1) Avoid routing cables over lube oil reservoirs, lube oil conditioners, and hydraulic oil storage areas.
2) Consideration should be given to the pulling direction to minimize sidewall pressure and cable pulling tension.
3) Cables should only be pulled into clean raceways. Any abrasions or sharp edges, which might damage the cable, should be removed. A mandrel should be pulled through all underground ducts prior to cable pulling.
4) Pulling winches and other necessary equipment should be of adequate capacity to ensure a steady continuous pull on the cable.
5) Cable on reels should be unreeled and fed into the raceway without subjecting the cable to a reverse bend or overruns as it is unreeled.
6) Some suitable means, such as a flexible feeder tube or cable protector, should be used to protect and guide the cable from the cable reel into the raceway. The radius of the feeder tube or cable protector should not be less than the minimum bending radius of the cable.
7) A swivel should be attached between the pulling eye and the pulling rope. All sharp points of the hardware which attaches the cable to the eye, such as bolts and cable clamps, should be thoroughly taped to prevent such projections from catching at conduit ends or damaging conduits.
8) Temporary bracing may be required during pulling installation to prevent damage to trays.
9) Trays and trenches should be periodically cleaned, as necessary, to prevent accumulation of debris.
10) Conduit prelubrication, if used, should be done in accordance with the pulling lubricant manufacturers' recommendations. Excessive residue from cable pulling lubricants should be wiped from exposed cables as they are pulled out of a conduit.
11) Some methods of supports and maximum spacing for conductor supports are listed in ANSI/NFPA 70-1984 [10]. Recommendations for supports for special cables such as armor, shielded and coaxial should be obtained from the manufacturer. In vertical trays, securing the cable to the tray rungs every 2 ft to 5 ft will

normally provide support for most cable types. When split blocks are used, they should be spaced 6 ft to 8 ft apart.

12) Sufficient cable slack should be left in each manhole and temporarily supported so that the cable can be trained to its final location on racks, hangers, or trays along the sides of the manhole.
13) Cables in horizontal trays exposed to falling objects should be protected.
14) Where covers are used on trays containing power cables, consideration should be given to ventilation requirements or cable derating, or both.
15) Cable systems entering electrical equipment enclosures from the top should be designed to prevent water from entering the equipment.
16) Special care should be exercised during welding, soldering, and splicing operations to prevent damage to cables.

A.10 Acceptance Testing of Installed Cables—Recommendations

This section applies to Section 12 of this standard.

A.10.1 Recommendations

1) It is recommended that medium-voltage power cables be dc high potential tested in accordance with NEMA WC8-1976 [A12], NEMA WC7-1971 (R1976) [A11], and NEMA W3-1980 [A10] or AEIC CS5-1982 [A1], and AEIC CS6-1982 [A2].
2) The low-voltage power cable insulation resistance tests should measure the insulation resistance between any possible combination of conductors in the same cable and between each conductor and station ground, with all other conductors in the same cable grounded. The test voltage should be a minimum of 500 V dc. The minimum acceptable insulation resistance is

$$R \text{ in m}\Omega = \begin{pmatrix}\text{rated}\\ \text{voltage}\\ \text{in kV} + 1\end{pmatrix} \cdot \left(\frac{1000}{\text{length in ft}}\right)$$

3) Testing of control cable and prefabricated cable assemblies in a similar manner is recommended. Cable manufacturers' recommendations should always be considered.
4) Insulation resistance measurements should be performed on instrumentation cables if circuit performance is dependent upon level of insulation resistance. Cable manufacturers' recommendations should always be considered.