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Zambian Standard

Guide for Substation Fire Protection

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Ministry of Local Government and Housing
Ministry of Mines and Minerals Development
National Council for Construction
The University of Zambia, School of Engineering
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NATIONAL FOREWORD

This Zambia Standard has been prepared by the Electrical Construction Standard Technical Committee in accordance with the procedures of the Bureau.

The standard is technically equivalent to the IEEE Std 979-1994(R2004)

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1. General

1.1 Scope

This guide was developed to identify substation fire protection practices that generally have been accepted by industry.

1.2 Purpose

The purpose of this document is to give design guidance in the area of fire protection to substation engineers. Existing fire protection standards, guides, etc., that may aid in the design of specific substations or substation components, are listed in the annex.

NOTE — No recommendation listed in this document should be followed if it is less restrictive than that specified in any local code or ordinance.

2. Control and relay buildings

2.1 General

This clause contains recommendations for fire protection practices that should be used as a guide in designing substation control and relay buildings.

2.2 Cable

Cable installed either in trays, below the floor (raised floor), or in trenches cast into the floor could spread a fire from one area or piece of equipment to another. Therefore, the following precautions are suggested: Removable covers for trenches should be made of metal or fire-retardant material. If the floor is raised, use of a fire protection system beneath the floor should be considered. When cables are installed in either covered trays, under raised floors, or in trenches cast into floors, consideration should be given to the installation of cable fire breaks. Cable fire breaks should be repaired and maintained to correct damage that may occur when cables are removed or installed. The cable used in substation control houses should be of a material that does not readily propagate a fire. The cables used should be qualified by the flame test parameters specified in IEEE Std 383-1974 [B46].

2.3 Exits

Most control houses should have a minimum of two exits. These exits should be located at opposite ends of the building to prevent the possibility of personnel being trapped by a fire. These doors should open outward and be equipped with illuminated exit signs. Panel and equipment arrangements should be designed so personnel can exit the equipment area from both ends. Additional guidance can be found in ANSI/NFPA 70-1993 [B22], ANSI/NFPA 101-1994 [B26], and ANSI/NFPA 101A-1995 [B27].

2.4 Door locks

Panic hardware on all doors should override any exterior lock or padlock to allow egress from the building. This feature is recommended because personnel may enter the building without first unlocking all of the exterior doors.

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2.5 Fire extinguishers

2.5.1 Portable extinguishers

Portable fire extinguishers should be located in accordance with ANSI/NFPA 10-1994 [B2]. Locations adjacent to normal entrance/exit doors are suggested. See clause 7 for guidance in selection of the type of extinguishing agent.

2.5.2 Fixed extinguishing systems

Local fire codes may require fixed fire-extinguishing systems, or their installation may be necessary due to the critical location or type of substation. Guidance in selection of this type of system may be found in clause 7.

2.6 Alarms

It may be desirable to equip unattended substations with smoke or heat detectors to sense a fire. Duct smoke detectors, installed in the return ducts of heating and cooling equipment, provide an effective means of detecting fire. The detectors should activate an audible/visual fire alarm at the substation site, the master station (if the substation is equipped with supervisory control equipment), and, if desired, the local fire station. Attended substations should be equipped with similar devices that should actuate a local alarm. See clause 6 for guidance in the selection of the detection system.

2.7 Combustible materials

The use of combustible materials with flame-spread, fuel-contributed, and smoke-developed ratings greater than 25 should be avoided in the selection of desks, chairs, filing cabinets, storage boxes, display boards, building insulation, interior wall panels, mounting boards, etc. The flame spread is calculated utilizing ANSI/NFPA 255-1990 [B29].

2.7.1 Housekeeping

Good housekeeping practices should be followed to eliminate the accumulation of combustible materials, e.g., discarded papers, prints, cups, newspapers, etc. Waste cans should be fire approved and self-closing.

2.7.2 Storage

The storage of paper products, cleaning fluids, and other combustible materials in a control building should be minimized. If stored in the control building, they should be kept in a separate area having a minimum 1 h rating to prevent a fire from spreading to the main control and relay areas. Flammable liquids should be stored only in safety cans approved by Underwriters Laboratories. Guidance for the storage of flammable liquids can be found in ANSI/NFPA 30-1993 [B18].

2.8 Ventilation

Since most fires produce extremely heavy smoke that inhibits manual fire fighting, special portable or fixed exhaust and ventilating systems that bring in outside air should be utilized to remove or reduce the smoke. This is especially important in confined areas where manual fire

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fighting is the only practical method of fire extinguishment. Fixed exhaust and ventilating systems should shut down automatically during a fire and be equipped with an override device to allow for smoke removal when fire fighters deem it necessary. The fan override switch should be located outside the fire hazard area, clearly marked, and easily accessible to fire fighters. For additional guidance, see ANSI/NFPA 204M-1991 [B28] and SMACNA [B53].

2.9 Lighting

Exit lights and emergency lighting sufficient to provide egress from the building should be considered. These lights should be supplied per ANSI/NFPA 101-1994 [B26] and ANSI/NFPA 101A-1995 [B27].

2.10 Construction

The control and relay building should be constructed of fire-resistive or noncombustible materials. The building should be located and designed so that the largest credible fire (e.g., of an oil-filled transformer, a circuit breaker, or neighboring plants or storage facilities) will not involve or affect the operation of the equipment within the building or vice versa.

2.10.1 Fire ratings

All fire walls, doors, floors, and ceilings should have a fire rating commensurate with the largest credible fire they could encounter. All fire doors should be equipped with self-closing devices to maintain the fire rating of the wall.

2.10.2 Floor and wall openings

In multistory structures and fire-rated rooms, all floor and wall openings should be sealed in a manner that will not reduce the fire rating of the floor or wall. Guidance for installations of cable penetrations can be found in IEEE Std 634-1978 [B50].

2.10.3 Conduits

Conduits should be sealed at ceiling, floor, and wall penetration(s) to prevent the transfer of liquid fires, smoke, flammable gases, or vapors from one area to another. Consideration should be given to using conduits made of fire retardant materials.

2.10.4 Heating equipment

Portable heating equipment should not be used in control buildings unless their design, installation, electrical supplies, etc., are deemed suitable by the fire protection engineer or another responsible individual. Clearances for heatproducing appliances should be adequate to minimize the risk of igniting adjacent combustible material. Guidance for air-conditioning systems can be found in ANSI/NFPA 90A-1993 [B25].

2.11 Uses

Substation control and relay buildings should not be used for any other purpose. If welding, repair, storage of spare clothing, storage of crated spare parts, oil testing, etc., is unavoidable, a separate fire-rated area should be provided.

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2.12 Telephones

A list of emergency telephone numbers, in the order in which they should be called in a fire emergency, should be located by the telephone in a conspicuous place in the operator's area. This list should be preceded by the substation name, address, and telephone number. These numbers and a telephone should be located outside of the building.

2.13 Batteries

The level of hydrogen gas given off from batteries should be calculated using manufacturer's guidelines. If this gas level is large enough to cause an explosion, the guidance found in 8.2 should be followed.

3. Transformers

3.1 General

Transformers generally contain the largest quantity of combustible substance located in a substation. Therefore, special attention should be given to their location, relay protection, and fire protection. Fires in oil-insulated transformers result principally from the breakdown of insulation. This may be caused by overloads, switching or lightning surges, gradual insulation deterioration, low oil level, moisture or acid in the oil, or failure of an insulating bushing. Arcing that follows an electrical breakdown can burn through the tank or vaporize the oil, thereby creating pressure sufficient to force off the cover or rupture the tank. A considerable amount of burning oil may be expelled over a large area, and an intense fire may follow. The flexible connection joints often used in transformer oil conservator systems can fail because of damage resulting from arcing, fire, or some other cause, contributing further to fire propagation. Special attention should be given to protecting these joints from fire and damage. Another possible source of fires from power transformers is combustible gas accumulation within the transformer tank. These gases are generated by a variety of causes and can reach sufficient concentration to pose a possible explosive hazard. These gases can be detected by performing periodic combustible gas-in-oil analysis on oil samples taken from each power transformer.

3.2 Fixed fire-extinguishing systems

Consideration should be given to the installation of fixed fire-extinguishing systems in substations where transformers are located near substation buildings, other transformers or other major equipment, residences, etc. Clauses 6 and 7 offer additional guidance in selecting extinguishing agents and in designing fixed extinguishing systems and firedetection systems.

3.2.1 Fixed water extinguishing systems

The most common type of extinguishing agent employed to protect transformers is water. A water system is a special fixed pipe system connected to a reliable source of water and equipped with discharge nozzles toprovide a specific water discharge pattern and distribution over the transformer. The piping system is connected to the water supply through an automatically actuated valve that initiates flow of water to the nozzles. The automatic valve is actuated by heat-sensing devices located around the perimeter of the transformer. The system should be designed so that the water discharge will not cause a flashover. This is recommended to avoid spurious tripping caused by false operation of the water extinguishing system. Consideration should be given to the automatic tripping of the transformer and the deenergization of its pumps and fans

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upon the activation of the water system. Sometimes, because of low ambient temperatures or high wind, spot-type heat-sensing devices located around the perimeter of outdoor transformers can operate too slowly to activate the fire-extinguishing systems. This delay could allow the transformer sufficient time to fail catastrophically and possibly render the fire-extinguishing system inoperative. For general design and guidance, see ANSI/NFPA 15-1990 [B11].

3.2.1.1 Water pressure

Substations often must be located in areas where the local community's water mains may not be of sufficient size to supply the fixed water extinguishing system or where water mains may not exist. At sites such as these, alternate methods may have to be utilized. A series system of nitrogen bottles or an engine-driven pump can be utilized to supply the pressure to drive the water from a holding tank. The holding tank may be filled from low-pressure mains, a private well, or a tank truck. Another method is to use a pressurized tank designed to meet NFPA standards. For general guidance, see ANSI/NFPA 20-1993 [B14], ANSI/NFPA 22-1993 [B15], and ANSI/NFPA 24-1992 [B16].

3.2.1.2 Water systems freeze protection

In areas that are subject to freezing temperatures, consideration should be given to the installation of freeze protection (heat tracing) or to providing a "dry system."

3.2.1.3 Water capacity

The water system should be capable of supplying 0.25 gal/min/ft2 (0.17 L/s/m2) of transformer area, including the tank and radiators, for a minimum of 30 min for each transformer protected.

3.2.1.4 Cable buses

The water spray system should also be installed to protect any enclosed transformer cable bus systems that could be exposed to a transformer fire.

3.2.2 Foam systems

Occasionally, foam systems are installed to extinguish transformer fires. These systems are activated similarly to fixed water systems. The advantage of this system is that it forms a blanket of foam over the engulfed area and provides a smothering effect, thus reducing the spread of fire. The disadvantage of a foam system is that all foams are electrically conductive and could cause flashover problems. For special design features, see ANSI/NFPA 16-1995 [B12].

3.3 Actuation of fire-extinguishing systems

The earlier a fire is detected, the higher the degree of fire-extinguishing-system effectiveness is achieved. This minimizes fire damage, and could prevent transformer catastrophic failure. Many of the transformer built-in detection sensors could be used to actuate the fire-extinguishing system (for example, hot-spot temperature sensor, high oil temperature sensor, sudden pressure surge sensor, combustible gas detection sensor, etc.). These sensors have the advantage of being in place and readily available. However, because of possible spurious operation of some transformer sensor devices, a double contingency arrangement requiring the operation of two sensors concurrently is recommended in order to initiate fire-extinguishing system operation.

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3.4 Oil containment

Transformer fires are almost always associated with a rupture of the exterior tank of the transformer. This rupture, depending on its location on the tank and the size of the transformer, could allow a large amount of flaming liquid to be spread over a large portion of the substation yard. Also, even after the fire is extinguished, the transformer may still leak a sizable amount of combustible and environmentally damaging liquid over the yard. Therefore, special precautions should be taken to collect and contain the oil. For general guidance, see ANSI/NFPA 30-1993 [B18] and IEEE Std 980-1987 [B52].

3.4.1 Yardstone

The voids obtained with the use of yardstone in combination with the substation grading can be used to retain or spread out a given amount of oil. The objections to this system are that oil can be absorbed into the ground, and if the site is graded to hold oil, it will also hold rain water.

3.4.2 Berms

Oil can be contained in a specified area by constructing a berm or curb around a transformer. The berm should be constructed of a material, such as asphalt, concrete, etc., to form a liquid-tight container. The berm should enclose an area large enough to hold the largest amount of oil that is expected to leak from the transformer plus rainfall and, if applicable, the total quantity of water from a fixed water extinguishing system. It should also be able to withstand the expected hydraulic head and provide adequate fire rating. The objections to this system are that rain water can be trapped or that a pool of burning oil could be formed outside of the transformer fixed fire protection system. Also, the berm could present a problem during testing and in bringing oil-handling equipment, laboratory trucks, etc., close to the transformer. However, berms offer a positive means of assuring that oil spills or oil fires are contained in the area surrounding the leaking transformer and do not spread to expose other equipment or buildings. For additional guidance, see ANSI/NFPA 30-1993 [B18] and IEEE Std 980-1987 [B52].

3.4.3 Pits

Various types of holding pit designs are presently being utilized in substations. The grade surrounding oil-filled equipment is contoured so that oil is collected in the pit. Concrete, clay, or lined pits are sometimes filled with crushed stone, gravel, or shells. Pits should be designed so that collected oil and water will not weaken equipment foundations.A limitation to pit containment is that oil may not penetrate fill which may become frozen in cold climates. The most common designs include those listed in the following subclauses.

3.4.3.1 Sump pumps

Pits may utilize a sump pump to remove collected water. The pump is manually operated in attended substations or automatically operated in unattended substations. Automatic drainage should be equipped with oil-detecting controls. A high water level generally activates an alarm. Automatic operation of the pump is normally de-activated when a fixed extinguishing system is activated to avoid oil discharge.

3.4.3.2 Holding tanks

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Water and oil may be piped from a pit to a holding tank or pond. The oil is then removed with a skimmer.

3.4.3.3 Drainage pipes

Drainage pipes from pits should be provided with a specific gravity valve that opens to allow water to pass, but closes when oil attempts to pass.

3.4.3.4 Fire-quenching or oil-retention pits

These pits are filled with fairly uniform-sized material, such as crushed stone, of sufficient volume to provide the necessary holding capacity. This type of pit is usually surrounded by a berm or curb to prevent the entrance of runoff rain water. This type of construction will usually prevent an oil pool fire but will usually require the installation of some form of drainage facilities. Before selecting this containment method, consideration should be given to the local water table, freezing temperatures and, in some locations, the possibilities of sand or dust storms.

3.4.3.5 Shallow pits

Shallow pits have lined or unlined covered ditches or piping that allows the oil and water to be diverted to another location in the substation for removal.

NOTE — All materials used in the construction of pits, drainage pipes, drainage ditches, holding tanks, etc., should be of noncombustible materials that are capable of withstanding the thermal shock of the oil fire followed by the cooling effect of the water. Also they should have adequate mechanical strength to withstand any traffic or equipment-handling weights to which they may be subjected. The holding tanks, ponds, berms, piping, etc., should be sized to handle the maximum amount of oil available, the quantity of water that may be used in fighting the fire, and any collected rainfall.

3.4.3.6 Oil separation

Water and oil may be piped to an oil separator that will retain oil but allow water to pass through after separation. For details of traps, oil stop valves, etc., refer to IEEE Std 980-1987 [B52].

3.4.4 Grading

The substation grading, depending on the topography of the site, may be contoured to permit the oil to flow to an area of the substation that will not endanger other pieces of equipment. The possible problem with this system is that during an oil fire a larger portion of the substation will be involved in the fire. This could make extinguishment and cleanup more expensive and difficult. Also, even though the oil is directed to an area normally unoccupied by equipment, this area could be used for temporary storage and pose an unnecessary danger.

3.5 Surge arresters

Surge arresters should be located to minimize the possibility of a missile from an exploding arrester striking porcelain bushings or rupturing transformer radiators and causing an oil leak. Arresters should be rigidly supported and properly grounded. If separate conductors are utilized to ground arresters mounted on transformers, they should not contact the radiators.

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4. Separation and general information

4.1 General

This clause contains guidelines for separating oil-filled equipment from other equipment, buildings, etc., and general information for use in locating oil-filled equipment. Some factors to consider in the decision-making process in determining protection needs are

a) Fire insurance implications
b) Probability of public rebuke from an environmental contamination standpoint as a result of an unchecked fire
c) Possible reduction in outage time that fixed protection would afford
d) Potential for an unchecked fire to damage any structures, lines, or related exposures that could impair operation of backup neighboring units

4.2 Insulating oil

Flash point is the minimum temperature at which a liquid will give off vapor in sufficient amount to form a flammable air-vapor mixture that can be ignited. Liquids with a flash point above 200 ? F (93 ? C) are classified as a Class IIIB combustible liquid according to ANSI/NFPA 30-1993 [B18]. Insulating oil has a flash point temperature of approximately 295 ? F (146 ? C) and is therefore a Class IIIB combustible liquid. Therefore, based on its high flash point temperature, the oil can be handled and stored in a safe manner. But, when installed in electrical equipment, this oil does possess the qualities to be considered a fire hazard. This is due to the high temperatures that can be produced during an electrical fault or an external fire that engulfs an oil-filled piece of equipment. Furthermore, when oil is subjected to intense heat, as from an electrical arc, it is possible to crack the oil into dangerous gases, such as hydrogen, methane, acetylene, and ethane, which greatly contribute to the hazard. Therefore, the placement in substations of transformers or other pieces of oil-filled equipment should be of concern to the designer and engineer. Every attempt possible should be made to locate oil-filled equipment away from other equipment, substation buildings, fire hazards present in neighboring properties, etc. Actual tests by Ontario Hydro in 1967 have shown that when large oil fires develop in transformers, the temperature above the transformer can reach 1800–2000 ? F (982–1093 ? C). With a wind velocity of 15 mi/h (24 km/h) to 25 mi/h (40 km/h), temperatures up to 1500 ? F (816 ? C), 30 ft (9.1 m) to 40 ft (12.2 m) from the fire source, can be produced.

4.3 Fire barriers

The amount of oil contained in power transformers and circuit breakers varies with the manufacturer, voltage ratings, and MVA ratings. Some typical values are given in table 1. The magnitude of the possible fire area and the hazard resulting from the rupture of large oil-filled equipment tanks can be emphasized by the fact that 1000 gal (3785 L) of oil will cover an unrestricted area (e.g., an epoxy-painted concrete floor) of slightly over 1600 ft2 (149 m2) to a depth of 1 in (2.5 cm). When the design and size of the containment facilities utilized are inadequate, it may be necessary to install some form of fire barrier to protect other substation equipment or neighboring properties. These barriers should be totally constructed of noncombustible materials such as concrete block, brick, sheet steel, reinforced concrete, etc. They should be designed to withstand the largest credible fire to which they may be subjected.

Removable fire barriers should be considered when space is needed for equipment maintenance or replacement.

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Table 1— Typical oil quantities in equipment

Three-phase transformers		Circuit breakers	
Gallons of oil	Typical MVA ratings	Gallons of oil per tank of three-tank breaker	kV ratings
12 000 and above	100 MVA and above	1000 and above	230 kV
10 000–11 999	50–99 MVA	500–999	138 kV
8000–9999	30–49 MVA	499 and below	69 kV
2000-7999	5–29 MVA		
1999 and below	5 MVA		

4.4 Transformer outdoor installations

Subclauses 4.4.1–4.4.5 give recommendations for separation, barrier installations, and extinguishing systems for the installation of outdoor transformers.

4.4.1 Separation of large transformers from buildings

Transformers containing 2000 gal (7571 L) or more of insulating oil should be at least 20 ft (6.1 m) from any building. If these large oil-filled transformers are located between 20 and 50 ft (6.1–15.2 m) of a building, the exposed walls of the building should constitute, or be protected by, at least a 2 h fire-rated barrier. The barrier should extend in the vertical and horizontal directions such that any point of the transformer is a minimum of 50 ft (15.2 m) from any point on the wall not protected by the barrier. Should it be necessary to encroach on the above minimums, the installation of a transformer fire protection system should be considered. Some jurisdictions require a combination of barriers and fire protection systems.

4.4.2 Separation of small transformers from buildings

Transformers containing less than 2000 gal (7571 L) of insulating oil should be separated from buildings by the minimum distances shown in table 2.

Table 2— Separation of small transformers from buildings

Transformer rating	Recommended minimum distance from building*
75 kVA or less	10 ft (3.0 m)
76–333 kVA	20 ft (6.1 m)
More than 333 kVA	30 ft (9.1 m)

*Guidance for recommended minimum distances from buildings in electric generating plants are given in ANSI/NFPA 850-1992 [B31] and ANSI/NFPA 851-1992 [B32].

Where a transformer is installed less than the minimum distance, the building should have fire-resistive wall construction. Guidance can be found in NFPA 255-1990 [B29].

4.4.3 Separation between large transformers

Large oil-filled transformers should be separated by at least 30 ft (9.1 m) of clear space and/or a minimum 1 h firerated barrier.

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4.4.4 Fire barrier size

The height of a fire barrier should be at least 1 ft (0.30 m) above the height of the oil-filled circuit breaker tank, transformer tank and its oil conservator (if applicable), transformer bushings, pressure-relief vents, etc. The fire barrier should extend at least 2 ft (0.61 m) horizontally beyond the line of sight between all points on adjacent transformers. The height of the fire barrier should be not less than that required to break the line-of-sight from any point on the top of the transformer tank and its oil conservator (if applicable) to any adjacent transformer bushing and surge arrester mounted on the transformer. Consideration should be given to the rating factors of the transformers when barriers are used.

4.4.5 Extinguishing systems

Automatic extinguishing systems should be considered for all liquid-cooled transformers, except those that are adequately separated in accordance with 4.4.1, 4.4.2, 4.4.3, and 4.4.4, or that qualify as

a) Spare transformers not intended to be used in place, or
b) Transformers containing less than 500 gal (1893 L) of combustible transformer liquid.

4.5 Waterways

When substations are located where an oil spill could contaminate ground water, streams, rivers, or other water systems, special attention should be paid to prevent insulating oil from being released. For Federal Regulations regarding oil spills, see CFR, Title 40, Part 300 [B34]. Also, flaming oil on top of the water could endanger nearby docks or other facilities, although this situation is unlikely except in the case of a large spill.

4.6 Pressure reliefs

The discharge from any oil pressure relief device should be directed away from any nearby equipment to prevent damage from flaming oil.

4.7 Explosion venting

To minimize the structural and mechanical damage from an explosion of indoor oil-filled equipment, such as transformers, circuit breakers, or regulators, explosion relief and venting devices should be installed. Guidance can be found in ANSI/NFPA 68-1994 [B21].

4.8 Supports

Structures supporting disconnect switches, etc., should be kept as low as possible when they are placed near oil-filled equipment to avoid the extreme high temperatures at the upper levels of a fire. Any essential structure or support that may be subjected to an oil fire should be constructed of steel rather than aluminum. Steel can withstand temperatures of 1000 ? F (538 ? C) without structural damage (see 4.2), while aluminumcan only withstand 350 ? F (177 ? C). The placement of any supports directly over a transformer should be avoided.

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4.9 Miscellaneous hazards

Trash storage, decorative fences made of combustible materials, dry grass and weeds, etc., are all fire hazards that should be kept at a sufficient distance from equipment to minimize their possible damage. Vandalism that can result in a fire should be a concern in the substation design and security study.

5. Cable installation practices

5.1 General

Guidance for selection of cable may be found in clause 2.

5.2 Outdoor installations

The most common type of outdoor cable installations found in substations are listed in 5.2.1 through 5.2.4.

5.2.1 Direct burial

Direct burial of cables is a method whereby cables are laid in an excavation in the earth with cables branching off to various pieces of equipment. The excavation is then backfilled. Care should be taken to prevent the accumulation of combustible materials during the period of time when the cables are lying in the trench prior to backfilling.

5.2.2 Tunnels (gallery)

Walk-through cable tunnels may be used where there will be a large number of cables. The cable trays in this system should be separated by a distance sufficient to ensure that a fire in one tray will not propagate to an adjacent tray. If flame-retardant cables are utilized, recommended separation distances are given in IEEE Std 384-1992 [B47] and IEEE Std 525-1992 [B49]. If cables are not flame-retardant or the proper separation cannot be achieved, a fire-resistive barrier or shield can be used between the trays or a fire-retardant coating may be applied to the cables. Fire hazards can also be minimized by utilizing fire breaks. Consideration should also be given to the installation of a fire-detection system, a fixed extinguishing system, locating fire-fighting equipment at the tunnel entrances, and keeping air flows through the tunnels to a minimum.

5.2.3 Permanent trenches

Trench systems consist of main runs that bring large groups of cables through the centers of equipment groups, with smaller trenches, short runs of conduit, or direct burial cable branching off to individual pieces of equipment. These trenches may also feed directly into the control and relay building. The trenches may be made of treated wood, castin-place concrete, large bituminized fiber pipes, or precast materials. Note that fire barriers around cable systems can interfere with cable maintenance work.

The fire barriers should be designed with consideration for future cable maintenance crew operations, inspected periodically, and restored after cable maintenance work is performed. Consideration should be given to the installation of fire stops between the main trench and the smaller branch trenches and where they enter the control and relay buildings or other equipment.

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The use of combustible materials in the construction of these trenches and their covers should be avoided. Consideration should be given to ventilating the trench system to prevent the buildup of combustible gases from either natural or other sources. Trenches should be located in a manner that will prevent any combustible liquids, such as insulating oil, from entering the trench and possibly igniting the cables. Guidance for the installation of cable penetration fire stops can be found in IEEE Std 634-1978 [B50]. All of these considerations would also be applicable to tunnels listed in 5.2.2.

5.2.4 Underground conduit

Conduit systems may be made of various materials, with manholes or pull boxes located at reasonable pulling lengths. These manholes and pull boxes should be located and constructed in a manner to prevent any flammable liquids from entering and possibly igniting the cables. Consideration should be given to the installation of fire stops where the cables enter and leave manholes and pull boxes, and where the cables leave the conduit system.

5.3 Vertical cable runs

Fire stops or fire breaks, should be installed in vertical cable runs since fire will more readily propagate vertically than horizontally. For additional guidance, see FM Data Sheet 5-31 [B42].

6. Fire detection systems

6.1 General

There are many attended and unattended substations in which it may be desirable to have fire and/or smoke detection systems installed. The installation of detection systems should be considered in areas of high cable concentration, transformer installations, etc. Brief descriptions of the most common types of detectors are given in 6.2 through 6.5.

6.2 Heat detectors

Heat detector types include fixed-temperature, rate-compensated, rate-of-rise, and combination fixed-temperature and rate-of-rise, with thermally sensitive elements of the spot-pattern or line-pattern design.

6.2.1 Fixed temperature detectors

The various types of fixed temperature detectors are as follows:

a) Bimetallic strip thermostat
b) Snap-action disk thermostat
c) Thermostatic cable
d) Thermistor line sensors
e) Fusible metal
f) Quartzoid bulb

Neither bimetallic thermostats nor snap-action thermostats are destroyed or permanently damaged by actuation. The fusible metal, quartzoid bulb, and any section of thermostatic cable adversely affected by heat should be replaced following actuation.

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6.2.2 Rate-compensated, rate-of-rise, and combination fixed-temperature rate-of-rise detectors

Rate-compensated detectors are spot detectors that alarm at a predetermined air temperature, but are designed to compensate for thermal lag. Rate-of-rise devices can be set to operate rapidly, are effective across a wide range of ambient temperatures, usually recycle more rapidly, and tolerate slow increases in ambient temperatures without giving an alarm. ***Caution:*** **Rate-of-rise detectors are subject to spurious alarm due to rapid, harmless temperature changes, such as from closing an exterior door of a heated room.** 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 a drop in ambient temperature. The various types of combination fixed temperature and rate-of-rise detectors include the following:

a) Thermopneumatic detector (spot pattern)
b) Thermoelectric detector (spot pattern)
c) Thermopneumatic tube detector (line pattern)

6.3 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.

6.3.1 Photoelectric detectors

Photoelectric detectors are of the spot type or light-scattering type. In each, visible products of combustion partially obscure or reflect a beam between a light source and a photoelectric receiving element. The disruption of the light source is detected by the receiving unit and an alarm actuated.

6.3.2 Combustion products detectors

Ionization detectors and condensation nuclei detectors are spot detectors that alarm at the presence of invisible combustion products. Ionization detectors have proven to be reliable and are the most common type of early warning detectors. They will alarm in the presence of both visible and invisible combustion products. Condensation nuclei detectors operate on the cloud-chamber principle, which allows invisible particles to be detected by optical techniques.

6.3.3 Flame detectors

Flame detectors are spot detectors that are usually used in flammable liquids operations and have limited use in substations. These detectors alarm at the presence of light from flames, usually in the ultraviolet or infra-red 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.

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6.3.4 Air sampling detectors

Air sampling detector systems continuously draw air samples through sampling heads or ports to detect submicron particles generated during the incipient stages of a fire. To detect the presence of these particles, the systems use either the light-scattering or cloud chamber method. Both systems are capable of several levels of preprogrammed alarm thresholds. It is feasible to provide a staged, early-warning regime that responds to increasing levels of concern.

6.3.5 Linear beam smoke detectors

Linear beam smoke detectors consist of a light transmitter and a light receiver that electronically evaluates the received light. If smoke passes through the beam and the received signal falls below a preset value, an alarm is activated. Slow changes to the received signal caused by dust accumulation or other environmental influences are offset by means of a compensating circuit. If the limits of compensation are reached, if the beam is obstructed, or if the housing cover is removed, the receiver initiates a fault signal. These detectors are capable of monitoring over long distances and are ideal for large or narrow rooms, e.g., corridors, store-rooms, and machine halls.

6.4 Application

The selection, placement, and spacing of flame, heat, and smoke detection devices in confined areas should be based on consideration of the design, configuration, and utilization of the area, together with draft conditions due to natural or mechanical ventilation. Guidance for these installations may be found in ANSI/NFPA 72-1993 [B23]. Automatic detection devices should detect smouldering or slowly developing fires.

6.4.1 Cable tray fire detectors

Guidance for the installation of smoke detectors or line type thermal detectors installed in cable trays may be found in ANSI/NFPA 72-1993 [B23].

6.4.2 Combination of detectors

Consideration should be given to combinations of various types of fire detectors to achieve the desired level of protection.

6.5 Fire detection supervision

Fire detection systems should be electrically supervised to comply with the requirements of ANSI/NFPA 70-1993 [B22] and ANSI/NFPA 72-1993 [B23].

7. Fire-extinguishing systems

7.1 General

This clause is to be used as a guide in the selection of fixed-pipe fire-extinguishing systems that may be installed in substations.

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7.2 Water

Water should be used with discretion in areas of electrical equipment. Provision should be made to prevent inadvertent operation of a water-suppression system. When water is used, an adequate drainage system should be provided. Before selecting water for use indoors, it should be determined if the equipment is watertight. Water should not envelop energized bushings or surge arresters by direct impingement unless authorized by the equipment manufacturer.

7.2.1 Carbon dioxide

Carbon dioxide is a noncombustible gas that can penetrate and spread to all parts of a fire eliminating the oxygen. 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 more, whereas the minimum concentration required for fire extinguishment is 30%. When used, consideration should be given to the potentially detrimental corrosion and thermal shock effects of carbon dioxide on electrical/electronic equipment and the danger to personnel. Carbon dioxide is ineffective for outdoor applications because wind can dissipate it rapidly. For personnel safety in enclosed or confined areas, precautions should be taken to provide a manual shut-off valve on the carbon dioxide system to prevent accidental actuation of the system when maintenance is being performed in the area. Supervisory control is available. For additional guidance, see ANSI/NFPA 12-1993 [B6].

7.2.2 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 extinguish the flame. These agents, however, reduce visibility, pose a breathing hazard, and tend to clog ventilating equipment filters. Dry chemicals should not be used where delicate electrical equipment is located, for in such installations the insulation properties of dry chemicals might render the contacts inoperative. If this type of extinguishing agent is used, it could present additional clean-up problems. Also, if used in a fixed system, it should be activated automatically to extinguish the fire before any of the components involved are hot enough to cause re-ignition of the fire. If a re-ignition occurs, the system may not have enough extinguishing agent left to put out the fire. Dry chemical extinguishing agents are all corrosive. The most corrosive of those listed in this subclause is monoammonium phosphate. For additional guidance, see ANSI/NFPA 17-1994 [B13].

7.2.3 Halogenated compounds

A halogenated compound is one that contains elements from the halogen series, which comprises fluorine, chlorine, bromine, and iodine. Halogen atoms form noncombustible gases when they replace the hydrogen atoms in hydrocarbon compounds such as methane (CH4) or ethane (C2H6). Common types are Halon 1211 and Halon 1301. Except for Halon 1301, bromotrifluormethane (CBrF3), most halogenated compounds are corrosive when moisture is present. Also, halon will break down into corrosive and toxic by-products in the presence of a sustained electrical arc.Caution should be exercised to prevent personnel from being exposed to Halon 1301, especially when electrical arcing is present. Halon 1301 is commonly used for total room flooding while Halon 1211 is more often used for localized application. Halon 1211 is a more effective extinguishing agent, but is more toxic because it contains chlorine. For additional guidance, see ANSI/NFPA 12A-1992 [B7] and ANSI/NFPA 12B-1990 [B8]. Halons 1301 and

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1211 are considered to be environmentally damaging CFCs and will not be available in the USA after 1995.

7.2.4 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, medium, 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, fluoroprotein foam, or synthetic foam concentrates. All foams are electrically conductive and should not be used on fires involving exposed energized electrical equipment. The clean-up costs for a site where foam has been used to extinguish a fire could be significant. A foam system should be compared to a water system for protection of outdoor oil-filled equipment when there is an inadequate or insufficient water supply or when oil and water containment is limited. Factors for consideration in selecting the appropriate system include the following:

a) System cost comparison
b) Extinguishing agent supply capacity and quick refill capability
c) Allowable temperature range for storage and shelf life of foam
d) Effect of environmental conditions (wind, temperature, etc.) on the foam blanket and fire-extinguishing performance after release

For additional guidance, see ANSI/NFPA 11-1994 [B3], ANSI/NFPA 11A-1994 [B4], and ANSI/NFPA 11C-1990 [B5].

7.3 Application

The design of fixed fire-extinguishing systems, whether manual or automatic, should include a device to alert the substation operators of a system operation or of any abnormal conditions. Fire-extinguishing systems should be electrically supervised to comply with the requirements of ANSI/NFPA 72-1993 [B23]; electrically run fireextinguishing systems should be supervised as defined in ANSI/NFPA 70-1993 [B22]. In unattended substations utilizing an automatic system, consideration should be given to a system that automatically shuts off when the fire is extinguished or after a predetermined time interval, and then returns to the automatic operational mode.

7.3.1 Testing

The design of a fixed fire-extinguishing system should provide for operational testing. Automatically and electrically operated tripping devices should also have provisions for manual actuation. These devices should be located so they are readily accessible in the event of a fire and should be plainly marked and protected from accidental actuation. For additional guidance in the design and testing of fixed extinguishing systems, see ANSI/NFPA 13-1994 [B9], ANSI/NFPA 15-1990 [B11], and ANSI/NFPA 25-1995 [B17].

7.3.2 Hazards

If the use of water could cause undesirable consequences in the areas selected to be protected, beyond those expected from the fire, fixed automatic fire-extinguishing systems utilizing carbon dioxide, Halon, foam, or dry chemical may be provided. An automatic time-delay release with a predischarge alarm should be provided in areas where personnel must be evacuated before the

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agent is discharged. Consideration should also be given to the installation of a separate emergency disarming circuit for personnel safety. The fire-extinguishing system selected should be designed in accordance with the appropriate NFPA standard.

7.3.3 Ventilation

In areas where forced ventilation would circulate smoke or gaseous extinguishing agents, or both, to other enclosed areas, mechanical ventilation systems should be shut down upon system actuation. Fire dampers should be closed by mechanical or electrical releases on fire protection systems discharge, unless specifically designed as part of a smoke-control system in accordance with ANSI/NFPA 90A-1993 [B25] and SMACNA [B53].

7.3.4 Portable extinguishers

Portable fire extinguishers utilizing water or a water base should not be used on fires involving energized electrical equipment unless specifically class C listed and tested. Additional guidance in locating portable fire extinguishers may be found in ANSI/NFPA 10-1994 [B2].

7.3.5 Hose stations

When installed, hose stations should be equipped with nozzles that are safe for use near energized electrical equipment. Refer to clause 10 for information. Additional guidance in installing standpipe and hose systems may be found in ANSI/NFPA 14-1993 [B10].

8. Substation components

8.1 General

Recommendations for the miscellaneous components used in substations are discussed in 8.2 through 8.12.

8.2 Batteries

The hydrogen gas given off from batteries that are located in confined areas can, at certain concentrations, become an explosion hazard. Therefore, a continuously operating exhaust system should be installed when batteries are located in a room sized to contain only the battery(ies) or are located in a confined space where the buildup and retention of hydrogen gas could reach potentially explosive concentrations. The entrance door(s) to a battery room should have a "No Smoking" or "No Open Flame" warning sign posted on it. Lighting switches should be located outside of the room. All codes should be followed concerning the type of lighting fixtures, wiring, and installation of eye-wash stations. Precautions should also be taken to assure that the acid fumes will not be present in a concentration sufficient to cause damage to nearby relay contacts.

8.3 Surge arresters

Surge arresters should be properly sized and located to minimize the possibility of an equipment fire initiated from surges.

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8.4 Direct-stroke lightning

If needed, direct-stroke lightning protection, e.g., grounded lightning masts, static wires, etc., should be installed so that all equipment and buildings are protected. Guidance in the installation of this protection can be found in ANSI/NFPA 780-1992 [B30].

8.5 Grounding

All equipment in the substation should be properly grounded with correctly sized grounding conductors and proper terminations to dissipate fault currents. This is necessary to prevent failure of the grounding conductor or termination, which could result in more severe equipment damage and an associated fire. Guidance in grounding equipment can be found in IEEE Std 80-1986 [B45].

8.6 Fault-sensing and interrupting devices

The proper relaying or fault-sensing devices in combination with an interrupting device should protect all circuits and equipment. The combination of the devices used should operate and isolate the fault before any further and more serious problems could occur.

8.7 Metal-clad switchgear

Consideration should be given to the installation of a fixed extinguishing system for the protection of metal-clad switchgear that contains oil-filled equipment. Consideration should be given to the installation of smoke detectors on the ceiling of the switchgear room above the switchgear lineups. For guidance, see FM Data Sheet 5-19 [B41].

8.8 Oil-filled reactors

Consideration should be given to the installation of a fixed extinguishing system for the protection of oil-filled reactors. If the reactor(s) is enclosed in a sound-reducing housing, the fixed fire-extinguishing system should be installed both inside and outside the housing.

8.9 Power capacitors

Power capacitor units located outdoors, which contain a combustible dielectric fluid, should be a minimum of 10 ft (3.0 m) from any building not of fire-resistive construction. Capacitor units located indoors, which contain a flammable dielectric fluid, should be separated from adjacent areas by a 1 h fire-rated barrier.

8.10 Diesel or gasoline engines

A substation may contain diesel-, propane-, or gasoline-powered engines for fire pumps or standby electrical power. Installation of these engines should conform to ANSI/NFPA 37-1994 [B19]. Electrical apparatus on engines and generators should be fully spark-protected. For design requirements for propane fuel use, see ANSI/NFPA 58-1995 [B20].

8.11 Fuel-handling systems

Substation fuel-handling systems should conform to ANSI/NFPA 30-1993 [B18]. Buried tanks and piping should be corrosion-protected, and loading points for fuel should be located at the

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perimeter of the substation. Underground tanks should be located in a clearly marked area and should not be subjected to vehicle loads.

8.12 Relay and control panels

Panels should be designed and constructed to meet the recommendations for flame retardance contained in IEEE Std 420-1982 [B48].

8.13 Gas-insulated components

Consideration should be given to the control of SF6 gas and the mitigation of gas by-products that may be generated as either a direct or indirect result of fire. Precautions regarding the harmful effects of SF6 gas and SF6 gas by-products are given in IEEE Std C37.122-1993 [B43] and IEEE Std C37.122.1-1993 [B44].

8.14 High-pressure oil-filled-cable pumping plants

Consideration should be given to the installation of a fixed extinguishing system for the protection of oil-filled-cable pumping plants and storage tanks.

9. Indoor substations

9.1 General

Guidance for fire protection practices that should be used as a guide in designing indoor substations are discussed in 9.2 through 9.6.

9.2 Cable

The cable installed in trays or in troughs under floors could spread a fire from one area or piece of equipment to another. Therefore, the cable used in indoor substations should be resistant to fire propagation. When certain cable constructions are subjected to a fire, chlorine and hydrogen chloride gas is driven off. When combined with water, chlorine forms hydrochloric acid. This acid will attack the contacts of relays, wiring terminations, etc., and this could prolong the substation restoration time. The cables used should be qualified by the flame-test parameters specified in IEEE Std 383-1974 [B46]. Guidance for cable selection may be found in clause 2. If cable splices are utilized they should be made so as not to degrade the quality of the circuit.

9.2.1 Smoke

When cables burn, they can generate smoke, the amount dependent on the cable construction. The density of this smoke could impair the ability to fight the fire. Therefore, consideration should be given to the installation of a low smoke cable. Guidance on smoke emission can be found in ASTM E-84-81a [B33].

9.3 Oil-filled equipment

If possible, the use of oil-filled equipment inside a building should be avoided. When oil-filled equipment is installed in a building, it should be installed in a transformer room or vault as described in 9.3.2. Guidance for protection and vaults for indoor substation equipment is given in ANSI/NFPA 70-1993 [B22]. If practical, and the substation design affords the option of locating the oil-filled equipment in an outdoor (roofless) court, then this option should be followed. If

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these courts must have a roof, then they should have adequate ventilation to the outside. Also, all openings from outdoor courts into the building should be sealed to prevent smoke from entering other portions of the substation or building. It is recommended that the oil-filled equipment be protected with a fixed extinguishing system.

9.3.1 Oil containment

In general, oil-filled equipment should have an oil-containment system. See clause 3 for various examples of oilcontainment installations.

9.3.2 Transformer vaults

All walls and ceilings of transformer vaults should be constructed with a fire rating sufficient to withstand the largest credible fire that could be expected. Since vaults usually contain a removable section for transformer replacement, attention should be paid to the fire rating of the joints. Any ventilation system used in these installations should have automatic dampers to prevent smoke or gaseous extinguishing agents from entering the air system.

9.4 Extinguishing systems

When a fixed extinguishing system utilizes an extinguishing agent that could cause a breathing hazard, it should not be activated until an audible warning is sounded and enough time is given for all personnel to evacuate the building. The system should also have a manual control to stop its operation to allow an operator to manually extinguish a small fire or to allow time for an injured operator to be evacuated. It is also recommended that self-contained breathing apparatus be available for the operator's use. For design guidance, see FM Data Sheet 5-4 [B40] and local restrictions.

9.5 Fire barriers

Indoor substations are usually arranged with little separation between components to minimize buildings costs. Therefore, consideration should be given to the installation of fire barriers between major pieces of equipment. The barriers should have a rating high enough to withstand the largest credible fire they may encounter.

9.6 Construction features

The recommendations that are listed in clause 2 should also be followed in the designs for indoor substations.

10. Fire fighting

10.1 General

This clause gives guidance for fire-fighting practice to be used in fighting substation fires.

10.2 Training

Personnel who routinely perform construction, operation, and maintenance work in substations should be trained in fire fighting. This training should consist of the techniques of fire fighting and a printed fire-fighting procedure should be issued. Also, instructions should be given on the

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alarms, operation, maintenance, and testing of fire-extinguishing systems. Special instructions should be given to fighting a fire near energized equipment.

10.3 Fire departments

The local fire departments should be given tours of the substations in their districts. Equipment functions, voltage levels, PCB levels, hazardous material levels, water availability, methods of reporting fires, entry procedures, etc.,should be discussed during this tour. To prevent confusion in the event of a fire, a specific contact person, such as the power dispatcher, should be designated, and a list of hazardous materials should be posted. If possible, a “dry run”should be conducted to test the effectiveness of the fire-fighting plans.

10.4 Available water

Consideration should be given to the amount of water available for fire fighting from local mains via a stand-pipe or the carrying capacity of the local fire department. If it is determined that this quantity is insufficient, the company should consider installing its own well, storage tanks, or pond. In all cases, local community fire code requirements, if any, should be followed.

10.5 De-energizing equipment

If at all possible, company personnel should de-energize the entire substation or, at a minimum, the equipment involved in the fire, before the local fire department is allowed on the site. This is recommended because of the electrocution danger to the fire fighter by either direct contact with energized equipment or indirectly with the water stream and hose acting as a conductor.

10.6 Energized equipment

If conditions are such that the equipment cannot be de-energized and the fire cannot be extinguished by nonconducting agents, water spray nozzles may be used as a last resort. Tests performed by several utilities substantiate that water spray nozzles can be used safely and effectively on voltages as high as 138 kV, phase-to-phase, with the following restrictions:

a) Only spray-type nozzles are used.
b) The minimum distance from the equipment is at least 10 ft (3.0 m).
c) The fire fighter does not stand in a pool of water.

Table 3 shows the dangers of using the wrong type of nozzle or standing too close to the energized equipment while extinguishing fires. It should be noted that these values will vary with the conductivity of the water, wind, humidity, etc. The resistivity of the water used in these figures varied from 450 ? ·cm to 1000 ? ·cm. Additional guidance on the use and effect of using water from hoses to fight fires is given in the *Fire Protection Handbook* [B39].

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Table 3— Current return through hose stream

	Source voltage (kV)		
	4	13.2	34.5
Distance from source to hose nozzle (ft)	40 30 20 10	40 30 20 10	40 30 20 10
Nozzle size and flow characteristics	Current return to firefighter in milliamperes*		
1-1/8 in nozzle, 80 psi, 250 gal/min solid stream	0 3 7 13	0 14 25 50	1 28 65 96
I in nozzle, 80 psi, 200 gal/min solid stream	0 1 5 11	0 0 21 42	0 18 55 96
2-1/2 in nozzle, 100 psi, 250 gal/min solid stream	0 0 3 7	0 0 13 25	0 0 36 66
2-1/2 in nozzle, 100 psi, 250 gal/min 10° spray	0 0 0 0	0 0 0 0	0 0 0 0 0

*For guidance on the effects of these magnitudes of currents on the human body, see IEEE Std 80-1986 [B45] and EPRI [B35] and [B38]. It should be noted that the maximum current return value should be below the safe let-go value.

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