SAFETY CONSIDERATIONS WITH RAILROAD ELECTRIFICATION:

A PRELIMINARY REVIEW AND ASSESSMENT

DRAFT FINAL REPORT

JUNE 1996

IKE C. TINGOS

U.S. Department of Transportation
Volpe National Transportation Systems Center
55 Broadway, Kendall Square
Cambridge, MA 02142-1093

FRANK L. RAPOSA

F.L. Raposa Services
24 Brewster Lane
Acton, MA 01720-4254

REPORT DOCUMENTATION PAGE

2. Report Date
   June 1996

3. Report Type and Dates Covered
   Final Report
   December 1993 - June 1996

4. Title
   Safety Considerations With Railroad Electrification: A Review and Assessment

5. Funding Numbers

6. Author(s)
   Ike C. Tingos
   Frank L. Raposa*

7. Performing Organization ....
   U.S. Department of Transportation
   Research and Special Programs Administration
   John A. Volpe National Transportation Systems Center
   Kendall Square
   Cambridge, MA 02142-1093

8. Performing Organization Report Number

9. Sponsoring/Monitoring Organization
   U.S. Department of Transportation
   Federal Railroad Administration
   Office of Research and Development
   Washington, DC 20593

10. Sponsoring/Monitoring Agency Report Number

11. Supplementary Notes
    * F.L. Raposa Services
    Under subcontract to Unisys Corporation
    4 Cambridge Center
    Cambridge MA 02142

12a. Distribution/Availability
    This document is available to the public through the

National Technical Information Service, Springfield, VA 22161

12b. Distribution Code

13. Abstract

Electrified high-speed trains are one of the alternative transportation modes being considered for relieving air and ground traffic congestion in the United States. Electrified high-speed rail systems will require substations, wire networks along the right of way, means for power transfer from the wayside to moving trains, control of power to traction motors, and trainline power for train control and passenger comfort loads. Guidelines are required to assure that the construction and operation of electrified rail systems will not jeopardize the safety of the general public, passengers or system employees.

This report presents the results of a preliminary study of safety considerations and an analysis of electrified railroad systems. The analysis was directed at identifying electrically related hazards that are present in such systems and reviewing the means for mitigating these hazards.

The primary hazards of an electrical system are the potentially harmful effects resulting from electric shocks, the fire hazard resulting from electric arcs and the potential injury and equipment damage resulting from electrically caused explosive blasts. A major conclusion reached from this study is that these hazards are currently at acceptable levels for existing electrified operations and such levels should be achievable for new high-speed start up operations. It requires the appropriate use of system and equipment safety standards, and the use of suitable safety rules and safe work practices for the construction, operation and maintenance of the system.

PREFACE

The increase in congestion in air and ground traffic has renewed the interest in alternative transportation modes for intercity travel in the United States. One of the alternative ground transport modes being considered is the use of high speed rail with electrification as the primary method for traction energy. Such electrified systems will require substations for processing electric utility supplied power, wire networks for electric power distribution along the railroad right of way, means for transferring this wayside power to moving trains, propulsion control of onboard traction motors, and trainline power for control and passenger comfort loads.

Guidelines are required for newly emerging or proposed systems to assure that the construction and operation of electrified systems will not jeopardize the safety of the general public, passengers, or system employees. Such guidelines will assist the Federal Railroad Administration (FRA) in assuring that the safety, availability and reliability of the system is consistent with the regulatory mandates of the FRA and the expectations of the riding public.

In support of these goals the FRA Office of Research and Development, in 1993, developed requirements for an assessment of the safety considerations of electrified systems. Support for the development of these requirements was highlighted through safety related workshops held by the Transportation Research Board (TRB). This report was sponsored by the FRA Office of Research and Development. It presents a preliminary review and assessment of some of the safety considerations related to electrification.

The authors wish to acknowledge the support of Gerard Deily of the FRA Office of Research and Development for his guidance and detailed review of this report. The authors also wish to acknowledge the support of Amtrak and the other members of the National Traction Power Committee for making available their electrical safety rules and safe work practices and also for the comments they provided on the September 1995 draft of this report. Acknowledgement is also given to Kevin Kesler and Brian Mee of ENSCO, Inc. for their support to the analysis of safety rules.

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1. INTRODUCTION

The increase in air and auto traffic congestion over the past quarter century has renewed interest in alternative transportation modes for intercity travel. Several railroad corridor studies have considered the potential for the use of electrification as one means for providing an efficient alternative ground transport option. Innovative and new high-speed rail systems, such as those portrayed by the Swedish X-2000 tilt train, the French T.G.V., and the German ICE are among the candidate technologies that have been analyzed in these corridor studies. New systems using these technologies will require substations for processing electric utility supply power, wire networks for power distribution along the right of way, means for transferring this power to a train, power conditioning for the control of traction motors, and trainline power for train control and passenger comfort loads. New motive power equipment for non-electrified rail also make use of similar electrical technologies for propulsion, control and trainline power systems.

Due to the excellent safety record to date of operators of well established electrified rail operations, existing Federal Railroad Administration (FRA) regulations are largely silent in the topic area of electrical safety issues. However, it cannot be assumed that new operations will be always under the jurisdiction of experienced operators of electrified operations.

This report presents the results of a study of safety considerations and analysis of electrified systems. The analysis was directed at identifying and evaluating electrically related hazards that could be present in such systems. As part of this analysis the following activities were performed:

- Development of an electrified railroad system model description
- Definition of electrical hazards and risk reduction strategies
- Preliminary review of potentially relevant federal regulations and related industry standards and practices
- Hazards analysis
- Hazard risk assessment.

Section 2 of this report contains a detailed description of the elements of an electrified railroad. This section provides a discussion of the function of each of the equipment subsystems and how they are integrated into a typical electrified system. The electrification system elements discussed were used as the basis for the hazards analysis and electrical safety standards review.

Section 3 of this report reviews the primary hazards of a railroad electrical system, namely the hazards resulting from electric shocks, arcs and explosive blast effects of malfunctioning electrical equipment. Another hazard discussed is the potentially adverse effect of electromagnetic fields. This section reviews the impacts of electrical hazards on system operation, employees, riders and the general public. The mitigation of electrical hazards through the use of equipment safety standards and safe work practices also is reviewed and discussed. Hazard risk reduction strategies and methods through the use of employee safety rules and safe work practices are thoroughly reviewed as part of the requirements analysis.

Electrical safety standards were reviewed and the results are presented in Section 4. The railroad system description, the hazard definitions, and electrical safety requirements previously developed were used to provide the basis for the regulations and standards review. Numerous federal regulations are reviewed along with the electrically related standards and recommended practices published by several industry standards organizations. The review of regulations, standards and recommended practices was initially done from the equipment perspective discussed in Section 2. The review was then extended to a system perspective with an in-depth examination of the role that regulations and standards provide for safety rules and safe work practices and risk reducing strategies.

In the context of this study, the term "standard" encompasses any published document that either reflects an industry-wide consensus to define such elements as design, performance, measurement, installation, and construction requirements, to describe guidelines and recommended practices related to these elements, or that describes regulations having statutory or other authority. This definition is consistent with U.S. industry groups which prepare standards and with government agencies such as the FRA, FAA, USCG and OSHA which have standards having regulatory authority. The specific terms standard, recommended practice or guideline, and regulation are used in this report where it is felt helpful to better understand the intent of the document being discussed.

A brief hazards analysis was performed and the results are discussed in Section 5. The analysis consisted of preparing a preliminary hazards list (PHL), and then performing a preliminary hazard analysis (PHA) of a selected number of identified hazards. The PHAs performed concentrated on the potential adverse effects to the employees who have to maintain the system, and the naturally occurring hazardous events of lightning and static electricity. Although these hazards are present in railroad systems in general, the need for extensive wiring along the right of way can increase its vulnerability to these hazards and requires that careful consideration be given to the potentially adverse effects of these naturally occuring phenomena. The existence of these hazards and their potentially adverse effects have been long recognized in the electric utility industry. That industry's experience has been carefully reviewed as part of the preliminary hazard analysis.

Section 6, along with Appendices C and E, contains the results of the hazard risk assessment including a discussion of the probability of a hazardous event and its potential severity to electrified railway operations. A brief review is given of the FRA accident/incident reporting system and the annual accident/incident bulletin published by the FRA. The review focused on reported electrically-related accidents and incidents as a means for providing some context of the relative hazard of electrified operations in relation to diesel electric operations. This section concludes with a risk assessment of the lightning strike hazard. Several case examples are presented for various electrification installation scenarios.

The government regulations, industry standards and recommended practices and industry specific safety rules reviewed as part of this study are listed in Appendix A. A database was developed comparing risk reduction methods to industry safety rule requirements, regulations and standards. This database is contained in Appendix B. The quantitative aspects of lightning strikes and static electricity are discussed in Appendices C and D. A detailed comparision of different methodologies for assessing the risk of a lightning strike is given in Appendix E.

The role of the requirements for electrical standards as they relate to both traction power and motive power systems was the subject of recent Transportation Research Board (TRB) workshops on safety related research. The workshop held in April 1991, Workshop on Safety Factors Related to High-Speed Rail and Maglev Passenger Systems, identified the need for research to assess U.S. and foreign electrical safety standards, design codes and practices as they related to high-speed rail and maglev systems (Transportation Research Circular 387, January 1992). The workshop held in October 1993, Workshop on Safety Research Related to High-Speed Rail and Maglev Passenger Systems, discussed the results of the research conducted to date and the plans for more extensive assessments of electrical standards and practices as they related to the construction, operation and maintenance of electrified railroad systems (Transportation Research Circular 432, July 1994). The results of the study reported here was performed as part of the follow up to these ongoing activities.

This report documenting the study results is intended to furnish a basis for dialogue among government and industry entities associated with electrified railroads. It should be considered a "living document" whose contents and conclusions may change in future editions in response to technical dialogue, technological advances, and operational experience.

2. RAILROAD ELECTRIFICATION SYSTEM DESCRIPTION

An electrified railroad makes use of electric energy supplied by a utility. This energy is then transmitted over or on the railroad right of way where electrical traction power equipment can transfer it from the wayside to the train and thus provide propulsion power to the train. A typical electrified railroad system would consist of the following major subsystem elements:

- Substation
- Overhead Contact System
- Power for Signal and Communication Systems
- Vehicle (Locomotive, power car, etc.)
- Railroad Transmission Networks.

Figure 2.1 shows the key equipment components of an electrified railroad. Each major subsystem element has been further defined by the major components that make up the subsystem. These major subsystem components are also listed in the figure. The equipment components that are part of the substation subsystem include transformers, switchgear and disconnect switches, surge protection equipment, and supervisory control equipment to name a few. The overhead contact subsystem would include the catenary, phase breaks, section breaks, and surge protection equipment [1].

The components and equipment contained in each of the lists shown in Figure 2.1 represent the material and equipment items that could be found in each particular subsystem. However, they may or may not be used in every design or electrified system configuration. For example, autotransformers are listed as one of the components that comprise the overhead contact subsystem. In certain electrified configurations autotransformers may not be part of the specific implementation of that system. The specific configuration and layout of an electrified system is a design-based decision based on performance, cost, geographic factors, availability of electric energy and a variety of other factors [2][3]. The major subsystem elements, and their components are described in greater detail in the sections that follow.

The use of third rail dc power for railroad applications, other than urban transit systems, has found limited usage in the U.S. The notable exception to this is the third rail system in use on the Long Island Rail Road. It is unlikely that any future expansion of railroad electrification will include the use of third rail power with the possible exception of urban systems. Third rail systems, because of their proximity to the running rail, require special precautions for the safety of workers and the general public. Therefore, third rail systems have been included in this preliminary review and assessment.

Railroad Transmission Networks

- Support Structure
- Insulators
- Line Conductors
- Surge Arresters

Substation

- Transformers
- Circuit Breakers
- Surge Arresters
- Bus Structures
- Supervisory Control
- Air-Disconnect Switches
- Load Interrupt Switches
- Shunt Reactors
- Capacitors
- Cabling/Wiring
- High Voltage Fuses
- Converters/Inverters
- UPS/Battery Systems
- Grounding Systems
- Bushings/Insulators
- Circuit Reclosers
- High Voltage Switches
- Low Voltage Switchgear
- Control and Relay Protection Systems

Overhead Contact System

- Contact Wire
- Messenger Wire
- Hangers
- Insulators
- Cantilever
- Tension System
- Droppers
- Phase Breaks
- Disconnect Switches
- Cabling/Conductors
- Ground Return Conductors
- Signal Impedance Bonds
- Surge Arresters
- Autotransformers
- Feeder and Static Wires

Vehicle

- Traction Motors
- Pantograph
- Rectifier/Power Conditioner
- On-Board Power (HEP)
- Trainline Distribution
- Braking Resistors
- Circuit Breakers
- Transformers
- Motor Control
- Lightning Arresters
- Batteries
- Interlocks
- Inverters

Power for Signal and Communication Systems

- Signal Power Supply Circuits
- Shielding of Power Supply Circuits
- Grounding System
- Impedance Bonds

Figure 2.1 Overhead Contact Railroad Electrification System

2.1 SUBSTATION

The railroad traction substation is comprised of equipment that enables power to be transformed from one voltage level to another or from one system to another.

The equipment found in a typical substation would include:

- Transformers
- Switchgear
- Surge Arresters
- Bushings and Insulators
- Supervisory Control
- Converters/Inverters
- Filters.

2.1.1 Traction Transformers

Traction transformers are used to step down the utility supplied high voltage power to a voltage level which is more suitable for railroad traction applications. For railway systems that make use of either railroad owned or utility owned subtransmission, the substation transforms the subtransmission voltage level to the traction voltage level.

2.1.2 Switchgear

Switchgear is an assembly of devices which switch and interrupt the flow of power. Often, in the routine operation and maintenance of a power distribution network, isolation and deenergization of portions of the network is required. Switchgear also provides protection to the electrical system from harmful overloads and short circuits. This equipment performs these functions under varying conditions. Switchgear equipment may include circuit breakers, air-disconnect switches, circuit reclosers, load interrupt switches, control and relay protection systems, and the necessary interlocks.

It is important to note that these interrupting devices may also be found apart from switchgear assemblies and may be located throughout the substation as individual equipment items. The performance and design specifications of the switchgear and the transformers used at the electric utility interface need to be preapproved by the utility company supplying the electric power.

2.1.3 Surge Arresters

Surge arrestors are used to limit the rise of either voltage or current from overvoltage sources to a predetermined value. Typical sources of overvoltage include:

- lightning strokes
- power frequency switching
- power system resonance.

2.1.3 Bushings and Insulators

Bushings and insulators are the insulating components which are used to electrically isolate energized equipment from other circuits and support structures.

2.1.4 Supervisory Control

Supervisory control is used to monitor traction power system status and to control the substation and other electrical equipment, usually from a remote location. This supervisory control arrangement allows personnel at a control center to direct, limit, reconfigure, sectionalize, and to shut down, if necessary, the flow of power throughout an electrified railroad.

2.1.5 Converters and Inverters

Electric utility power is typically distributed at 60 Hz. If the railroad system is designed to operate at a different frequency, converters and inverters are often used. Through the use of a converter/inverter, the utility supplied power is converted from the commercial 60 Hz frequency to the frequency used for traction. Converters are also used for ac to dc power conversion for those railways which use dc power for traction.

2.1.6 Filters

Filters are often used to reduce the harmonic currents and/or improve the power factor of the traction system load. Harmonic power filters are usually composed of reactors and capacitors. Power factor correction is usually achieved through the use of similar filters. Further, automatic capacitor switching for improved voltage regulation may also be another function of filters.

When utility companies provide power to large users of electricity there is often a concern about the impact that the connected load will have on the rest of the utility transmission system and its connected loads. Utility companies will wish to review the effects of voltage fluctuations, harmonics, single phase unbalance and negative sequence currents. The railroad traction system may introduce undesirable harmonics back into the utility system. Industry standards exist for the control of these effects and these standards may be a requirement of the electric utility. The utility may wish to restrict or penalize the railroad through higher electricity costs if these effects are not mitigated.

2.2 OVERHEAD CONTACT SYSTEM (OCS)

The OCS takes the energy supplied from each traction substation and distributes that energy to the catenary as well as other equipment located along the railroad right-of-way. Factors which influence the design of the OCS system include:

- climate
- vehicle design
- operating speed of the vehicle
- electrical loads and conditions
- structural limitations.

The OCS must be arranged so that feeding and sectionalizing of electric power can be accomplished in a coordinated fashion. The OCS must be designed so that faults can be effectively detected and those faulty sections can be optimally isolated.

The OCS can be grouped into three subsystems:

- catenary
- power feed
- support structures.

For those systems which make use of third rail power the catenary is replaced by the third rail.

2.2.1 Catenary

The catenary is made up of contact wire, messenger and auxiliary wires, hangers, insulators, phase breaks, and the tensioning system.

The contact wire of the OCS must perform its function of transferring power from the fixed distribution system to the moving vehicle under some harsh physical and electrical conditions. In most OCS designs, the contact wire must be maintained at a relatively high tension in order to insure smooth tracking of the vehicle mounted pantograph [1]. The contact wire is typically made of copper or a copper alloy. The messenger wire and auxiliary wire where used, suspends the contact wire by means of droppers/hangers.

Insulators are used to attach the tensioning system and other energized components to the support structures. Insulators physically attach as well as electrically isolate the energized conductors from the support structures.

A phase break is an insulated section of the catenary. Its function is to isolate the different phases connected to the power feed. To maintain a balanced load as seen by the utility grid, different sections of the OCS are fed from different electrical phases; for example, phase A-C might feed one catenary section and phase C-B might feed the adjacent catenary section. The phase break maintains mechanical continuity for the pantograph along the catenary and enables the required electrical isolation between adjacent phases to be maintained. Section breaks function similar to phase breaks and enable isolation of catenary segments within a catenary section.

2.2.2 Power Feed

The power feed connects the output of the traction substation to the catenary. The power feed is run along the right-of-way as part of the OCS and is periodically connected to the catenary. For electrified systems that operate with a feed-to-catenary voltage greater than the catenary-to-rail voltage, the power feed is periodically connected to autotransformers which change the power feed voltage level to the desired catenary-to-rail voltage.

2.2.3 Support Structures

The support structures for the OCS can consist of cantilever poles, portal towers and headspans. The actual construction used is specific to a given installation. The structures used depend on such factors as the OCS configuration, the number of parallel tracks that the OCS must span, and the possible joint usage of the structure with other railway systems.

2.3 POWER FOR SIGNAL AND COMMUNICATION SYSTEMS

Signaling and communication (S&C) systems are an integral part of railroad operations. These systems must provide safe, reliable, and economical train movement and train protection. The following discussion is limited to the source of power and related equipment for S&C systems.

2.3.1 Signal Power

Power is required by signal and communication system components at many locations along the right-of-way. Power must be supplied for various S&C equipment including:

- hot box detectors
- dragging equipment detectors
- telephone carrier repeaters
- snow melters at turnouts
- track signal circuits.

It is a common electric traction procedure to insure that the frequency of the signal power system is different from the traction power frequency. This is required to avoid interference from any harmonics of the traction power system.

2.3.2 Shielding of Power Supply Circuits

It is imperative that the integrity of the signaling and communications systems be maintained in the EMI environment created by the electrification system. The electrical and physical configuration of the OCS power system directly influences the magnitude of electrostatic and inductive fields and the level of radiated and conducted interference.

Shielding of signal power supply circuits and communication circuits is usually required. A barrier of attenuating material can be used to reduce any radiated interference associated with the OCS power system. Filters typically are used as part of S&C systems to suppress any conducted interference present in the OCS power system. Adequate system grounding is also required to prevent abnormal ground potential rise (GPR). A GPR might occur from an electrical ground fault condition which could then result in coupling unwanted signals into S&C systems [4].

2.3.3 Impedance Bonds

The railroad power distribution and the locomotive traction system introduce other problems to the wayside signal and control systems. The running rails are typically used as the return path for the traction current. But the rails are also used by the train control circuits for block protection. For both systems to function correctly together, impedance bonds must be utilized. An impedance bond is an iron-core coil of low resistance and relatively high reactance to provide a continuous path for the return of power frequency traction current around insulated rail joints. It confines the higher frequency alternating current energy of the train/block control system to its own track circuit. Most types of track signaling circuits require the track to be electrically divided into sections by the use of insulated joints. This, in turn, dictates the use of impedance bonds for continuous traction current return.

2.4 RAILROAD MOTIVE POWER VEHICLE

Railroad motive power vehicles include locomotives and self-powered cars of the type used in multiple unit (MU) configurations.

2.4.1 Pantograph

Electric energy is transferred from the overhead contact system to the locomotive or power car through the pantograph, which is located on the roof of the railway vehicle. The pantograph is designed to rub the energized contact wire, thereby providing an electrical path for power transfer from the catenary to the vehicle. For reliable train operation, the loss of contact between the pantograph and the contact wire must be minimized.

Depending on the train consist configuration, as well as the dynamic performance at the catenary-to-pantograph interface, a train consist may use single or multiple pantographs. As a consequence, the power collected by the pantograph may or may not be trainlined. Trainlined catenary voltage level power requires insulated high voltage cable mounted along the top of the cars in the consist. Lightning arrestors are usually connected at the pantograph to provide surge protection against lightning strokes to the catenary which may cause damage to the train consist.

2.4.2 Locomotive and Power Car Propulsion

Electric locomotives and power cars operating with an ac voltage input at the catenary voltage level generally require an input transformer. The transformer converts the catenary-supplied voltage to voltage levels which are more compatible with the traction motors and their associated power control equipment. The secondary of the transformer is connected to the power control equipment. This equipment is sometimes referred to as a power conditioning unit (PCU). The PCU controls the voltage and current to the traction motors to control tractive effort, speed, and braking. Railway vehicles operating with a dc input have a dc converter PCU in place of the input transformer to provide the necessary traction control.

The traction motors may either be dc or ac machines [5]. Further, for the case of ac machines, they could either be asynchronous (induction) or synchronous machines. For the case of the dc traction motor, the PCU typically consists of an ac to dc converter. For the case of the ac traction motor, a converter-inverter PCU is typically used to produce the variable-frequency voltage and current required for traction motor control. Both types of PCUs use some combination of rectifiers, thyristors, gate turn-off switches, and transistors as the main power control components.

Non-electric locomotives, such as diesel electric units, are typically configured with a traction generator or alternator connected to the output of the diesel engine. The PCU for this type of locomotive uses the electrical output of the generator or alternator for control of tractive effort and speed. The PCU equipment and traction motors may be configured with components that are similar to those used on the all-electric locomotive.

2.4.3 Braking System

Electric braking is used on almost all locomotives and power cars. The electric braking system can consist of some combination of regenerative and dynamic braking, which would be used along with friction brakes. In the case of regenerative braking the wayside electrical system must be capable of receiving, or must be receptive to, the regenerated electrical energy. If the wayside electrical system is not receptive to the regenerated electrical energy, the energy is diverted to the dynamic braking resistors. Dynamic brakes typically consist of vehicle mounted resistor grids which dissipate the braking energy as heat.

2.4.4 Control and Auxiliary Equipment

Other electrical equipment used on locomotives and power cars consist of disconnect switches, circuit breakers and related switchgear, power panels and other control and protection equipment. Auxiliary generators, transformers and motors are used for powering onboard auxiliary equipment loads.

The on-board power control equipment circuits are the sources of power harmonics as well as sources of electromagnetic interference (EMI). There are usually design features with these circuits which are intended to minimize the amount of interference injected back into the electric system and environment as either conducted or radiated interference. In addition, secondary filters may also be used to control the amount of power harmonics that exist at the pantograph-to-catenary interface.

Power factor correction is also typically used as a means for improving overall system performance. The power factor correction equipment may consist of additional filters and switchgear.

2.4.5 Passenger Cars

Passenger car equipment requires electric power for heat, air conditioning, and other passenger service amenities. Such power is typically obtained from a head end power (HEP) source located in the locomotive or power car. HEP may be produced by an auxiliary generator, or static inverter PCU in the case of a non-electric locomotive, or by the use of an auxiliary winding on the input transformer in the case of an all-electric locomotive. HEP is trainlined from the locomotive to the passenger cars typically as 480 V 3ϕ power through connecting cables from locomotive-to-car and from car-to-car along the train. Local power panels on each car distribute the power to the individual car loads.

2.5 RAILROAD TRANSMISSION NETWORKS

Railroad transmission networks are required to deliver power from substations near generating facilities to those substations located along the right of way. This power is transmitted at high voltages, typically 115 or 138 kV.

Transmission networks are comprised of:

- Support structures
- Insulators
- Conductors
- Surge arresters.

2.5.1 Support Structures

Steel towers are often used as support structures to carry the mechanical load of the transmission network. These towers often are designed and constructed to also support the mechanical loads associated with the signal power distribution system and in some cases the overhead contact system. For some installations, the transmission system support structure is an extension of the catenary support structure.

2.5.2 Insulators

Insulators are required to electrically isolate the high voltage energized conductor from the steel towers. Because of the electrical clearance required for high voltages, the insulators are longer in length than those encountered in the overhead contact system.

2.5.3 Conductors

The conductors used for high voltage transmission lines are often aluminum cable steel reinforced (ACSR). An ACSR cable is an aluminum conductor wrapped around a steel cable. The cross sectional area of the aluminum is sufficient to carry the required power, but the mechanical strength of the aluminum is not adequate for the stringing of the conductor across large spans. Therefore, steel in used to add mechanical strength to the cable. Other cable types could be used depending upon the expected electrical loads and the required span lengths.

2.5.4 Surge Arresters

Surge arresters, along with ground wires are used to to protect the railroad transmission network from lightning induced surges.

2.6 REFERENCES

1. American Railway Engineering Association, "Electrical Energy Utilization," Manual for Railway Engineering, Chapter 33, Chicago, IL, 1987.

2. Knesche, T., Electric Traction Power Supply Configurations on 10,000 Route Miles of U.S. Railroads, FRA/ORD/82-50. Electrak Inc., June, 1982.

3. Canadian Standards Association (CSA). Railway Electrification Guidelines, C22.3 No. 8-91, July, 1991.

4. Institute of Electrical and Electronics Engineers, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault, Std 367-1987, New York, NY, 1987.

5. Peters, J. and Anderson, G., Three-Phase Asynchronous A.C. Traction Motor Systems, Technology Assessment-Phase I, Design Evaluation and Equipment Description, Report R-778, Association of American Railroads, Chicago, IL, May 1991.

3. ELECTRICAL HAZARDS AND RISK REDUCTION STRATEGIES

The presence of electric power on railroads introduces the potential for certain hazards. The energy needed for propulsion of electric locomotives is significant. The energy consumed by the wayside signal system and trainline power is also substantial, and therefore should be considered. Typical voltages and frequencies of electric power currently in use are shown in Table 3.1.

TABLE 3.1 ELECTRIC POWER USAGE IN RAILROADS

Type	Voltage (V)	Usage
60 Hz	230,000	Transmission
60 Hz	138,000	Transmission
25 Hz	138,000	Transmission
25 Hz	110,000	Transmission
60 Hz	34,500	Distribution
25 Hz	12,000	Catenary
100 Hz	12,000	Signal Power
60 Hz	50,000	Catenary
60 Hz	25,000	Catenary
60 Hz	12,500	Catenary
100 Hz	6,900	Signal Power
100 Hz	4,400	Signal Power
100 Hz	3,300	Signal Power
100 Hz	2,400	Signal Power
25 Hz	2,400	Signal Power
100 Hz	2,300	Signal Power
DC	1,500	Catenary
DC	1,000	Third Rail
DC	750	Third Rail
DC	600	Third Rail
DC	600	Trainline
60 Hz	480	Wayside
60 Hz	480	Trainline
100 Hz	440	Signal Power
DC	74	Onboard Control
DC	32	Onboard Control

The transmission and distribution lines found on or near a railroad right-of-way may be railroad owned or may be utility owned and on the right-of-way by a lease agreement. The ranges of catenary voltage and frequency shown are currently as built systems and those that are planned. It is important to note that even the lowest voltages present in an electrified railroad environment are potentially dangerous as electric shock hazards.

3.1 ELECTRICAL HAZARDS

Electrical hazards can be classified into four general categories [1]. The categories are:

- shock hazards
- arcing hazards
- blast hazards
- electromagnetic field hazards.

3.1.1 Shock Hazard

An electrical shock is the adverse physical stimulation that occurs when current passes through parts of the body. The factors which influence the effects of the shock are:

- magnitude of the current flow
- body parts through which the current flows
- physical condition of the person being shocked.

The greater the flow of current through the body, typically the more severe the injury is that results from the shock. Also, current flow through the torso is extremely hazardous because it can cause organ failure (heart, lung, etc.). It can also cause internal burns in the body which may be beyond repair. Electrical shock can cause instantaneous death or, in the case of burn damage, it can lead to disabling injury and to possible death. The overall physical condition of the person involved also influences the effects of the shock. Typically, the better physical condition an individual is in the less severe the effects the shock will have on that person.

3.1.2 Arcing Hazard

An electric arc occurs when the voltage potential between two conductors is great enough to cause the breakdown of the dielectric capability of the material which occupies the space between conductors. In the case of air, this results in electric current flow through the plasma region which was previously occupied by air. The heat associated with this arc can reach as high as 50,000°K [1].

The factors which affect the severity of damage and injuries from electric arcs are:

- distance from the arc
- heat absorption coefficient of the material involved
- temperature of the arc
- time duration of the arc.

The farther a person or equipment is from the arc, the less severe the injury or damage will be from the arc. Similarly, the lower the temperature is of the arc, the less severe the injury or damage. The longer the time exposure is to the arc, the more severe the resulting injury or damage. Burns resulting from arcs are thermal in nature. They can therefore be grouped by the following definition of burns (per Cadick in reference [1]):

- First degree burns - outer layer burn, little permanent damage, no scarring after healing process

- Second degree burns - severe tissue damage and blistering, entire outer skin layer destroyed

- Third degree burns - complete destruction of the growth centers, where skin grafting would be required.

3.1.3 Blast (Explosion) Hazard

Electric arcs in air superheat the air instantaneously which in turn causes a rapid expansion of the air with a wavefront that can reach high pressures. Such pressure can cause electrical equipment to explode which not only damages the equipment involved but also results in debris becoming projectiles which in turn could cause additional injury. Arcs and blasts may appear to be related, but it is important to note that an arc is not always accompanied by a blast.

Electrical equipment which is enclosed in a shell or vessel can explode under certain overload conditions. For example, when a switching device is called upon to interrupt a current in excess of its maximum capacity, then an unsafe system failure may occur. In the case of an oil circuit breaker enclosed in a vessel, the arc resulting from the interruption process will quickly heat the entire circuit breaker assembly. This heating may cause extreme pressure buildup in the containment vessel resulting in the rupture of the vessel [2].

3.1.4 Electromagnetic Field (EMF) Hazard

Electromagnetic fields (EMF) are present any time there is the presence of voltage and electrical charge. Voltages and electrostatic charges create electric fields while moving electric charges (current) create magnetic fields. The type of electromagnetic fields produced by an electrification system are predominantly in the audio and radio frequency range [3]. At power frequencies and their harmonics (extreme low frequency range), the magnetic and electric fields associated with power lines and other equipment can be treated separately (quasistatically), though RF transients do occur due to power system switching.

The potential hazards of electromagnetic fields can be grouped into three categories:

- Electromagnetic field exposure or health-related effects
- Electromagnetic interference (EMI) to other systems and equipment
- Electromagnetic compatibility (EMC) between electrical and electronic systems.

Whether there is any influence of electromagnetic fields on the health of humans is still uncertain. Research continues on this topic. Positive effects have been noted (for specific field polarity and waveform), such as promoting bone growth after fractures, but they require higher field intensities than environmental EMF. Recent epidemiological studies have indicated a possible link between exposure to EMF in the power frequency range and certain adverse health effects. Laboratory studies, however, have not been able to confirm a biological mechanism for these weak EMF effects. Numerous organizations have done and continue to do research on the subject of EMF exposure effects on humans and have published reports on the results of their EMF studies [4][5].

The IEEE as well as other industry and governmental groups have developed interim standards and guidelines restricting certain frequency EMF levels for occupational and public exposures. Additonal references are listed in Section 8 which provide further information relating to the health-related concerns of EMF. To further qualify and/or quantify any potential EMF-related health hazards is beyond the scope of this study.

The interference effects associated with electromagnetic fields also present hazards which must be considered [6]. The traction power system, as well as other motive power equipment, typically impose non-sinusoidal currents into the electrified railway system. These non-sinusoidal currents produce varying levels of electrical noise into the environment [7][8]. An additional source of electrical noise is the result of the normal switching operations that occur in any electrical system. The electrical noise that is introduced might adversely affect the operation of the railroad signal and communication systems and other electrical systems and equipment located on or near the railroad right of way (ROW).

3.2 IMPACT OF ELECTRICAL HAZARDS ON SYSTEM OPERATION

Blast and arc are the major hazards with potential adverse impacts on the operation of electric systems. To a lesser extent, but as equally important, electromagnetic field hazards can also adversely impact system operation. The result of a blast event can disable and damage or destroy equipment. The energy generated from an arcing event can melt conductors, fuse the contacts of circuit breakers together, and/or cause other equipment damage. The consequence of such failures can lead to a situation of either uncontrolled current flow or lack of ability of protection equipment to interrupt current flow. Electromagnetic interference can result in equipment malfunction. The occurrence of any of these hazardous events can lead to situations varying from subsystems failing to system shutdown. Any failure must not result in an unsafe condition. If failures are deemed to be safety critical, they must either be avoided or be mitigated by other measures.

Functional and possibly even catastrophic failure from the above hazards are primarily the result of equipment operating outside of its design limits. Failures can happen from improper application of equipment components at the time of design and construction, incorrect installation, improper system operation, maintenance errors, and from power surges resulting in electrical overstress conditions beyond those envisioned in the original system specifications. Electrical overstresses can result from power frequency switching surges from load and power system switching, from resonance conditions caused by power harmonics in the system, and from overvoltage surges resulting from lightning strokes, or discharges, either on or nearby the system.

The magnitude of EMI/EMC effects and the need for mitigation must always be considered in a system where electrical and electronic devices perform safety critical functions. The electrical transients and noise generated by the traction power system and motive power equipment also can induce voltages into electronically controlled equipment. These induced voltages can introduce errors into the communication, signalling, and control systems of which these electronic devices are a part. Extensive and pre-operational testing is needed to prevent and mitigate adverse safety impacts of EMI/EMC effects.

3.3 IMPACT OF ELECTRICAL HAZARDS ON EMPLOYEES

The shock, arc and blast hazards can affect employees. The impact of these hazards usually are severe injury and sometimes death to the employee.

During events when high surge currents flow, shocks can occur from direct contact with energized equipment or with nearby structures. Fault currents flowing to ground could introduce high levels of voltage on grounded structures. These abnormal voltages are commonly referred to as step and touch potentials which, when they occur, can become serious shock hazards [9].

As discussed above, the heat associated with the arc can cause burns and lead to other unsafe activities or movements (fall from a ladder, inadvertent contact with exposed energized equipment and conductors, etc). The pressure buildup associated with the blast can cause a wavefront which can knock equipment, people, and other objects over. This blast may also send pieces of metal flying at high velocities as shrapnel.

If an employee is in the area or proximity of the arc or blast that employee could be exposed to the hazard. Places where the exposure is likely to be high include:

- switching substations
- ROW (third rail, catenary, power feed, signal and communication systems)
- power generation stations
- power cabinets onboard locomotives
- traction substations.

3.4 IMPACT OF ELECTRICAL HAZARDS TO THE GENERAL PUBLIC

The primary hazard of an electrified railroad system for the general public is electrical shock. If a ground fault occurs in the system and an effective grounding system is not in use, particularly as it pertains to passenger platforms, any person near the fault could receive an electrical shock from the presence of either an excessive step or touch potential. The magnitude of the step or touch potential associated with ground faults is directly proportional to the magnitude of the fault current. An additional shock hazard exists because of the exposure of the platform to the catenary or third rail.

The general public may also be affected by EMI. Electronic devices, such as heart pacemakers, may be susceptible to electromagnetic interference generated by an electrified railroad.

Voltages induced in microelectronic circuits could cause a device, such as a pacemaker, to function improperly while under exposure to the electromagnetic fields resulting from electrification.

3.5 MITIGATION OF ELECTRICAL HAZARDS AND IMPLEMENTATION OF SAFE WORK PRACTICES

Electrical safety standards have been in existence for many years and historically have resulted from consensus type activities of interested industry and professional groups. The development of safety standards continues as an ongoing activity. These standards have generally provided minimum performance requirements and guidance through recommended practices for the design, construction, maintenance and operation of electrical systems. These standards also have guided the development of safety rules and safe work practices for those personnel who work on such systems.

Figure 3.1 shows a typical hazard control model. This model illustrates the use of standards in the design of electrical systems and in the development of safety rules and safe work practices. As seen in Figure 3.1, the electrical hazards associated with electrical systems can be controlled or removed from the system through the design process, and through the development of safety rules and safe work practices.

Numerous standards organizations have issued system design standards and recommended practices for electrical systems. The development of safety rules and safe work practices have been influenced by a variety of organizations, including standards organizations, system constructors, and system operators. Specific attributes of a system and the environment in which it must operate in may have many unique qualities. These unique characteristics, therefore, require that each individual operator evaluate the operation of its own system and develop the needed safety rules and safe work practices that appropriately mitigate system hazards.

The goal of these rules and work practices is to assure safety during system operation and maintenance. In this context, safety includes:

- safety of individual workers and passengers
- safety of groups of workers
- prevention of damage to critical system components.

Electrified railroads have developed sets of safety rules and operating procedures from years of experience that serve to reduce the risks of the installation, operation and maintenance of an electrified railway to passengers, employees, as well as to ensure the integrity of the equipment that makes up the system. Damage to system components may increase the risk of injury to workers and passengers and must therefore be part of any assessment of safety rules and safe work practices.

Safety rules and work practices serve as the foundation for safe system operation and maintenance. Operation and maintenance procedures build upon the general or system-wide safety rules to incorporate requirements introduced by equipment design, system architecture, and operational needs.

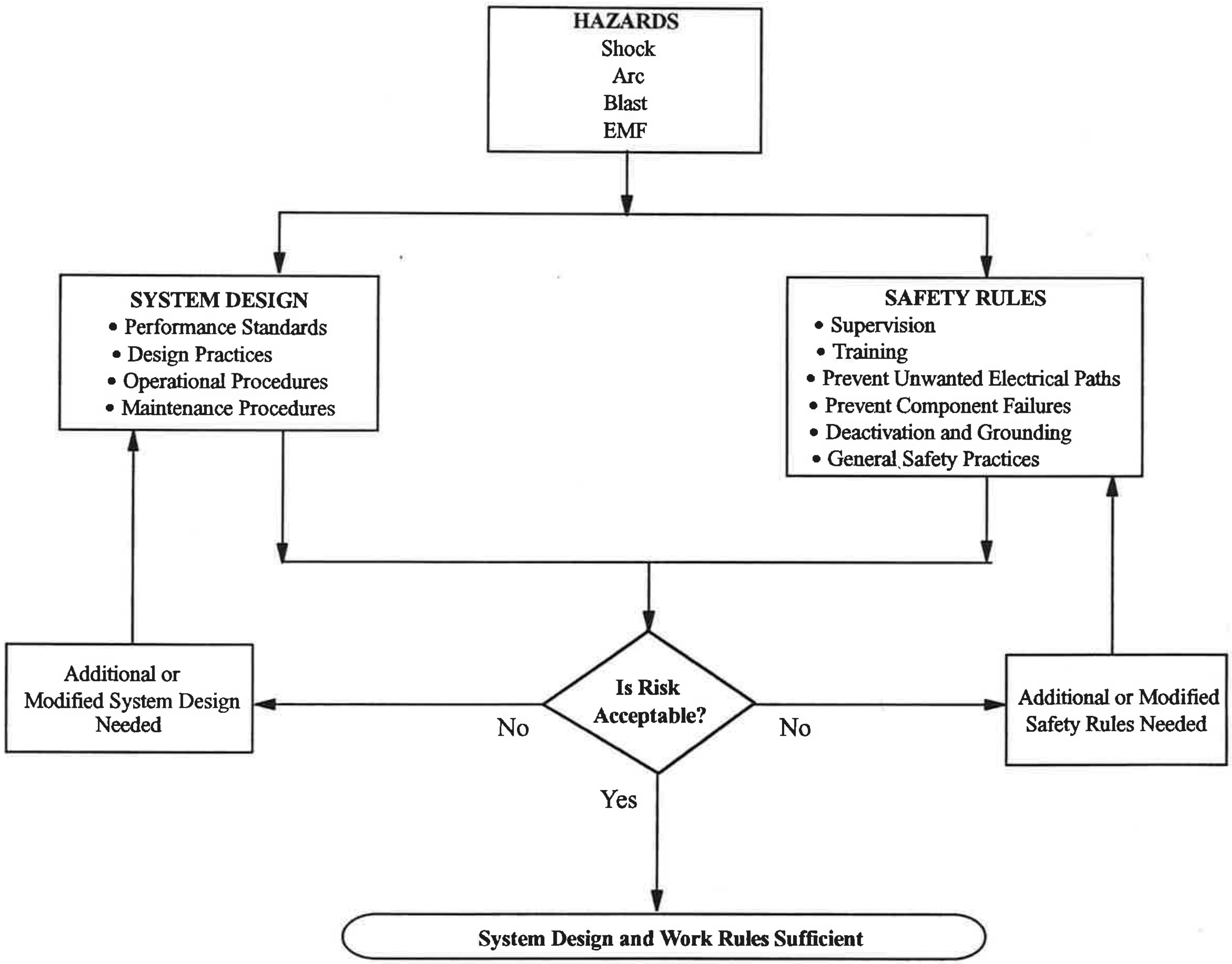

Figure 3.1 Hazard Control Model

3.6 RELATIONSHIP OF SAFETY RULES TO MAINTENANCE AND OPERATING PROCEDURES FOR RAILROADS

Electrical safety rules are the safety procedures and safety work practices for railroad employees who work on, near, or with electric circuits and equipment [10]. They provide one of the foundations for the development of operating and maintenance procedures. Operating procedures deal with specific requirements related to types of railroad equipment or specific locations or configurations encountered on the railroad. Maintenance procedures deal with the specific procedures and techniques required to safely inspect, repair and maintain the equipment components of the railroad. Safety rules, operating procedures, and maintenance procedures along with proper system design assure acceptable safety levels for passengers and employees.

Figure 3.2 depicts the relationship between maintenance and operating procedures and safety rules.

OPERATING PROCEDURES	**MAINTENANCE PROCEDURES**
Based on:	Based on:
Operational Requirements	Equipment Design
System Design and Architecture	Operating Environment
Maintenance Requirements	Railroad Experience
SAFETY RULES	
Based on:	
Safety Related Work Practices and Procedures	

Figure 3.2 - Relationship of Safety Rules to Maintenance and Operating Procedures

3.7 RISK REDUCTION STRATEGIES

One approach in the development of safety rules and work practices is to use risk reduction. Risk reduction is a process used to eliminate or control critical hazards. A critical hazard can become catastrophic and its occurrence determined to be unacceptable [11]. Risk management and risk reduction normally occurs during the design stage of a system, but can be implemented at any time in the system's life cycle.

As applied to electrical systems, risk reduction strategies are the methods, procedures and processes to reduce the hazards of being near or working on or with electrical circuits and equipment. Several strategies may be used to reduce the risks associated with the operation and maintenance of electrified railroads.

These strategies can be grouped into six basic areas as shown in Figure 3.3. The six risk reduction strategies depicted are:

- Preventing Unwanted Electrical Paths
- Deactivation, Grounding, and Bonding
- General Safety Practices
- Preventing Component Failure
- Training
- Supervision and Responsibility.

These six strategies individually and collectively contribute to the success of a system safety program plan. Each of the risk reduction strategies shown in Figure 3.3 can be further divided into more specific methods. Risk reduction strategies may be found in safety rules, maintenance procedures, operational procedures, or in system design standards. The likely areas in which each specific method is used are noted below.

To facilitate an analysis of safety rules, each of the specific risk reduction methods discussed above can be assigned a code consisting of a letter and a number. The letters associated with these risk reduction strategies are:

P Preventing Unwanted Electrical Paths
D Deactivation, Grounding, and Bonding
G General Safety Practices
C Preventing Component Failure
T Training
S Supervision and Responsibility.

Within each grouping, a number can be assigned to indicate which detailed individual method is being referenced. In some cases there may be overlap between methods. These detailed methods and their associated codes are discussed in detail below.

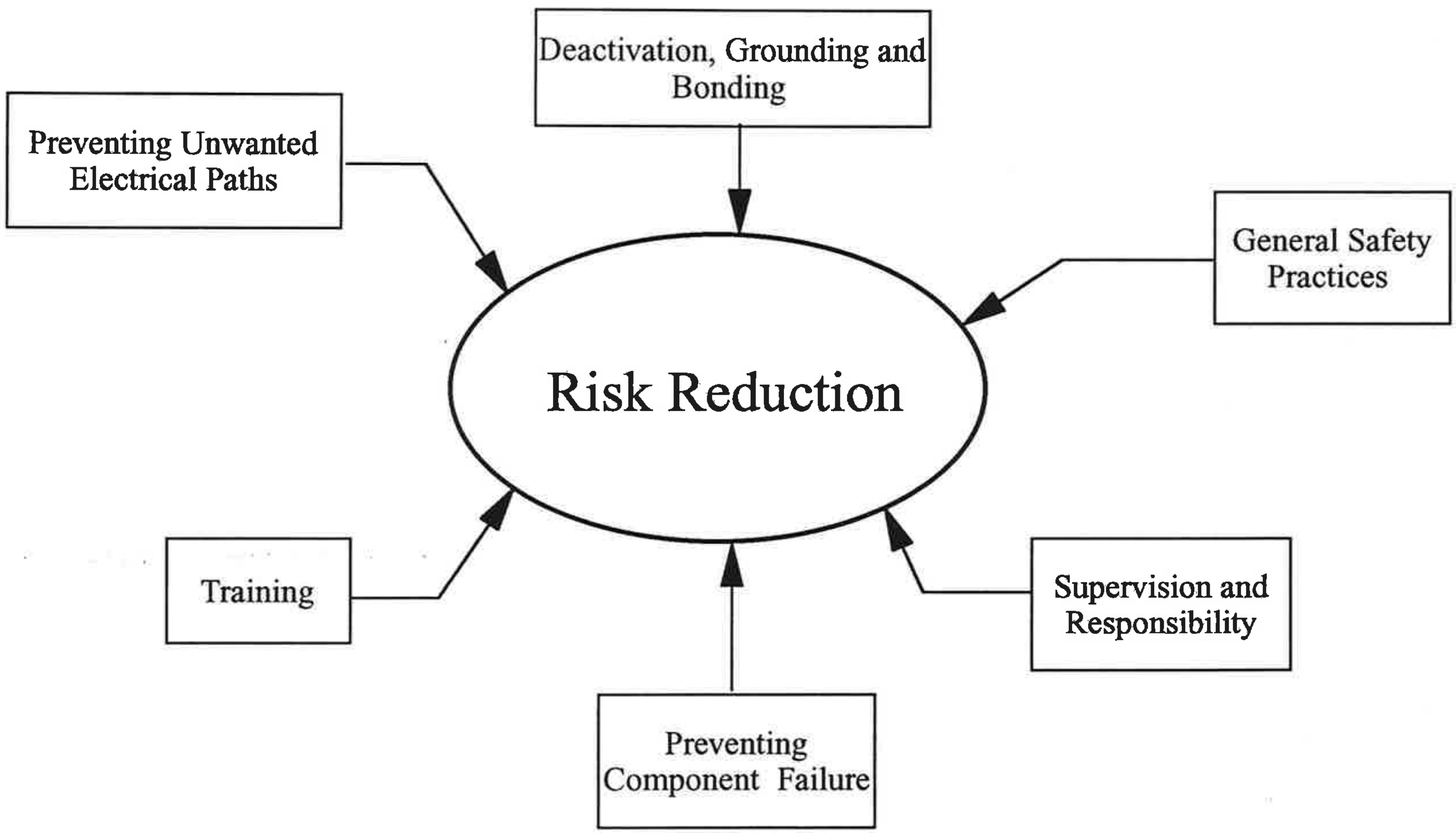

Figure 3.3 Risk Reduction Strategies

3.7.1 P - Preventing Unwanted Electrical Paths

This risk reduction strategy assures that the public, railroad workers and their tools do not accidentally form a path for electric current to flow. This unexpected current can cause injury or death to humans and damage to equipment. This strategy is used during both normal operation and during maintenance. The detailed methods of preventing unwanted electrical paths considered in the analysis include:

- P1 Insulation
- P2 Barricades and Barriers
- P3 Maintaining proper distance from energized conductors
- P4 Proper tools and equipment
- P5 Preventing personnel from tripping or falling into energized conductors
- P6 Preventing unintended contact with energized conductors
- P7 Preventing falling wires or tools contacting energized conductors.

All of the above methods provide the means to prevent unwanted electrical paths by isolation of the conductor.

Insulation requirements (P1) are normally found in equipment and system standards, although a guide for testing insulation properties may be contained in certain maintenance procedures. The use of barricades or barriers (P2) to prevent unauthorized access and isolation is normally prescribed in a safety rule or maintenance procedure.

Safety rules usually specify the minimum distances that employees are required to maintain between themselves and live conductors and exposed engergized equipment (P3). Industry standards and recommended practices typically delineate the proper distance required between conductors and personnel and between conductors and other electrical components. This distance is typically a function of voltage and is set primarily as a means of preventing voltage flashover. Voltage flashover can be caused by such conditions as switching surges, fault currents, and lightning strokes or discharges.

Safety rules provide information on the proper tools and equipment to be used on electrical components (P4). Different voltage levels require the use of tools or equipment with varying levels of insulation capability. This information may also be contained in maintenance procedures. The design of such tools and equipment must conform to industry standards and must be tested periodically to assure their insulation integrity.

The design and layout of electrical facilities, as well as safety rules, add to the preventive methods which would minimize the accidental contact with energized conductors (P5 and P6). This contact may be due to falling or tripping, as well as other activity in or around the electrical facilities.

Safety rules may suggest methods to prevent dropping of tools or the means to catch or deflect them before contacting an exposed conductor (P7).

3.7.2 D - Deactivation, Grounding and Bonding

Deactivation and grounding is accomplished by railroad or electric utility personnel, either by automatic switching, remote switching, or manual connection of grounding equipment to conductors. This method is usually used during maintenance activities or as a result of an accident to allow safe passage of employees, passengers, rescue workers, or fire fighters. Deactivation and grounding is also required when fire fighting activity occurs on or near electrified railroad property. The specific deactivation and grounding methods/procedures are:

- D1 Removing hazard (deactivation and removal of power in conductor)
- D2 Confirming removal of power from conductor
- D3 Bonding
- D4 Tagout/Lockout and chain of custody
- D5 Prevent bridging by improper operations
- D6 Grounding conductors.

The removal of the power in a conductor is the basic method of assuring safety. Safety rules normally define the industry accepted steps for both planned power shutdowns and emergency shutdowns (D1).

A basic principle of electrical safety is to not rely on notification that a conductor has been de-energized, but to test for energization (D2) at the work site for confirmation. Additionally, a three step measurement process is typically recommended by safety rules or maintenance procedures. The three step process consists of:

- Testing the measuring instrument for its proper operation
- Measuring the circuit for verification
- Retesting of the instrument to ensure that a zero reading is valid and not the result of a failure occurring after the initial test.

Bonding is the permanent or temporary joining, or connecting, of metallic parts and equipment (D3). Safety bonds can be used either as a continuous low impedance, highly conductive path for fault current flow or can be used to maintain an equipotential between two objects.

Safety rules establish a procedure to be used by workers on site and in the controlling facilities to prevent restoration of power to a circuit previously de-energized (D4). Typically, a safety rule provides information on the steps to be followed by an employee at the work site to communicate with a power director or dispatcher. A pre-established lockout and tagout procedure is followed [10]. Safety rules provide for a system of locks and tags for use on electrical equipment and controls. This is the detailed method used for the prevention of movement of switches, circuit breakers or other equipment previously set to a safe configuration. The tags provide a visual indication that the nonstandard settings are required for safety of workers. The locks provide positive means of preventing power restoration since the employee who applied the lock is supposed to be the only one with the key. This is particularly important when more than one group of workers is working in the affected area. Safety rules also provide for transfer of authority for tags and locks to other shifts of workers and supervisors.

Certain types of railroad equipment, such as MU cars with a high voltage bus between cars and multiple pantographs or contact shoes, can allow electric power to flow from an energized section of the railroad system to a de-energized section if the train is in a position where contact is made on both sections of a catenary or third rail. Safety rules inform trainmen of this hazard and require that trains be operated so that such electrical bridging cannot occur (D5).

Safety grounds (D6) are created by attaching temporary leads from conductors or equipment terminals to ground and to grounded components. In particular, temporary grounds must be placed on all sides of a work area, and employees must only work in areas that are between temporary grounds. This provides for a safe work area. Safety rules instruct employees to attach appropriately sized grounds as a backup to ensure safety. If power is prematurely restored to a deenergized section (D6), these safety grounds will divert the energy to ground thereby adding another level of protection for the workers.

3.7.3 G - General Safety Practices

General safety practices are those practices and rules that relate to overall safety in the work environment and not specifically to electrical work. However, absence of these safety methods can lead to hazards when working on electrical equipment. The specific methods associated with general safety practices are:

G1 Safe work habits
G2 Safe work places.

Safe work habits (G1) usually include:

- Use of protective gear
- Request for clarification from superiors to eliminate misunderstandings
- Other basic safety practices.

The assurance of a safe workplace (G2) relates to both design criteria and safety rules. A properly designed work area can remain safe only if safety rules ensure that equipment, tools, and materials are not allowed to be placed or used improperly. Misuse of equipment may create a hazard or negate the safety design of a facility.

3.7.4 C - Preventing Component Failure

If a maintenance and operations program can prevent or mitigate failures of electrical system components, then the hazards associated with the actual failure of these components can be avoided. The specific methods/procedures for prevention of component failure are:

C1 Operating procedures
C2 Inspection procedures
C3 Maintenance procedures
C4 Protection against damage from impact, weather or overload.

Railroad operating procedures (C1) must ensure that the procedures do not create a hazard or increase the risk of damage to system components. Inspection procedures during operation and maintenance periods (C2) ensure that system components are undamaged and will operate normally when required. Safety rules may require employees to perform inspections on a number of components during the completion of other work.

Maintenance procedures provide details on the method used to repair, overhaul, or adjust system components (C3). Safety aspects of specific equipment and apparatus should be provided in these procedures. Maintenance procedures provide detailed inspection requirements for specific components along with tolerances for safe operation.

Safety rules may instruct employees of methods to be used or proper tools and equipment needed to avoid damage to system components during inspection, maintenance, or other procedures (C4). Design standards of components directly influence the level of protection. The design of the overall electrical system must provide methods to prevent or minimize overload of critical components. Components that could be affected by impacts or adverse environmental conditions should comply with appropriate design standards or be housed in appropriate enclosures.

3.7.5 T - Training

Training involves education of employees in the hazards associated with operation and maintenance of the railroad electrical equipment. The level of training required for safety varies with the responsibility of the individual. The detailed training methods/procedures include:

- T1 Rules and procedures
- T2 How to recognize and avoid hazards
- T3 Proper selection and use of tools and equipment.

Employees must learn the necessary rules and procedures associated with their particular job or craft and all employees need basic safety training (T1). Training should be implemented to inform employees about the use of rule books, timetables, and other references available to them.

Safety rules may provide employees with information on how to recognize general or specific hazards (T2). Methods to avoid or reduce the risk from these hazards can also be covered by safety rules.

Safety rules may ensure that the correct type of tools and equipment are used for certain critical procedures (T3). Safety rules may also designate which type of employees are to make decisions on tool and equipment usage.

3.7.6 S - Supervision and Responsibility

Railroads have distributed the responsibilities for maintaining safety into three basic levels. At the lowest level, each person is required to be responsible for his/her own personal safety to the extent of the training received for his job. If such an employee believes a hazardous condition exists he/she can communicate this information to the next level of supervision.

A higher level of training is given to designated employees that supervise the work of others. This extra training enables them to recognize additional hazards. Such employees are made responsible for communicating this information to the system level, responding to appropriate directions, and communicating these directions to the individual workers.

At the system level, employees such as Power Supervisors or Dispatchers are aware of system operational conditions and needs not available at the personal or local level. These employees are trained in the proper response to reports of hazardous conditions or requests for maintenance operations from the local or personal level.

The risk reduction methods associated with supervision and responsibility can be categorized as:

- S1 Responsibility for personal safety
- S2 Responsibility for safety of others
- S3 Responsibility for safe system operation and maintenance
- S4 Communication between all levels of supervision and workers of hazardous conditions and directions for hazard abatement.

Safety rules establish which employees have the overall responsibility and authority for system-wide safety. The proper methods and procedures to assure this safety and to communicate them to higher authorities and individual workers are also contained in safety rules.

Safety rules identify the extent that each person is responsible for his or her own safety (S1). These rules also detail the requirements for employees to be able to take on the responsibility for the safety of other individuals (S2). Safety rules inform these employees of the correct procedures to use in exercising their responsibility (S3).

Procedures for communicating perceived hazards and receiving direction and information for safety are also contained in these rules (S4). Each employee should have the necessary guidance on proper methods of communicating information on hazardous conditions and should understand the proper response to the other levels. This type of communication must take place within the railroad organization as well as between the railroad and outside agencies such as utilities, rescue workers, and contractors.

3.8 REFERENCES

1. Cadick, J., Electrical Safety Handbook, McGraw-Hill, New York, NY, 1994.

2. Greenwald, E. K., Electrical Hazards and Accidents - Their Cause and Prevention, Van Nostrand Reinhold, New York, NY, 1991.

3. Canadian Standards Association (CSA), Railway Electrification Guidelines, C22.3 No. 8-91, July, 1991.

4. Dietrich, F. et al, Safety of High Speed Guided Grounded Transportation Systems: Comparision of Magnetic and Electric Fields of Conventional and Advanced Electrified Transportation Systems, DOT/FRA/ORD-93/07, Electric Research and Management, Inc., August 1993.

5. Wenzel, T., etal, Electromagnetic Fields (EMF) and Rail Maintenance Workers: Final Report of An Exposure Survey and Feasibility Investigation, National Institute for Occupational Safety and Health, January 1996.

6. Sing, F. et al, The UMTA Rail Transit EMI/EMC Program: Overview and Summary, UMTA-MA-06-0153-85-4, February 1987.

7. Holmstrom, F. and Edelson, C., Radiated Interference in Rapid Transit Systems, Volume I: Theory and Data, UMTA-MA-06-0153-85-10, April 1988.

8. Holmstrom, F. and Edelson, C., Radiated Interference in Rapid Transit Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-11, June 1988.

9. Institute of Electrical and Electronics Engineers, IEEE Guide for Maintenance Methods on Energized Power Lines, Std 516-1987, New York, NY, December 10, 1987.

10. National Fire Protection Association, Inc. Electrical Safety Requirements for Employee Workplaces, NFPA 70E, Batterymarch Park, Quincy, MA. 1988.

11. U.S. Department of Defense, System Safety Program Plan, MIL-STD-882C, January 19, 1993.

4. ELECTRICAL SAFETY STANDARDS REVIEW

4.1 INITIAL SURVEY

A preliminary survey of electrical safety standards was conducted. This preliminary survey focused on electrical systems and equipment standards. Electrical safety rules and safe work practices such as those found in the Code of Federal Regulations, National Electrical Safety Code and other similar standards were identified as being distinct from standards that are related to the equipment aspects of an electrified system. Those standards related to safety rules and work practices are part of a separate survey which is discussed in section 4.4.

The major sources of U.S. standards for electrical safety identified from the survey included the Institute of Electrical and Electronics Engineers (IEEE), American National Standards Institute (ANSI), Underwriters Laboratories (UL), National Electrical Manufacturers Association (NEMA), the National Fire Protection Association (NFPA), and to a more limited extent the Association of American Railroads (AAR), the American Railway Engineering Association (AREA), and the Canadian Standards Association (CSA). Most of the industry-wide standards usually are jointly issued standards with ANSI. For example, IEEE Std. 519-1992, "IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters," is also a recognized ANSI standard.

The publications of the above U.S. standards groups fall into three broad categories. One category of standards is equipment specific and typically defines equipment performance and certain design features, installation and test requirements of a particular piece of equipment or the equipment elements of a system. An example of this type of standard would be ANSI/IEEE C37.20-1987, "IEEE Standard for Metal-Clad and Station-Type Cubicle Switchgear". Equipment meeting this standard must satisfy certain service conditions, must have certain performance and construction features, and must satisfy certain test requirements which are defined by the standard.

The second category of standards can be considered as system level standards which define recommended procedures, practices and guidelines in a particular area. An example would be ANSI/IEEE Std 120-1989, "IEEE Master Guide for Electrical Measurements in Power Circuits". The third category of standards can be considered as practices and guidelines for establishing a standard of performance at a particular system interface. An example of this type of standard would be ANSI/IEEE Std 519-1992 "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power

Systems". This standard both defines the limits of power harmonic disturbances that equipment or a subsystem can inject into the power system, and that can potentially adversely affect other equipment and/or communication facilities as well as the recommended means to achieve the limits given by the standard.

The survey also identified, from a review of prior Volpe Center studies, several European standards organizations known to have electrical safety standards. These organizations include, but are not limited to, the British Standards Institute, the German Standards Institute (DIN), International Electrotechnical Commission (IEC), International Union of Railways (UIC), Association of German Electrical Technicians (VDE), and the Association of German Engineers (VDI).

Contacts were made with both ANSI and IEEE to determine the extent of cross referencing between ANSI and IEEE standards and the above European standards. It was determined from discussions with representatives of ANSI that there is no cross referencing, since there is apparently no formal coordination between U.S. and foreign standards groups with respect to the individual standards published by each of these groups. This will most likely make it difficult to easily develop standards cross references among the various groups.

It also was determined that there has been some level of informal coordination at the individual standard working group or committee level for some standards. Apparently, in the U.S., the IEEE has recognized the need for establishing more formal coordination, and efforts in that direction are currently underway between it and the European based IEC. A joint IEEE and IEC workshop meeting was recently held to begin the process of the harmonization of selected power equipment standards produced by the IEEE Power Engineering Society and IEC's Switchgear and Controlgear Committee [1]. One outcome of the meeting was the recommendation that an official liaison be established between these respective groups to enable more active participation in the standards development process.

As part of this initial survey, a preliminary review was made to determine the relative similarities of the standards of the U.S. and European organizations described above. Table 4.1 provides a brief summary of the correspondence between U.S. and selected European Standards. The summary shows for example, that ANSI/ASTM standards are similar in many cases to DIN standards and that AAR and AREA standards have similarities to UIC standards. The correspondence shown below is intended only as a guide for further standards review.

TABLE 4.1 CORRESPONDENCE BETWEEN U.S. AND EUROPEAN STANDARDS

U.S.	Corresponds To	European
ANSI, ASTM		DIN
IEEE, NEMA, UL		VDE
ANSI, IEEE		DIN-VDE
ANSI, IEEE, UL		DIN-IEC
ANSI, IEEE		VDI
AAR, AREA		UIC

The member railroads of the National Traction Power Committee (NTPC) made available for review their electrification related safety rules and recommended safe work practices. The member railroads of the NTPC constitute the majority of currently electrified railroads in the U.S. These safety rules also are listed in Appendix A.

4.2 PRELIMINARY REVIEW OF STANDARDS

Selected standards from the above organizations were identified for initial review. Included in the review were selected government regulations known to contain electrical safety standards. These standards are listed in Appendix A. The standards reviewed have either been in abstract form or in some limited cases in full text form.

A standards review key is listed for each of the standards given in Appendix A. The key has the following meaning:

- ♦ Standard reviewed, copy of standard at the Volpe Center.
- □ Standard reviewed, copy of standard at local public (Boston, MA) and private (e.g. university) libraries.
- ● Abstract of standard reviewed.

4.2.1 ANSI/IEEE Standards

The most recent version of IEEE Std 100-1992, "IEEE Standard Dictionary of Electrical and Electronics Terms," contains abstracts for all joint ANSI and IEEE standards which are published by the IEEE. This enabled an initial screening to be made of all IEEE and most of the ANSI standards considered to be relevant. From this initial screening, approximately 100 ANSI and IEEE standards were identified as having potentially applicable safety requirements for railway equipment and system operation. These standards are listed in Appendix A of this report.

Most UL and NEMA standards are component/equipment specific and are similar in content to the IEEE standards discussed above. As of this writing a more detail review of UL and NEMA standards has been temporarily deferred because of time constraints.

4.2.2 Railway Specific Standards

Selected railway specific standards published by the AAR and AREA were reviewed. Most of these standards are generally in the form of recommended practices. The AAR standards pertain principally to rolling stock equipment whereas the AREA standards are more specific to infrastructure. Several standards were identified as having potential applicability to railroad electrical safety. Section F of AAR Manual of Standards and Recommended Practices, contained 21 such standards related to locomotives and electrical equipment. Section A, Part III of the AAR manual identified one electrical standard specific to passenger cars.

The AREA Manual for Railroad Engineering, has one chapter dedicated to the subject of recommended practices for electrical systems. Chapter 33, "Electrical Energy Utilization," contains more than 100 pages and discusses numerous relevant topics varying from mechanical and electrical clearances; catenary system construction, performance, ampacity guidelines; power supply requirements, catenary voltage, power feeding and catenary sectionalizing; signaling system compatibility, shielding and impedance bonds. To a limited extent, Chapter 33 also discusses electrical systems for locomotives and other rolling stock.

The Canadian standard, which deals with electrification guidelines, also was reviewed, since it is directly applicable to this analysis. This standard is specific to the infrastructure and discusses many of the same issues as given in the AREA standard.

4.2.3 NFPA Standards

Several NFPA standards were identified as having potential application to railway electrical safety. The scope of most of these NFPA standards do not have explicit applicability to railroads. However, many of the safety issues covered by these standards are present in an electrified railroad and are of interest. The initial review identified six such NFPA standards and these are listed in Appendix A.

4.2.4 U.S. Government Standards

Most of the pertinent U.S. government standards are published in the Code of Federal Regulations (CFR). Selected sections from the CFR also were reviewed. With respect to standards for work practice requirements, 29CFR, Labor, contains the OSHA regulations. The FRA safety regulations are given in 49CFR, Transportation. Other parts of the CFR that were examined for relevant electrical safety standards included 14CFR, Aeronautics and Space, for FAA regulations and 46CFR, Shipping, for the safety regulations of the Coast Guard (USCG) and the Maritime Administration, (MARAD).

4.3 STANDARDS ANALYSIS FOR ELECTRIFICATION RELATED EQUIPMENT

The standards listed in Appendix A were further reviewed and analyzed for their potential applicability to the railroad electrification system elements discussed in Section 2. As evident from the data given in Appendix A, most of the standards listed in there are not railroad specific but are standards used in nearly all electrical equipment and related industries. The intent of this next level of review and analysis was to identify those standards that would appear to be applicable to the specific materiel, components and equipment, and subsystems found in electrified railroad systems.

In addition to the standards listed in Appendix A, a brief review of UIC standards also was made to determine applicability of UIC standards to the electrification system equipment elements described in Section 2. The intent of the UIC standards review conducted at this time was not intended to be an in-depth review of all possible UIC standards and their relationship to the electrification system equipment elements that were described in Section 2. The level of the UIC review was to show that railroad specific standards do exist for all of the electrification equipment elements reviewed.

The following tables summarize the results of the standards review and analysis. The tables are organized by electrification system element and by the equipment items that make up each specific element. The structure of each of the tables lists the equipment item discussed in Section 2, the applicable standard by organization name and standard number, the subsystem component being addressed by the standard and a brief description of the standard. These tables were prepared in a database format with sort capability. The sort chosen for these tables is by equipment item, and they have been sorted according to the equipment item identification (ID) listed at the end of each table.

4.3.1 Substation Components and Equipment

Table 4.2 identifies the standards that would be considered applicable to the components and equipment of the substation element. More than 100 standards were identified as applicable since the equipment installed in a traction substation closely resembles the equipment that would be installed in electric utility and other industry substations. It was found that every hardware item considered for the substation contains one of more related standards. In some cases, such as transformers, numerous standards were found to be applicable.

4.3.2 Overhead Contact System

Table 4.3 identifies the standards considered applicable to the components and equipment that comprise the overhead contact system (OCS). Since the OCS element is specific to the railroad application, the number of general industry standards found to be applicable were small in number. The primary U.S. standard, or recommended practice, found to be applicable was that of the AREA. Several of the IEEE standards related to electrical transmission and distribution systems were found also to be applicable to the OCS because of the similarity of the system function. In a few cases, however, not every equipment item discussed in the system description was found to have a standard associated with it. One case was the equipment required for tensioning the catenary. Further analysis is required for this element to identify standards that could be applicable.

4.3.3 Power Supply for Signal and Communications Systems

Table 4.4 identifies the standards applicable to the power supply and other related parts for signal and communication system power. Most of the standards listed in Table 4.2 for the substation would also be applicable to signal and communication power facility and were not repeated in Table 4.4 for the sake of brevity. Additional standards analysis is also required for this electrification element.

4.3.4 Motive Power Vehicles

Table 4.5 identifies the standards applicable to electric locomotives and power cars. The table shows a relatively uniform cross section between general industry standards and those specific to rail systems. Standards have been identified for almost all equipment items. It is expected that additional standards analysis would fill in any of the remaining gaps.

4.3.5 Railroad Transmission Networks

Table 4.6 identifies the standards applicable to railroad transmission networks. The standards given in the table are all industry based standards since railroad transmission networks are similar to electric utility transmission networks.

TABLE 4.2 - SUBSTATION ELEMENT

Item Number	Standards Source	Standard Number	Subsystem Component	Description of Standard
1	UIC	613 O	General	Graphical symbols for electric traction.
1	IEEE	Std. 510-1983	General equipment	Recommended practice for safety in high voltage and high power testing.
1	IEEE	Std. 141-1986	General equipment	Recommended practice for electric power distribution for industrial plants.
1	IEEE	Std. 242-1986	General equipment	Protection and coordination of industrial and commercial power systems.
1	AREA	Chapter 33, Part 3	General	Recommended voltages for new construction.
1	IEEE	Std. 693-1984	General equipment	Guide for seismic design of substations.
1	IEEE	C37.123-1991	Gas insulated substations	Installation and operation of ac gas insulated substation.
1	AREA	Chapter 33, Part 6	General	Power supply requirements for railroad electric traction systems
1	UIC	603 R	General	Measures to be taken to prevent the formation of sparks from traction current.
1	IEEE	Std. 979-1984	General equipment	Guide for substations fire protection.
1	IEEE	Std. 1127-1990	General equipment	Guide for design, construction and operation of substations for environmental acceptance.
1	IEEE	C37.122-1983	Gas insulated substations	Installation and operation of ac gas insulated substation.
2	IEEE	Std. 1109-1990	Connection to utility grid	Guide for the interconnection of user-owned substations to electric utilities.
2	IEEE	Std. 519-1992	Static power converters	Guide for harmonic control and reactive compensation of static power converters.
3	IEEE	Std. 142-1991	Grounding	Grounding of industrial and commercial power systems.
3	IEEE	Std. 367-1987	Grounding	Recommended practice for determining ground potential rise and induced voltage from a fault.
3	IEEE	C62.92.4-1991	Grounding	Guide for the application of neutral grounding in electric utility systems.
3	IEEE	Std. 80-1986	Grounding	Guide for safety in ac substation grounding.
3	IEEE	Std. 32-1972	Grounding devices	Controlling the ground current or potentials to ground of ac system.
3	NFPA	70 Article 250	Grounding	General grounding requirements- more in each component sections.
3	NFPA	70B - 6-1.5	Grounding	Maintenance of grounding equipment.
3	IEEE	C62.92.5-1992	Grounding	Guide for the application of neutral grounding for transmission and subtransmissions systems.
4	NFPA	70B- 6-1.3	Bus structures	Maintenance and inspection of exposed conductors.
4	IEEE	Std. 605-1987	Bus structures	Guide for design of substation rigid-bus structures.
5	IEEE	Std. 525-1987	Cable/Wiring	Guide for the design and installation of cable systems in substations.
5	NFPA	70B Chapter 8	Cable/Wiring	Recommended practice for the maintenance of power cables.
5	NFPA	70B Chapter 21	Cable tray	Recommended maintenance procedures for cable tray systems.
5	IEEE	Std. 404-1986	Cable/Wiring	Standard for extruded cable joints and laminated dilectric cable.
5	IEEE	Std. 386-1985	Cable/Wiring	Standard for insulated connector systems for power distribution systems above 600 volts.
5	IEEE	Std. 422.1986	Cable/Wiring	Guide for the design and installation of cable systems in power generating stations.
6	NFPA	70B Chapter 7	Transformers	Recommended practice for the maintenance of liquid filled and dry type power transformers.
6	IEEE	C57.125-1991	Power transformers and reactors	Guide for failure investigation, documentation and analysis for transformers and reactors.
6	NFPA	70 Article 450	Transformers	Recommended application, system configuration, and installation of transformers.
6	IEEE	C57.109-1985	Transformers	Guide for transformer through-fault current duration.
6	IEEE	C57.12.59-1989	Dry transformers	Guide for dry type transformer through-fault current duration.
6	IEEE	C57.12.11-1980	Oil filled transformers	Guide for installation of oil-immersed transformers.
6	IEEE	C57.114-1990	Power transformers and reactors	Seismic guide for power transformers and reactors- installation info.
6	IEEE	C57.94-1982	Distribution and power transformers	General requirements for dry type distribution and power transformers-solid or encapsulated windings.
6	IEEE	C57.12.01-1989	Distribution and power transformers	General requirements for dry type distribution and power transformers-solid or encapsulated windings.
6	IEEE	C37.91-1985	Protective relay , power transformers	Guide for protective relay applications to network and power transformers.
6	IEEE	Std. 980-1987	Transformers	Guide for containment and control of oil spills in substations.
7	NFPA	70B - 6-2	Switchgear assembly	Recommended maintenance proceudres for switchgear assemblies.
7	IEEE	C37.20.3-1987	Switchgear assembly	Recommended guidelines and precautions to include tamper resistant switchgear.
7	IEEE	C37.20.2-1987	Switchgear assembly	Recommended guidelines and precautions to include tamper resistant switchgear.
7	IEEE	C37.59-1991	Switchgear	Guide for conversion of power switchgear.
8	IEEE	C37.61-1963	Circuit reclosers & fault interrupters	Guide for the application, operation and maintenance of automatic circuit reclosers.
8	IEEE	C37.63-1984	Circuit reclosers & fault interrupters	Requirement for overhead, padmounted, dry vault, and submersible automatic circuit reclosers.
8	IEEE	C37.60-1991	Circuit reclosers & fault interrupters	Requirement for overhead, padmounted, dry vault, and submersible automatic circuit reclosers.
9	ANSI	C37.30-1992	Air switches	Requirements for high-voltage air switches.
9	NFPA	70B - 6-1.4	Air- disconnecting switches	Inspection and maintenace of air switches.
9	ANSI	C37.48-1987	Air switches	Guide for application, operation and maintenance of H.V. distribution air switches.
9	ANSI	C37.34 - 1971	Air switches	Test code for high-voltage air switches.

TABLE 4.2 - SUBSTATION ELEMENT

Item Number	Standards Source	Standard Number	Subsystem Component	Description of Standard
10	NFPA	70B 6-6	Oil circuit breakers	Recommended practice for the maintenance of oil circuit breakers.
10	ANSI	C37.12 - 1981	Circuit breakers	Performance and structural requirements for H.V. circuit breakers.
10	ANSI	C37.010 - 1979	Circuit breakers	Application guide for C.B. selection and importance of expected switching characteristics.
10	NFPA	70B 6-5	Vacuum circuit breakers	Recommended practice for the maintenance of vacuum circuit breakers.
10	ANSI/IEEE	C37.06 - 1979	Circuit breakers	Design and applications requirements, system description and operating characteristics.
10	ANSI/IEEE	C37.04-1979 , (R1989)	Circuit breakers	Sets construction limits to ensure that loading and internal pressure is not excessive.
10	NFPA	70B 6-4	Air Circuit Breakers	Recommended maintenance procedures.
10	NFPA	70 Article 240, Parts G&H	Circuit breakers	Installation recommendations for circuit breakers.
11	NFPA	70B - 6-7	Interrupter switches	Recommended practice for the maintenance of interrupter switches.
11	IEEE	Std. 578 - 1976	Load interrupter switches	Work rule practices for LIS.
11	ANSI	C37.35 - 1976	Load interrupter switches	Work rule practices for LIS.
12	NFPA	70B Chapter 11	Fuses	Recommended maintenance practices for fuses.
12	IEEE	C37.48-1987	High voltage fuses	Guide for application, of H.V. fuses, single-pole air switches, fuse disconnecting switches, etc.
13	IEEE	C62.11-1987	Surge arresters	Standard for metal oxide surge arrestors for AC power circuits..
13	NFPA	70B 6-8.2	Surge arresters	Recommended maintenance procedures for surge arresters.
13	IEEE	C62.2-1987	Surge arresters	Guide for the application of gapped silicon carbide surge arresters for alternating current systems.
13	NFPA	70, Artilce 280	Surge arresters	Installation requirements for surge arresters.
14	IEEE	C37.109-1988	Reactors	Guide for the protection of shunt reactors.
14	NFPA	70, Article 470	Reactors	Installation and application guide of reactors and resistors.
14	IEEE	C57.21-1990	Reactors	Requirements, terminology, and construction and test for shunt reactors rated over 500 kVA.
15	NFPA	70, Article 460	Capacitors	Application and installation guide for capacitors.
15	IEEE	Std. 18-1980	Shunt power capacitors	A guide to application and operation of power capacitors.
15	IEEE	Std. 824-1985	Capacitors	Standard for series capacitors in power systems.
15	NFPA	70B Chapter 6-8.3	Capacitors	Recommended practice for the maintenance of capacitors.
15	IEEE	C37.99-1990	Shunt capacitor banks	Guide for the protection of shunt capacitor banks - used in substations.
16	IEEE	Std. 1035-1989	Converters	Test procedures for utility interconnected static power converters.
16	IEEE	Std.936-1987	Self commutated converters	Guide for self commutated converters.
16	IEEE	Std. 597-1983	Converters	Requirements for general purpose thyristor dc drives.
16	IEEE	Std. 428-1981	Power Controllers	Requirements for thyristor ac power controllers.
17	IEEE	C57.19.00-1991	Power apparatus bushings	General requirements and test procedure for outdoor power apparatus bushings.
17	NFPA	70B-6-1.2	Insulators	Maintenance and inpsection recommendations.
18	IEEE	Std. 390-1987	Pulse transformers	Standard for pulse transformers used in electronic equipment
18	IEEE	Std. 799-1987	Transformers	Guide for handling and disposal of transformer grade insulating liquids containing PCBs.
18	NFPA	70B Chapter 6-8.5	Instrument transformers	Recommended practice for the maintenance of instrument and auxilliary transformers.
18	IEEE	C57.13-1978	Instrument transformers	Standard requirement for instrument transformers.
18	IEEE	C57.13.3-1983	Instrument transformers	Standard requirement for instrument transformers.
18	IEEE	Std. 295 -1969	Electronic power transformers	Application guidance for power transformers and inductors used in electronic equipment.
18	IEEE	Std. 388-1992	Transformers	Standard for transformers and inductors in electronic power conversion equipment.
19	IEEE	C37.20.1-1987	Switchgear assembly	Standard for metal-clad low-voltage power circuit breaker switchgear.
19	IEEE	C37.21	Switchgear assembly	Standard for control switchboards.
19	NFPA	70B - 6-2	Switchgear assembly	Recommended maintenance proceudres for switchgear assemblies.
20	ANSI	C37.11 - 1979	Supervisory control	Design requirements for operation of control sequence in a fault clearing action.
20	ANSI	C37.1 - 1979	Supervisory control	Guidelines supevisory control devices in substations, Interface and environmental conditions.
21	IEEE	C37.97-1979	Protection for buses	Guide for protective relay applications to power system buses.
21	IEEE	C37.108-1989	Protective relay , power transformers	Guide for protective relay applications to network and power transformers.
21	IEEE	C57.13.1-1981	Relaying current transformers	Guide for field testing of relaying current transformers.
22	IEEE	Std. 450-1987	Lead-acid batteries	Recommended practice for maintenance,testing, and replacement of lead storage batteries.
22	IEEE	Std. 446-1987	UPS- batteries	Recommended practice for emergency and standby power systems.
22	IEEE	Std. 944-1988	UPS	Application and testing of UPS for power generating stations.
22	NFPA	70, Article 480	Storage batteries	Installation and application guide for storage batteries.
22	IEEE	Std. 1106-1987	Nickel cadmium batteries	Recommended practice for maintenance, testing and replacement of nickel-cadmium batteries.
22	NFPA	70B 6-8.4	Lead-acid storage batteries	Recommended practice for the maintenance of lead batteries.

TABLE 4.2 - SUBSTATION ELEMENT

Item Number	Standards Source	Standard Number	Subsystem Component	Description of Standard
22	IEEE	Std. 484-1987	Lead-acid batteries	Recommended practice for installation design and installation of large lead storage batteries.
22	NFPA	70B Chapter 22	UPS	Recommended maintenanace practices for UPS systems.

Item No.	Definition of Grouping
	Substation - System
1	General
2	System Interface
3	Grounding
4	Bus Structures
5	Cabling/Wiring
	Power Equipment
6	Transformers
7	Switchgear
8	Circuit Reclosers
9	Air-Disconnect Switches
10	Circuit Breakers
11	Load Interrupt Switches
12	High Voltage Fuses
13	Surge Arresters
14	Reactors
15	Capacitors
16	Converters/Inverters
17	Bushings, Insulators
	Control Equipment
18	Transformers
19	Switchgear, Low Voltage
20	Supervisory Control
21	Protective Relay Systems
22	UPS/Battery Systems

TABLE 4.3 - OVERHEAD CONTACT SYSTEM ELEMENT

Item Number	Standards Source	Standard Number	Subsystem Component	Description of Standard
1	IEEE	Std. 1067-1990	General equipment	Guide for in-service use, care, maintenance, and testing of conductive clothing for use .
1	UIC	603 R	General	Measures to be taken to prevent the formation of sparks from traction current.
2	IEEE	Std. 789-1988	Lines	Performance requirements for communications and control cables in high voltage environments.
2	UIC	605 OR	system interface	Protection from corrosion - measures to be taken on direct current catenaries.
2			Connection to Power Feed	
2	IEEE	Std. 776-1987	Lines	Guide for inductive coordination of electric supply and communication Lines.
3	UIC	792 R	Grounding	Principles for manufacture and use of portable units for earthing overhead traction power lines.
3	IEEE	Std. 1048-1990	Grounding	Guide for protective grounding of power lines.
4	UIC	606-1 OR	Clearances	Consequences of the application of the kinematic gauges on the design of the contact lines.
4	AREA	Chapter 33, Part 2	Clearances	Recommended clearance specifications for electrification .
5	IEEE	Std. 935-1989	Lines	Guide on terminolgy for tools and equipment to be used in live-line working.
5	IEEE	Std. 978-1984	Lines	Guide for in-service maintenance and electrical testing of live-line tools.
5	IEEE	Std. 516-1987	All energized power lines	Guide for maintenance methods on energized power lines.
5	AREA	Chapter 33, Part 4.2	Catenary	Catenary system design criteria.
5	UIC	600 OR	Catenary	Electric traction with aerial contact line.
5	UIC	606-2 OR	Catenary	Installation of 25 kV and 50 or 60 Hz overhead contact lines.
5	UIC	791 R	Catenary	Quality assurance of overhead line equipment.
5	IEEE	Std. 524-1992	Power feed	Guide to the installation of overhead transmission line conductors.
6	AREA	Chapter 33, Part 4.1	Contact Wire	Recommendation for determining contact wire ampacity.
6	UIC	870 O	Contact wire	Technical specification for grooved contact wires.
7			Messenger wire	
8			Hangers	
9	IEEE	Std. 957-1987	Insulators	Guide for cleaning Insulators.
9	IEEE	Std. 987-1985	Insulators	Guide for application of composite insulators..
9	IEEE	Std. 1024- 1988	Insulators	Practice for specifying distribution composite insulators (suspension type).
10			Phase breaks	
12	UIC	791 R	Power Feed	Quality assurance of overhead line equipment.
12	IEEE	Std. 935-1989	Lines	Guide on terminolgy for tools and equipment to be used in live-line working.
12	IEEE	Std. 978-1984	Lines	Guide for in-service maintenance and electrical testing of live-line tools.
12	AREA	Chapter 33, Part 4.3	Power Feed	Electrification feeding and sectionalizing arrangements.
12	IEEE	Std. 516-1987	All energized power lines	Guide for maintenance methods on energized power lines.
12	IEEE	Std. 524-1992	Power feed	Guide to the installation of overhead transmission line conductors.
13			Auto-transformer	
14	NFPA	70B - 6-1.4	Disconnect switches	Inspection and maintenance of air switches
18	IEEE	Std. 951-1988	Transmission structures	Guide to the assembly and erection of metal transmission structures.
18	UIC	791 R	Structures	Quality assurance of overhead line equipment.

TABLE 4.3 - OVERHEAD CONTACT SYSTEM ELEMENT

Overhead Contact System

Definition of Grouping

Item No.	
	OCS System
1	General
2	System Interface
3	Grounding
4	Clearances
	Components
5	Catenary
6	Contact Wire
7	Messenger Wire
8	Hangers
9	Insulators
10	Phase Breaks
11	Tensioning Equipment
12	Power Feed
13	Autotransformer
14	Section Breaks
15	Insulators
16	Surge Arresters
17	Connections/Attachments
18	Structures
19	Cantilevered Poles
20	Portals
21	Headspan Supports

TABLE 4.4 - POWER FOR SIGNAL AND COMMUNICATION SYSTEMS ELEMENT

Item Number	Standards Source	Standard Number	Subsystem Component	Description of Standard
1	UIC	734 R	General	Adaptation of safety installations to high-speed requirements.
1	UIC	736 R	General	Signalling relays.
1	UIC	737-3 i	General	Application of thyristors in railway technology.
1	UIC	737-2 i	General	Measures to be taken for improving sensitivity in the shunting of track circuits.
1	UIC	737-1 i	General	Track circuits.
1	UIC	738 R	General	Processing and transmission of safety information.
3			Cross Bond	
3			Neutralizing Wire	
3			Ground Wire	
6			Rail Insulating Joints	
6			Impedence Bonds	

Power for Signal and Communication Systems

Definition of Grouping

Item No.	
	PSCS - System
1	General
2	System Interface
3	Grounding/Bonding
4	Shielding
	Components
5	Signal/Communication Power
6	Impedence Bonds
7	Surge Arresters

TABLE 4.5 - VEHICLE ELEMENT

Item Number	Standards Source	Standard Number	Subsystem Component	Description of Standard
1	UIC	895 OR	General	Technical specification for the supply of insulated electric cables for railway vehicles.
1	UIC	614 O	General	Definition of the rated output of electric locomotives and motive power units.
1	UIC	610 O	General	Rules for the testing of electric rolling stock.
1	UIC	611 OR	General	Regulations to be observed for the acceptance of electric locomotives.
1	UIC	613 O	General	Graphical symbols for electric traction.
1	UIC	616 OR	General	Rules for electric traction equipment.
1	NFPA	130 Ch.4 - 3.7	Wiring and cables	Mechanical and environmental protection for power cables.
1	AAR	Std S-501	Wiring and cables	Physical properties of materials for wire and cable.
1	AAR	Std S-538	Wiring and cables	Recommended practice for wiring power, control, lighting, and auxiliary apparatus.
2	UIC	737-3 R	Converter/Inverter	Application of thyristors in railway technology.
2	UIC	737-4 R	Converter/Inverter	Measures for limiting the disturbance of light current installations by electric traction .
3	IEEE	Std. 1100-1992	Grounding	Recommended practice for grounding sensitive electronic equipment.
3	UIC	533 O	Grounding	Protection by the earthing of metal parts of vehicles.
4	AREA	Chapter 33, Part 8.2	Pantograph	Locomotive mechanical interaction with the catenary.
5	UIC	618 O	Transformer	Rules for traction transformers and reactors.
5	IEEE	Std. C57.111-1989	Transformer	Guide for acceptance of silicone insulating fluid and its maintenance in transformers.
6	IEEE	Std. 444-1973	Rectifier/ power conditioner	Standard practices and requirements for thyristor converters for motor drives .
6	IEEE	Std. 597-1983	Thyristor DC drives	Practices and requirements for general purpose thyristor dc drives.
6	IEEE	Std. 519-1981	Static power converters	Guide for harmonic control and reactive compensation of static power converters.
6	NFPA	130 Ch. 4 - 3.4	Static power converters	Motor controls to be rated and tested in accordance with methods of IEEE 11.
8	IEEE	C37.96-1988	Motor protection	Guide for ac motor protection - induction motors and synchronous motors.
8	AREA	Chapter 33, Part 8.1	Motor control	Types of traction motor control circuits.
8	IEEE	Std.620-1987	Traction motors	Guide for construction and interpretation of thermal limit curves for squirrel-cage motors.
8	NFPA	70B Chapter 14	Traction motors	Recommended maintenance procedures for rotating equipment.
8	UIC	619 O	Traction motors	Rules for rotating electrical machines for rail and road vehicles.
8	NFPA	70, Article 430	Motors and motor circuits	Recommended installation of motors, etc.
8	NFPA	130 Ch. 4 - 3.3	Traction motors	Insulation and mechanical requirements for motor leads.
8	IEEE	Std 11-1980	Traction motors	Standard for rotating electric machinery for rail and road vehicles.
9	NFPA	130 Ch.4 - 3.5	Propulsion & braking resistors	Cooling requirements and protective devices for resistor elements.
9	UIC	649 O	Resistors	Rules for ohmic resistors used in the power circuits of electrically powered vehicles.
9	NFPA	70, Article 470	Resistors	Installation and application guide for reactors and resistors.
11	UIC	626 OR	Head End Power	Production of electric power on diesel tractive units for supplying the train cable.
12	UIC	552 OR	Train-line Power Distribution	Electric power supply for trains.
12	UIC	550-1 OR	Train-line Power Distribution	Electrical switch cabinets on passenger stock.
12	AAR	Std S-501	Trainline distribution	Functions and ratings of trainline power recepticles.
12	UIC	550 OR	Train-line Power Distribution	Power supply installations for passenger stock.
12	UIC	554-1 OR	Train-line Power Distribution	Power supply to electrical equipment on stationary railaway vehicles.
12	UIC	554-2 OR	Train-line Power Distribution	Power supply to mechanically refridgerated wagons running in rafts.
13	NFPA	130 Ch.4 - 3.8	Circuit breakers	Venting requirements for propulsion circuit breakers.
14	NFPA	130 Ch.4 - 6.4	Lightning arrestors	Lightning arresters required for
15	UIC	550 OR	Battery	Power supply installations for passenger stock.
15	NFPA	130 Ch.4 - 3.9	Batteries	Fire safety requirements for battery installations.
16	UIC	618 O	Reactors	Rules for traction transformers and reactors.

TABLE 4.5 - VEHICLE ELEMENT

Vehicle

Item No.	Definition of Grouping
	Vehicles-System
1	General
2	System Interface
3	Grounding
	Power Subsystems/Equipment
4	Pantograph/Power Collector
5	Transformer
6	Converters/Inverters
7	Alternator/Rectifier
8	Traction Motors
9	Dynamic Brake Resistors
10	Auxiliary Motors/Controllers
11	Head-End Power
12	Trainline Power Distribution
	Components
13	Circuit Breakers
14	Surge Arresters
15	Batteries
16	Reactors
17	Capacitors

TABLE 4.6 - RAILROAD TRANSMISSION NETWORK ELEMENT

Item Number	Standards Source	Standard Number	Subsystem Component	Description of Standard
1	UIC	791 R	Support Structure	Guide to the installation of overhead transmission line conductors
1	IEEE	Std. 951-1988	Support Structure	Guide to the assembly and erection of metal transmission structures
2	IEEE	Std. 1024-1988	Insulators	Practice for specifying distribution composite insulators (suspension type).
2	IEEE	Std. 987-1985	Insulators	Guide for the application of composite insulators
2	IEEE	Std. 957-1987	Insulators	Guide for cleaning insulators
3	IEEE	Std. 524-1992	Line Conductors	Guide to the installation of overhead transmission line conductors
3	UIC	791 R	Line Conductors	Quality assurance of overhead line equipment
4	IEEE	C62.11-1987	Surge Arresters	Standard for metal oxide surge arresters for AC power circuits
4	NFPA	70B 6-8.2	Surge Arresters	Recommended maintenance procedures for surge arresters
4	IEEE	C62.2-1987	Surge Arresters	Guide for the application of gapped silicone carbide surge arresters
4	NFPA	70, Article 280	Surge Arresters	Installation requirements for surge arresters.

Railroad Transmission Network
Definition of Grouping

Item No.	Components
1	Support Structures
2	Insulators
3	Line Conductors
4	Surge Arresters

4.4 SURVEY OF SAFETY RULES, AND RECOMMENDED SAFE WORK PRACTICES

The major sources of U.S. standards for this subject identified from the preliminary survey included the Code of Federal Regulations (CFR), the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE), the National Fire Protection Association (NFPA), and the U.S. electrified railroads, most of which are located in the Northeast and who are part of the National Traction Power Committee. The survey of foreign standards was limited to those of the International Union of Railways (UIC).

Selected reports from the National Transportation Safety Board (NTSB) were also included in the survey. The reports surveyed were those known to have findings, conclusions and recommendations related to railroad work practices. In addition, selected FRA Office of Research and Development reports in related subjects were also included in the survey. The survey also uncovered several text references which contain in depth treatment of the subject of work practices, particularly as they relate to electrical systems.

More than 80 standards and recommended practices were identified as having electrical safety work rules and practices requirements that potentially could be applicable to railroad systems.

4.4.1 Preliminary Review

The standards identified from the survey were reviewed and nearly 70 were found to be directly applicable either in whole or in part. Table 4.7 contains the results of the preliminary review. The table has been organized alphabetically by organization. Column 1 indicates the numerical location of the source in the table. Column 2 indicates the source of the referenced item. Column 3 depicts the title of the source. Column 4 is the document number associated with each of the references. Column 5 gives of the date of the publication. Column 6 provides information which gives some insight into the purpose and structure of the standard. Column 7 shows those sections or parts of the standard which are applicable to safety rules and safe work practices for railroad electrical systems.

In addition to OSHA and FRA regulations and railroad specific electrical operating instructions, several ANSI/IEEE national standards are listed in the table such as the National Electrical Safety Code. Several NFPA recommended practices are also listed in the table such as Electrical Safety Requirements for Employee Workplaces, and Electrical Equipment Maintenance.

TABLE 4.7 SURVEY OF SAFETY RULES, REGULATIONS, STANDARDS, AND RECOMMENDED PRACTICES

No.	Source	Title	Number	Date	Comments	Sections
1	AAR	Standards and Recommended Practices , Locomotives and Electrical Equipment	Vol. F	1973	R.P. for electrical equipment on locomotives both electric and diesel electric	Partial
2	AAR	Typical Procedures for Power Testing of Diesel Electric Locomotives		1960	High voltage cautions	D
3	Amtrak	Maintenance of Way Employees Safety Rules and Instructions	NRPC-1908	July 1992	General safety rules + overhead line, electrical equipment, circuits, and apparatus	All
4	Amtrak	Emergency Evacuation from Amtrak trains	NRPC-1910	Nov 1989	Entry and evacuation procedures for Amtrak locomotives and passenger cars	Partial
5	Amtrak	Tunnel and Evacuation Emergencies on Amtrak Trains,	SAFE-015	Dec 1990	Training program for emergency response agency training for Amtrak or CSX tunnels	Partial
6	Amtrak	Electrical Operating Instructions	AMT-2	April 1990	Safety instructions for employees in electrified territory	All
7	Amtrak	Guidelines for Transportation Department Supervision		April 1974	Working distance from dangling wires	Partial
8	Amtrak	Northeast Corridor Special Instructions		April 1989	Operational rules for the electrified Northeast Corridor	Partial
9	Amtrak	Mechanical Instruction Manual		May 1975	Maintenance instructions for cars and equipment including electrical equipment	Partial
10	Cadick	Electrical Safety Handbook		1994	R.P. on all aspects of safety with regard to electrical equipment and lines	All
11	FRA	Railroad Operating Rules	217	1993	Rules and practices for trains and other rolling equipment	All
12	FRA	Clearance of overhead signal wires and cables	236.72	1993	Design clearance distance for signal wires	Partial
13	FRA	Insulation or grounding of metal parts	229.83	1993	Grounding or Insulation requirements of non-current carrying parts of electric locomotives	Partial
14	FRA	Eye and Face Protection	214.117	1993	Requirements for eye and face protection when potential of injury results from radient agents	All
15	FRA	Current Collectors	229.77	1993	Design requirements for pantographgs including locking and grounding	Partial
16	FRA	Emergency Pole, shoe insulation	229.81	1993	Locomotives required to have pantograph poles or third rail insulating shoes	All
17	FRA	Head Protection	214.113	1993	Requirements for protective helmets for impact of objects and electrical shock and burns	All
18	FRA	Open-wire transmission line clearance to other circuits	236.73	1993	Design clearance for transmission lines > 750 volts to signal or communication circuits	Partial
19	FRA	Hand Operated Switches	229.87	1993	Requires covering of switches > 150 Volts, or notation not to operate under load	Partial
20	FRA	Federal Railroad Administration, Department of Transportation	200-268	1993	Requirements protection against injury from high voltage equipment in locomotives	Partial
21	FRA	Protection against personal injury	229.41	1993	Basic safety design for locomotive equipment including high voltage equipment	Partial
22	FRA	Program of instruction on operating rules	217.11	1993	Requires railroads to instruct all employees as required on operating rules	All
23	FRA	Accident/Incident Bulletin No. 162 Calendar Year 1993	162	1993	Statistics on railroad accidents and injuries	Partial
24	FRA	Accident/Incident Bulletin No. 161 Calendar Year 1992	161	1992	Statistics on railroad accidents and injuries	Partial
25	FRA	Personnel Safety on Electrified Railroads	FRA/ORD-80/36	June 1980	Analysis to increase safety on electrified railroads, particularly involving rescue personnel	Partial
26	IEEE	National Electrical Safety Code	NESC	1993	Practical work rules for working with electrical lines and equipment	All
27	IEEE	Guide to the Installation of Overhead Transmission Line Conductors	Std 524-1992	1992	Construction of transmission lines, not reviewed for work rule practices for railroads to date	Partial
28	IEEE	Guide for in-Service Maintenance and Electrical Testing of Live Line Tools	Std 978-1984	1984	Methods for bench testing and checking live line tool safety	Partial
29	IEEE	Guide for Cleaning Insulators	Std 957-1987	1987	Methods for recommended for washing insulators to maintain proper operation	Partial
30	IEEE	Guide for Protective Grounding of Power Lines	Std 1048-1990	1990	Provides work rules related to bonding and grounding practices	All
31	IEEE	Power Frequency Electric and Magnetic Fields from AC Power Lines	Std 644-1987	1987	Measurement of fields near power lines, not applicable to railroad procedures	Partial
32	IEEE	Guide for Tools and Equipment to be used in Live Line Working	Std 935-1989	1989	Information on hot tools and equipment, no work rules	Partial
33	IEEE	Guide for Maintenance Methods of Energized Power Lines	Std 516-1987	1987	Guide for Maintenance Methods of Energized Power Lines	All
34	Kurtz	The Lineman's and Cableman's Handbook		1992	Details on all aspects of electrical line work, contains OSHA rules in one section	46
35	Morrow	Maintenance Engineering Handbook		1966	R.P. for maintenance activities required on electrical equipment	Partial
36	MNCR	Electrical Operating Instructions	MN-290	Jan. 1989	Work Rules for electrical work applying to all operating departments	All
37	NJT	Electrical Operating Instructions	TRO-3	June 1991	Instructions for employees in electrified territory	All
38	NFPA	Electrical Safety Requirements for Employee Workplaces	NFPA 70E	June 1988	R.P. for working on or near electrical equipment	Partial
39	NFPA	Electrical Equipment Maintenance	NFPA 70B	Aug. 1990	R.P. for working on electrical equipment, de-energizing and grounding procedures	Chap.20
40	NFPA	Fixed Guideway Transit Systems	NFPA 130	Aug. 1993	R.P. practices to reduce risk of fire or to assist in fire fighting activities	6-11
41	NTSB	Results of a Survey on Occupational Training in the Railroad Industry	NTSB-SIR-79-1	Sept 1979	Survey of training in railroads ,included some data on electrical Class A and B workers	Partial
42	NTSB	Safety Effectiveness Evaluation of Rail Rapid Transit Safety	NTSB-SEE-81-1	Jan. 1981	Evaluation of rapid transit accidents mostly involving fire although some were electrical fires	Partial
43	NTSB	Head-end Collision of Amtrak Passenger Train No 74 and Conrail Train	NTSB-RAR-81-4	April 1981	Transcript of dispatchers requesting removal of electric power to third rail after collision	Partial
44	NTSB	Eight Subway Train Fires on NYCTA with Evacuation of Passengers	NTSB-SIR-81-5	Sept 1981	Special investigation of a series of motor control group electrical fires on subway cars	Partial
45	NTSB	Railroad Accident Report BART Fire on train 117 in Transbay Tube	NTSB-RAR-79-5	July 1979	Includes excerpts from BART Operating Rules relating to electrical power	App.G
46	NYCTA	Interagency Standard Operating Procedure Response to NYCTA Emergencies	NYCTA SOP No. 1	Aug. 1975	Emergency response procedures for New York Transit, Fire Department, and other agencies	Partial
47	OSHA	Subpart V Power Transmission and Distribution	1926.95-960		Work rules for electric distribution lines	All

TABLE 4.7 SURVEY OF SAFETY RULES, REGULATIONS, STANDARDS, AND RECOMMENDED PRACTICES

No.	Source	Title	Number	Date	Comments	Sections
48	OSHA	Safety Related Work Practices	1910.331-335		Basic safety-related work rules from OSHA	All
49	OSHA	Wiring design and Protection	1910.304		Requirements for grounding of equipment in terms of design rather than work rules	Partial
50	OSHA	General Requirements	1910.303		Requirements for working clearances and safe design of equipment areas	Partial
51	OSHA	Special Systems	1910.308		Safety requirements for design of electrical systems over 600 Volts	Partial
52	OSHA	Electrical	29 CFR 5	1981	Electrical section of OSHA Regulations	All
53	PATCO	Power Procedure Book		July 1990	Procedures for chain of custody , electric utility interface, and general electrical safety	All
54	PATH	Procedure for Routine Removal and Restoration of Third Rail Power		May 1991	Procedure for chain of custody of power removal and restoration on third rail	All
55	PANY NJ	High Tension Administrative and Safety Rules		June 1983	High Level Work Rules for High Tension Administration and Safety of Employees	All
56	ProRail	New Catenary Prepares Metro-North for High Speed Rail		Oct 1994	Work rule related aspects on upgrading of catenary on Metro North	Partial
57	SEPTA	Electric Traction Instructions	ET001	July 1990	General electrified territory instructions	All
58	SEPTA	Request for Planned Electrical Power Interruption (form)	11-91-9348-F775	Nov 1991	Form used to plan and request removal of electric power for maintenance activities	All
59	SEPTA	Indication of Voltage 650 Volts Direct Current	SOP # 020-15	Sept 1988	Specific test procedures	All
60	SEPTA	Operational Test Direct Current Breakers	SOP #020-14	Sept 1988	Specific test procedures	All
61	SEPTA	Blocking Power Traction Feeders			Emergency and routine procedures for removal and restoration of traction power	All
62	SEPTA	D.C. Cable Testing	SOP # 020-14-16	Sept 1988	Procedures for DC cable testing	All
63	SEPTA	A.C. Cable Testing	SOP # 020-1-13	Sept 1988	Procedures for AC cable testing in substations including coordination with Power Director	All
64	LIRR	Electrical Operating Instructions	CT-290	June 1991	General, AC electrified, and DC electrified territory instructions	All
65	LIRR	Safety Rules - Engineering Department Employees	S-7C	May 1986	Work rules for Overhead Line Work, on or about electrical circuits, apparatus, or equipment	All
66	UIC	Rules for Rotating Electrical Machines for Rail and Road Vehicles	O 619	Jan 1971	Requirements for electrical equipment testing and certification	Partial
67	UIC	Rules for Electric Traction Equipment	OR 616	Jan 1980	Requirements for electrical equipment testing and certification	Partial
68	VNTSC	Recommended Emergency Preparedness Guidelines for Passenger Trains	FRA/ORD-93/24	Dec 1993	R.P. safety aspects of emergency evacuation and coordination with rescue officials	Partial
69	PATH	Electrical Work Permit	PA 2497A	May 1965	R.P. for removal of power and grounding and chain of custody records	All

4.4.2 Detailed Review and Analysis

A detailed review of selected standards listed in Appendix A was made using the results of the risk reduction requirements analysis discussed in Section 3. The standards that were reviewed in detail included:

- ANSI/IEEE C2-1993 National Electrical Safety Code (NESC)[2]
- ANSI/IEEE Standards 516[3], 957[4], 1048[5]
- NFPA Standards 70E[6], 70B[7], 130[8]
- Code of Federal Regulations(CFR)
  - 29CFR (Labor)[9]
  - 49CFR (FRA)[10].

The NTPC member safety rules listed in Appendix A also were included in the detailed review. In addition, selected reports from the National Transportation Safety Board (NTSB) were included in this review. The NTSB reports included in the review were those known to have findings, conclusions and recommendations related to railroad safety rules and safe work practices. A total of 23 standards, safety rules, and recommended practices were part of the detailed review.

The primary intent of the review was to identify the specific risk reduction method(s) that are addressed by the standards and safety rules reviewed. The secondary intent of the review was to identify, if any of the risk reduction methods analyzed in Section 3 were not covered by the standards, safety rules and safe work practices expected to be used in electrified systems. The level of this review was made down to the applicable section the standard, safety rule or recommended practice.

Table B.1 in Appendix B contains the results of the review. The table has been structured as a database. It contains the following five fields:

Column 1- Sequence Number for use during later reference
Column 2- Rule Source identifying Standard/Rule/Practice title and issuing organization
Column 3- Standard/Rule/Practice Number identifying the location of the specific standard or rule within each document
Column 4- Description of each specific safety rule
Column 5- Risk Reduction Method code numbers as described in previous sections.

Table B.1 contains 1579 records.

Section 3 of this report discussed the use of risk reduction strategies as part of the requirements analysis of safety rules and safe work practices. More than 25 risk reduction methods under the six categories given were discussed as part of this strategy and these were covered in detail in Section 3. Column 5 of Table B.1 identifies those specific risk reduction method(s) which are addressed by particular sections of the referenced standard/rule/practice.

The National Electrical Safety Code addresses all of the risk reduction measures previously discussed with the exception of a specific railroad safety rule requirement to prevent inadvertent electrical bridging resulting from the connecting of cars that makeup a train. The same could be said for the newest OHSA regulations for parts 1910 and 1926 which are reflected in Table B.1. The railroad related safety rules reviewed covered all of the risk reduction strategies discussed in Section 3.

Table 4.8 summarizes the risk reduction methods for the selected industry standards and government regulations used in the matrix in Table B.1. Table 4.9 summarizes the same results for the selected railroads used in the risk reduction analysis. These tables contain the number of occurrences that a risk reduction category was found to be applicable to a particular standard or regulation.

For example, the review of the safety rules of the NESC, Part 4, showed that 65 occurrences in the NESC rules addressed risk reduction category P, preventing unwanted electrical paths. For risk reduction category D, deactivation, grounding and bonding, 33 occurrences were found in the NESC. Measures which address risk reduction category S, supervision and personal responsibility, were found to be more dominant in the NESC and IEEE 516 standards compared to the other standards and regulations reviewed. It should be noted that both of these industry consensus standards were used extensively by OSHA in its newly issued electric utility industry regulations contained in Part 1910, Section 269 of Subpart R. As expected, the FRA regulations contained in CFR 49 contained only a few specific risk reduction measures for electrified systems.

Table 4.9 summarizes the number of risk reduction occurrences found in the railroad operating instructions selected for review. Although the format and organization of the operating instructions of the electrified railroads reviewed differed from each other, it was found that they all contained similar instructions. In order to keep the Table B.2 matrix to a reasonable length (in its current form it is 31 pages long), it was decided to present in this review a more limited set of operating instructions. The risk reduction methods reviewed from the selected railroad operating instructions did show similar broad coverage as the general industry standards. As expected the instructions themselves were more specific to railroad operation and maintenance.

TABLE 4.8 RISK REDUCTION METHODS FOR SELECTED INDUSTRY STANDARDS AND GOVERNMENT REGULATIONS

Standard/Regulation	Risk Reduction Categories					
	P	D	G	C	T	S
NESC Part 4	65	33	54	22	14	40
IEEE 516	73	2	97	15	30	20
IEEE 957	6	3	4	13	4	4
IEEE 1048	20	14	0	24	58	0
NFPA 70B	9	24	1	14	5	1
NFPA 70E	29	32	13	9	13	0
NFPA 130	2	5	1	0	1	1
OSHA CFR 29	119	99	81	12	55	9
FRA CFR 49	0	12	0	0	3	0
Total	323	212	251	109	183	75

TABLE 4.9 RISK REDUCTION METHODS FROM SELECTED ELECTRIFIED RAILROAD OPERATING INSTRUCTIONS

Standard	Risk Reduction Categories					
	P	D	G	C	T	S
Amtrak AMT2	47	57	9	120	43	84
Amtrak NRPC - 1910	1	1	0	0	22	0
Amtrak NRPC - 1908	17	6	28	3	4	0
Amtrak NEC	0	5	1	11	3	1
BART EMERGENCY PLAN	1	7	0	0	1	1
LIRR S-7C	9	9	16	1	5	7
LIRR C.T. 290	12	11	14	1	4	15
Metro North MN-290	11	15	9	2	4	19
NJ TRANSIT TR03	106	124	31	129	48	91
NYCTA SOP1	4	28	2	24	5	15
PA NYNJ HTASR	30	42	31	8	4	3
PATCO	12	5	3	7	2	0
SEPTA ET 001	20	49	10	16	14	40
SEPTA other	0	14	0	7	0	8
Total	270	373	154	329	159	284

4.5 REFERENCES

1. Institute of Electrical and Electronics Engineers, "IEC and IEEE Hold Joint Technical Meeting," The IEEE Standard Bearer, Vol.9, No.3, New York, NY, July, 1995.

2. Institute of Electrical and Electronics Engineers, National Electrical Safety Code, ANSI C2-1993, New York, NY, August 3, 1992.

3. Institute of Electrical and Electronics Engineers, Guide for Maintenance Methods on Energized Power-Lines, Std 516-1987, New York, NY, February 1986.

4. Institute of Electrical and Electronics Engineers, Guide for Cleaning Insulators, Std 957-1987, New York, NY, June 11, 1987.

5. Institute of Electrical and Electronics Engineers, Guide for Protective Grounding of Power Lines, Std 1048-1990, New York, NY, April 17, 1990.

6. National Fire Protection Association, Electrical Safety Requirements for Employee Workplaces, NFPA 70E, Batterymarch Park, Quincy, MA, 1988.

7. National Fire Protection Association, Electrical Equipment Maintenance, NFPA 70B, Batterymarch Park, Quincy, MA, 1990.

8. National Fire Protection Association, Fixed Guideway Transit Systems, NFPA 130, Batterymarch Park, Quincy, MA, 1993.

9. Code of Federal Regulations, Title 29, Labor, Parts 1910-1926. Department of Labor. Office of the Federal Register, National Archives and Records Administration. 1994.

10. Code of Federal Regulations, Title 49, Transportation, Parts 200-399. Department of Transportation (USDOT). Office of the Federal Register, National Archives and Records Administration. 1993.

5. HAZARDS ANALYSIS

The prevention and minimization of avoidable accidents is the desired result of risk reduction. A method to accomplish this is through a hazards analysis, taking into consideration the characteristics of a system throughout its life cycle. A hazards analysis consists of the following:

- Identifying the hazards of a system
- Assessing probability of occurrence and consequences of such hazards
- Providing methods to control or eliminate such hazards.

Many of the hazards of the elements of an electrified railroad system have been identified through the compilation of a preliminary hazards list (PHL). A PHL is a listing of the possible hazards inherent in a system. A preliminary hazards list is typically developed concurrent with or prior to conducting a preliminary hazard analysis (PHA) [1]. The purposes of the PHA are to identify from the PHL safety critical areas within a system, to identify and roughly evaluate hazards, and to begin to consider safety design criteria.

5.1 PRELIMINARY HAZARDS LIST

The development of the PHL was accomplished concurrently with the standards review process previously discussed. A hazards list was prepared for the operation and maintenance of electrified railway equipment. The PHL development began with a brainstorming session from which the collective experience of the participants was used to identify hazards inherent to such a system. The PHL produced was not considered to be an exhaustive list. It was considered to represent a reasonable cross section of operating conditions and maintenance activities from which hazards and their causes could readily be identified. The PHL developed used the following categories:

- Hazard
- Railroad Subsystem
- Equipment Component
- Mishap

- Hazard Description
- Cause of Mishap.

The hazard categories listed in the PHL are based on the discussion in Section 3, and uses the hazards of arc, blast, shock, and EMF. These include the hazards to persons from electric shock, the thermal hazards to persons and equipment from arcs, the explosive hazards from blasts, and the operational hazards of electromagnetic fields. The category used for system components is based on the railroad electrification system discussion given in Section 2. Mishap is the term used to describe the unplanned event, or accident condition, which in turn could have resulted in injury or death, damage to equipment, and/or loss of functional performance [2]. The description of mishaps given in the table are examples of unplanned events or the conditions which lead to an unplanned event. The hazard description provides further information on the specific conditions which cause the hazard as well as its probable effect.

The cause of mishap category identifies the likely equipment deficiency or work practice condition that would have lead to the mishap. Naturally occurring events such as lightning, static electricity, and earthquakes have been included in the cause of mishap category to highlight the situations where these occurrences could have been the primary contributing cause of the mishap. It is recognized, even with naturally occurring hazardous events of the types discussed here, that design, performance and construction standards as well as appropriate safe work practices should provide some level of protection against the hazard in question.

Table 5.1 contains the results of the preliminary hazards list developed as part of this effort. The PHL shown has more than 90 entries and is organized by the hazards arc, blast, EMF, shock, and other. The distribution of the hazards listed in Table 5.1 shows that nearly 60% of the entries are fire-hazard related, when the arc and blast hazards are taken together. About 33% of the entries are electric shock-hazard related. This result is similar to the findings of other investigators who have concluded that the principal hazard of electrical systems is the fire hazard [3]. Although there are numerous reported incidents of electric shock, most of these incidents are minor in nature and relatively few have resulted in electrocution or death (per Adams in reference [3]).

Nearly all of the equipment/subsystem elements of an electrified railroad system are listed in the preliminary hazards list. For example, the use of circuit breakers are expected to be in every subsystem element and are shown accordingly. Circuit breakers have different operating and failure modes which could result in arcing, blast and shock hazards. The possible hazards resulting from a pantograph failure are specific to the vehicle itself and are reflected accordingly in the PHL.

The cause of mishap category is fairly split by the failure of equipment design standards and the failure to use appropriate safety rules and safe work practices. This finding remphasizes the need for both complete and adequate equipment and system standards as well as the use of adequate safety rules and safe work practices as the foremost means of protection against electrical hazards. As seen from the PHL, these equipment standards include those which are design, performance, construction and installation oriented.

Table 5.1 Preliminary Electrical Hazards List for Electrified Railroads

Item	Hazard	Subsystem	Component	Mishap	Hazard Description	Cause of Mishap
1	ARC	All	Surge arrester	Over- voltage flashover.	Flashover creates high energy arcing.	Equipment design, Lightning
2	ARC	All	Air blast breaker	Energy from arc is over-stretched with air blast.	Arc ignites flammable material.	Equipment design, Work rule
3	ARC	All	Wiring, power cable	Vibrating environment.	Loose connection - arcing fire hazard and/or equipment failure.	Equipment design
4	ARC	All	Circuit breakers	Mechanical stress to breaker, from seismic disturbance and weather.	Mechanical failure of circuit breaker. Excessive current flow.	Equipment design, Lightning
5	ARC	All	Shunt capacitors	Harmonic resonance .	Capacitor fuses blow, system unprotected from line surges.	Equipment design
6	ARC	All	Circuit breaker	Overvoltage due to lightning strike. No surge arrester protection.	Dielectric breakdown and circuit breaker failure.	Equipment design, Lightning
7	ARC	All	Circuit breaker	Overvoltage switching degrades circuit breaker performance.	Over exertion of equipment. Premature component failure.	Equipment design, Lightning
8	ARC	All	Power harmonic filter	Negative sequence voltage causes overheating in electric machinery.	Insulation breakdown.	Equipment design
9	ARC	All	Oil circuit breaker	Insulation breakdown due to infrequent maintenance .	Flashover and meltdown of breaker. Fault current continues.	Equipment design, Work rule
10	ARC	All	Surge capacitor banks	Loose connection after testing completed. Link not secured properly.	Overvoltage not clamped. Damage to other components.	Work Rule
11	ARC	Substation, Vehicle	Rotating machinery	Slow interruption of fast rising overvoltage waveform.	Insulation breakdown of motor windings.	Equipment design
12	ARC	All	Wiring, power cable	Overvoltages resulting from power frequency switching .	Insulation breakdown.	Equipment design
13	ARC	All	Harmonic filters	Inadequate filtering of system with phase controlled rectifiers .	Harmonics cause excessive heating to other components.	Equipment design
14	ARC	All	Power harmonic filters	Triplen frequency current flow in neutral conductors of transformer.	Insulation breakdown due to transformer overheating.	Equipment design
15	ARC	All	Circuit breaker	Current interruption during normal and abnormal operation.	Arcing fire hazard to breaker and/or to nearby equipment.	Equipment design
16	ARC	All	Grounding	Poorly grounded surge protection equipment.	Potential fire hazard from fault currents and power surges.	Equipment design, Work rule
17	ARC	Vehicle	Pantograph	Momentary loss of contact.	Fire hazard to vehicle roof. Potential penetration into vehicle.	Equipment design, Work rule
18	ARC	Vehicle	Pantograph	Lightning strokes to overhead electrical system.	Fire hazard to vehicle and electrical breakdown of equipment.	Equipment design, Lightning
19	ARC	Vehicle	Dynamic brake resistor	Overtemperature.	Fire hazard to the dynamic brakes and to nearby equipment.	Equipment design, Work rule
20	ARC	Vehicle	Pantograph	Insulation breakdown caused by defective and dirty insulators.	Fire hazard to vehicle roof. Potential penetration into vehicle.	Equipment design, Work rule
21	ARC	Substation, Vehicle	Transformer	Improper grounding of tank during oil replacement procedure.	Electrostatic discharge creates an ignition source.	Work rule
22	ARC	Substation, Vehicle	Switchgear	Power for tripping protection control equipment not available.	Battery maintenance not adequate for reliable operation.	Work rule
23	ARC	Substation, OCS	System grounding	Improper readings taken during ground resistance measurement.	Overvoltage breakdown from poor ground resistance.	Work rule, Lightning
24	ARC	All	Equipment grounding	Grounding not adequate.	Fault not diverted to ground. No interruption device operates.	Equipment design, Work rule
25	ARC	All	Wiring, power cable	Harmonic and resonant voltages resulting from harmonic currents.	Insulation breakdown.	Equipment design
26	ARC	All	Wiring, power cable	Combustion from arcing or ignition from other sources.	Insulation burns. Smoke and toxic fumes released into air.	Equipment design, Work rule
27	ARC	All	Wiring, power cable	Switching impulse voltage.	Insulation breakdown.	Equipment design
28	ARC	All	Wiring, power cable	Lightning impulse voltage caused by lightning stroke.	Insulation breakdown.	Equipment design, Lightning
29	ARC	All	Wiring, power cable	Electrostatic discharge produces an ignition source.	Spark discharge becomes a fire hazard.	Equipment design, Work rule
30	ARC	All	Wiring	Loose connection.	Pitted surfaces adversely equipment performance.	Work rule
31	ARC	All	All	Proper cleaning of equipment not performed.	Dirt and grime reduces creepage distance.	Work rule
32	ARC	All	Insulators	Liquid cleaner used during maintenance to clean insulator.	Solvent in liquid cleaner dissolves insulating material.	Work rule
33	ARC	All	Transformer	Drying out of transformer after extend down time not sufficient.	Moisture on insulating materials provides path for current flow.	Work rule
34	ARC	All	Cables	Mechanical damage of cable allows moisture to penetrate insulation.	Line-to-ground or line-to-line fault.	Equipment design, Work rule
35	ARC	All	Circuit breaker	Inspection fails to observe contact erosion from severe fault.	Contact erosion enables excessive overtravel of spring plate.	Work rule
36	ARC	Vehicle	Motor	Distortion of coils due to abnormal forces not observed.	Failure between motor turns to ground.	Work rule
37	ARC	Vehicle	Motor	Mechanical dust or other contaminants accumulate in machine.	Excessive heating from reduced ventilation.	Work rule
38	ARC	Vehicle	Motor controller	Dust, grease and grime not cleaned from controller devices.	Contacts and interlocks do not function as required.	Work rule
39	ARC	OCS	Overhead catenary	Pantograph loss of contact.	Arcing damage as well as loss of train power.	Equipment design
40	ARC	OCS	Overhead catenary	Lightning surges and abnormal electrical system operation.	Overvoltage breakdown.	Equipment design, Lightning
41	ARC	All	All	Equipment installed in damp environment.	Oxidation causes resistance increase at electrical connection.	Equipment design, Work rule
42	BLAST	All	Batteries	Overcharging.	Rupturing of battery housing container.	Equipment design, Work rule
43	BLAST	All	Transformer	Transformer operated above rated temperature for excessive time.	Rupturing of transformer tank.	Equipment design
44	BLAST	All	Batteries	Loss of ventilation.	Explosive atmosphere.	Equipment design
45	BLAST	Substation	Gas filled breaker	Loss of pressure within circuit breaker, loss of dielectric capability.	Excessive transients onto system. Hazard to equipment.	Equipment design, Work rule
46	BLAST	All	Circuit breaker	Overheating due to unexpected continuous current loading.	Insulation breakdown.	Equipment design
47	BLAST	All	Circuit breaker	Max. recovery voltage exceeded, insulation and interruption failure.	Uninterrupted fault or disconnect.	Equipment design, Work rule
48	BLAST	All	Circuit breaker	Mechanical stress from seismic disturbance and weather.	Mechanical failure of circuit breaker subassemblies.	Equipment design, Lightning
49	BLAST	Substation, Vehicle	Transformer	Improper procedure for adding insulating oil to transformer tank.	Air or moisture enters tank. Insulating capability compromised.	Work rule
50	BLAST	Substation, Vehicle	Transformer, Inverters	Spacing and clearance not sufficient for adequate ventilation.	Overtemperature of conductors causes insulation failure.	Equipment design, Work rule
51	BLAST	Substation, Vehicle	Filter capacitor	Voltage rating not sufficient for surge conditions.	Overvoltage ruptures capacitor.	Equipment design, Lightning
52	BLAST	All	Transformer	Deterioration of insulating fluid causes excessive heat buildup.	Windings shorted by insulation failure.	Work rule

Table 5.1 Preliminary Electrical Hazards List for Electrified Railroads

Item	Hazard	Subsystem	Component	Mishap	Hazard Description	Cause of Mishap
53	BLAST	Vehicle	Motor	Deterioration of armature winding not noticed.	Mechanical stress causes abrasion of insulation.	Work rule
54	EMF	All	Power harmonic filters	Source of EMI to communication, signaling and control systems.	Electromagnetic Interference .	Equipment design
55	EMF	All	EMI filters	Electrical interference.	Train control false signals and interruption of communications.	Equipment design
56	EMF	All	Harmonic filters	Inadequate filtering of power, control, communication, signal lines.	Transients into train control and communication circuits.	Equipment design
57	EMF	All	Control electronics	Electrostatic discharge produces EMI and high voltage stress.	ESD causes EMI; dielectric failure from voltage stress.	Equipment design, Static electricity
58	EMF	OCS	Overhead catenary	Inadequate means for discharging accumulated static charge.	Electrostatic discharge produces shock hazard.	Work rule, Static electricity
59	SHOCK	All	Circuit breaker	Mechanical stress from seismic disturbance and weather.	Insulation breakdown and failure to disconnect.	Equipment design, Lightning
60	SHOCK	All	Filter capacitor	Capacitor to be worked not disconnected, short-circuited, grounded.	Electric shock hazard if worked on.	Work rule
61	SHOCK	OCS	Overhead catenary	Excessive movement and/or displacement.	Loss of vertical & horizontal clearances to nearby structures.	Equipment design, Work rule
62	SHOCK	All	System grounding	Earth connection not sufficient to maintain low ground impedance.	Fault interrupt device malfunction. Excessive ground current.	Equipment design, Work rule
63	SHOCK	Substation	Gas filled breaker	Loss of pressure within circuit breaker, loss of dielectric capability.	Inability to stop current flow.	Work rule
64	SHOCK	Substation	System grounding	Grounding integrity for both operational and safety grounding.	Step potential hazard from fault current flow in earth.	Equipment design, Work rule
65	SHOCK	OCS	Overhead catenary	Insulator surfaces full of dirt and contamination.	Grounding from excess leakage current across insulators.	Work rule
66	SHOCK	Substation, Vehicle	Transformer	Improper grounding of tank during oil replacement procedure.	Electrostatic discharge creates a shock hazard.	Work rule
67	SHOCK	Substation, Vehicle	Rotating machinery	Improper grounding of machines during maintenance.	Shock potential under normal operating conditions.	Work rule
68	SHOCK	All	Equipment grounding	Grounding not adequate.	Insulation breakdown failure.	Equipment design, Work rule
69	SHOCK	All	Oil circuit breaker	Insulation breakdown from infrequent maintenance .	Flashover and meltdown of breaker. Fault current continues.	Equipment design, Work rule
70	SHOCK	All	Wiring, power cable	Mechanical abrasion and/or impact from foreign objects.	Insulation breakdown.	Equipment design, Work rule
71	SHOCK	OCS	Overhead catenary	Galvanic corrosion problems with dissimilar metals.	Loss of grounding or high impedance grounding.	Equipment design, Work rule
72	SHOCK	All	Wiring, power cable	Overtemperature of conductors.	Insulation breakdown failure.	Equipment design
73	SHOCK	All	Circuit breaker	Overheating due to unexpected continuous current loading.	Insulation breakdown.	Equipment design
74	SHOCK	OCS	Third rail	Accidental contact.	Electrical shock hazard where exposed to accidental contact.	Equipment design, Work rule
75	SHOCK	All	Grounding	Grounding integrity for both operational and safety grounding.	Inability to interrupt fault current.	Equipment design, Work rule
76	SHOCK	All	Grounding	Grounding integrity for both operational and safety grounding.	Open ground return circuit.	Equipment design, Work rule
77	SHOCK	All	Circuit breaker	Max. recovery voltage exceeded, insulation and interruption failure.	Dielectric capability of oil is reduced by excessive heat.	Equipment design
78	SHOCK	All	Insulators	Contaminated insulators on overhead catenary system.	Surface leakage causes insulation breakdown and fault current.	Equipment design, Static electricity
79	SHOCK	All	Wiring, power cable	Moisture.	Insulation failure caused by moisture penetration.	Equipment design, Work rule
80	SHOCK	Substation	Circuit breaker	During hipot operation main shield accumulates electrostatic charge.	Accumulated charge remains after hipot operation.	Work rule, Static electricity
81	SHOCK	Substation, OCS	All	Barricade/barrier not used between energized and deenergized part.	Shock hazard to maintenance worker.	Work rule
82	SHOCK	All	All	Deenergized equipment not properly grounded.	Nearby energized equipment induces electrostatic charge.	Work rule, Static electricity
83	SHOCK	All	All	Live line worker does not wear leather gloves over rubber gloves.	Mechanical abrasion causes rubber glove insulation failure.	Work rule
84	SHOCK	All	All	Improper inspection of protective clothing and equipment.	Nick or cut in insulated material reduces level of protection.	Work rule
85	SHOCK	All	All	Voltage tester gives improper voltage indication.	Improper use of equipment.	Work rule
86	SHOCK	OCS	Overhead catenary	Static charge on ungrounded conductors produces a lethal voltage.	Static charge accumulates on ungrounded conductors.	Equipment design, Work rule
87	SHOCK	OCS	Overhead catenary	Loss of catenary support structure grounding.	Touch potential from fault current flow down structure.	Equipment design, Work rule
88	SHOCK	C&S	Power & control cables	Static charge on ungrounded conductors produces a lethal voltage.	Static charge accumulates on ungrounded conductors.	Equipment design, Work rule
89	OTHER	Substation	Gas filled breaker	Compartment not ventilated and purged prior to maintenance work.	Arcing produces toxic and irritant by-products	Work rule
90	OTHER	Substation vault	Wiring, power cable	Equipment arcing and heating causes hazardous gas atmosphere.	Work in confined space prior to analysis of air quality.	Work rule
91	OTHER	Substation vault	Wiring, power cable	Worker enters vault without outside attendant.	Deficiency in oxygen overcomes worker.	Work rule
92	OTHER	Substation	Transformer	Handling requirements for different types of insulating liquids.	Hazardous material improperly handled and disposed of.	Work rule

5.2 PRELIMINARY HAZARD ANALYSIS

5.2.1 General Comments

A preliminary hazard analysis (PHA) is the initial effort in the hazard analysis. It is normally done during the system design phase of the system life cycle. It can also be done at any point in the life cycle of the system. The purposes of the PHA are to identify safety critical areas within the system, identify and roughly evaluate hazards, and begin to consider safety criteria.

The PHA begins the process of hazard discovery, assessment and hazard control [2]. The hazard discovery is the search for potential harm, and generally uses the results of the PHL as the starting point. After having identified the potential hazards, it is then necessary to analyze and evaluate their causes in sufficient detail so that a control strategy can be developed [1].

When conducting a PHA, the following activities as a minimum should be undertaken:

- A review of historical safety experience and solutions applied in similar systems

- An identification of the safety requirements and regulations pertaining to personnel safety, environmental hazards, and toxic substances with which the system must comply

- An examination of safety related equipment for adequacy.

Safety requirements include the use of both operational and maintenance safeguards. Safety related equipment includes interlocks, redundancy, and fail-safe designs in both hardware and software.

Extensive PHAs were considered to be beyond the scope of the present study and not required as part of a preliminary review and assessment. However, the initial part of the PHA was done for the maintenance of a traction substation to illustrate the role of safety rules and safe work practices as a means for reducing hazards. Also the initial part of a PHA was done for two of the naturally occurring hazardous events, namely the potential for lightning strokes, or discharges, to an electrified system, and the potential for electrostatic discharge to the system from sources of static electricity. The potentially adverse impacts of these two particular naturally occurring events have been topics of extensive research, have been well documented, and are presented here as illustrative examples.

5.2.2 Preliminary Hazard Analysis of Traction Substation Maintenance

Maintenance activities are a very important function for assuring the satisfactory operation of an electrical system. In addition to enabling equipment to accomplish satisfactory performance and to achieve normal life expectancy, these activities help reduce hazards to life and property that can result from equipment failure or malfunction. Some of the elements of an effective maintenance program include [4]:

- Work to be done by qualified personnel
- Surveys and analyses to determine maintenance requirements and priorities
- Programmed routine inspections and suitable tests
- Analysis of inspection and test reports so that proper corrective measures can be prescribed
- Performance of the necessary work
- Complete but concise records.

5.2.2.1 General Considerations

As seen from the PHL, all of the hazards analyzed in this study can be found in the traction substation. The PHL shows that the substation contains numerous potential conditions that could lead to a hazardous situation. Even though most railroad traction substations are not occupied by personnel, the hazards found in a traction substation are still present when maintenance activities are performed in and around them. Ideally, all maintenance work should be done with the substation deenergized, and with all equipment locked out and tagged out and all circuits and equipment properly grounded. For operational reasons maintenance and repair work is often done with a portion of the substation still energized. Some maintenance work may be required when all of the substation is energized.

5.2.2.2 Traction Substation Equipment

Figure 5.1 shows a simplified one-line diagram of the main components of a typical traction substation. Switches DS1 through DS5 are typically air disconnect devices connected directly to the electric utility supply lines. These lines may be operating at 138 kV or higher and the disconnect switches are typically air insulated and mounted on poles. Circuit breakers CB1 and CB2 provide fault protection to the substation and these breakers are normally mounted on bushings near ground level. Two transformers are shown each with secondary load-side circuit breakers CB3 and CB4. The transformers are generally installed as outdoor units and the load-side circuit breakers may either be located outdoors or inside a building. The catenary feeder disconnect switches DS6 through DS8 are connected to the catenary feed circuits. More load-side circuit breakers and disconnect switches may be used for multiple catenary feeders. Other typical substation equipment not shown consists of surge arresters, low voltage switchgear, motors and controls, harmonic filters, power factor correction equipment, supervisory control equipment, and where necessary converters/inverters.

5.2.2.3 Equipment Maintenance

Maintenance programs for electrical equipment include the following tasks [5]:

- Inspections
- Cleaning
- Calibration
- Replacing components/equipment
- Repairing defective components/equipment
- Operational testing.

Transformers

Transformers require periodic inspection, testing, and monitoring to determine if they are operating within their design limits. Testing is required to determine the condition of the transformer. Typical tests include; electrical performance under load, insulation resistance, cooling system measurements, evidence of coolant leaks, and inspections for overall general condition. The integrity of the transformer's insulation is an important consideration for proper operation. Insulation breakdown within a transformer leads to arcing, blasts, and possible electric shocks. Therefore insulation testing is very important.

Types of insulation used in traction substation transformers include air, sulfur hexaflouride (SF6), insulating fluid and rubber coating on conductors (used on windings). The insulating liquids most often used in transformers go under the names of Rtemp, Silicone and Wescosol. Liquid filled transformers have their cores and coils immersed in a liquid. The liquid acts as an electrical insulation medium and it also helps to transfer heat from the windings to the cooling fins.

Insulating fluid may become contaminated over time. Contaminants include:

- Oxygen
- Water/ moisture
- Sludge deposits.

If tests indicate that the insulating liquid is not in satisfactory condition, then the liquid must be either reconditioned, reclaimed, or replaced.

Circuit Breakers and Disconnect Switches

Circuit breaker and disconnect switch inspection and maintenance must also be frequent and periodic. Since circuit breaker failure can potentially cause damage to the system it is protecting, it is imperative that this inspection and maintenance cycle be adhered to. When performing the inspection of the circuit breaker the condition of the following components must be evaluated:

- Operating mechanism
- Condenser bushings
- Insulating materials
- Contacts
- Mechanical lever system
- Oil or other fluid (if used).

Unlike the transformer, which is primarily a static electrical device, circuit breakers and disconnect switches have moving parts which wear during use. Therefore, the frequency of inspections and maintenance should depend on the switching duty of this equipment. Also, a circuit breaker or disconnect switch which has been exposed to an extreme fault current should also receive immediate attention to determine the extent of the damage, if any, and the need for replacement.

There are numerous types of circuit breakers which include air blast, vacuum, SF6, and magnetic circuit breakers, to name a few. Air blast, oil and vacuum circuit breakers are expected to be the primary protection devices used in traction substations. Disconnect switches are either air insulated or SF6 type devices. When performing any activity on circuit breakers and disconnect switches, it is important to make sure that all the electrical leads are dead and that the frame of breaker or disconnect switch is grounded.

For proper operation of circuit breakers and disconnect switches, the circuit disconnecting contacts must function as designed. These contacts need special attention because if they are not in proper mechanical and electrical condition then excessive arcing will occur. This arcing may lead to device failure and for sealed units could also result in an explosive blast. To function properly the contacts must be kept clean, smooth, and in good alignment.

5.2.2.4 Safety Rules and Safe Work Practices

General Considerations. Prior to beginning any maintenance activity all workers involved should be briefed on the activity and must have adequate tools and clothing on hand to perform their functions. A qualified employee should be designated to direct the work and be responsible for safety coordination. All workers must wear protective clothing and use insulated tools designed for the job at hand. They must be made aware of what equipment is to be deenergized and what will remain energized during the maintenance activity. When disconnecting conductors and equipment, the power source end should be removed first. When reconnecting, the deenergized part should be connected first. Testing with two different devices is the recommended means for determining the power status of circuits/equipment [6].

Workers should consider all the effects of their actions, taking into account their own safety as well as the safety of others. Workers and their supervisors must assume that all exposed conductors and equipment are energized, until otherwise verified by test and inspection.

Work on Deenergized Equipment. Safety rules and safe work practices contain the procedures to be followed to effectively isolate the circuits and equipment to be worked on [7]. Verification procedures including testing are normally required prior to isolating the circuits and equipment from the power source. Lockout and tagout procedures are a key element to insure safety. All members of a work group must place their lockout and tagout devices on the appropriate circuits and equipment. Grounds must be placed on the deenergized equipment as a guard against unauthorized reenergization. Work in confined and enclosed work spaces require special precautions for assuring that the space is safe to work in.

Upon completion of the work, only the owner of a lock and tag will be allowed to remove his/her lock and tag. This will ensure that everyone involved in the maintenance activity will be aware that the electrical equipment is about to be reenergized. After completion of the maintenance activity, all work must be carefully inspected prior to reenergizing. Upon reenergizing, all circuits and equipment should be tested to verify correct operation.

Work Near Energized Equipment. In the case of work to be done near energized equipment, barricades must be erected to define the work area. Barricades provide the means for distinguishing between the location of energized and deenergized equipment in the substation. Barriers, guards, and other means of isolation, if necessary, must also be used to provide physical isolation from energized parts.

Workers must use caution, and they need to observe approach distance rules for themselves, their tools and equipment when in close proximity to energized conductors and equipment.

Alertness and adequate illumination are required to prevent accidental contact with energized equipment. Conductive apparel is not to be worn where its presence could result in an electrical contact hazard. The use of conductive materials and equipment are to be handled in a manner to prevent electrical contact. Using insulated tools and equipment is mandatory and such equipment requires frequent inspection and testing to assure their insulating integrity. Work performed on overhead lines requires the use of suitable guarding, protective equipment rated for the voltages involved, and insulated platforms or other appropriate means to provide isolation from ground in the event of accidental contact with the overhead line.

Work on Energized Equipment.

Although almost all railroad related maintenance work on circuits exceeding 480 V is done with such circuits deenergized, safety rules and safe work practices must address the situation when work on energized equipment is necessary.

Only qualified workers who have been trained to work safely on energized conductors and equipment are to be allowed to work on conductors and equipment which have not been deenergized. The use of proper personnel protective equipment, insulating shielding materials, and insulated tools are to be required. The National Electrical Safety Code [8] lists the following additional safeguards that are to be taken:

- Insulate the worker from the energized parts
- Isolate or insulate the worker from ground and grounded structures, and voltages other than the one being worked on
- Avoid working on conductors/equipment in any position from which a shock or slip will tend to bring the body toward exposed parts which are at a voltage different from the voltage on the worker's body.

Insulated aerial devices, ladders, and other support equipment shall be rated and tested for the voltages involved. Such equipment should be tested before the work is started to ensure the integrity of the insulation.

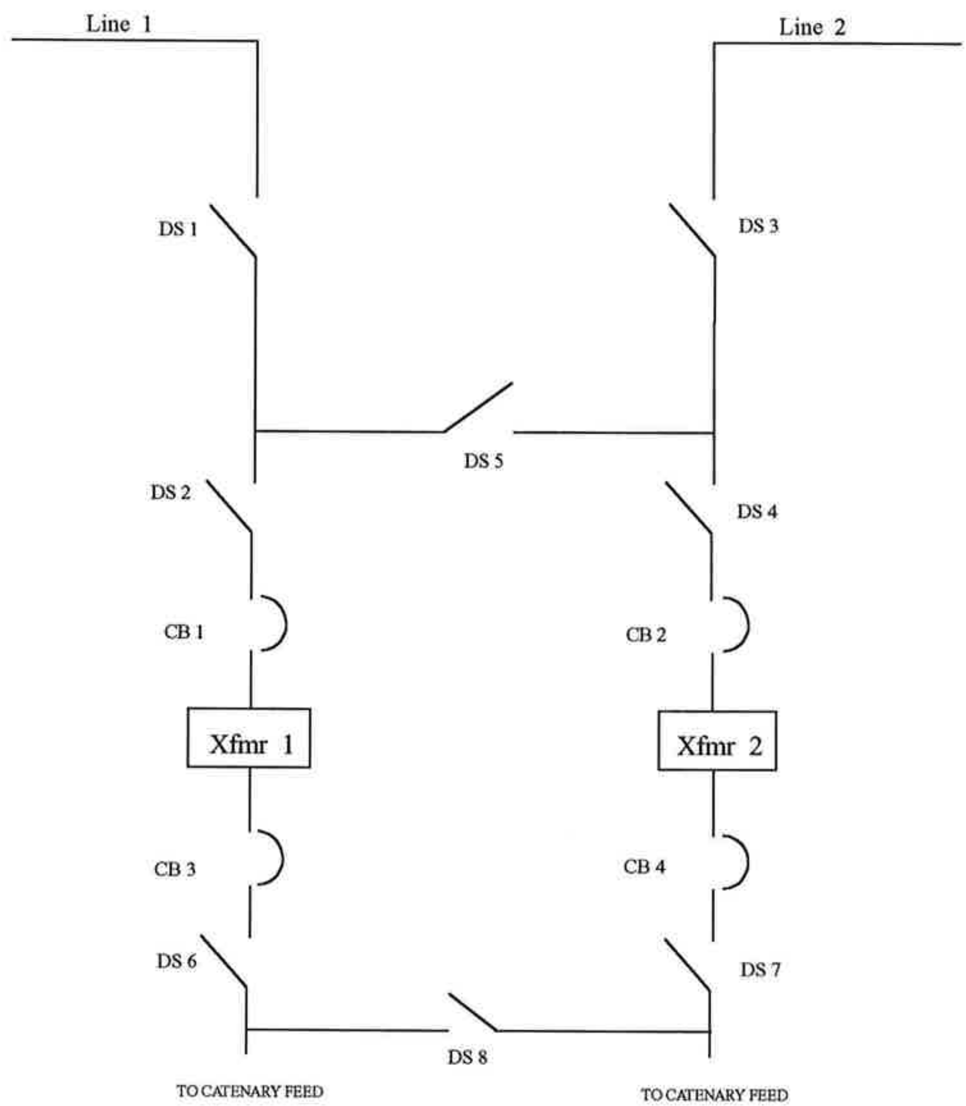

Figure 5.1 Typical Traction Substation One-Line Diagram

5.2.3 Preliminary Hazard Analysis of Lightning Strokes

The potential of a lightning flash which could cause either personal injury and/or property damage has been identified in the preliminary hazards list. A lightning flash to the earth results in a stroke, or surge current discharge from the atmosphere to the earth. The potential for bodily harm and physical damage from lightning has been a long recognized hazard. The Canadian draft standard on guidelines for railway electrification, addresses the subject of the lightning hazard as one of the overvoltage conditions that must be considered for electrified systems [9].

5.2.3.1 Background

A large body of historical data on lightning exists [10]. Ongoing research continues to update the data on the incidence of lightning discharges and their strikes in terms of their severity, frequency and density. The effects of various mitigation measures for achieving protection is also the subject of ongoing research. This is particularly true in the electric utility industry. Extensive measurements have been made of direct lightning strokes, or discharges, to the power transmission system. Power system designs have been developed and evaluated for withstanding the effects of strokes. The design philosophy apparently followed has been to achieve a desired level of service by balancing out any expected outages against the incremental costs of additional protection.

This preliminary hazard analysis has drawn on the experience of the electric power industry in dealing with lightning as a hazard. The following sections discuss the potential adverse effects from lightning and reviews some of the quantitative methodologies developed for assessing lightning strikes.

5.2.3.2 Historical Safety Experience

An electrified railway can be considered to be roughly analogous to an electric utility. Railway traction substations have the same general equipment and they usually are configured similar to electric utility distribution substations. The catenary operates at typical voltages of 11 or 12 kV to 25 kV (and sometimes at 50 kV) which is equivalent to utility level subtransmission voltages. The catenary has the same general geographic exposure as electric power transmission lines. However, high voltage transmission lines with 160 kV to 238 kV ratings have heights approaching 100 feet above the ground. A typical catenary height above ground for at grade construction would be in the 20 to 30 foot range. For elevated structures it might range from 40 to 60 feet above the ground.

Electric utility experience with the adverse impacts of direct lightning strokes dates back to the early part of this century when long distance transmission lines first came into widespread use. The lightning hazard to high voltage transmission lines became apparent as direct strikes from lightning caused electrical outages and in some instances physical damage to the transmission system. Extensive research had been done in the period just prior to World War II and is still an ongoing activity.

The incidence of lightning strokes in a geographical region has been found to be approximately related to the thunderstorm activity in that region. For a given region, the number of thunderstorm days per year is called the keraunic level. Maps of annual thunderstorm activity are called isokeraunic maps, and these maps have been extensively developed for most of the major land masses on earth. The isokeraunic map for the continental U.S. (CONUS) is shown in Figure 5.2 [11]. In a hazard analysis, an isokeraunic map is used as part of the analysis to identify the frequency of lightning strokes and to estimate their potential density over a particular area.

Isokeranunic maps exist for all of North America. As seen from Figure 5.2, most of the northeastern U.S. lies within the keraunic level of 30 (which means that the mean number of thunderstorm days per year is 30). The transcontinental mid-portion of the U.S. is located between keraunic levels 40 and 50. A small area in south central Florida is in the highest keraunic region of the country and experiences more than 100 thunderstorm days per year. Most of the gulf coastal region has a keraunic level of 70. All of the coastal area in the west has a keraunic level of 10.

Much of the historical analysis of lightning probability and severity by the electric utility industry apparently has been based on the keraunic level of 30 [12]. This is most likely the result of early measurements, since most of these measurements were made for areas in the northeast where the keraunic level for much of that region is 30. It has been claimed that many of the design procedures developed from these measurements can be extrapolated to other keraunic levels by a simple ratioing of the keraunic level of interest to a base keraunic level of 30 [12].

5.2.3.3 Lightning Currents and Overvoltages

Electric power transmission and distribution lines, because of their geographical layout over long distances, are quite vulnerable to lightning. Lightning-related surge voltages in the electric power system are the result of the stroke current contained in the lightning discharge. The resulting surge voltages which arrive at a substation, or other equipment connected to the system (such as an electric locomotive in an electrified railway), are typically caused by:

- Lightning flash terminating on the overhead shield wire with a subsequent flashover to a phase conductor. This is sometimes denoted as a backflash

- Lightning flash terminating directly on a phase conductor which is usually called a shielding failure

- Lightning flash terminating nearby to the system and inducing a surge voltage into the system.

Line shielding has been found to be a very effective method of protecting phase conductors from direct strokes. This is accomplished through the use of a grounded conductor running above the transmission line phase conductors and periodically grounded at steel towers or through other means of connecting to the ground. Stroke current flowing in a shield wire is shunted to ground. This prevents the stroke from entering the phase conductors as long as an insulation capability is maintained between the shield and the phase conductors. Depending on the magnitude of the resulting surge voltage, there may be a significant amount of surge current induced in the phase conductors.

For a lightning stroke on or nearby a transmission line, the lightning surge voltage magnitude and its wave shape at the equipment location is a function of:

- Magnitude and waveshape of the stroke current

- Distance of the stroke from the line for the induced stroke case

- Transmission tower, steel pole or power ground lead surge impedance

- Transmission line surge impedance

- Tower footing or pole ground resistance

- Lightning impulse critical flashover voltage of the line insulation.

Measurements of lightning stroke current have been shown to have peak current median values of about 30 kA. The largest recorded measured value is about 270 kA [13].

5.2.3.4 Adverse Effects From Lightning Strikes

The resulting impact of a lightning stroke directly into the electrical system is typically a very high surge current which flows into the system as a result of the lightning discharge. The surge current, in conjunction with the system impedance, produces an overvoltage on the system. The impact of a geographically nearby strike is an induced current into the system which is typically at a lower value of current compared to the direct strike condition.

The effects of lightning strokes to power systems can be grouped in the following broad categories:

- Structural damage to the electrical system with no resulting fire
- Structural damage and fire damage to the electrical system
- Overvoltage flashover with no power system outage
- Overvoltage flashover with power system outage.

System outage here is meant to be a fault current condition which causes system protective equipment to open and to thus deenergize the system. Along with a system outage there may or may not be physical damage to the system or other structures nearby resulting from the effects of the stroke current or voltage.

Experimental observations have shown that the direct lightning strike to the electrical system is the principal hazard requiring protection [12][14]. A system designed to withstand overvoltage resulting from the surge current of a direct strike generally has the insulation capability to safely withstand the lower overvoltage resulting from an induced strike. This is especially true of systems which operate at levels of 69 kV or higher.

Protection from the direct strike hazard is still considered to be the primary requirement for lower voltage systems. This includes the voltages typically used in railroad catenaries. However, the ability of these systems to safely withstand the lightning overvoltage is less certain. The insulation levels that are normally built into lower voltage systems have not in general been inherently capable of absorbing the effects of a lightning produced high voltage without insulation failure. Insulation failure at these voltages almost always result in an outage as well as some damage to the system.

In addition to the hazard of potentially destructive overvoltages, there is the fire risk of a lightning stroke. This risk depends upon both the magnitude and duration of the stroke current. The waveform, or shape, of the stroke current can be characterized as steeply rising to a maximum or crest value followed by an exponential type decay. There is some experimental data to show that a 10-kA crest stroke current with a decay time lasting for 10 μsec will not ignite the wood, but that one lasting for as long as 40 msec would result in the wood catching on fire.

5.2.3.5 Lightning Strike Hazards to Personnel

Another potentially very serious effect of lightning is that of the electric shock hazard to operating personnel or to the general public. The major hazard to be considered here is not only the direct stroke accident, but also the potential hazard for injury resulting from current flow in nearby structures. A lightning flash that results in surge current flowing in a structure produces a voltage gradient along that structure. This situation could result in a potentially very serious or perhaps even a lethal shock hazard to anyone nearby [15].

The result of surge current flowing to ground through a vertical structure creates what is called the touch potential hazard. Surge current flowing through or along the surface of the earth creates what is called the step potential hazard. The terms "touch" and "step" are defined by ANSI/IEEE industry standards [16]. Touch potential (or voltage) is defined as the potential or voltage difference between a grounded metallic structure and a point on the earth's surface approximately one meter away. Step potential (voltage) is defined as the potential difference between two points on the earth's surface separated by a distance of approximately one meter.

Figure 5.2 [15] illustrates the above two definitions. As shown in this figure, the potential rise in the case of the step voltage condition imposes on a person a voltage gradient between that person's feet. For the touch voltage case a voltage gradient exists between the point on a structure touched by a person and the ground upon which that person is standing. These potential differences, or voltage gradients, exist when current flows through a structure to the earth or material upon which a workman is working on or standing on. Of particular concern for the lightning strike is the surge current condition that would likely occur where such a voltage gradient could be dangerously high.

The Canadian draft standard on railway electrification guidelines, Reference [9], has recommended limits for step and touch potentials as part of the requirement for grounding of facilities. The grounding system for station buildings, platforms, yards and maintenance shops is to limit the maximum step or touch potential to 120 V rms during the worst design fault condition and to 12 V rms under the worst case operating conditions.

5.2.3.6 Lightning Stroke Severity and Probability

The relative severity of the lightning hazard is dependent on the magnitude of the overvoltage which results from a direct or induced stroke current to the system. In addition to the magnitude of the stroke current, the degree of the severity of the hazard also depends on its frequency of occurrence. The magnitude of the overvoltage is directly related to the magnitude of the surge current that results from the strike.

Stroke current magnitude as well as its probability of occurrence has been a subject of extensive investigation in the electric utility industry, and data on these factors is continually being updated and refined. Appendix C contains spreadsheet type files which were developed from several of the sources reviewed. The spreadsheet summarizes the pertinent equations often used to model lightning stroke severity.

One measure of the magnitude of the severity of a lightning stroke is given by what is called the lightning stroke current probability curve. As discussed above, the magnitude of the overvoltage is directly related to the surge current resulting from a stroke. Lightning stroke probability curves are generally given as the percentage of strokes that exceed a given value of stroke current. The probability $P(I_o)$ that the magnitude of the stroke current (I_o) will equal or exceed I_o (for I_o in kA) can be estimated. Such a curve can be found in Appendix C along with the pertinent equations for its development.

Figure C.1 and Table C.1 in Appendix C show the resultant values for the probability $P(I_o)$, for a range of stroke currents. From this curve we can see that about 95% of all stroke currents would have expected values of the order 10 kA or more. About 50% of the stroke currents would have values not exceeding about 30 kA, and less than 5% of all stroke currents would be expected to have a crest value exceeding 100 kA.

The relative frequency of lightning strokes within a specified area is generally specified by the ground flash density (N_g) which is usually given in flashes per km^2. However, data on the average annual value of N_g in the U.S. has not been generally available, but can be estimated from known keraunic levels (K). The relationship between ground flash density and keraunic level has been developed and can be found in Appendix C. Figure C.2 and Table C.2 in that appendix show the relationship of N_g to K, for a range of keraunic values. Using K=40 as the average keraunic value for CONUS, the ground flash density comes out to be about 13 ground flashes per square mile. For most of the northeast where K=30, the flash density is about 9 strokes per square mile per year.

The induced surge voltage which results from the stroke current can be estimated and its development also can be found in Appendix C. As seen from that appendix, the surge voltage depends on several physical parameters as well as the characteristics of the lightning discharge.

Table C.1 in Appendix C shows the expected surge voltage for a specified transmission line height. The surge voltage magnitude is proportional to the surge current magnitude. For a surge current of 30 kA and for a line having a nominal voltage of 25 kV, which would be a typical catenary voltage level, the surge voltage would result in a voltage rise of about 22% above the nominal 25 kV. For a surge current of 60 kA, the voltage rise would nearly double to about 43% above the nominal value. This is further discussed in that appendix.

For transmission lines the density measure is sometimes given as the number of strokes per year for a given distance of transmission line. This density measure is further discussed in Appendix C. From the analysis given in that appendix and for a keraunic level of 30 which is the typical value for the northeastern U.S., about 96 flashes per year of direct strokes would be expected to occur for each 100 miles of line, or an average of about 8 flashes a month to the line. For south central Florida which has a keraunic level of 100, about 460 flashes per year would occur for each 100 miles of line or about 38 direct strike flashes a month.

Most of the historical data found in the literature which uses this type of density measure, has been based on an isokeraunic level of 30, which is again the level found in much of the Northeast. Line density estimates can be made for the other isokeraunic levels. This could be accomplished by using the level 30 density as a base level reference and then by simple ratioing of the isokeraunic levels obtain a density measure for the keraunic level of interest. The relative accuracy of this straight line approximation for extrapolating to other keraunic levels can be seen in Figure C.4 in Appendix C.

5.2.3.7 Utility Experience With Lightning Hazards

The data developed by many researchers on lightning over the past 20 years indicates that the lightning stroke data which was used during the early history of the development of high voltage transmission lines apparently had underestimated one aspect of the severity of the hazard. The probability of higher surge current magnitudes is now considered to be more severe than originally believed to be. However, the relationship of lightning to keraunic levels or thunderstorm activity has been shown to be a valid one, although recent data shows a stronger relationship to thunderstorm hours rather than to thunderstorm days. The relative severity of the hazard is directly related to surge current magnitude as well as the frequency of lightning strikes.

The use of the grounded shield wire running along and above the power line has been shown to be a very effective method for achieving protection from lightning. In the case of the direct stroke, the lightning discharge is conducted directly to ground through the shielding wire to grounded support structures. Voltage breakdown of the system is prevented as long as the insulation integrity of the power line is maintained.

In summary, electric transmission and distribution line design procedures have been in use for some time which use lightning stroke current probability curves in conjunction with isokeraunic levels. These procedures have been used to estimate the probability of an outage condition for a specific system design. The design philosophy apparently has been based on achieving a desired service level, translated into expected outage conditions. The design approach evaluates various design parameters against probable outages and a design is selected that would be able to operate successfully up to a given value of surge current. The system design parameters include tower height, tower footing impedance, conductor wire span length, physical separation distances of the conductor wire from the tower at the connection point to the tower, conductor sag distance to ground at the midspan point, and separation distances of shielding ground wires both at the tower and at the midspan point.

5.2.3.8 Lightning Strike Hazards to Structures

Structures that are at ground level in and of themselves do not attract lightning. A tall structure becomes an attractor to lightning only if the lightning would have struck the earth in the general vicinity of the structure. However, for certain tall structures, such as radio towers and high rise buildings (heights greater than 60 m), the incidence of a lightning flash may be triggered by the presence of these structures [14].

A hazard index for structures, particularly for building type and tower type structures, has been developed by various standards organizations [17] as a means for assessing the risk of a lightning strike. The index discussed in Reference [13] uses six elements to categorize the level of hazard. These elements include:

- Type of construction used
- Contents contained within the structure
- Degree of isolation of the structure from its surroundings
- Type of terrain the structure is on
- Height of the structure relative to its surroundings
- Keraunic level for the location of the structure.

Additional factors to be considered in developing hazard levels include public safety as well as the usage of the structure. The use of the hazard index will be discussed further as part of the discussion of assessing the risk of a lightning strike.

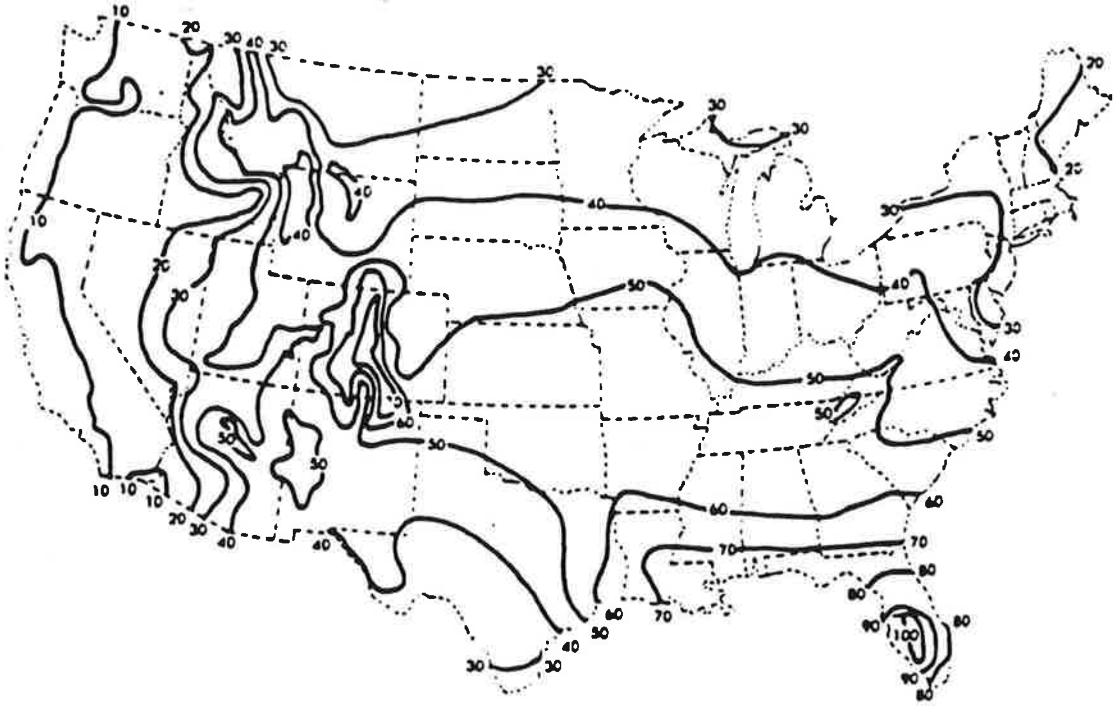

Fig. 5.2 **Isokeraunic curves for the continental United States.**

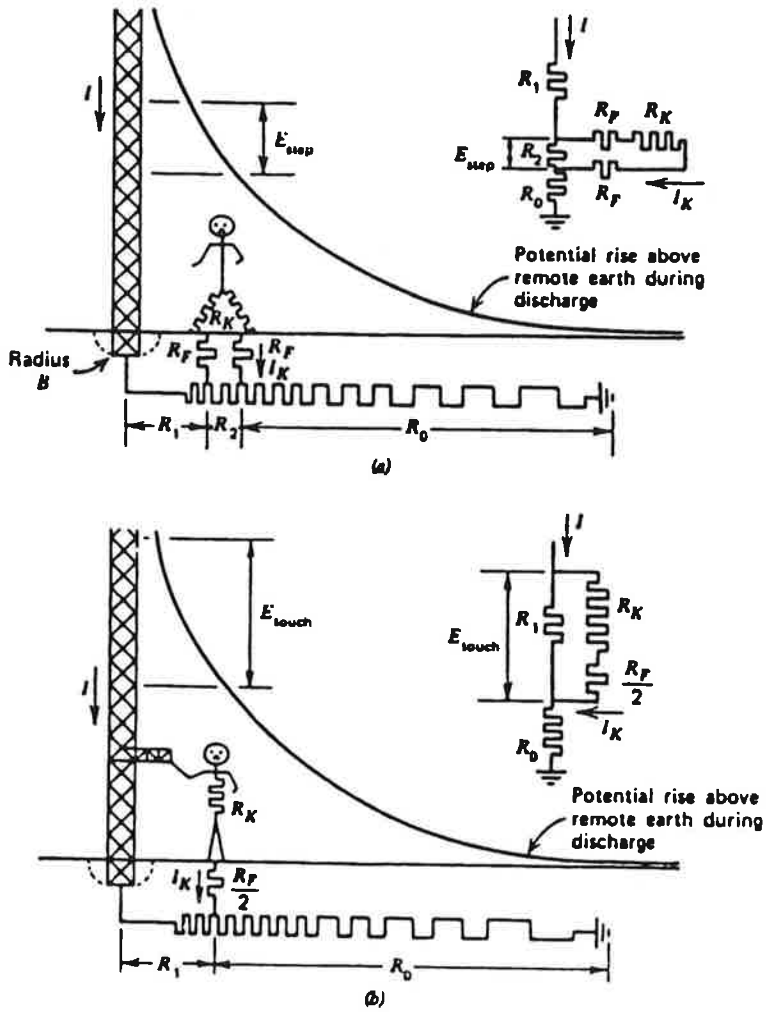

Fig. 5.3 *Step voltage (a) and touch voltage (b) at a grounded structure.*

5.2.4 Preliminary Hazard Analysis of Static Electricity

Static electricity results when electric charge accumulates on objects. The result is an electrostatic field which is created about a charged object.

5.2.4.1 Background

Static electricity is a very common occurrence and exists almost everywhere in nature [18]. Examples of its existence include the small amounts of charge that accumulate when a person combs one's hair and in large amounts when sparks are emitted from machinery. Lightning is a form of static electricity and probably represents the most extreme magnitude for an electrostatic discharge.

5.2.4.2 Generation of Static Electricity

Static charge can be made to exist on an object through any of several methods. Static charge is usually generated either by induction, frictional motion, ion bombardment, or by physical contact. Poor electrical conductors, that is materials with high dielectric strength, are excellent accumulators of static electricity.

Induction Process. The induction process is a result of the phenomenon of attraction of unlike electrical charges. The accumulated charge on an insulator, or insulated object, will attract an equal and opposite charge on the nearest surface of any conducting body when it is brought close to the insulator. Momentary contact of the conducting body to ground will leave an accumulated charge on its surface nearest to the charged object. Charge can also be induced on an object (such as an insulated wire elevated above the surface of the earth) if a charged body (such as a cloud) moves into its vicinity.

Frictional Motion Process. The frictional motion process is a result of two substances of different composition which are brought together into moving physical contact with each other. One of the substances gives up some of its electrons to the other substance. Although the total net charge of the two substances when taken together remains the same, one of the substances becomes negatively charged along its contact surface. The other substance becomes positively charged along its contact surface as a result of some of its electrons being "stripped" away by the other substance. If the substances are nonconductive and if they are pulled apart, each substance will retain its net charge. Electrostatic charging by frictional motion is enhanced by the speed of separation, or the speed of relative movement of one substance with respect to the other.

Ion Bombardment Process. The ion bombardment process is a result of the surface of a substance being subjected to bombardment by an ion shower. An example of an ion shower is that which would originate at a corona point. Corona in air is a luminous discharge and is the ionization of air caused by a high voltage gradient surrounding a conductor. The exposed surface becomes charged either by an attachment of the ions to the surface or by surrendering electrical charge to the surface of the ions. Once the high voltage gradient exceeds a critical value, actual breakdown of the air occurs which then results in an arcing flashover.

Contact Process. The contact process of static electrification is a result of a charged object being brought into contact with an uncharged object. Some of the charge will be transferred from the charged object to the previously uncharged object.

5.2.4.3 Energy Storage and Electrostatic Voltage

The magnitude of electrostatic voltage that can exist on an object is determined by the amount of electrostatic energy that exists on that object. The energy that can be accumulated on an object for a specified charge magnitude can be estimated through an equivalent capacitance model. The development of this model can be found in Appendix D.

In the atmosphere, the amount of charge (q) that can be accumulated on the object is based on the maximum voltage (V) that can be supported before breakdown of the air dielectric occurs. The maximum electric field that can be sustained in air before breakdown is of the order of 3×10^6 V/m [19].

5.2.4.4 Historical Safety Experience of Electrostatic Hazards

The most recognized hazard of static electricity historically has been associated with static electricity as an ignition source in flammable atmospheres and with combustible liquids. This results in a fire hazard to personnel, and as a fire hazard to industrial processes where the potential for a spark discharge could result in a fire to the industrial process or to its byproducts, or result in some form of physical interference with the process itself [20]. The hazards of static electricity now have been extended to physical damage to certain electronics equipment and as a source of electromagnetic interference (EMI) [21].

Static Electricity as an Ignition Source Hazard in Flammable Atmospheres and With Combustible Liquids. Static charge is built up when moving liquids are in contact with other materials. An example would be a liquid flowing through a pipe such as a hydrocarbon. The static charge which has accumulated in the liquid as it exits the pipe leaves a static charge on the pipe. If the pipe is insulated from ground, it accumulates charge as a function of the liquid flow and eventually could obtain enough voltage for a spark discharge from the pipe to ground. The spark could then be an ignition source for either the liquid or other nearby flammable material.

Static Electricity as a Personnel Hazard. The primary hazard to personnel is the ignition hazard. This hazard requires the presence of flammable or combustible material. The small electrostatic spark an individual experiences after walking across a nylon carpet rug contains more than enough energy to ignite a flammable vapor. A person insulated from ground can acquire sufficient charge to reach a potential of several thousand volts. A simple model for estimating the electrostatic charge and potental on a human can be found in Appendix D. It is not uncommon for static charge on a human to build to voltage levels of 10 kV or more. In certain industrial operations, electrostatic voltages of about 50 kV have been observed [22].

Using the model values found in Appendix D, results in the charge storage in a human to be of the order of 1.25 mJ to 375 mJ. The spark ignition energy for certain gas mixtures is of the order of 2 mJ [11], and depending upon the mixture and environmental conditions can become as low as 0.4 mJ [22]. Reference [22] reports that the majority of ignition incidents recorded has occurred at an energy level of about 25 mJ. This corresponds to an electrostatic voltage level of about 13 kV when a capactance value of 300 pF is used in the model equations given in that appendix.

Another hazard of static electricity is the electric shock hazard. Shock from static electricity can result in discomfort and under certain circumstances injury to personnel. In most situations discharge energies are less than 100 mJ. The injury primarily occurs from involuntary body reaction to the shock. A discharge of this level is itself not dangerous to humans, but involuntary reactions such as falls or entanglements with machinery are among the major sources of injury.

When an employee is working in an electric field, his/her body is being charged. If the worker comes in contact with a grounded object there is the potential for a shock. This shock could cause involuntary reactions and, if working from a ladder or platform, could cause the worker to fall. Serious injuries could result from the fall.

If discharge energies approach a magnitude of several joules, the resulting shock could render an individual unconscious [23].

Although considered rare, discharge energies of several joules could occur as a result of an individual touching a highly charged and well insulated object.

It is important to note that the use of proper protective clothing and equipment would mitigate the severity of such a hazard.

Static Electricity as an Industrial Process Hazard. Processes that involve mixing, blending and the movement of non conducting materials can become a source of static electricity. Other processes from which static electricity may be generated include operations involving coating, spreading and impregnating.

The primary hazard to be considered is the spark ignition hazard. If as part of the process, flammable liquids, vapors and combustible materials are present, a static discharge must be considered as a probable source of ignition. In addition to the ignition hazard, the presence of static electricity may also result in physical interference to the process itself. The hazard here then becomes the probable accident to workers as well as the potential failure of critical process equipment to function properly.

Static Electricity as an ESD Hazard Event to Sensitive Electronic Equipment and Components. In recent years, static electricity has been identified as a probable cause of damage to certain electrical and electronic equipment. With the advent of microprocessors and integrated circuits in electronic equipment, as well as other sensitive electronics components, the electrostatic discharge (ESD) resulting from either direct contact or from induction through the presence of an electrostatic field now has been recognized as a hazard. This hazard occurs in the form of a sparking or nonsparking electrostatic discharge, and it has been shown to be the cause of physical damage to circuit components in such equipment.

The electrostatic discharge for this hazard is sometimes called an ESD event. One of the primary causes of component failure appears to be the result of excessive voltage stress, caused by the electrostatic field, on the dielectric material used for component fabrication. The ESD event causes dielectric failure of these materials, thus creating a short circuit. Another failure mode is the thermal damage (i.e., shorts or opens in circuit elements with low thermal mass) which occurs as a result of injected current flow into the device, where the injected current is a consequence of the ESD event. Industry and government standards have recently been introduced to better define the ESD hazard. References [21], [24] and [25] contain selected lists of such standards.

Static Electricity as a Source of EMI. Electrostatic discharge produces electromagnetic fields. The fields produced by an ESD event have broadband frequency characteristics. The broadband spectra ranges from low kilohertz to low gigahertz frequencies. The fields are transient in nature and have maximum levels of the order of a few kilovolts/meter for E fields and a few tens of amperes/meter for H fields [25]. These levels are well within those which represent potential EMI problems to sensitive signaling, communication and control equipment. The broadband radiated interference limits recommended by the SAE for rapid transit vehicles when measured at a distance of 100 feet from the track centerline varies from about 30 mV to well under 1 mV depending on the frequency range of interest [26]. This of course indicates that the EMI fields produced from electrostatic discharges must be attenuated through the use of shields and filters.

5.2.4.5 Control of Electrostatic Hazards

Control of the generation itself of static electricity would appear to be the primary means for the control of electrostatic hazards. However, as discussed above, since static electricity is such a pervasive phenomenon and exists almost everywhere, its elimination would be very difficult to accomplish.

An important measure for the control of electrostatic hazards is to eliminate it from becoming an ignition source. To prevent static electricity from becoming an ignition source requires that ignitible mixtures or material be removed from any area where static electricity may be discharged as a spark. Alternative measures for isolation and removal would include the use of adding inert gases to enclosed tanks of flammable materials, and the use of mechanical ventilation systems for circulating air.

Another measure most often used is to control the amount of static charge that can be accumulated on an object or person by dissipating that charge before it reaches the spark discharge level. Methods for accomplishing this include bonding and grounding, conductive clothing (particularly conductive shoes), and if possible, humidification of the environment.

The EMI hazard is most effectively controlled by providing the potentially affected equipment with immunity from EMI. This is usually accomplished by shielding sensitive equipment and by filtering all power and signal lines to such equipment so as to prevent conducted interference from entering such equipment.

Design guidelines have been developed [21][25] to specifically address the ESD hazard to sensitive electronic equipment. These guidelines vary from the specifics of the electronic circuit design itself and the circuit fabrication processes used, to the design of equipment enclosures, and to the handling of components during manufacturing and shipping, including the use of special antistatic packaging. Installation guidelines have been developed which include the use of grounding methods and recommend minimum handling of sensitive components. One of the recommended grounding methods is the use of ground straps for personnel involved in the installation of sensitive components.

5.3 REFERENCES

1. Roland, H. and B. Moriarty, B., System Safety Engineering and Management, John Wiley and Sons, Inc., New York, NY, 1990.

2. U.S. Department of Defense, System Safety Program Plan Requirements, MIL-STD-882C, January 19, 1993, page 6.

3. Adams, J.,Electrical Safety, A Guide to the Causes and Prevention of Electrical Hazards, IEEE Power Series 19, The Institution of Electrical Engineers, London, United Kingdom, 1994, page 99.

4. National Fire Protection Association, Electrical Equipment Maintenance, NFPA 70B, Batterymarch Park, Quincy, MA, 1990.

5. Westinghouse Electric Corporation, Westinghouse Electrical Maintenance Hints, Trafford, PA, 1974.

6. Gill, A., Electrical Equipment Testing and Maintenance, Reston Publishing Co., Reston, VA, 1982.

7. National Fire Protection Association, Electrical Safety Requirments for Employee Workplaces, NFPA 70E, Batterymarch Park, Quincy, MA, 1988.

8. Institute of Electrical and Electronics Engineers, National Electrical Safety Code, ANSI C2-1993, New York, NY, August 3, 1992.

9. Canadian Standards Association (CSA), Railway Electrification Guidelines, C22.3 No.8-M91, July 1991, p.19.

10. Meliopoulos, A., "Lightning and Overvoltage Protection,", Standard Handbook for Electrical Engineers, Section 27, McGraw-Hill, New York, NY, 1993.

11. Glover, J. and Sarma, H.,Power System Analysis and Design, PWS Publishing Co, Boston, MA, 1994, p.507.

12. Central Station Engineers, Electric Transmission and Distribution Reference Book, Westinghouse Electric Corp., 1964, pp.542-609.

13. T. Bernstein, "Lightning Protection for Buildings, Equipment and Personnel," Electrical Hazards and Accidents, Van Nostrand Reinhold, New York, NY, 1991, pp. 135-155.

14. Eriksson, A. and Meal, D., "The Incidence of Direct Lightning

Strikes to Structures and Overhead Lines,"IEEE Conference on Lightning and Power Systems, London, June 1984.

15. Marshall, J., Lightning Protection, John Wiley & Sons, New York, NY, 1973, pp.104-108.

16. Institute of Electronics and Electrical Engineers, The New IEEE Standard Dictionary of Electrical and Electronics Terms, Std 100-1992, New York, NY, 1992.

17. National Fire Protection Association, Lightning Protection Code, 1992 Edition, NFPA 780, Batterymarch Park, Quincy, MA. August 1992, pp.34-36.

18. Schmieg, G., "Static Electricity: Causes, Analysis and Prevention," Electrical Hazards and Accidents, Van Nostrand Reinhold, New York, NY, 1991.

19. Haase, H., Electrostatic Hazards, Their Evaluation and Control, Verlag Chemie, Weinheim, Germany, 1977.

20. National Fire Protection Association, Static Electricity, NFPA 77, Batterymarch Park, Quincy, MA, August 20, 1993.

21. McAteer, O., Electrostatic Discharge Control, McGraw-Hill, New York, NY, 1990.

22. Cross, J., Electrostatics, Principles, Problems and Applications, Adam Hilger, Bristol, England, 1987.

23. British Standards Institute, Control of Undesirable Static Electricity, Part 1, General Considerations, Part 1, BS5958, 1992.

24. Institute of Electrical and Electronics Engineers, IEEE Guide on Electrostatic Discharge (ESD): Characterization of the ESD Environment, Std C62.47-1992, New York, NY, March 16, 1993.

25. Boxleitner, W., Electrostatic Discharge and Electronic Equipment, IEEE Press, New York, NY, 1989.

26. Society of Automotive Engineers, Electromagnetic Compatibility and Interference of Rapid Transit Vehicles, Recommended Practice ARP 1393, April 3, 1976.

6. HAZARD RISK ASSESSMENT

The principal focus of this report has been the discussion of the hazards of electrification and the means for mitigating these hazards. After a hazard is identified some method must be followed to determine how probable a hazard event is, and what are the consequences associated with the hazard. This section addresses a preliminary assessment of these hazards through risk assessment.

6.1 RISK ASSESSMENT-GENERAL CONSIDERATIONS

Risk can be defined in a number of different ways, but its definition has one element common to all ways of defining it. That common element is that risk entails the probability of the occurrence of an adverse event. Several definitions of risk that have relevance to this study (per Hammer in reference [1]) include:

- The probability of an accident
- The probability of a person being injured or killed
- The loss or losses a manufacturer or operator or user can suffer from an accident or series of accidents.

Implicit in these definitions is the need to consider uncertainty when describing or measuring risk. Another way of describing risk is that risk is the likelihood of an adverse effect in terms of hazard severity and probable occurrence [2].

Risk assessment is the evaluation of a particular risk to decide whether or not the outcome that the risk presents is reasonable and that it can either be accepted, or that it must be reduced by some protective measure, or that it is unacceptable and to the extent possible must be eliminated. One of the results of a risk assessment is its use to determine whether or not probable losses over some period of time are acceptable losses. Another use is to decide on the amounts that can be justifiably expended to mitigate the risk to an acceptable level.

Methods for quantifying risk generally fall into two categories, the relativistic method and the probabilistic method [1]. Both methods have similar objectives which is to arrive at some measure of the risk and to determine its degree of acceptance and/or the need for mitigation.

The relativistic method of risk assessment generally involves assigning a range of qualitative ratings. These ratings then enable the risk being evaluated to be divided among several categories of acceptance. The ratings are typically used as a screen from which the relative safety level of that risk can be identified. The probabilistic method of risk assessment generally relies on the ability to calculate probability values for the occurrence of a risk. In a manner similar to the relativistic method, the probability of occurrence also is compared to a rating system that enables the calculated risk to be measured against some rating criteria.

MIL-STD-882C is a widely recognized source for system safety engineering and safety management [2]. The recommended method for performing risk assessments in MIL-STD-882C, as well as in several industry standards, is to rely on some combination of both methods. However, even with the use of the qualitative descriptors found in that standard, heavy reliance is made of the use of quantitative methods to develop hazard risk indices as part of the screening process. A brief summary of the MIL-STD-882C approach follows.

Tables 6.1 and 6.2 describe hazard severity and likelihood categories. Table 6.1 describes the hazard as varying from catastrophic, critical, marginal, or to negligible. Numeric ratings are listed for each of these categories. Table 6.2 identifies the likelihood of a hazard occurring. These are shown as frequent, probable, occasional, remote or improbable. The definitions for each of these categories are also given in the tables.

TABLE 6.1 HAZARD SEVERITY CATEGORIES

Description	Category	Definition
Catastrophic	I	Death, system loss or severe environmental damage.
Critical	II	Severe injury, occupational illness, major system or environmental damage.
Marginal	III	Minor injury, occupational illness, or minor system or environmental damage.
Negligible	IV	Less than minor injury, occupational illness, system or environmental damage.

TABLE 6.2 HAZARD LIKELIHOOD CATEGORIES

Description	Category	Description
Frequent	A	Will occur frequently in the system.
Probable	B	Will occur several times in life of system.
Occasional	C	May occur at sometime in life of system.
Remote	D	Unlikely but possible to occur.
Improbable	E	So unlikely, can be assumed not to occur.

Using Tables 6.1 and 6.2, a hazard risk assessment matrix can be developed similar to the form shown in Table 6.3. This table combines the categories listed in the prior tables into an index where frequency of occurrence and hazard category have been combined. The table also shows suggested quantitative probability criteria recommended in MIL-STD-882C for the frequency of occurence of a hazard where the hazard event is shown in the table as the variable X. The variable X represents an expected value usually measured over some period of time.

TABLE 6.3 HAZARD RISK ASSESSMENT MATRIX

Hazard Category / Frequency	(I) Catastrophic	(II) Critical	(III) Marginal	(IV) Negligible
(A) Frequent ($X > 10^{-1}$)	IA	IIA	IIIA	IVA
(B) Probable ($10^{-2} < X < 10^{-1}$)	IB	IIB	IIIB	IVB
(C) Occasional ($10^{-3} < X < 10^{-2}$)	IC	IIC	IIIC	IVC
(D) Remote ($10^{-6} < X < 10^{-3}$)	ID	IID	IIID	IVD
(E) Improbable ($X < 10^{-6}$)	IE	IIE	IIIE	IVE

Using the hazard risk index shown above, one can relate the hazard risk to the degree of acceptance of such a risk. The suggested criteria given in MIL-STD-882C are:

Hazard Risk Index	Acceptance Criteria
IA,IB,IC,IIA,IIB,IIIA	Unacceptable
ID,IIC,IID,IIIB,IIIC	Undesirable (Management Decision Required)
IE,IIE,IIID,IIIE,IVA,IVB	Acceptable With Review by Management
IVC,IVD,IVE	Acceptable Without Review

Acceptance criteria such as that shown above have been used in prior USDOT safety reviews [3].

6.2 HAZARD SEVERITY FOR ELECTRIFIED RAILWAYS

Table 6.4 shows the relationships of the primary hazards of electrified railways using the hazard severity indices described above. As previously discussed, the primary hazards of an electrified railway can be grouped into the hazards resulting from the potential of fire resulting from an electric arc, an electric shock to persons, explosive or blast effects of electric equipment failures, and electromagnetic fields (EMF).

The potential for injury and damage resulting from an electric arc is usually associated as a fire hazard although other hazards can result from arcing. The second hazard is the potential for injury and death to humans associated with an electric shock. The blast hazard is the potential damage and injury which could result from the explosive effects of electric arcs occurring within the confined spaces of electrical equipment. The explosive effects of an elecrtic arc is usually categorized as a blast hazard since the primary damage is from the explosive effects of the hazard as opposed to the fire damage effects. It is known that the electromagnetic interference (EMI) is a hazard, particularly as source of interference to sensitive control and communication systems.

TABLE 6.4 HAZARD SEVERITY FOR ELECTRIFIED RAILROADS

Hazard	Category	Mishap	Description
Arc Shock Blast EMI	I	Death or System Loss.	Fatal electrical shock or burn or large-scale equipment failures. Entire railroad rendered inoperable.
Arc Shock Blast EMI	II	Severe Injury or Occupational Illness. Major System Damage.	Severe electrical shock or burn or major equipment failure. Major portions of railroad rendered inoperable.
Arc Shock EMI	III	Minor Injury or Occupational Illness. Minor System Damage.	Minor electrical shock, burn, or other minor injuries or equipment failure. Isolated sections of railroad rendered inoperable.
Shock EMI	IV	Less Than Minor Injury. Less Than Minor Damage.	Less than minor electrical shock or equipment failure. Railroad operations not impacted.

All hazards have the potential to cause death, severe injuries and major system damage, either directly or indirectly, up to the total loss of a system. System here is meant to include any major segment of a railway whose loss essentially shuts down that segment of the operation. The hazards of shock, arcs and EMI would be the hazards of most concern for the minor injuries and incident mishaps of an electrified railway.

6.3 RAILROAD REPORTED ACCIDENTS AND INJURIES

6.3.1 FRA Accident/Incident Reporting

The FRA maintains an accident/incident reporting system, in accordance with 49CFR Part 225 [4]. The regulation requires that railroads, including those which provide commuter or other short haul rail passenger service, must file monthly accident/incident reports whenever such accidents/incidents occur. There are nearly 800 railroads that have the responsibility for reporting into the FRA accident/incident information system. Specifically excluded from reporting requirements are those rapid transit operations located in an urban area that are not connected into the general railroad system [5].

Reportable events fall into three basic categories; train accidents, highway-rail accidents, and any other event that results in death, injury or occupational illness. A train accident must be reported if the damages exceed $6400, and a highway-rail collision is reportable regardless of severity. Incidents that result in death or injuries to either authorized or unauthorized persons on a railway system also must be reported.

An annual Accident/Incident Bulletin [6] is published by the FRA and is based on the monthly reports submitted throughout the prior year. Among the numerous statistics presented in the annual report, the bulletin summarizes reported accident/incidents by type and name of railroad, by state, by accident/incident cause, accident severity, and casualties including fatalities by type of person (e.g., job category). Casualties to individuals reported include those who were authorized individuals and those who were not authorized (tresspassers) to be on railroad property.

The reporting system for casualties to railroad personnel is organized by casualty occurrence codes. There are more than 300 such casualty occurrence codes listed in reference [5]. These codes cover both railway equipment and maintenance of way and structures. In addition to the casualty occurrence codes, there are about 80 codes for reporting specific injuries including occupational illnesses. Occupational illnesses are defined in 49 CFR Part 225.

There are 9 occurrence codes for reporting electrically related casualties. Three of the codes are related to railway equipment and the remaining 6 codes deal with maintenance of way and structures. These are summarized in the following table, and the code designations listed were those effect in October 1992 [5].

TABLE 6.5 ELECTRICALLY RELATED CASUALTY OCCURRENCE CODES

Code	Occurrence
	While Operating Or On Locomotive
101	Burn or Electric Shock Equipment Standing
101T	Burn or Electric Shock Equipment Moving
	Servicing Or Maintaining Equipment
820	Electrical Flash, Shock or Burn
	Maintenance Of Way And Structures
870	Electrical Flash, Shock or Burn
892	Working On or About Signal, Communications, Catenary-Flying or Falling Objects, Burns and Similar Occurrences Not Elsewhere Classified
942	Electrical Flash, Shock or Burn-Other
942T	Electrical Flash, Shock or Burn-Equipment Moving
947	Electrical Flash, Shock or Burn Due to Contact With Catenary, Pantograph or Third Rail-Other
947T	Electrical Flash, Shock or Burn Due to Contact With Catenary, Pantograph or Third Rail-Equipment Moving

As can be seen from this table, the primary hazards, namely shock, arc and blast are part of the casualty events listed by the FRA. However, since these hazards are listed and reported as a group, it is not possible to differentiate among each of these specific hazards and what their distribution would be of the reported casualties. A future detailed examination of the reporting records might shed some light on how many incidents were actually the result of arcs and blasts as opposed to electrical shocks.

6.3.2 Reported Electrically Related Casualties

There are about ten railroads, including the three utility owned private coal hauling railroads that have electrified operations over all or over some part of their system. The traffic on the seven public systems is nearly all passenger traffic. This group includes; Amtrak (ATK), Long Island Railroad (LI), Metro North Commuter Railroad (MNCW), New Jersey Transit Rail Operations (NJTR), Northeast Illinois Regional Commuter Rail (NIRC), Port

Authority Trans Hudson (PATH), and the Southeastern Pennsylvania Transportation Authority (SEPA). The private coal hauling railroads include the Black Mesa and Lake Powell (BMLP), American Electric Power Service Corp (AEPS) and the Texas Utilities Service Co (TES). The 4-letter codes shown in parentheses are the railroad codes used with the FRA accident/incident reporting system.

A review of the accident/incident bulletins was made for the three most recent reporting years. The seven electrified passenger traffic railroads reported electrically related injuries for the period 1991 through 1993. Tables 6.6 and 6.7 summarize the reported electrically related injury data; this data was extracted from the accident/incident bulletins for those years. Table 6.6 includes the signal and communications casualty code (892). Table 6.7 presents the same data but with the signal and communications code removed.

Included in both tables are the total of all injuries reported by year for each of the railroads listed in the tables. For example, Amtrak, in Table 6.6, reported for 1993 that it experienced 18 electrically related injuries out of a total number of 1286 injuries from all causes. For Amtrak for this particular year, we have a ratio of about 1.4% of electrically related injuries to the total number of injuries. Summing all years and all railroads for the 1991-1993 period gives us 166 electrically related injuries compared to a total of all injuries of 9920, or a ratio of about 1.7%. Table 6.7 shows similar but slightly smaller ratios when the signaling and communications casualty code is removed. During the reporting period of 1991-1993, there were no electrically-related fatalities to employees reported by any of these railroads.

Tables 6.8 and 6.9 show electrically related incidents reported by all railroads for the 1991-1993 time period. The casualties listed in Table 6.8 include those related to signal and communications systems and Table 6.9 excludes that particular code. The casualties reported in these tables have been divided into the two major groups, namely locomotive/equipment related casualties and maintenance of way related casualties. About 57 railroads reported electrically related injuries and these included the seven railroads listed in Tables 6.6 and 6.7. Thus, an additional 50 railroads reported electrically related incidents/accidents for the time periods reviewed; these railroads are diesel electric powered systems.

Table 6.8 shows that the average number of casualties for locomotive equipment was about 46 per year for the years shown. This compares to an average of about 20 casualties per year for the electrified railroads listed in Table 6.6. Table 6.8 shows the average number of maintenance of way casualty occurrences to be about 126 per year for the years shown in the table. This compares to about 35 casualties per year for the electrified railroads shown in Table 6.6.

The average number of casualties per railroad for the railroads listed in Table 6.6 was about 8.6 casualties for the locomotive/equipment related occurrence codes and about 15.1 casualties for the maintenance of way related occurrence codes. Similar data for the 57 railroads listed in Table 6.8 shows about 2.4 casualties for the locomotive/equipment category and about 6.7 casualties per railroad for the maintenance of way category.

Table 6.10 compares electrically related casualties to industry reported totals for all casualty codes. For example, in 1993 the total number of electrically related injuries was 113 out of a total number of 18,319 casualties reported for all casualty codes. The electrically related injuries were about 0.6% of the total injuries reported. The industry wide total reported casualties seem to be dominated by injuries related to maintenance of way compared to injuries related to locomotives and equipment.

Table 6.11 summarizes railroad reported fatalities. It can be seen that the dominant fatalities were those incurred by trespassers. For the existing electrified railroads, there were no electrically related fatalities reported for employees and contractors. Also for the existing electrified railroads, the number of electrically related trespasser fatalities varied between 1 and 3 percent of the total number of trespasser fatalities from all causes [6].

TABLE 6.6 INJURIES TO EMPLOYEES OF ELECTRIFIED RAILROADS WITH S&C

Occurence Code	Railroad Name: ATK 1991	ATK 1992	ATK 1993	LI 1991	LI 1992	LI 1993	MNCW 1991	MNCW 1992	MNCW 1993	NIRC 1991	NIRC 1992	NIRC 1993	NJTR 1991	NJTR 1992	NJTR 1993	PATH 1991	PATH 1992	PATH 1993	SEPA 1991	SEPA 1992	SEPA 1993	Total
101		1														1						2
101T		1	1				1															3
820	7	3	5	13	7	4	8	2								2	3	1				55
870	3		3	13	9	7	6	3	7	1				2	1	1		1				57
892	5	7	6				2		3				5	4	1			2		1	1	37
942			2	1	1	1								1		2		1				9
942T			1													1						2
947																			1			1
947T																						
Total	15	12	18	27	17	12	17	5	10	1	0	0	5	7	2	7	3	5	1	1	1	166
All Injuries Total	1150	1132	1286	978	815	669	599	547	550	123	90	91	231	243	218	208	207	220	196	164	203	9920
Ratio Electrical/All	1.3%	1.1%	1.4%	2.8%	2.1%	1.8%	2.8%	0.9%	1.8%	0.8%	0.0%	0.0%	2.2%	2.9%	0.9%	3.4%	1.4%	2.3%	0.5%	0.6%	0.5%	1.7%

TABLE 6.7 INJURIES TO EMPLOYEES OF ELECTRIFIED RAILROADS WITHOUT S&C

Occurence Code	Railroad Name: ATK 1991	ATK 1992	ATK 1993	LI 1991	LI 1992	LI 1993	MNCW 1991	MNCW 1992	MNCW 1993	NICR 1991	NICR 1992	NICR 1993	NJTR 1991	NJTR 1992	NJTR 1993	PATH 1991	PATH 1992	PATH 1993	SEPA 1991	SEPA 1992	SEPA 1993	Total
101		1																				1
101T		1	1				1															3
820	7	3	5	13	7	4	8	2								2	3	1				55
870	3		3	13	9	7	6	3	7	1				2	1	1		1				57
942			2	1	1	1								1		2		1				9
942T			1													1						2
947																			1			1
947T																						
Total	10	5	12	27	17	12	15	5	7	1	0	0	0	3	1	6	3	3	1	0	0	128
All Injuries Total	1150	1132	1286	978	815	669	599	547	550	123	90	91	231	243	218	208	207	220	196	164	203	9920
Ratio Electrical/All	0.9%	0.4%	0.9%	2.8%	2.1%	1.8%	2.5%	0.9%	1.3%	0.8%	0.0%	0.0%	0.0%	1.2%	0.5%	2.9%	1.4%	1.4%	0.5%	0.0%	0.0%	1.3%

TABLE 6.8 ELECTRICALLY RELATED INCIDENTS WITH S&C (892)

RR	←— Locomotive/Equipment Occurrence Code 101, 101T, 820 —→ 1991	1992	1993	←— Maintenance of Way Occurrence Code 870, 942, 942T, 947, 947T,892 —→ 1991	1992	1993
ALS		1				
AM	1					
ARR		1				
ATK	7	5	6	8	7	6
ATSF				7	7	4
BCLR				1		
BN	4	4		34	28	12
BPRR			1			1
BRC				1		
CAGY		1				
CC					1	
CNW	1	2				2
CP				1		
CPVM				1		
CR	3	3	5	11	5	7
CSX	3	1	1	12	10	6
CWR	1					
DME					1	
DRGW	1	2	1	1	1	
EJE		1				
FEC				2		
FRVR					1	
GTW				1	1	
HBT						1
IAIS	1					
IC				2	3	3
LI	13	7	4	14	10	8
LRWN			1			
MET			1			
MNCW	9	2		8	3	10
NERR					1	
NICD				1		1
NIRC				1		
NJTR				5	7	2
NOT				1		
NS		2			2	1
NTRY						1
NW				1	2	3
OTVR		1				
PATH	3	3	1	4		4
PBR		1			1	
PLE					1	
SEPA				1	1	1
SOO	1			7	7	6
SP	7	4	1	5	12	7
SRC		1				
SSW				2	1	1
TCWR						1
TMBL			1			
TNER			1			
UP	2	7	3	15	16	11
URR				2		
WC		1	1	1		
WE	1				1	
WSOR		2				
Total By Year:	58	52	28	150	130	99
Total By Category:	138			379		

TABLE 6.9 ELECTRICALLY RELATED INCIDENTS WITHOUT S&C (892)

RR	<— Locomotive/Equipment Occurrence Code 101, 101T, 820 —>			<— Maintenance of Way Occurrence Code 870, 942, 942T, 947, 947T —>		
	1991	1992	1993	1991	1992	1993
ALS		1				
AM	1					
ARR		1				
ATK	7	5	6	3		6
ATSF				4	4	2
BN	4	4		2	2	
BPR			1			
CAGY		1				
CNW	1	2				2
CR	3	3	5	2		1
CSX	3	1	1		3	1
CWR	1					
DRGW	1	2	1	1	1	
EJE		1				
IAIS	1					
IC					1	
LI	13	7	4	14	10	8
LRWN			1			
MET			1			
MNCW	9	2		6	3	7
NIRC				1		
NJTR					3	1
NOT				1		
NS		2				
NTRY						1
NW						1
OTVR		1				
PATH	3	3	1	4		2
PBR		1			1	
SEPA				1		
SOO	1			3	1	
SP	7	4	1		2	1
SRC		1				
SSW				1		
TMBL			1			
TNER			1			
UP	2	7	3	1	2	3
WC		1	1			
WE	1					
WSOR		2				
Total By Year:	58	52	28	44	33	36
Total by Category:	138			113		

TABLE 6.10 REPORTED INJURIES FOR TRAIN AND NON-TRAIN INCIDENTS

Codes	Reporting Year		
Locomotive/Equipment	1991	1992	1993
101	8	7	3
101T	7	4	1
820	43	39	24
Subtotals	58	50	28
MOW			
870	32	23	27
942	13	11	11
942T	1	3	2
947	6	8	4
947T	1	0	1
892	107	98	68
Subtotals without 892	53	45	45
Subtotals with 892	160	143	113
Industry Subtotal: Train Incidents	5217	4453	3894
Industry Subtotal:Non-Train Incidents	17131	15664	14198
Industry Total	22348	20117	18092

TABLE 6.11 RAILROAD REPORTED FATALITIES

	Reporting Year		
All Railroads	1991	1992	1993
All Causes			
Employees/Contractors	57	46	69
Trespassers	675	646	663
Electrified Railroads			
All Causes			
Employees/Contractors	11	4	4
Trespassers	172	117	133
Electrically Related Causes			
Employees/Contractors	0	0	0
Trespassers	4	4	2

6.4 LIGHTNING HAZARD RISK ASSESSMENT

The exposure risk from lightning has been thoroughly studied and documented. Quantitative methods of assessing the risk from lightning have been developed, tested and updated. The risk assessment discussion on lightning which follows is intended as an illustrative example of performing a risk assessment.

6.4.1 Risk Assessment-General Considerations

The exposure risk from lightning is essentially determined as the probability of a structure being hit by a lightning stroke or discharge. This probability or expected event is further modified by the extent to which a direct or nearby strike would likely cause damage to the structure and injury to people in or nearby the structure.

There are several methods for assessing the magnitude of such a risk. One method considered is that contained in the lightning protection standard of the National Fire Protection Association (NFPA) [7]. This method makes use of a risk index value. This value is related to the isokeraunic level (see distinction in sect. 5.2.2.2) for the vicinity of the structure and to certain values assigned to certain characteristics of the structure. These characteristics include the use of the structure, its type of construction, its contents and/or consequential effects, its degree of isolation with respect to its surroundings and the type of terrain that the structure is located in. The lightning strike risk value determined from these factors is a relative risk rating.

Alternative methods for assessing the risk of the lightning hazard can be found in European standards such as the British Standards Institute (BSI) [8]. The method given in the British standard is a more quantitative approach which involves first determining the probability of a strike. The probability value determined is then also modified by a set of index values assigned to the type and use of the structure in a general manner similar to the NFPA standard. The risk value determined with this method can be expressed as the probable number of strikes per year. As noted in Appendix E, the BSI standard appears more suitable for use where railway facilities are involved.

6.4.2 Risk Assessment Methodology

The approach recommended for estimating the risk of a lightning strike is based on and is a modification of the British method of determining the probable number of lightning strikes per year to an exposed area. This recommended method makes use of lightning flash density (flashes/km^2) which is the expected number of lightning strikes per unit of area, the area of the structure/facility in question, and a set of weighting factors related to the type of structure, construction materials used, its relative location with respect to other structures, the general topography surrounding the structure, and the occupancy and contents of the facility. The risk assessment factor values given in the NFPA standard have been revised to reflect the weighting factors that would be applicable for use with the recommended risk assessment approach.

Table 6.12 lists the classification criteria to be used. Four categories are listed and are based on structure usage and the consequential effects of a failure. The consequential effects vary from minor loss of operation, to significant and severe disruption, to major consequences in terms of environmental and human cost.

Table 6.13 classifies the exposure level as a function of the overall risk factor (R). As seen from the table, exposure level is given as one of four classes which are listed as negligible, low, medium, and high. Dependent on the consequential loss rating and the R value determined from the risk assessment, a structure or facility will fall into one of these four classes.

Note that Table 6.13 follows the general format of the hazard risk assessment matrix found in MIL-STD-882C and discussed above in Section 6.1. The frequency of occurrence descriptor and probability values given in Table 6.12 have been tailored to the lightning hazard risk assessment. For the obvious reason of the lightning stroke phenomenon, the improbable type category listed in Table 6.3 above has been dropped from Table 6.12.

TABLE 6.12 CLASSIFICATION OF STRUCTURES AND CONTENTS

Structure Usage and Consequential Effects of Damage to Contents	Consequential Loss Rating
Domestic dwellings and structures with facilities equipment of low value and small cost penalty due to loss of operation	1.0
Commercial and industrial buildings with essential operations and sensitive equipment where its damage and downtime could cause significant disruption	2.0
Commercial or industrial applications where loss of operations, control and other processes could have severe financial costs	3.0
Highly critical operations and processes where loss of control or equipement may lead to severe environmental or human cost(e.g. nuclear plant, chemical works, etc.)	4.0

TABLE 6.13 CLASSIFICATION OF EXPOSURE LEVEL

Consequential Loss Rating	Exposure Level			
	R<0.005	0.005=R<0.0499	0.05=R<0.499	R>0.5
1	Negligible	Negligible	Low	Medium
2	Negligible	Low	Medium	High
3	Low	Medium	High	High
4	Medium	High	High	High
NOTE. Exposure level categories in this table are based on a lightning risk assessment only. If transients of other origins are present, consideration should be given to upgrading protectors. For example, if the risk assessment suggests a surge protection device suitable for medium exposure level is appropriate, the presence of inductive switching transients may make the selection of a high exposure device more appropriate.				

A more detailed discussion of the recommended method for estimating the risk of a lightning strike, including the appropriate equations and data to be used, is given in Appendix E.

6.4.3 Lightning Risk Assessment Results

Several cases were analyzed to evaluate the potential risk of a lightning strike. The cases evaluated were structured to include at grade and elevated track right-of-way in both urban and rural areas and traction substations located in both urban and rural areas. The analysis considered a variety of terrain conditions.

The specific cases considered were:

- Traction substation in an urban location on flat terrain
- Traction substation in a rural location on flat terrain
- Traction substation in a rural location on hilly terrain
- Railway Right-of-Way in an urban location and at grade
- Railway Right-of-Way in a urban location and elevated
- Railway Right-of-Way in a rural location and at grade
- Railway Right-of-Way in a rural location and elevated.

The above cases used keraunic level as the parameter to determine the overall risk factor (R). The lightning risk exposure level was then determined following the suggested breakdown given in Table 6.13. The consequential loss rating category selected for these cases was category 2 from Table 6.12, which is the category to be used for the consequential effects resulting in significant disruptions.

The results of the cases analyzed can be found in Appendix E. As can be seen from the results, operating in an urban environment would have exposure levels varying from negligible to medium for the category 2 loss rating. For operating in a rural or open environment, the exposure levels would vary from low to high. Using a keraunic level of 40, which defines large portions of the continental U.S. (CONUS), operating in a urban environment would result in exposure levels of low to medium. Operating in a rural or open area the exposure levels then become medium to high. As expected the elevated track and hilly location for substation conditions results in a high exposure risk to a lightning strike for most of the keraunic levels expected to be found in the CONUS.

The keraunic level versus geographic region can be found in Table E.22 in Appendix E. These are summarized below for selected CONUS regions.

Keraunic Level for Selected CONUS Regions

Region	Keraunic Level
West	10
Northeast	30
Midwest	50
S.Florida	90

Using the overall risk values determined for the cases considered above, the risk exposure levels for these CONUS regions are summarized below.

Lightning Exposure Risk for Traction Substations

Region	Rural Territory	Urban Territory
West	Medium	Negligible
Northeast	High	Low
Midwest	High	Low
S.Florida	High	Medium

For the traction substations cases considered, the assumption made was that these installations would be located in hilly regions with the substation being the dominant height structure. Only the West Coast region had a Negligible risk for the traction substation cases considered. The results of this assumption are apparent for all other CONUS regions since the resulting exposure risk rating was determined to be High for the rural territory cases.

Lightning Exposure Risk for Railway Right-of-Way

Region	Rural Territory	Urban Territory
West	Medium	Low
Northeast	Medium	Low
Midwest	Medium	Medium
S.Florida	High	Medium

For the railway right-of-way cases considered, the assumption for the elevated track cases was that the right-of-way became the dominant height structure. The resultant exposure risk ratings varied between Low and Medium, except for the Southern Florida region where the exposure risk rating was High since the keraunic level is 90 or higher. From the results given in Appendix E, it also can seen that an exposure risk rating of High will be reached for elevated track in any rural territory where keraunic levels exceed 60. CONUS regions in the Southeast, Gulf Coast and all of Florida have keraunic levels of 60 or higher.

The data from which the above results were obtained can be found in Appendix E. As can be seen from the above, significant lightning hazards to electrified railroads can occur to non-urban trackage and wayside equipment in many regions of the U.S.

However, technological means for dealing with lightning strikes when they occur have reached a high level of maturity in the electric power industry. Hazards due to lightning should be considered no barrier to the decision to electrify a railroad.

6.5 REFERENCES

1. Hammer, W. Product Safety Management and Engineering, Prentice-Hall Inc, Englewood Cliffs, N.J., 1980.

2. System Safety Program Requirements, U.S. Department of Defense, MIL-STD-882C, 19 January 1993.

3. Dorer, R. and Hathaway, W., Safety of High Speed Magnetic Levitation Transportation Systems: Preliminary Safety Review of the Transrapid Maglev System, DOT/FRA/ORD-90/09, November 1990.

4. Code of Federal Regulations, Title 49, Transportation, Part 225, Federal Railroad Administration (FRA), Department of Transportation (USDOT), Office of the Federal Register, National Archives and Records Administration. 1992.

5. FRA Guide for Preparing Accidents/Incidents Reports, Federal Railroad Administration, DOT/FRA/RRS-22, October 1992.

6. Accident/Incident Bulletin No. 162, Calendar Year 1993, Federal Railroad Administration, June 1994.

7. National Fire Protection Association, Lightning Protection Code, NFPA 780, Batterymarch Park, Quincy, MA, 1992.

8. British Standards Institute, Code of Practice for Protection of Structures Against Lightning, BS 6651, 1992.

7. FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

7.1 FINDINGS

The following are the findings made from this study:

1. There are numerous industry-wide standards, guidelines and recommended practices related to the design, performance, installation, operations and maintenance for nearly all of the types of equipment that would find usage in electrified railway systems. However, most of the standards identified from the review are standards for electrical systems in general and are not railroad specific. Therefore, their applicability to the railway environment would necessarily be initially by analogy. In a manner similar to that seen in other countries, railway electrification-specific standards would be expected to evolve as a result of increasing usage of electric energy for traction.

2. The standards review showed that there may be some railroad specific equipment, one example being impedance bonds, that do not appear to be covered by any related industry standards. It should be recognized that the review of industry standards conducted in this study was not intended to be all inclusive and in fact, standards not uncovered in this review may exist for such equipment. Also for the case of an impedance bond, industrial standards were found for all of the component parts that make up an impedance bond.

3. Historically, there has been little formal coordination between foreign and domestic standard organizations, particularly as to the technical content of specific standards which are issued by these organizations. The extent of any coordination to date has been informal and done at the level of selected working committees to informally conduct reviews and make comments to planned standards revisions. Further, it was found that there is little formal cross referencing on the contents of such standards, which makes it difficult in finding the comparability of the many standards which purportedly deal with the same subject matter. Efforts by the IEEE, NEMA and EEI in the U.S. and the IEC in Europe are now underway to develop formal liaison relationships between certain IEEE standards groups and the IEC. A recent IEEE/IEC workshop addressed the means for expediting the harmonization of IEEE and IEC standards for certain types

of electric power equipment that would be germane to railroad electrification.

4. The hazard risk reduction methods for safe work practices reviewed in this study were found to be already embodied in existing government regulations and industry-wide standards. Again, the regulations and standards identified in these findings were not found to be railroad specific, but were general purpose and electric utility specific regulations and standards. The government regulation found to be the most encompassing with regard to safe work practices is the recently revised OHSA standard, 29CFR parts 1910 and 1926. The industry standards found to be the most encompassing with respect to safe work practices are the National Electrical Safety Code, ANSI C2-1993, for electric power generation, transmission and distribution type systems, and the Electrical Safety Requirements for Employee Workplaces, NFPA 70E for general industry usage.

5. The safety rules reviewed of the currently electrified railroads in the U.S. were found to achieve the desired hazard risk reduction strategies for operation and maintenance safety rules and safe work practices. As to be expected, the rail industry safety rules reviewed were found to be more suited to the railway's operating environment than were the more general regulations and standards pertaining to electrical systems.

6. Because of system configuration similarities, the hazards of lightning and static electricity to an electrified railway have the same relative frequency and severity as that which exists for the electric utility industry. The protective design and special construction practices developed and used by the electric industry can similarly be applied to a railway and should be able to achieve similar levels of protection for electrified railways.

7. Reported electrically related incidents and accidents to railroad employees are a very small percentage of the total number of reported railroad incidents and accidents from all causes. Further, the number of electrically related incidents and accidents by railroads with electrified train operations is similar in magnitude to the number of electrically related incidents and accidents reported by the railroad industry as a whole.

8. For the three most recent years of incident and accident statistics publicly available for review, four fatalities

were identified as being electrically related. All fatalities were found to be trespassers and were not railroad employees.

7.2 CONCLUSIONS

Based on the findings of this study, several conclusions have been reached, of which the first is fundamental:

1. The primary hazards of electrical systems in general are the hazards resulting from electric shocks, electric arcs and explosive blasts. Electric shocks are well known to cause severe injury and even possible death. Electric arcs can cause severe burns to individuals and also can be the cause of equipment and facility fires. Explosive blasts can cause injuries and damage to other equipment and facilities. The design of electrified railways and their operating procedures must take these hazards into account, especially in situations specific to the railroad environment.

2. The hazard of most likely concern to the general public would be that of an electric shock. Passengers on station platforms could be exposed to the overhead catenary. This hazard is considered to be remote for normal system conditions because of the physical distance between catenary and platform. However, the possibility of broken catenary could result in energized catenary coming into close proximity to a platform. Station platform structures also could be subjected to ground fault currents which could expose individuals to step and touch voltage shock hazards. Careful system design is required to ensure that all of these hazards remain as remote hazards.

3. An additional hazard of an electrified railway is the potential exposure to electromagnetic fields (EMF). These fields, when in the form of electromagnetic interference (EMI), can cause equipment to malfunction and to even be the cause of system shutdown. In some circumstances, EMI may also become the cause of failure of life safety medical appliances.

4. The hazards from electrified railway systems can be maintained to acceptable levels by appropriate system and equipment design and through the development and use of safety rules and safe work practices. Industry-wide

standards, guidelines and recommended practices already exist and can be used for achieving appropriate safety levels in new system and equipment design. Federal regulations, industry-wide standards and guidelines also exist for electrical power system employee safety rules and safe work practices. Where necessary, these standards could be augmented by providing specific requirements for electric railway systems.

5. Any wide-scale increase in railroad electrification is not expected to significantly impact the total number railroad worker accident incidents and injuries that are reported by the FRA each year. The adoption of appropriate safety rules and safe work practices (such as those already developed by NTPC members), would be expected to further reduce electrically related accidents and incidents that are reported. Increasing usage of railway electrification may become problematic for dealing with the situation of trespassers and vandals. Cursory reviews of electrical accidents in European systems also has shown trespasser and vandal problems. It will most likely require more public education about the increased hazards to the public associated with the use of electricity as traction energy on railroads.

6. The general results of this study can also be extended to the electrical system parts of diesel electric operation, because:

   - The power supply for signal and communication systems may be the same for both types of operation

   - Electrical equipment on diesel electric locomotives, particularly traction equipment, is similar to that found on all-electric locomotives.

7.3 RECOMMENDATIONS

The following recommendations are made:

1. It is recommended that prior reviews made of foreign electrical safety standards be updated to reflect the results of this study. The continued progress by the European community towards harmonization in electrical safety standards as well as other railroad topic areas also should be reflected in any planned updating of prior

reviews. Foreign built trainsets will undoubtedly satisfy the originating country's national safety standards for equipment, but may be found to deviate from U.S. standards. Further, the supporting infrastructure for these new systems will need to be constructed in this country and be operated by railroads with a labor force having a skilled background in U.S. knowledge and practice. The correspondence between foreign standards and relevant U.S. standards is needed. This will provide the assurance that such equipment will operate and be maintained safely and reliably given the construction practice and operating conditions which exist in the U.S.

2. Potentially new operators of electrified railway systems in the U.S. will require the same in-depth knowledge as current operators to operate such systems safely and reliably. It is recommended that a process be initiated to develop a model set of safety rules and safe work practices for use by potentially new operators. This model should build upon the extensive knowledge of current operators of electrified systems (such as those participating in the NTPC) and also be compatible with the existing regulatory framework.

3. More public education is needed on the potential hazards of electrified systems. Such education can address many of the problems of unauthorized access to an electrified railway system. More detailed education of the hazards of electrified systems may be required for rescue and other public officials to enable safe and timely response to emergencies. State governments should consider requiring training for local police and fire fighters on the hazards of electrified railroad systems. It is recommended that prior FRA studies in these areas (such as, Personnel Safety on Electrified Railroads, FRA/ORD-80/36, published in 1980) be updated and expanded to include the specific safety issues related to railway electrification that have been addressed here.

8. SELECTED BIBLIOGRAPHY

The key references used in the preparation of this report as well as other selected references are listed below. This list of is not intended to represent a complete compilation of all possible material on the subject. However, it does represent a fairly wide cross section of academic work, research and analysis, industry standards and government regulations addressing safety issues, and in particular those which are concerned with electrical safety.

Accident/Incident Bulletin No. 162, Calendar Year 1993, Federal Railroad Administration, June 1994.

Adams, J., Electrical Safety, A Guide to the Causes and Prevention of Electrical Hazards, IEE Power Series 19, The Institute of Electrical Engineers, London, England, 1994.

American Railway Engineering Association, "Electrical Energy Utilization," Manual for Railway Engineering, Chapter 33, Chicago, IL, 1987.

Association of American Railroads, "Locomotive and Electrical Equipment," Manual of Standards and Recommended Practices, Section F, Washington, D.C., 1985.

Association of American Railroads, "Passenger Car Requirements," Manual of Standards and Recommended Practices, Section A, Part III, Washington, D.C., 1984.

Bing, A. and Parker, J., Safety of High Speed Magnetic Levitation Transportation Systems: Comparision of U.S. and Foreign Safety Requirements for Application to U.S. Maglev Systems, DOT/FRA/ORD-93/21, September 1993.

Bernstein, T., "Lightning Protection for Buildings, Equipment and Personnel," Electrical Hazards and Accidents, Van Nostrand Reinhold, New York, NY, 1991.

Boxleitner, W., Electrostatic Discharge and Electronic Equipment, IEEE Press, New York, NY, 1989.

British Standards Institute, Code of Practice for Protection of Structures Against Lightning, BS 6651, 1992.

British Standards Institute, Control of Undesirable Static Electricity, Part 1. General Considerations, BS 5958, 1992.

Cadick, J., Electrical Safety Handbook, McGraw-Hill, New York, NY, 1994.

Canadian Standards Association (CSA), Railway Electrification Guidelines, C22.3 No. 8-91, July, 1991.

Central Station Engineers, Electric Transmission and Distribution Reference Book, Westinghouse Electric Corp., 1964.

Code of Federal Regulations, Title 49, Transportation, Parts 200-399. Department of Transportation (USDOT). Office of the Federal Register, National Archives and Records Administration. 1993.

Code of Federal Regulations, Title 29, Labor, Parts 1910-1926. Department of Labor. Office of the Federal Register, National Archives and Records Administration. 1994.

Creasey, W. and Goldberg, R., Safety of High Speed Guided Ground Transportation Systems: Potential Health Effects of Low Frequency Electromagnetic Fields Due to Maglev and Other Electric Rail Systems, DOT-FRA/ORD-93/31, August 1993.

Croft, T. and Summers, W., American Electricians Handbook, McGraw-Hill, New York, NY, 1992.

Cross, J., Electrostatics: Principles, Problems and Applications, Adam Hilger, Bristol, England, 1987.

Dorer, R. and Hathaway, W., Safety of High Speed Magnetic Levitation Transportation Systems: Preliminary Safety Review of the Transrapid Maglev System, DOT/FRA/ORD-90/09, November 1990.

Dorer, R. et al, Safety of High Speed Magnetic Levitation Transportation Systems: German High-Speed Maglev Train Safety Requirements-Potential for Application in the United States, DOT/FRA/ORD-92/02, February 1992.

Eriksson, A. and Meal, D.,"The Incidence of Direct Lightning Strikes to Structures and Overhead Lines," IEEE Conference on Lightning and Power Systems, London, June 1984.

FRA Guide for Preparing Accidents/Incidents Reports, Federal Railroad Administration, DOT/FRA/RRS-22, October 1992.

Glover, J. and Sarma, H.,Power System Analysis and Design, Second Edition, PWS Publishing Co, Boston, MA, 1994.

Greenwald, E. K., Electrical Hazards and Accidents - Their Cause and Prevention, Van Nostrand Reinhold, New York, NY, 1991.

Haase, H., Electrostatic Hazards, Their Evaluation and Control, Verlag Chemie, Weinheim, Germany, 1977.

Hammer, W., Product Safety Management and Engineering, Prentice-Hall Inc, Englewood Cliffs, N.J., 1980.

Holmstrom, F. and Edelson, C., Radiated Interference in Rapid Transit Systems: Volume I: Theory and Data, UMTA-MA-06-0153-85-10, April 1988.

Holmstrom, F. and Edelson, C,. Radiated Interference in Rapid Transit Systems: Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-11, June 1988.

Institute of Electrical and Electronics Engineers, Guide for Protective Grounding of Power Lines, Std 1048-1990, New York, NY, April 17, 1990.

Institute of Electrical and Electronics Engineers, Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations, Std 487-1992, New York, NY, 1992.

Institute of Electrical and Electronics Engineers, Guide for Cleaning Insulators, Std 957-1987, New York, NY, June 11, 1987.

Institute of Electrical and Electronics Engineers, The New IEEE Standard Dictionary of Electrical and Electronics Terms, Std 100-1992, New York, NY, 1992.

Institute of Electrical and Electronics Engineers, Guide on Electrostatic Discharge (ESD): Characterization of the ESD Environment, Std C62.47-1992, New York, NY, March 16, 1993.

Institute of Electrical and Electronics Engineers, Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations, Std 487-1992, New York, NY, November 4, 1992.

Institute of Electrical and Electronics Engineers, Guide for Maintenance Methods on Energized Power-Lines, Std 516-1987, New York, NY, February 1986.

Institute of Electrical and Electronics Engineers, Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems, Std. C62.2-1987, New York, NY, 1988.

Institute of Electrical and Electronics Engineers, National Electrical Safety Code, ANSI C2-1993, New York, NY, August 3, 1992.

John A. Volpe National Transportation Systems Center, Safety of High Speed Magnetic Levitation Transportation Systems: High-Speed Maglev Trains; German Safety Requirements RW-MSB, DOT/FRA/ORD-92/01, January 1992.

Knesche, T., Electric Traction Power Supply Configurations on 10,000 Route Miles of U.S. Railroads, FRA/ORD/82-50, Electrak Inc., June, 1982.

Kurtz, E. and Shoemaker, T., The Lineman's and Cableman's Handbook, McGraw-Hill, New York, NY, 1992.

Kusko, A., Personnel Safety on Electrified Railroads, FRA/ORD-80/36, Alexander Kusko Inc., June 1980.

Markos, S., Recommended Emergency Preparedness Guidelines for Passenger Trains, DOT/FRA/ORD-93/24, December 1993.

Marshall, J., Lightning Protection, John Wiley & Sons, New York, NY, 1973.

McAteer, O., Electrostatic Discharge Control, McGraw-Hill, New York, NY, 1990.

Meliopoulos, A., "Lightning and Overvoltage Protection," Standard Handbook for Electrical Engineers, Section 27, McGraw-Hill, New York, NY, 1993.

National Fire Protection Association, Static Electricity, NFPA 77, Batterymarch Park, Quincy, MA, August 20, 1993.

National Fire Protection Association, Electrical Safety Requirements for Employee Workplaces, NFPA 70E, Batterymarch Park, Quincy, MA, 1988.

National Fire Protection Association, Electrical Equipment Maintenance, NFPA 70B, Batterymarch Park, Quincy, MA, 1990.

National Fire Protection Association, Fixed Guideway Transit Systems, NFPA 130, Batterymarch Park, Quincy, MA, 1993.

National Fire Protection Association, Lightning Protection Code, 1992 Edition, NFPA 780, Batterymarch Park, Quincy, MA. August 1992.

National Fire Protection Association, National Electrical Code, NFPA 70, Batterymarch Park, Quincy, MA, August 1992.

Rashid, M., Power Electronics - Circuits, Devices, and Applications, Prentice-Hall, Englewood Cliffs, NJ, 1993.

Roland, H. and Moriarty, B., System Safety Engineering and Management, John Wiley and Sons, Inc., New York, NY, 1990.

Rusck, S., "The Protection of Distribution Lines," Lightning Volume 2, Chapter 23, Academic Press, New York, NY, 1977.

Schmieg, G., "Static Electricity: Causes, Analysis and Prevention," Electrical Hazards and Accidents, Van Nostrand Reinhold, New York, NY, 1991.

Shell Safety Committee, Static Electricity, Technical and Safety Aspects, Shell Oil Company, The Hague, Netherlands, June 1988.

Sing, et al, The UMTA Rail Transit EMI/EMC Program: Overview and Summary, UMTA-MA-06-0153-85-4, February 1987.

Society of Automotive Engineers, Electromagnetic Compatibility and Interference Control of Rapid Transit Vehicles, Recommended Practice ARP 1393, April 3, 1976.

U.S. Department of Defense, System Safety Program Requirements, MIL-STD-882C, 19 January 1993.

Uman, M. and Rubinstein, M., "Lightning," The Electrical Engineering Handbook, Chapter 38, CRC Press, Boca Raton, FL, 1993.

Additional References Related to EMF

American Conference of Governmental Industrial Hygienists (ACGIH), Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, 1994-1995.

Duchene, A. et al, Guidelines on Protection Against Non-Ionizing Radiation (NIR), International Radiation Protection Association, Pergamon Press, Elmsford, NY, 1991.

European Committee for Electrotechnical Standardization (CENELEC), Human Exposure to Electromagnetic Fields - Low Frequency (0 Hz to 10 kHz), ENV 50166-1, January 1995.

European Committee for Electrotechnical Standardization (CENELEC), Human Exposure to Electromagnetic Fields - High Frequency (10 kHz to 300 GHz), ENV 50166-2, January 1995.

Goellner, D. and Zackhiem, B., Safety of High Speed Guided Ground Transportation Systems: Review of Existing EMF Guidelines, Standards and Regulations, DOT/FRA/ORD-93/27, August 1993.

Goellner, D. et al, Safety of High Speed Guided Ground Transportation Systems: EMF Exposure Environments Summary Report, DOT/FRA/ORD-93/28, August 1993.

Goldberg, R. et al, Safety of High Speed Guided Ground Transportation Systems: An Overview of Biological Effects and Mechanisms Revelant to EMF Exposures from Mass Transit and Electric Rail Systems, DOT/FRA/ORD-93/32, August 1993.

Institute of Electrical and Electronics Engineers, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields 3 kHz to 300 GHz, C95.1-1991, New York, NY, 1992.

Institute of Electrical and Electronics Engineers, IEEE Standard Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields-RF and Microwave, C95.3-1991, New York, NY, August 21, 1992.

Minister of Supply and Services Canada, Limits of Exposure to Radiofrequency Fields at Frequencies from 10 kHz-300 Ghz, Safety Code 6, 1991.

National Institute of Environmental Health Sciences and U.S. Department of Energy, Questions and Answers About EMF - Electric and Magnetic Fields Associated with the Use of Electric Power, DOE/EE-0040, January 1995.

Volpe National Transportation Systems Center, Executive Summary, Final Environmental Impact Statement/Report and 4(f) Statement, Northeast Corridor Improvement Project, Electrification - New Haven, CT to Boston, MA, May 1995.

Volpe National Transportation Systems Center, Record of Decision, Final Environmental Impact Statement/Report and 4(f) Statement, Northeast Corridor Improvement Project, Electrification - New Haven, CT to Boston, MA, May 1995.

Wenzel, T., etal, <u>Electromagnetic Fields (EMF) and Rail Maintenance Workers: Final Report of an Exposure Survey and Feasibility Investigation</u>, National Institute for Occupational Safety and Health January 1996.

World Health Organization (WHO), <u>Electromagnetic Fields (300 Hz to 300 Ghz)</u>, Environmental Criteria 137,1993.

APPENDIX A. SELECTED REVIEW OF ELECTRICAL SAFETY REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

The preliminary survey of railroad specific and related industry electrical safety standards identified many organizations which have pertinent regulations, standards and recommended practices. Selected standards from the following North American organizations were identified from the survey and reviewed accordingly:

- Association of American Railroads (AAR)
- American National Standards Institute (ANSI)
- American Railway Engineering Association (AREA)
- Canadian Standards Association (CSA)
- US Government Code of Federal Regulations (CFR)
- Institute of Electrical and Electronics Engineers (IEEE)
- Insulated Power Cable Engineers Association (IPCEA)
- National Fire Protection Association (NFPA)

The standards from these organizations which were selected for review are listed in this appendix. The above organizations as well as those standards selected for review were not intended to be all inclusive with respect to the subject of electrical safety standards. For example, there are other organizations, including the National Electrical Manufacturers Association (NEMA), the Society of Automotive Engineers (SAE) and the Underwriters Laboratories (UL), which are known to have standards related to the subject of this study. The limited scope of this study did not permit a comprehensive review of the standards from all possible organizations having standards related to electrical safety.

Selected member railroads of the National Traction Power Committee (NTPC) made available for review their electrification related work rules and recommended work practices. The member railroads of NTPC constitute the majority of currently electrified railroads in the U.S. With their permission, the titles of their work rules and work practices reviewed as part of this study also are listed in this appendix.

The comprehensive review of foreign electrical safety standards was considered to be beyond the scope of this preliminary survey although a preliminary review of available standards from the International Union of Railways (UIC) was made. Also, two particular standards of the British Standards Institute (BSI) were known to be particularly relevant to certain aspects of this study. Those BSI standards were related to lightning protection and to static electricity and were included in this survey and standards review.

A key is given after each of the standards listed below. These keys have the following meaning;

- ♦ Standard reviewed and a copy of the standard resides at the Volpe Center
- □ Standard reviewed and a copy of the standard resides at local Boston area public and private (e.g., university) libraries
- ● Abstract of the standard reviewed.

A.1 Association of American Railroads (AAR)

Passenger Car Requirements, Manual of Standards and Recommended Practices, Section A, Part III.♦

Locomotive and Electrical Equipment, Manual of Standards and Recommended Practices, Section F.♦

RP-510, Recommended Alarm Signals for Diesel-Electric Locomotives, 1960.

RP-511, Circuits Requiring Circuit Breaker or Fuse Protection, undated.

RP-517, Traction Motor, Carbon Brush, Locomotive, 1975.

RP-540, Recommended Specification for Fractional Horsepower Motors for Diesel-Electric Locomotives, 1960.

RP-549, Power Sequence-Transition, Locomotive, 1960.

RP-550, Coupling-Quick Connect/Disconnect-Locomotive, 1978.

RP-551, Installation, Inspection, Maintenance and Testing of Radio Controlled Equipment as Applied to Locomotives and Locotrol Car in REC-1 Service, 1976.

RP-552, Recommendations on Radio Controlled Locomotive Unit Operation, 1974.

RP-553, Testing Receptacles-Locomotive, 1970.

S-500, Communication Module Application-Locomotive Control Stand, 1978.

S-501, Wire and Cable Specification, 1985.

S-502, Wire and Cable Insulating Material, No.589, 1967.

S-503, Wire and Cable Insulating Material, No.590, 1972.

S-506, Wire and Cable Insulating Material, No.591, 1976.

S-508, Lead-Acid Batteries and Compartments, 1985.

S-512, 27 Point Control Plug & Receptacle, 1983.

S-518, Specification for Dynamic Braking Control, 1971.

S-532, Control Stand-Locomotive, 1978.

S-540, Tape-Electrical, PVC, 1966.

S-541, Locomotive Electrical Schematic Diagrams, 1983.

S-542, Locomotive Wiring Diagram Symbols, 1985.

A.2 American National Standards Institute (ANSI)

ANSI C2 - 1993, National Electrical Safety Code (NESC).♦

A.3 American Railway Engineering Association (AREA)

Electrical Energy Utilization, Manual for Railway Engineering, Chapter 33.♦

A.4 Canadian Standards Association (CSA)

CAN/CSA - C22.3 No. 8-M91, Railway Electrification Guidelines.♦

<u>Reference Key:</u>

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

A.5 Code of Federal Regulations (CFR)

Aeronautics and Space, 14CFR 150 through 171, 1994.♦

Labor, 29CFR 1910.269, 1910.301 through 1910.399, 1926.400 through 1926.449, 1993.♦

Transportation, 49CFR 229.77 through 229.91, 1993.♦

Shipping, 46CFR 110.01 through 113.10 (USCG), 200 through 300, (MARAD), 1993.♦

A.6 Institute of Electrical and Electronics Engineers (IEEE)

Std. 11-1980, IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles.♦

Std. 16-1955, IEEE Standard for Electric Control Apparatus for Land Transportation Vehicles.♦

Std. 18-1980, IEEE Standard for Shunt Power Capacitors.●

Std. 32-1972, IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices.●

Std. 80-1986, IEEE Guide for Safety in AC Substation Grounding.●

Std. 91-1984, IEEE Standard Graphic Symbols for Logic Functions.♦

Std. 91a-1991, Supplement to IEEE Standard Graphic Symbols for Logic Functions.♦

Std. 100-1992, IEEE Standard Dictionary of Electrical and Electronics Terms.♦

Std. 120-1989, IEEE Master Test Guide for Electrical Measurements in Power Circuits.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. 141-1986, IEEE Red Book, Recommended Practice for Electric Power Distribution for Industrial Plants.♦

Std. 142-1991, IEEE Green Book, Recommended Practice for Grounding of Industrial and Commercial Power Systems.♦

Std.242-1986, IEEE Buff Book, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.♦

Std. 295-1969, IEEE Standard for Electronics Power Transformers.●

Std. 315-1975, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams.♦

Std. 367-1987, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage From a Power Fault.♦

Std. 386-1985, IEEE Standard for Separable Insulated Connector Systems for Power Distribution Systems Above 600 V.●

Std. 388-1992, IEEE Standard for Transformers and Inductors in Electronic Power Conversion Equipment.●

Std. 390-1987, IEEE Standard for Pulse Transformers.●

Std. 404-1986, IEEE Standard for Cable Joints for Use with Extruded Dialectric Cable Rated 5000 Volts through 46,000 Volts, and Cable Joints for Use with Laminated Dielectric Cable Rated 2500 Volts Through 500,000 Volts.●

Std. 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations.●

Std. 444-1973, IEEE Standard Practices and Requirements for Thyristor Converters for Motor Drives.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. 446-1987, IEEE Orange Book, Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications.♦

Std. 450-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations.●

Std. 484-1987, IEEE Recommended Practice for Installation Design And Installation of Large Lead Storage Batteries for Generating Stations and Substations.●

Std. 487-1992, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Power Stations.♦

Std. 510-1983, IEEE Recommended Practice for Safety in High-Voltage and High Power Testing.●

Std. 516-1987, IEEE Guide for Maintenance Methods on Energized Power-Lines.♦

Std. 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.♦

Std. 524-1992, IEEE Guide to the Installation of Overhead Transmission Line Conductors.♦

Std. 525-1987, IEEE Guide for the Design and Installation of Cable Systems in Substations.●

Std. 597-1983, IEEE Practices and Requirements for General Purpose Thyristor DC Drives.●

Std. 605-1987, IEEE Guide for Design of Substation Rigid-Bus Structures.●

Std. 620-1987, IEEE Guide for the Construction and Interpretation of Thermal Limit Curves for Squirrel-Cage Motors over 500 hp.●

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. 644-1987, IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines.♦

Std. 693-1984, IEEE Recommended Practice for Seismic Design of Substations.●

Std. 738-1986, IEEE Standard for Calculation of Bare Overhead Conductor Temperature and Ampacity Under Steady-State Conditions.♦

Std. 776-1992, IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines.♦

Std. 789-1988, IEEE Standard Performance Requirements for Communications and Control Cables for Application in High Voltage Environments.●

Std. 799-1987, IEEE Guide for the Handling and Disposal of Transformer Grade Insulating Liquids Containing PCBs. ♦

Std. 824-1985, IEEE Standard for Series Capacitors in Power Systems.●

Std. 935-1989, IEEE Guide on Terminology for Tools and Equipment to Be Used in Live Line Working.♦

Std. 936-1987, IEEE Guide for Self-Commutated Converters.●

Std. 944-1988, IEEE Application and Testing of Uninterruptible Power Supplies for Power Generating Stations.●

Std. 951-1988, IEEE Guide to the Assembly and Erection of Metal Transmission Structures.●

Std. 957-1987, IEEE Guide for Cleaning Insulators.♦

Std. 978-1984, IEEE Guide for In-Service Maintenance and Electrical Testing of Live-Line Tools.●

Std. 979-1984, IEEE Guide for Substation Fire Protection.●

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. 980-1987, IEEE Guide for Containment and Control of Oil Spills in Substations.●

Std. 987-1985, IEEE Guide for the Application of Composite Insulators.●

Std. 1024-1988, IEEE Recommended Practice for Specifying Distribution Composite Insulators (Suspension Type).●

Std. 1031-1991, IEEE Guide for a Detailed Functional Specification and Application of Static VAR Compensators.●

Std. 1048-1990, IEEE Guide for Protective Grounding of Power Lines.♦

Std. 1067-1990, IEEE Guide for In-Service Use, Care, Maintenance, and Testing of Conductive Clothing for Use on Voltages up to 765 kV AC.●

Std. 1070-1988, IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components.♦

Std. 1100-1992, IEEE Emerald Book, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment.♦

Std. 1106-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations.●

Std. 1109-1990, IEEE Guide for the Connection of User-Owned Substations to Electric Utilities.●

Std. 1119-1988, IEEE Guide for Fence Safety Clearances in Electric-Supply Stations.●

Std. 1127-1990, IEEE Guide for the Design, Construction, and Operation of Safe and Reliable Substations for Environmental Acceptance.●

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. c37.04-1979 (R1989), IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.□

Std. c37.09-1979, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.□

Std. c37.010-1979, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.□

Std. c37.1-1979, IEEE Standard Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automatic Control.□

Std. c37.13-1990, IEEE Standard for Low-voltage AC Power Circuit Breakers Used in Enclosures.●

Std. c37.20.2-1987, IEEE Standard for Metal-Clad Switchgear and Station-Type Cubicle Switchgear.□

Std. c37.20.3-1987, IEEE Standard for Metal-Enclosed Interrupter Switchgear.□

Std. c37.30-1992, IEEE Standard Requirement for High-Voltage Air Switches.□

Std. c37.35-1976, IEEE Guide for the Application, Operation, and Maintenance of High-Voltage Air Disconnecting and Load Interrupter Switches.□

Std. c37.48-1987, IEEE Guide for the Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches and Accessories.□

Std. c37.59-1991, IEEE Standard Requirement for Conversion of Power Switchgear.□

<u>Reference Key:</u>

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. c37.60-1991, IEEE Standard Requirements for Overhead, Pad-Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for AC Systems.□

Std. c37.61-1973, IEEE Guide for the Application, Operation, and Maintenance of Automatic Circuit Reclosers.□

Std. c37.63-1984, IEEE Standard Requirement for Overhead, Pad-Mounted, Dry Vault, and Submersible Automatic Line Sectionalizers for AC Systems.□

Std. c37.91-1985, IEEE Guide for the Protective Relay Applications to Power Transformers.□

Std. c37.96-1988, IEEE Guide for AC Motor Protection.□

Std. c37.99-1990, IEEE Guide for the Protection of Shunt Capacitor Banks.□

Std. c37.108-1989, IEEE Guide for the Protection of Network Transformers.□

Std. c37.109-1988, IEEE Guide for the Protection of Shunt Reactors.□

Std. c37.122-1983, IEEE Standard for Gas-Insulated Substations.□

Std. c37.123-1991, IEEE Guide to Specifications for Gas-Insulated Substation Equipment.□

Std. c57.12.01-1989, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers - Including Those with Solid Cast and/or Resin-Encapsulated Windings.♦

Std. c57.12.11-1980, IEEE Guide for the Installation of Oil-Immersed Transformers (10 MVA and Larger, 69-287 kV Rating).♦

Std. c57.12.59-1989, IEEE Guide for Dry-Type Transformer Through-Fault Current Duration.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. c57.13-1978, IEEE Standard Requirements for Instrument Transformers.♦

Std. c57.13.1-1981, IEEE Guide for Field Testing of Relay Current Transformers.♦

Std. c57.13.3-1983, IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases.♦

Std. c57.19.00-1991, IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings.♦

Std. c57.21-1990, IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated over 500 kVA.♦

Std. c57.94-1982, IEEE Recommended Practice for Installation, Application, Operation and Maintenance of Dry-type General Purpose Distribution and Power Transformers.♦

Std. c57.109-1985, IEEE Guide for Transformer Through-Fault Current Duration.♦

Std. c57. 114-1990, IEEE Seismic Guide for Power Transformers and Reactors.♦

Std. c57.125-1991, IEEE Guide for Failure Investigation, Documentation, and Analysis for Power Transformers and Reactors.♦

Std. c62.11-1987, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits.●

Std. c62.2-1987, IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems.●

Std. c62.47-1992, IEEE Guide on Electrostatic Discharge (ESD)-Characterization of the ESD Environment.♦

Std. c62.92.4-1991, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part IV - Distribution.●

<u>Reference Key:</u>

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Std. c62.92.5-1992, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part V- Transmission Systems and Subtransmission Systems.●

A.7 Insulated Power Cable Engineers Association (IPCEA)

IEEE S135, IPCEA P-46-426 Power Cable Ampacities, Volume I-Copper Conductors, 1962.♦

IEEE S135, IPCEA P-46-426 Power Cable Ampacities, Volume II-Aluminum Conductors, 1962.♦

A.8 National Fire Protection Association (NFPA)

NFPA 70, National Electrical Code, 1993.♦

NFPA 70B, Electrical Equipment Maintenance, 1990.♦

NFPA 70E, Electrical Safety Requirements for Employee Workplaces, 1995.♦

NFPA 77, Static Electricity, 1993.♦

NFPA 130, Fixed Guideway Transit Systems, 1993.♦

NFPA 780, Lightning Protection Code, 1993.♦

A.9 Railroad Work Rules and Recommended Work Practices

AMT-2, Electrical Operating Instructions, Manual of Instruction for Transportation Department Employees, National Railroad Passenger Corporation (AMTRAK), April 1, 1990.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

NRPC-1908, Safety Rules and Instructions-Maintenance of Way Employees, AMTRAK, July 1, 1992.♦

C.T. 290, Electrical Operation instructions, Long Island Railroad, June 1991.♦

S-7C, Safety Rules-Engineering Department Employees, Long Island Railroad, November 1, 1959.♦

MN-290, Electrical Operating Instructions, Metro-North Commuter Railroad, January 1, 1989.♦

SOP No. 1, Response to NYCTA Emergencies, New York City Transit Authority, August 25, 1975.♦

TRO-3, Electrical Operating Instructions, NJ Transit Rail Operations, June 22, 1991.♦

SOP Power Book No.______, Section A-Power Procedures, PATCO, July 2, 1990.♦

SOP Power Book No.______, Section B-Power Distribution, AC&DC, PATCO, July 2, 1990.♦

Procedure for Routine Removal & Restoration of Third Rail Power, PATH, May 2, 1991.♦

High Tension Administration & Safety Rules, Port Authority of NY&NJ, June 1983.♦

ET 001, Electric Traction Instructions, South Eastern Pennsylvania Transportation Authority (SEPTA), July 1990.♦

SOP #020-1-13, A.C. Cable Testing, SEPTA, September 15, 1988.♦

SOP #020-14-16, D.C. Cable Testing, SEPTA, September 15, 1988.♦

Blocking Power Traction Feeders, SEPTA.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

Request for Planned Electrical Power Interuption-Instructions, SEPTA.♦

A.10 British Standards

BS 5958, Code of Practice for Control of Undesirable Static Electricity, 1991.♦

Part 1. General Considerations.

Part 2. Recommendations for Particular Industrial Situations.

BS 6651, Code of Practice for Protection of Structures Against Lightning, 1992.♦

A.11 International Union of Railways Standards

UIC 533 O, Protection by the Earthing of Metal Parts of Vehicles, 1977.♦

UIC 550 OR, Power Supply Installations for Passenger Stock, 1978.♦

UIC 550-1 OR, Electrical Switch Cabinets on Passenger Stock, 1990.♦

UIC 552 OR, Electric Power Supply for Trains Taken From the Train Cable, 1978.♦

UIC 554-1 OR, Power Supply to Electrical Equipment on Stationary Railway Vehicles From a Local Mains System or Another Source of Energy at 220 V or 380 V, 50 Hz, 1979.♦

UIC 554-2 OR, Power Supply to Mechanically-Refridgerated Wagons Running in Rafts, 1978.♦

UIC 600 OR, Electric Traction with Aerial Contact Line, 1981.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

UIC 603 R, Measures to be Taken to Prevent the Formation of Sparks From Traction Current in Areas where Filling and Emptying Installations for Inflammable Liquids or Gases are Located, 1981.♦

UIC 605 OR, Protection from Corrosion - Measures to be Taken on Direct Current Catenaries to Reduce the Risks on Adjacent Pipping and Cable Systems, 1981.♦

UIC 606-1 OR, Consequences of the Application of the Kinematic Gauges Defined by UIC Leaflets in the 505 Series on the Design of the Contact Lines, 1987.♦

UIC 606-2 OR, Installation of 25 Kilovolts and 50 or 60 Hertz Overhead Contact Lines, 1986.♦

UIC 611 OR, Regulations to be Observed for the Acceptance of Electric Locomotives, Rail Motor Vehicles and Multiple Unit Sets for Running on International Services, 1988.♦

UIC 613 O, Graphical Symbols for Electric Traction, 1968.♦

UIC 614 O, Definition of the Rated Output of Electric Locomotives and Motive Power Units, 1990.♦

UIC 616 OR, Rules for Electric Traction Equipment, 1980.♦

UIC 618 O, Rules for Traction Transformers and Reactors, 1971.♦

UIC 619 O, Rules for Rotating Electrical Machines for Rail and Road Vehicles, 1971.♦

UIC 626 OR, Production of Electrical Power On Diesel Tractive Units for Supplying the Train Cable, 1989.♦

UIC 649 O, Rules for Ohmic Resistors Used in the Power Circuits of Electrically Powered Vehicles, 1971.♦

UIC 734 R, Adaptation of Safety Installations to High-Speed Requirements, 1986.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

UIC 736 R, Signalling Relays, 1974.♦

UIC 737-1 i, Combination of Track Circuits and Treadles, 1980.♦

UIC 737-2 i, Measures to be Taken for Improving Sensitivity in the Shunting of Track Circuits, 1980.♦

UIC 737-3 R, Application of Thyristors in Railway Technology: Measures for the Prevention of Functional Disturbance in Signalling Installations, 1985.♦

UIC 737-4 R, Measures for Limiting the Disturbance of Light Current Installations by Electric Traction, 1986.♦

UIC 738 R, Processing and Transmission of Safety Information, 1990.♦

UIC 791 R, Quality Assurance of Overhead Line Equipment, 1990.♦

UIC 792 R, Principles for the Manufacture and Use of Portable Units for Earthing Overhead Electric-Traction Power Lines Through the Rail, 1982.♦

UIC 870 O, Technical Specification for Grooved Contact Wire, 1956.♦

UIC 895 OR, Technical Specification for the Supply of Insulated Electric Cables for Railway Vehicles, 1976.♦

Reference Key:

♦ Standard reviewed, copy of standard at Volpe Center.

□ Standard reviewed, copy of standard at local public and private libraries.

● Abstract of standard reviewed.

APPENDIX B. PRELIMINARY ANALYSIS OF WORK RULES, REGULATIONS AND RECOMMENDED PRACTICES

Table B.1 contains the results of the preliminary analysis of industry standards dealing with work rules, regulations and recommended work practices. This table is structured as a database which contains the following fields:

- Row identification number
- Organization name and standard/rule name
- Standard/rule number
- Description of the standard/rule
- Risk reduction method code number

The risk reduction method code number is described in detail in Section 3 of this report.

The following standards/rules are contained in Table B.1:

- ANSI/IEEE C2-1993 National Electrical Safety Code (NESC)
- ANSI/IEEE Std 516, Std 957, Std 1048
- NFPA Std 70E, Std 70B, Std 130
- CFR 29CFR (Labor), 49CFR (FRA)
- National Transportation Safety Board (NTSB) RAR-79-5
- AMTRAK AMT-2, NRPC 1910, NRPC 1908, NEC Special Instructions
- Long Island Railroad S-7C, C.T. 290
- Metro North MN -290
- NYCTA SOP No. 1
- NJT TRO-3
- PANYNJ High Tension Administrative Rules, High Tension Safety Rules
- SEPTA ET-001, Blocking Traction Power Feeders.

The formal organizational names and standards/rule titles for the above list can be found in Appendix A.

Table B.1 has been organized by the standard/rule organization name and by the standard/rule number. The database itself consists of 1579 records. The structure of the database has been organized such that other database sorts could be made. An example of one such sort would be by risk reduction method.

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1	NESC Part 4	410.A.1	Employers to inform those working on or near high voltage of safety rules	T1				
2	NESC Part 4	410.A.2	Employers to provide training including information on wearing apparel	T3				
3	NESC Part 4	410.A.3	Employers to use positive procedures to ensure compliance with these rules	G1				
4	NESC Part 4	410.A.4	Employer's decision on application of rules to particular situations to be used	G1				
5	NESC Part 4	410.B.1	Employees to be informed on emergency procedures and resuscitation	T1				
6	NESC Part 4	410.B.2	Employees working on lines or equipment to be regularly instructed in first aid'	T1				
7	NESC Part 4	410.C.1	A designated person to be responsible for safe operation of lines and equipment	S3				
8	NESC Part 4	410.C.2	One person to be designated in charge of each group of workers	S2				
9	NESC Part 4	411.A.1	Access to rotating or energized equipment to be restricted to authorized people	P2				
10	NESC Part 4	411A..2	Diagrams to be on file for those responsible for that section of system	S2				
11	NESC Part 4	411.A.3	Employees to be instructed on character of equipment or lines before work	T2	G1			
12	NESC Part 4	411.A.4	Employees to be instructed to take additional precautions under unusual conditions	T2	S1			
13	NESC Part 4	411.B.1	Adequate supply of protective devices and equipment and first aid equipment to be available	G1				
14	NESC Part 4	411.C.1	Protective equipment shall be inspected or tested to ensure proper working condition	P4	T3			
15	NESC Part 4	411.C.2	Insulating gloves, sleeves and blankets to be inspected before use	P4	C2			
16	NESC Part 4	411.C.3	Body belts, safety straps, and other personal equipment to be inspected	P4	C2			
17	NESC Part 4	411.D	Warning signs to be displayed near exposed energized parts	G2	T2			
18	NESC Part 4	411.E	Means to identify lines before work is undertaken, including underground facilities	G1				
19	NESC Part 4	420.A.1	Employees should study the safety rules and be tested periodically	T1				
20	NESC Part 4	420.A.2	Employees should familiarize themselves with first aid, rescue, and fire fighting	T1				
21	NESC Part 4	420.B.1	Employees shall do only tasks they are trained for and under direction of qualified persons	T1	S2			
22	NESC Part 4	420.B.2	If in doubt, request instructions for supervisor before working	S1	S2			
23	NESC Part 4	420.B.3	Nonqualified persons shall work in electrified areas only when authorized	S2				
24	NESC Part 4	420.C.1	Heed warning signs and warn others who are in danger from energized equipment'	S1	S2			
25	NESC Part 4	420.C.2	Report equipment defects, and hazardous conditions to supervision	S4				
26	NESC Part 4	420.C.3	If not required do not approach electrified equipment and remain clear of overhead work	P3	G1	P6		
27	NESC Part 4	420.C.4	When working on energized lines take into account own safety, safety of others, effects on system, property, and the public	S2				
28	NESC Part 4	420.C.5	Do not take conducting objects with insulating handles near exposed energized lines	P3	P6			
29	NESC Part 4	420.C.6	Use care when using metal ropes, tapes or wires due to induced voltages	P6				
30	NESC Part 4	420.C.6	Use approved devices for measuring clearance from energized conductors	P4				
31	NESC Part 4	420.D	Consider electric equipment to be energized unless positively de-energized	G1	D2			
32	NESC Part 4	420.E	Consider ungrounded metal parts to be energized at highest voltage unless tested	G1	D2			
33	NESC Part 4	420.F	Keep all parts of body away from switches, circuit breakers or any sources of arc	G1				
34	NESC Part 4	420.G.1	Ensure battery area are ventilated before working	G2				
35	NESC Part 4	420.G.2	Avoid smoking, flames, or sparks near batteries	G1				
36	NESC Part 4	420.G.3	Use eye and skin protection when handling battery electrolyte	G1	P4			
37	NESC Part 4	420.G.4	Don't handle energized parts of batteries unless precautions from short circuits and shocks are taken	G1				
38	NESC Part 4	420.H	Employees shall use protective equipment provided. Equipment inspection prior to working	G1	P4			
39	NESC Part 4	420.I.1	Employees shall wear suitable clothing for assigned task and work environment	P4				
40	NESC Part 4	420.I.2	Don't wear exposed metal articles when working near energized lines or equipment	G1	P4			
41	NESC Part 4	420.J.1	Don't use any elevated structure for support without determining its security	G1	G2			
42	NESC Part 4	420.J.2	Wood ladders not to be reinforced with metal, painted only with nonconductive coating	P4				
43	NESC Part 4	420.J.3	Metal ladders not to be used near energized equipment	G1	P4			
44	NESC Part 4	420.J.4	Restrict the use of special conductive ladders to intended work	P4				
45	NESC Part 4	420.K.1	Use safety straps when working in elevated positions	G1	P4			
46	NESC Part 4	420.K.2	Inspect safety straps prior to use	G1	C2			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS		
47	NESC Part 4	420.K.3	Determine that straps, snaps, or fastenings are engaged before trusting safety straps	G1	C2	
48	NESC Part 4	420.L	In fighting fires near energized equipment use suitable fire ext or de-energize equipment	G1	P4	D1
49	NESC Part 4	420.M	Install protective tags on remotely controlled equipment prior to work	D4		
50	NESC Part 4	420.M	Avoid being in a position where injury could occur when working on automatic equipment	S1	G1	
51	NESC Part 4	420.N	Use proper tools and protective clothing when installing fuses	G1	P4	
52	NESC Part 4	420.O	Cable reels should be blocked against rolling	G1		
53	NESC Part 4	420.P.1	Street light lowering ropes or chains shall be examined periodically	C2		
54	NESC Part 4	420.P.2	Suitable device provided for disconnecting lamps of > 300 V	P4		
55	NESC Part 4	421.A.1	1st level supervisor shall adopt precautions within authority to prevent accidents	S2		
56	NESC Part 4	421.A.2	1st level supervisor shall see that safety rules and ops procedures are observed by employees	S2		
57	NESC Part 4	421.A.3	1st level supervisor shall make necessary records and reports	G1		
58	NESC Part 4	421.A.4	1st level supervisor shall Prevent unauthorized persons from approaching work area	S2	P2	
59	NESC Part 4	421.A.5	1st level supervisor shall Prohibit use of unsuitable or uninspected tools	S2	P4	
60	NESC Part 4	421.B.1	Use warning signs, traffic control, or barriers while working	P2		
61	NESC Part 4	421.B.2	Use danger signs and barricades if energized or moving parts are exposed	P2		
62	NESC Part 4	421.B.3	Guard or protect crossed or fallen wires, notify proper authority, correct with proper tools if available	S2	S4	P4
63	NESC Part 4	421.C	Escort non-qualified persons or visitors in the vicinity of electric lines or equipment	S2		
64	NESC Part 4	422.A.1	Take precautions when setting poles near energized lines	P4	G1	
65	NESC Part 4	422.A.2	Avoid contact with trucks or equipment without ground when setting poles unless protective equipment is work	G1	P4	
66	NESC Part 4	422.B.1	Check poles and structure before climbing	G1	C2	
67	NESC Part 4	422.B.2	If indicated to be unsafe, guy or brace structure before climbing	G1	G2	
68	NESC Part 4	422.C.1	Prevent cables being installed from contacting energized wires, consider new cables energized unless grounded	P7		
69	NESC Part 4	422.C.2	Control sag of wires being installed or removed to prevent danger to pedestrian or vehicles	G2	P6	
70	NESC Part 4	422.C.3	Check strain on supporting structure before installing additional wires	C4		
71	NESC Part 4	422.C.4	Avoid contact with moving winch lines	G1		
72	NESC Part 4	422.C.5	Equipment or lines are free from dangerous leakage or induction or have been effectively grounded	D3	D6	
73	NESC Part 4	423.A	Protect openings to manholes with barriers	P2	S2	
74	NESC Part 4	423.B.1	Test atmosphere of manholes prior to entry	S1		
75	NESC Part 4	423.B.2	If flammable gases are detected, ventilate prior to entry	G1		
76	NESC Part 4	423.B.3	Test for oxygen deficiency unless forced ventilation is used	G1		
77	NESC Part 4	423.C.1	Do not smoke in manholes	G1		
78	NESC Part 4	423.C.2	Take extra precaution for ventilation if open flames are used in manholes	G1		
79	NESC Part 4	423.C.3	Test and clear flammable gases prior to use of open flames	G1		
80	NESC Part 4	423.D.1	Locate cables and other buried utilities prior to excavating	C4		
81	NESC Part 4	423.D.2	Hand tool for excavating shall have insulating handles	P4	P1	
82	NESC Part 4	423.D.3	Mechanized equipment not to be used hear cables and utilities	C4	T3	
83	NESC Part 4	423.D.4	If a gas or fuel line is broken, extinguish flames, notify authorities, keep public away	S2	S4	P2
84	NESC Part 4	423.E.1	When underground facilities are exposed they should be identified and protected	C4		
85	NESC Part 4	423.E.2	When multiple cables exist, protect those not being worked on	C4		
86	NESC Part 4	423.E.3	Before cutting into a cable or opening a splice, the cable should be identified and verified	G1	C4	
87	NESC Part 4	423.E.4	Positively identify cable to be worked on if multiple cables exist	C3		
88	NESC Part 4	423.F	Avoid being in manholes if power rodding equipment is used	G1		
89	NESC Part 4	430	Communications employees shall observe section 43 and section 42 rules	T1		
90	NESC Part 4	431	Do not approach within the distances proscribed in the rules	P3		
91	NESC Part 4	432	Do not approach supply conductors within approach distance on joint use structures	P3		
92	NESC Part 4	433	An attendant shall be available on the surface when working in a joint use manhole	G1		

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
93	NESC Part 4	434	Metallic or semiconductive sheath conductivity shall be maintained by bonding when working in manholes	C3	C4			
94	NESC Part 4	440	Supply employees shall observe section 44 and section 42 rules	T1				
95	NESC Part 4	441.A.1	Do not approach 50-300 V conductors within specified distance unless:	P3				
96	NESC Part 4	441.A.1.a	Line or part is de-energized	D1				
97	NESC Part 4	441.A.1.b	Employee is insulated from the energized line or part.	P1	P4			
98	NESC Part 4	441.A.1.c	Energized part or line is insulated from the employee and other lines	P1				
99	NESC Part 4	441.A.2	At voltages fro 300 V to 72.5 KV employees shall be protected from phase-phase and phase-ground	P6				
100	NESC Part 4	441.A.2.a	Exposed grounded lines shall be guarded or insulated	P1	P6			
101	NESC Part 4	441.A.2.b	When rubber glove method is used, employees shall wear sleeves and other lines shall be covered with insulating protection	P4	P1			
102	NESC Part 4	441.A.3	For voltages over 72.5 KV approach distance may be reduced if transients are known and controlled	P3				
103	NESC Part 4	441.A.4	Altitude correction factors shall be applied above 3000 feet to approach distances	P3				
104	NESC Part 4	441.A.5	Calculation of approach distances	P3				
105	NESC Part 4	441.B.1	Clear insulation distance	P3				
106	NESC Part 4	441.B.2	Clear insulation distance for rubber gloves and hot sticks	P3				
107	NESC Part 4	441.B.3	Work at grounded end of open switch permitted if gap of switch equals approach distance	P3				
108	NESC Part 4	441.B.4	Approach distances for work on insulators and shorting of insulators	P3				
109	NESC Part 4	441.C.1	Live line tool length	P3	P4			
110	NESC Part 4	441.C.2	Live line conductor support tool length	P3	P4			
111	NESC Part 4	442.A.1	A designated (switching control) person shall keep informed about operating conditions of system	S3	S4			
112	NESC Part 4	442.A.2	Records shall be maintained showing changes in operational condition	S4				
113	NESC Part 4	442.A.3	A designated person shall issue or deny authorization for switching as required for safe and reliable operation	S3				
114	NESC Part 4	442.B	Authorization from designated person to be secured before working or de-energizing circuits	S3				
115	NESC Part 4	442.C	Qualified persons shall obtain authorization before switching sections of circuits	S3				
116	NESC Part 4	442.D	Instructions to re-energize not issued until all employees requesting deactivation have reported clear.	D4				
117	NESC Part 4	442.E.1	Equipment treated as de-energized shall have tags attached at points of reactivation	D4				
118	NESC Part 4	442.E.2	Controls to be deactivated shall also be tagged with physical tags	D4				
119	NESC Part 4	442.E.3	Tags to be placed to identify plainly the equipment or circuits being worked on	D4				
120	NESC Part 4	442.F.1	If controls with tags open automatically, leave open until closing is authorized	D4				
121	NESC Part 4	442.F.2	When circuits open automatically, local ops rules determine number of times they may be closed	C4				
122	NESC Part 4	442.G	Each oral message concerning switching of lines or equipment shall be repeated to sender and identity of sender obtained.	D4	S4			
123	NESC Part 4	443.A.1	When working on energized lines, insulate employee from line or isolate employee from ground	P1	P6			
124	NESC Part 4	443.A.2	Employees shall not place dependence for their safety on covering (insulation) of wires	S1				
125	NESC Part 4	443.A.3	Employees working on lines higher voltage than safety equipment shall assure that no leakage or induction exists or that the lines have been grounded	P4	D6			
126	NESC Part 4	443.A.4	Proper tools to be used for cutting into energized conductors or conductors not positively determined to be de-energized	P4				
127	NESC Part 4	443.A.5	Metal tapes, ropes not to be used without proper distance from energized lines,	P3				
128	NESC Part 4	443.A.6	Non insulating substances not bonded to ground within approach distance considered to be energized	G1				
129	NESC Part 4	443.B	No employee to work alone in inclement weather or at night at > 750 Volts	G1	S2			
130	NESC Part 4	443.C	Manual switch opening and closing methods	C1				
131	NESC Part 4	443.D	Work in a position so that a shock or slip with not bring contact with conductor	P5				
132	NESC Part 4	443.E	Open switches designed for use under load first when de-energizing to protect employees	C4	D1			
133	NESC Part 4	443.F	Connect to de-energized parts first, then energized parts of lines	C1	G1			
134	NESC Part 4	443.G	De-energize switchgear before working with protective barriers removed	C3				
135	NESC Part 4	443.H	Do not open transformer secondaries when energized. Bridge circuit if it cannot be de-energized	C3				
136	NESC Part 4	443.I	Disconnect, short-circuit, and ground capacitors prior to work	D1	D6			
137	NESC Part 4	443.J	Special precautions for gas-filled SF6 equipment, toxic by products from arcing	S1				
138	NESC Part 4	443.K	Employee on surface when working in manhole	G1				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
139	NESC Part 4	443.L	Unintentional ground on delta circuits to be removed as soon a practical	C4				
140	NESC Part 4	444.A.1	Precautions to be taken before de-energizing equipment for work	D1				
141	NESC Part 4	444.A.2	If one employee is in sole charge of section and disconnect, coordination not required	S3				
142	NESC Part 4	444.A.3	Records to be kept on interactive systems	G1				
143	NESC Part 4	444.B	Employee in charge of work shall apply to designated person for de-energizing line'	S2	S4			
144	NESC Part 4	444.C	Tags and records of switches opened to de-energize work area	D4				
145	NESC Part 4	444.D	Protective grounds to be installed after de-energizing lines	D6				
146	NESC Part 4	444.E.1	Work may proceed after de-energizing and grounding, re-energizing only under supervision of employee in charge	S2	D1	D6	D4	
147	NESC Part 4	444.E.2	Each additional employee desiring same equipment to be de-energized to follow same tag procedure	S1	S2	D1	D6	D4
148	NESC Part 4	444.F.1	Employee in charge when all are clear remove protective grounds request that tags be removed	D4				
149	NESC Part 4	444.F.2	Employee in charge may transfer permission to work and responsibility to other person	D4	S2			
150	NESC Part 4	444.G.1	Designate person may direct removal of tags, removal reported to designated person records kept	D4				
151	NESC Part 4	444.G.2	Name of re-energize request must match de-energize request unless transfer of authority has occurred	G1				
152	NESC Part 4	444.H	Lines re-energized only after grounds removed and protective tags removed	D4	C4			
153	NESC Part 4	445.A.1	Protective grounds sized to carry induced current and fault current at point of grounding for time needed to clear line	D6				
154	NESC Part 4	445.A.2	Connect grounding device to ground first	C1				
155	NESC Part 4	445.A.3	Test previously energized part prior to attaching ground	C4	G1	D6		
156	NESC Part 4	445.A.4	Complete ground connection before entering safe approach distance	D6	P3			
157	NESC Part 4	445.B	When removing protective grounds, disconnect at previously energized part before disconnecting at ground end	D6	G1	C4		
158	NESC Part 4	446.A	Employees for live-line work to be trained in specific techniques before permitted to do such work	T1	T2	T3		
159	NESC Part 4	446.B.1	Insulated devices to be tested at voltages involved.	P4				
160	NESC Part 4	446.B.2	Insulated devices to be maintained in a clean condition	P4	C3			
161	NESC Part 4	446.C	Clear insulation distance to be maintained on hot line insulator work	P3				
162	NESC Part 4	446.D.1	Conductive liner for bonding aerial devices to energized lines	P4				
163	NESC Part 4	446.D.2	Employee bonded by shoes leg clips or other means	P4	G1			
164	NESC Part 4	446.D.3	Electrostatic shielded clothing to be used	P4				
165	NESC Part 4	446.D.4	Positive bonded connection to energized conductor prior to employee contact'	C1	P4			
166	Amtrak AMT-2	3.0-1	Employees must know and obey these instructions	T1				
167	Amtrak AMT-2	3.0-2	Employees must be familiar with their department's safety rules and instructions	T1				
168	Amtrak AMT-2	3.0-3	Conditions likely to effect electric operation to be reported to Power Director	S4				
169	Amtrak AMT-2	3.0-4	Employees in electrified territory to be familiar with location of telephones and radios	S4	G1			
170	Amtrak AMT-2	3.0-5	Power director to be notified immediately if necessary to de energize catenary or third rail	S4				
171	Amtrak AMT-2	3.0-6a	Employees working must obtain permission and use protection when working near catenary of third rail	S4	P4			
172	Amtrak AMT-2	3.0-6b	Employee in charge to call attention of inexperienced employees to dangerous conditions	S2	T2			
173	Amtrak AMT-2	3.0-7	During high or low temperatures additional inspection of catenary and third rail required	C2	C1			
174	Amtrak AMT-2	3.0-8	During high wind, engineer to observe pantograph and slow to prevent damage	C1	C4			
175	Amtrak AMT-2	5.1.1	All overhead wires considered live unless known to be de-energized and grounded	D1	T2	D6	G1	
176	Amtrak AMT-2	5.1.2	Until wires are de-energized and grounded, non class A approach distances	P3	P5			
177	Amtrak AMT-2	5.1.3	Consider third rail live at all times unless known to be de-energized	G1	D1			
178	Amtrak AMT-2	5.1.4	Tools clothing and body not to contact energized third rail	P6	P5			
179	Amtrak AMT-2	5.1.5	No work on high voltage transmission circuits unless protection provided by both railroad and utility	D1	S4			
180	Amtrak AMT-2	5.1.6	Conductors, pilots, engineers and foreman responsible for safety of crew	S2				
181	Amtrak AMT-2	5.1.7	Tank cars or open cars to be unloaded after deactivating and grounding catenary	D1	G2	D6		
182	Amtrak AMT-2	5.2.1-1	Conditions likely to affect electric operation reported to Power Director	S4	T2			
183	Amtrak AMT-2	5.2.1-2	Describe such conditions using proper names and locations, coordinate for de-energizing	T2	S4			
184	Amtrak AMT-2	5.2.2	Don't touch dangling wires, protect others, report to Power Director	S2	P3	P6	P2	

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
185	Amtrak AMT-2	5.2.3	Loose or broken impedance bonds regard as energized, report to Power Director	T2	S4			
186	Amtrak AMT-2	5.2.4	When catenary or third rail failure occurs, protect tracks notify Power Director	C4	S4	C1		
187	Amtrak AMT-2	5.2.5	If damage to catenary, give drop pantograph signal to oncoming trains, notify Power Director	C4	S4	C1		
188	Amtrak AMT-2	5.2.6	When reporting emergency situation use "Power Emergency" repeated 3 times	S4	C1			
189	Amtrak AMT-2	5.3	Signal for drop or raise pantographs	C1				
190	Amtrak AMT-2	5.4.1	All work near any wire must comply with 5.1.2	P3				
191	Amtrak AMT-2	5.4.2	Non-railroad employees not permitted to work near wires unless protected by class A employee	S2	T2			
192	Amtrak AMT-2	5.4.3	Emergency repair work on roof of car, locomotive, or equipment by or supervised by class A employee	S1	S2	T2	.	
193	Amtrak AMT-2	5.5.1	Foreman of wire train to know that all have received and understood his instructions, responsible for enforcement	S2	S4	T2	T1	
194	Amtrak AMT-2	5.5.2	Foremen of wire train to obtain clearance from Power Director	S4				
195	Amtrak AMT-2	5.5.2.a	Designation of de-energized circuit and extent of clearance to be explained and signed	S4	T2	S2		
196	Amtrak AMT-2	5.5.2.b	Advise of re-energizing and sign clearance	S4	T2	S2		
197	Amtrak AMT-2	5.5.3	Foreman to inform class A of extent of clearance needed if class A is to obtain	S4	S2			
198	Amtrak AMT-2	5.5.4	Alter class A obtains clearance, to inform foreman and deliver clearance form	S4	T2			
199	Amtrak AMT-2	5.5.5	If foreman leaves immediate area, assign class A to take charge and advise each gang member of identity of class A	S4	S2			
200	Amtrak AMT-2	5.5.6.a	Employee with clearance to personally direct raising of grounding pantograph and verify contact with wire	S2	C1			
201	Amtrak AMT-2	5.5.6.b	Employee with clearance first to ascend to top of equipment	S2	C1			
202	Amtrak AMT-2	5.5.6.c	Employee with clearance to personally direct application of grounding devices	S2	C1	D6	D3	
203	Amtrak AMT-2	5.5.6.d	Employee with clearance to direct attention of gang to location of energized circuits near work	S2	T2			
204	Amtrak AMT-2	5.5.6.e	Employee with clearance to be able to observe movements of all persons on top of equipment or assign additional class A's	S2				
205	Amtrak AMT-2	5.5.6.f	Employee with clearance to direct removal of grounds, last to descend, and direct lowering and locking of grounding pantograph	S2	C1			
206	Amtrak AMT-2	5.5.7	All persons boarding wire train to personally report to foreman and sign clearance	T2				
207	Amtrak AMT-2	5.5.8	Work on energized circuits or near energized wire to be supervised by class A who will monitor tools and distances to wires	S2	P3	P4		
208	Amtrak AMT-2	5.5.9	Only class A to approach within 3 feet of 12,000 V lines	P3				
209	Amtrak AMT-2	5.6.1	Third rail to be considered live, do not touch third rail or protection board, advise passengers and public	P3	T2	S2		
210	Amtrak AMT-2	5.6.2	To de-energize third rail in emergency contact Power Director with name location and conditions	S4				
211	Amtrak AMT-2	5.6.3-1	When section of third rail to be de-energized, Power Director to coordinate with Train Dispatcher for Plate Orders	S4	D1	P5		
212	Amtrak AMT-2	5.6.3-2	No multiple DC electric trains or DC locomotives permitted to operate in or out of de energized section to prevent bridging	D5				
213	Amtrak AMT-2	5.6.4-1	Portable jumpers to be used by class A when contact with third rail lost by loco	C1	T2	P4		
214	Amtrak AMT-2	5.6.4-2	Settings of controllers etc in train when using portable contact jumpers	C1	T2	C4	S1	
215	Amtrak AMT-2	5.6.4-3	Third rail jumpers applied first to contact shoe on loco then third rail, disconnected first from third rail	C1				
216	Amtrak AMT-2	5.6.5	Use dry insulated shoes or paddles to insulate loco from third rail, open switches in loco before applying	C1	C4	P4		
217	Amtrak AMT-2	5.6.6	Insulate shoes before removing main 750 V fuse in loco or MU	C1	C4			
218	Amtrak AMT-2	5.6.7	Insulate shoes before connecting or disconnecting 750 VDC bus jumpers on MU	C1	C4			
219	Amtrak AMT-2	5.6.8	Consider third rail live unless known to be de-energized and protected by a class A	T2	S2			
220	Amtrak AMT-2	5.6.9	Do not make contact between third rail and track rails or return system	C1	C4			
221	Amtrak AMT-2	5.7.1	Class A to have electric rules and maint of way rules in possession	T1				
222	Amtrak AMT-2	5.7.2	Class A is responsible for protection of each employee assigned to him	S2				
223	Amtrak AMT-2	5.7.3	Instruct foreman and all employees in gang of dangers and hazards at start of each tour of duty	S2	T2	T1		
224	Amtrak AMT-2	5.7.4	Class A to indicate to foreman and gang structure or portion that work is to be performed	S2	T1			
225	Amtrak AMT-2	5.7.5	If class A believes that an employee does not understand the instructions, that person shall not be permitted to work and Power Director notified	S2	T1	T2	S4	
226	Amtrak AMT-2	5.7.6	Class A to be in a position to observe movement of persons toward energized conductors	S2	P3			
227	Amtrak AMT-2	5.7.7	Class A not to assume that gang will follow instructions	S2				
228	Amtrak AMT-2	5.7.8	Class A not to engage in any work nor conversation but to monitor other workers for safety	S2				
229	Amtrak AMT-2	5.7.9	If class A leaves all work to stop	S2				
230	Amtrak AMT-2	5.7.10	If more than one Class A they coordinate extent of clearance and grounds	S2	S4			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
231	Amtrak AMT-2	5.7.11	When clearance is obtained and wire de-energized and grounded, class A will indicate to foreman and gang safe areas of work with signature of foreman	S2	T2			
232	Amtrak AMT-2	5.7.12	Class A to protect employees when clearance is released and ground removed	S2	P3			
233	Amtrak AMT-2	5.7.13	Class A to notify foreman or Power Director if employees aren't following his instructions	S2	S4			
234	Amtrak AMT-2	5.8.1	Work done on roof in catenary territory must follow these rules are class A must be present	T1	T2	S2		
235	Amtrak AMT-2	5.8.2	Consider all electric equipment under catenary energized unless known to be de-energized and grounded	G1	D1	D2	D6	D3
236	Amtrak AMT-2	5.8.3	Employees must know that pantographs down and grounding switches closed before certain work on locos and MU	G1	D1	D6	D3	
237	Amtrak AMT-2	5.8.4	Get permission from class A or B before work, notify class A or B when all are clear when work completed	G1	C1	S2	P5	
238	Amtrak AMT-2	5.8.5	Coupling or uncoupling of units to be de energized before control jumpers are applied or removed	C1	D1	D6		
239	Amtrak AMT-2	5.8.6	Pantographs down and grounding switches before applying or removing control jumpers on married pair units	C1	D1	D6	D3	
240	Amtrak AMT-2	5.8.7	When testing or inspecting single or coupled energized loco or MU, class B to take charge	C1	C2	S2	T2	
241	Amtrak AMT-2	5.8.8.A.1	Under de-energized wire class B to use catenary ground switch and lock with his lock, danger tags, had grounding devices	D1	D4	D6	S2	
242	Amtrak AMT-2	5.8.8.A.2	Individual danger tags to be removed by each employee when work complete, class B to re-energize	D4	S2			
243	Amtrak AMT-2	5.8.8.B	Under energized wire all employees to work by rule 5.4	T2	C1			
244	Amtrak AMT-2	5.8.9	No work on main power electric equipment when energized	P6	P7			
245	Amtrak AMT-2	5.8.9.A	When repair of cleaning required, class B to lower pantograph and close grounding switches	S2	D1	D6	D3	
246	Amtrak AMT-2	5.8.9.B	Each employee working on equipment place danger tags, and remove own tag when complete	S1	D4	P5		
247	Amtrak AMT-2	5.8.10	Pantographs not to be raised until all persons, tools and equipment are clear	C4	D4			
248	Amtrak AMT-2	5.8.11	Removal of bus jumper on married pair cars does not isolate second car	T2	P6			
249	Amtrak AMT-2	5.8.12	Limits for total MU cars including dead cars in trains	C1	C4			
250	Amtrak AMT-2	5.9.1	Pantograph poles on AC equipment, return to storage after use	C3	P4			
251	Amtrak AMT-2	5.9.2	Observe condition of pantographs at station stops, notify Power Director of defects	C2	C4	S4		
252	Amtrak AMT-2	5.9.3	Normal ops with rear pantograph up on locos	C1	C4			
253	Amtrak AMT-2	5.9.4	Pantographs to be dropped at visible defects or obstructions in catenary	G1	C4			
254	Amtrak AMT-2	5.9.5	Lower damaged pantograph, raise good pantograph and report to Power Director	C1	C4			
255	Amtrak AMT-2	5.9.6	Stop if pantograph damaged class A or B may use pantograph pole to clear catenary	C4	C1			
256	Amtrak AMT-2	5.9.6.A	Class A or B to repair pantograph only if overhead wire de-energized and grounded	D1	D6			
257	Amtrak AMT-2	5.9.6.B	Class A or B to note position of all overhead wires	S1	P6			
258	Amtrak AMT-2	5.9.7	Equipment not to be moved until broken pantographs secured and isolated	C4	C3	P6		
259	Amtrak AMT-2	5.9.8	Both pantographs live if one is up married pair cars live if either car pantograph is up'	P6	T2			
260	Amtrak AMT-2	5.9.9	Controller to off or break release before lowering pantographs	C4				
261	Amtrak AMT-2	5.9.10	Pantograph not to be raised when electric train is passing on turnout or crossover	C1	C4			
262	Amtrak AMT-2	5.9.11	Use of pantograph pole and condition of poles	P4	T2	T1		
263	Amtrak AMT-2	5.9.12	Dead electric equipment with damaged pantograph to be hauled only with pantograph tied down, grounding switch open and pinned	C1	C4			
264	Amtrak AMT-2	5.9.13	Electric equipment from elec to non elec track or vice versa only with pantographs down grounding switches pinned closed	C1	C4			
265	Amtrak AMT-2	5.10.1	Dispatcher to issue drop pantograph order for area of damaged catenary	S4	S3	C4	C1	
266	Amtrak AMT-2	5.10.2	Test pantographs before entering drop pantograph area	C1	C2			
267	Amtrak AMT-2	5.10.3	Employee observing pantographs not dropping will give drop pantograph order	C1	C2	C4		
268	Amtrak AMT-2	5.10.4	30 MPH speed limit unless otherwise stated in drop pantograph order	C1				
269	Amtrak AMT-2	5.10.5	Pantograph down button to be in down position in drop pantograph area	C1				
270	Amtrak AMT-2	5.11.1	Only class A or B permitted on top of equipment under catenary	S1	T2	G1		
271	Amtrak AMT-2	5.11.2	Responsible employees to forbid all others from climbing equipment under catenary unless deactivated and grounded and class A protection available	S2	S4			
272	Amtrak AMT-2	5.12.1	Electric equipment not to run into de-energized sections with pantographs up	D5				
273	Amtrak AMT-2	5.12.2-1	When electric equipment looses power and stops before power is restored, lower pantographs and notify Power Director	C1	C4	S4		
274	Amtrak AMT-2	5.12.2-2	When pantograph is entangled in catenary, stop equipment immediately	C1	C4			
275	Amtrak AMT-2	5.12.3	If defect in electric loco, lower pantograph, if not correctable, close pantograph grounding switches	C1	C4			
276	Amtrak AMT-2	5.12.4	After operation of the pantograph relay, raise pantograph only by use of up button	C1				

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	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
277	Amtrak AMT-2	5.12.5-1	Derailed electric equipment to be considered energized	G1	P6	P5		
278	Amtrak AMT-2	5.12.5-2	Engineer to drop pantographs and close grounding switch	C1	D1	D6	D3	
279	Amtrak AMT-2	5.12.5-3	Crew members to inform passengers and employees not to board or discharge until pantograph is lowered or overhead wire de-energized and grounded	S2	D1	D6	T2	D3
280	Amtrak AMT-2	5.12.5-4	Crew members not to make simultaneous contact with equipment and earth and prevent others also	P3	P6	C1	S2	
281	Amtrak AMT-2	5.12.6	Secure electric equipment set off enroute with hand brake and air brake	G1				
282	Amtrak AMT-2	5.12.7	Electric equipment not to pass AC motor stop sign with pantograph up	C1	C4			
283	Amtrak AMT-2	5.13.1	A plate order form is necessary to be filled out by employee requesting power de-energizing	D4				
284	Amtrak AMT-2	5.13.2	When plate order is in effect, plate signs or indications shall be illuminated and blocking devices placed to designate tracks for no electric equipment to operate	C1	D5			
285	Amtrak AMT-2	5.14.1	Phase breaks located as in timetable with signs one pole in advance	C1				
286	Amtrak AMT-2	5.14.2	Position lights when illuminated indicate that phase break is de-energized	C1				
287	Amtrak AMT-2	5.14.2.A	Controller to off position on single loco operating through phase break	C1	C4			
288	Amtrak AMT-2	5.14.2.B	Controller to off and drop pantographs on MU operating in phase break	C1	C4	D5		
289	Amtrak AMT-2	5.15.1	Dead sections designated by timetable and signs	C1				
290	Amtrak AMT-2	5.15.2	Place controller in off coast or break release before entering dead section	C1	C4	D5		
291	Amtrak AMT-2	5.16.1	Engineer to report arcing from sleet on catenary to Power Director for issuance of double pantograph order	C1	C4			
292	Amtrak AMT-2	5.16.2	Both pantographs to be up on lead unit under double pantograph order except in phase breaks	C1	C4	D5		
293	Amtrak AMT-2	5.16.2.A	Unlock pantographs on Jersey Arrow III cars under double pantograph order	C1	C4			
294	Amtrak AMT-2	5.16.2.B	When free of ice release unlock button to remove excess pressure on wire	C1	C4			
295	Amtrak AMT-2	5.16.4	Patrol trains assigned to remove sleet from contact wires, class A to accompany train, two pantograph poles and ground sticks to be carried	C1	C4	P4	S2	
296	Amtrak AMT-2	5.16.5	Patrol train engines to use two pantographs on lead and trailing pantograph on trailing unit, drop all pantographs in phase break	C1	C4	D5		
297	Amtrak AMT-2	5.16.6	Speed limit 30 MPH when contact wire heavily coated with sleet	C1	C4			
298	Amtrak AMT-2	5.16.7	Lower pantographs on electric equipment lest unattended to reduce arcing from sleet, observe pantographs for sleet buildup	C1	C4			
299	Amtrak AMT-2	5.16.8	Wire trains to be manned and held ready under sleet storms	C1				
300	Amtrak AMT-2	5.16.9-1	When pantograph lowers with arcing from sleet, master controller to be shut off	C1	C4			
301	Amtrak AMT-2	5.16.9-2	Stop train 5 ft catenary clearance and use pantograph pole to raise and lower pantograph without contacting wire	C1	C4	P4		
302	Amtrak AMT-2	5.16.9-3	If sleet must be removed from pantograph by hand, de-energize and ground wire	C1	D1	D6	D3	
303	Amtrak AMT-2	5.16.10	Lower pantograph for inspection, all pantographs on bussed MU cars	C1	C2			
304	Amtrak AMT-2	5.17.1	Maintenance of way equipment to be grounded if it is within approach distance of energized wires	C1	D1	P3		
305	Amtrak AMT-2	5.17.1.A	Distance for energized transmission, catenary, and signal power wires	P3				
306	Amtrak AMT-2	5.17.1.A	Distance for wires apparently de-energized but not grounded	P3				
307	Amtrak AMT-2	5.17.1.B	Distance for wires de-energized and grounded with/without supervision of class A	P3	S2			
308	Amtrak AMT-2	5.17.2	If foreman or operator thinks a hazard is present request protection of class A	T2	P3	S2		
309	Amtrak AMT-2	5.18.1	Operator must know that wires are de-energized and grounded when used in proximity to wires	P3	C1			
310	Amtrak AMT-2	5.18.2	Unless grounded equipment not to be used within 15 feet of electric wires	D6	P3			
311	Amtrak AMT-2	5.18.3	Location and working hours of such equipment reported to Power Director	S4				
312	Amtrak AMT-2	5.18.4	Operator or foreman to request class A if a hazard is suspected	S2	T2	S4		
313	Amtrak AMT-2	5.19.1	Class A to report to wreck derricks	S2	C1			
314	Amtrak AMT-2	5.19.2	Wreck derrick may work no closer than 8 feet of wires without class A	P3				
315	Amtrak AMT-2	5.19.3	Wires de-energized and grounded by class A for derrick within 8 feet of wires	P3	S2	D1	D6	
316	Amtrak AMT-2	5.19.4	Contact with wires supervised by class A protective cowl on derrick boom	P3	C4	S2		
317	Amtrak AMT-2	5.19.5	Electric traction dept. to remove or misalign catenary if required by derrick	T2	C1	C4		
318	Amtrak AMT-2	5.19.6-1	Employees in wrecking operation protected by class A.	S2				
319	Amtrak AMT-2	5.19.6-2	Third rail must be de-energized or approved protection applied	D1	P1	P2		
320	Amtrak AMT-2	5.19.7	Protect third rail from derrick outriggers	C4				
321	Amtrak AMT-2	5.20.1	Remote control boards for traction power control	T1				
322	Amtrak AMT-2	5.20.2	Operate remote control switches by direction of Power Director only	S3	C1			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
323	Amtrak AMT-2	5.20.3	Inspection and test of control boards at each shift change, report abnormal operation to Power Director	C2	C1	S4		
324	Amtrak AMT-2	5.20.4	Indications on control switches	T1	T2			
325	Amtrak AMT-2	5.20.5	Procedure for operating switches and verifying tagging and blocking	C1	S4	D4	D1	
326	Amtrak AMT-2	5.20.6	Procedure for closing open switches	C1	S4			
327	Amtrak AMT-2	5.20.7	Procedure for opening closed switches or circuit breaker controls	C1	C4	S4	D1	
328	Amtrak AMT-2	5.20.8	Notify Power Director of automatic operation of switches or abnormal temperature indications	C1	S4			
329	Amtrak AMT-2	5.20.9	Procedure to remove tags and blocking devices	S4	D4			
330	Amtrak AMT-2	5.20.10	Forward used red tags to appropriate official for record keeping	C1	D4			
331	Amtrak AMT-2	5.20.11	Operator to observe power plate order and hold trains for dispatcher as required	C1	S4			
332	Amtrak AMT-2	6.1	Spot train with doors not adjacent when transferring passengers, dismount then board, avoid simultaneous contact with both trains	C1	P6			
333	Amtrak AMT-2	6.2	Do not restore power to either train until transfer is complete	C1	P6			
334	Amtrak AMT-2	6.3	De-energize third rail prior to transfer process	D1	P6			
335	Amtrak AMT-2	6.4	Avoid simultaneous contract between two trains on adjacent track	P6	T2			
336	ANSI/IEEE Std 516	5.4.1.1	Do not perform maintenance on lines during thunderstorms	G1				
337	ANSI/IEEE Std 516	5.4.1.2	Make auto reclosers inoperative if possible during energized line maintenance	D1				
338	ANSI/IEEE Std 516	5.4.1.3	All equipment to be inspected for defects prior to use	C2	P4			
339	ANSI/IEEE Std 516	5.4.1.4	Protective glasses or other face protection to be worn if required by work performed	G1	P4			
340	ANSI/IEEE Std 516	5.4.1.5	The nominal voltage of a circuit should be checked to determine proper clearances	P3				
341	ANSI/IEEE Std 516	5.4.1.6	Maintain proper clearances when using conductive materials ropes, slings, etc	P3	G1			
342	ANSI/IEEE Std 516	5.4.1.7	Use insulated tools to verify insulating clearance distance	P3	P4			
343	ANSI/IEEE Std 516	5.4.1.8	Inspect insulated tools for damage before and after use	C2	D2			
344	ANSI/IEEE Std 516	5.4.1.9	When moving an energized conductor, check for flashover contact with trees or other objects	P6				
345	ANSI/IEEE Std 516	5.4.1.10	Persons not involved in work should be kept clear of work site	P2	G2			
346	ANSI/IEEE Std 516	5.4.2.1	Determine proper location on structures for placement of temporary rigging loads	C4				
347	ANSI/IEEE Std 516	5.4.2.2	Ensure that tools are properly engaged before transferring mechanical load to tools	C4	S4			
348	ANSI/IEEE Std 516	5.4.2.3	Sticks not to be overloaded	C4				
349	ANSI/IEEE Std 516	5.4.3.1	When passing conductive objects to workers at intermediate potential, do not decrease the insulating distance to ground	P3	G1			
350	ANSI/IEEE Std 516	5.4.3.2	To avoid shock, bond to any conductive object passed to worker	G1				
351	ANSI/IEEE Std 516	5.4.3.3	Drain charge from body by contacting structure with tool when moving from insulating ladder	G1				
352	ANSI/IEEE Std 516	5.4.4.1	At line potential, worker to be insulated from ground or objects at other potential	P2	P6			
353	ANSI/IEEE Std 516	5.4.4.2	The worker should be adequately shielded from the electric field	P1				
354	ANSI/IEEE Std 516	5.4.4.3	Worker to be bonded at the potential that work is being done	G1				
355	ANSI/IEEE Std 516	5.4.4.4	All objects passed to worker must be brought to worker's potential prior to touching	G1				
356	ANSI/IEEE Std 516	5.4.4.5	Be aware that heavy fault current will slam bundled conductors together with great force	G1	T2			
357	ANSI/IEEE Std 516	5.4.4.6	When working close to other conductors of objects, they should be covered or moved to prevent inadvertent contact	P1	P3	G1		
358	ANSI/IEEE Std 516	5.5.1.1	Workers doing energized line work should have formal training and periodic examination of rules and procedures	T1	T2			
359	ANSI/IEEE Std 516	5.5.1.2	Shield workers from electric fields as required	G1				
360	ANSI/IEEE Std 516	5.5.1.3	Formal written work rules should be provided for implementation of energized-line maintenance	T1				
361	ANSI/IEEE Std 516	5.5.1.4	Update procedures to take advantage of new equipment and work methods	T1	S4			
362	ANSI/IEEE Std 516	5.5.1.5	Frequent on-the-job discussions of work for intra-crew discussion and communication	G1	T1	T2	S4	
363	ANSI/IEEE Std 516	5.5.1.6-1	Leader of crew to be present and personally direct energized line work	S2	P1			
364	ANSI/IEEE Std 516	5.5.1.6-2	Assess physical and mental state of workers for ability to work safely	S1	S2			
365	ANSI/IEEE Std 516	5.5.1.6-3	Leader of crew to plan location of grounded and energized parts and safe clearance distances is advance	S2	P3	G2		
366	ANSI/IEEE Std 516	5.5.2.1	Workers to use conductive footwear at or above 230kV	P4				
367	ANSI/IEEE Std 516	5.5.2.2	Inspect condition of conductors, tie wires, and insulators, use special care if damaged	C2	G1			
368	ANSI/IEEE Std 516	5.5.3	The integrity of any insulating device used to support the worker should be ensured	G1	P4			

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	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS			
369	ANSI/IEEE Std 516	5.5.4.1	Conductive clothing to be work for work on circuits energized above 230kV	P4			
370	ANSI/IEEE Std 516	5.5.4.2	Bond conductive clothing to energized device before beginning work	G1			
371	ANSI/IEEE Std 516	5.5.4.3	Install protective gaps on adjacent structures before decreasing insulation clearance distance	P3	P4		
372	ANSI/IEEE Std 516	5.5.5.1	Rubber and synthetic gloves and sleeves are available for voltages through 36kV	P4			
373	ANSI/IEEE Std 516	5.5.5.2.1	Don gloves before entering hazardous area, remove only after leaving area	G1	P4		
374	ANSI/IEEE Std 516	5.5.5.2.2	Energized or neutral conductors in proximity should be covered	P3	P1	P6	
375	ANSI/IEEE Std 516	5.5.5.2.3	Use special care when working in proximity to fuses and lightning arrestors	G1			
376	ANSI/IEEE Std 516	5.5.5.2.4	Protective equipment is normally removed at the end of the day	G1			
377	ANSI/IEEE Std 516	5.5.5.3.1	Rubber gloves and sleeves should be inspected daily while in use	G1	P4	C2	
378	ANSI/IEEE Std 516	5.5.5.3.2	All other rubber protective equipment should be given a visual inspection before use	G1	P4	C2	P1
379	ANSI/IEEE Std 516	5.5.5.4.1	Rubber glove storage methods	G1	C4		
380	ANSI/IEEE Std 516	5.5.5.4.2	Protection and storage of other rubber protective equipment	G1	C4		
381	ANSI/IEEE Std 516	5.5.5.5	Common to use structure for work on 600V-7500V	C3	G1		
382	ANSI/IEEE Std 516	5.5.5.6	Additional insulation required for work 7500V-17000V	C3	G1	P1	
383	ANSI/IEEE Std 516	5.5.5.7	Line hose, blankets and aerial lifts preferred for work 17000V-26500V	C3	G1	P1	
384	ANSI/IEEE Std 516	5.5.5.8.1	Insulated aerial lift, gloving, insulated basket liners 26500V-36000V	C3	G1	P1	
385	ANSI/IEEE Std 516	5.5.5.8.2	Work in damp or foggy weather restricted by boom leakage current 26500V-36000V	C3	G1	P1	
386	ANSI/IEEE Std 516	5.5.5.8.3	Combination of gloves and live-line tools can be used if required	C3	G1	P1	P4
387	ANSI/IEEE Std 516	5.5.5.8.4	Collect and store lower-voltage rated gloves before starting work 26500V-36000V	G1	P4		
388	ANSI/IEEE Std 516	5.5.5.8.5	Ground chassis of aerial lift to neutral or temporary ground	G1			
389	ANSI/IEEE Std 516	5.6.1	Insulating aerial equipment should be rated and certified by the manufacturer	T3			
390	ANSI/IEEE Std 516	5.6.2	Insulating ladder	T3			
391	ANSI/IEEE Std 516	5.6.3	Insulating platform	T3			
392	ANSI/IEEE Std 516	5.6.4	Insulating tower boom	T3			
393	ANSI/IEEE Std 516	5.7.1	Conductor carts can be used as work platform	G1			
394	ANSI/IEEE Std 516	5.7.2	Helicopters can be used to lower and raise workers and as work platforms	G1			
395	ANSI/IEEE Std 516	5.8.1	Insulating tools made of wood or fiber reinforced plastic may be used at intermediate potential	G1	P4		
396	ANSI/IEEE Std 516	5.8.2	Insulating rope can be used for rigging support platforms etc, insulating chain to be used in high humidity	G1	P4		
397	ANSI/IEEE Std 516	5.8.3	Protective cover up equipment is used at lower voltages to insulate energized lines	G1	P1	P6	
398	ANSI/IEEE Std 516	5.9.1.1.1	Extend outriggers and ground aerial lift before raising boom	G1			
399	ANSI/IEEE Std 516	5.9.1.1.2	Operate lift to check for normal operation of all controls	G1	C2		
400	ANSI/IEEE Std 516	5.9.1.1.3	Clean soles of conductive footwear and inspect floor of bucket for dirt preventing good contact	G1	C2		
401	ANSI/IEEE Std 516	5.9.1.1.4	Workers to be secured with safety belt and legs in bucket at all times	G1	S1		
402	ANSI/IEEE Std 516	5.9.1.1.5	Avoid making contact with energized conductor if aerial lift is in contact with it	G1	S1		
403	ANSI/IEEE Std 516	5.9.1.1.6	Do not overstress bucket or platform by lifting excessive weight	G1	C4		
404	ANSI/IEEE Std 516	5.9.1.1.7	Fiberglass bucket not to be considered as an insulator	S1	T2		
405	ANSI/IEEE Std 516	5.9.1.1.8	Bond cables should have breakaway clamps allowing separation from conductors in an emergency	P4			
406	ANSI/IEEE Std 516	5.9.1.1.9	Do not safety off to two devices at the same time	C1	S1		
407	ANSI/IEEE Std 516	5.9.1.2.1	A worker capable of handling controls to be near aerial lift when workers are aloft	G1			
408	ANSI/IEEE Std 516	5.9.1.2.2	Test insulating capability of lift by contacting energized line each time lift is relocated	G1	C1		
409	ANSI/IEEE Std 516	5.9.1.2.3	Ensure bond cables remain securely attached during work	G1			
410	ANSI/IEEE Std 516	5.9.1.2.4	Keep insulating members of aerial lifts clean and dry	C4	G1		
411	ANSI/IEEE Std 516	5.9.1.3.1	Maintain clearance specified between grounded parts of truck and insulated boom assembly	P3			
412	ANSI/IEEE Std 516	5.9.1.3.2	Proper clearance between persons, conducting tools, and boom	P3			
413	ANSI/IEEE Std 516	5.9.2.1.1.1	Ends of structure-mounted ladders to be firmly secured to structure	G1			
414	ANSI/IEEE Std 516	5.9.2.1.1.2	Do not secure ladder to defective structure component or device to be moved	G1			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
415	ANSI/IEEE Std 516	5.9.2.1.1.3	Leader of crew to assure that rigging is safe before anyone mounts ladder	G1	S2			
416	ANSI/IEEE Std 516	5.9.2.1.2.1	Test dielectric current of ladder prior to mounting	G1				
417	ANSI/IEEE Std 516	5.9.2.1.2.2	Move ladder to safe de-energized position before mounting or dismounting	G1				
418	ANSI/IEEE Std 516	5.9.2.1.2.3	Control ladder movement with insulating tools, rope, chain, or combination	G1	P6			
419	ANSI/IEEE Std 516	5.9.2.1.2.4	Use safety strap around ladder except during mount/dismount	G1				
420	ANSI/IEEE Std 516	5.9.2.2.1.1	Equipment for base support of ladder to be sturdy enough for weight supported	G1				
421	ANSI/IEEE Std 516	5.9.2.2.1.2	Personnel to stay clear of ladder while being moved into position	G1				
422	ANSI/IEEE Std 516	5.9.2.2..2.1	Equipment used for base support of ladder to be grounded	G1				
423	ANSI/IEEE Std 516	5.9.2.2.2.2	Insulating sticks to be used to move ladder to energized device	G1	P4			
424	ANSI/IEEE Std 516	5.9.2.2.2.3	Check dielectric current on ladder before mounting for barehand work	G1	C2			
425	ANSI/IEEE Std 516	5.9.2.2.2.4	Electrically check ladder each time it is relocated	G1	C2			
426	ANSI/ıEEE Std 516	5.9.2.2.3	Add 8 ft to minimum clearances and allow for inadvertent movement of ladder	P3				
427	ANSI/IEEE Std 516	5.9.2.3.1	Lifting device for cable-supported ladder to be of adequate capacity	G1				
428	ANSI/IEEE Std 516	5.9.2.3.2	Ladder to be adequately supported and secured for all angles and positions	G1	G2			
429	ANSI/IEEE Std 516	5.9.2.3.3	Supervisor and operator to inspect ladder after setup	G2	S1	S2		
430	ANSI/IEEE Std 516	5.9.2.3.4	Use insulating link sticks between cable and ladder end to improve insulating qualities of setup	G1	G2	P1		
431	ANSI/IEEE Std 516	5.9.2.3.2.1	Lifting equipment should have power raise and power lowering capability	G2	P4			
432	ANSI/IEEE Std 516	5.9.2.3.2.2	When working on ladder, all movement of lifting device to be controlled from aloft	G1	G2			
433	ANSI/IEEE Std 516	5.9.2.3.2.3	One person capable of operating controls to be near device to warn others	G1	S2	P2		
434	ANSI/IEEE Std 516	5.9.2.3.3	Maintain minimum separation distances	P3				
435	ANSI/IEEE Std 516	5.9.3.1.1	Extend outriggers prior to extending insulated platform	G1				
436	ANSI/IEEE Std 516	5.9.3.1.2	Ground unit through body, not outriggers	G1	G2			
437	ANSI/IEEE Std 516	5.9.3.1.3	Check ground and support platform level before moving into position	G1	C2			
438	ANSI/IEEE Std 516	5.9.3.1.4	Raise hydraulic platforms to max height for 5 min	C1				
439	ANSI/IEEE Std 516	5.9.3.1.5	Workers near support platform near energized wires not to contact platform	P3	S1			
440	ANSI/IEEE Std 516	5.9.3.1.6	Bond cables to have break-away fittings	P4				
441	ANSI/IEEE Std 516	5.9.3.2.1	One person capable of operating controls to be near device when workers on platform	G1	S2			
442	ANSI/IEEE Std 516	5.9.3.2.2	Electrically test members of support platform prior to use	G1	C2			
443	ANSI/IEEE Std 516	5.9.3.2.3	Bonding cables to remain firmly attached during work	G1				
444	ANSI/IEEE Std 516	5.9.3.2.4	Insulating members of support platforms to be clean	G3				
445	ANSI/IEEE Std 516	5.9.3.3.1	Minimum clearance distance between top and grounded parts of platform	P3				
446	ANSI/IEEE Std 516	5.9.3.3.2	Insulated section not to contact grounded part of conductor or different potential	P6				
447	ANSI/IEEE Std 516	5.9.3.3.3	No portion of person or tool to be less than minimum clearance distance	P3				
448	ANSI/IEEE Std 516	5.9.3.3.4	Minimum clearance for grounded section to energized conductor	P3				
449	ANSI/IEEE Std 516	5.9.4.1.1	Tower booms to be erected at appropriate location	G1	G2			
450	ANSI/IEEE Std 516	5.9.4.1.2	Adequate factor of safety for support platform and tower boom	G1	G2			
451	ANSI/IEEE Std 516	5.9.4.2.1	Minimum distance plus factor for inadvertent movement	P3				
452	ANSI/IEEE Std 516	5.9.4.2.2	No portion of person or tools with less than minimum clearance distance	P3				
453	ANSI/IEEE Std 516	5.9.5.1.1	No contact with conductor cart unless worker and cart at same potential	G1	C1			
454	ANSI/IEEE Std 516	5.9.5.1.2	Nonconductive tag line to be used on conductor cart	P4				
455	ANSI/IEEE Std 516	5.9.5.1.3	Safety slings to be attached after cart wheels on conductor	G1	G2			
456	ANSI/IEEE Std 516	5.9.5.1.4	Ensure sufficient safety strap length when transferring to/from cart	G1	S1			
457	ANSI/IEEE Std 516	5.9.5.1.5	Procedure for cart use on bundled conductors	G1	C1			
458	ANSI/IEEE Std 516	5.9.5.2.1	Appropriate bonding and shielding to be used on cart	G1	C1	P2		
459	ANSI/IEEE Std 516	5.9.5.2.2	Weight on worker and cart not to increase sag of line beyond limits	G1	P6			
460	ANSI/IEEE Std 516	5.9.6.1.1	worker and helicopter pilot to be checked out on particular job to be done	T1	T2			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
461	ANSI/IEEE Std 516	5.9.6.1.2	All applicable work clearances to be discussed	T1	T2			
462	ANSI/IEEE Std 516	5.9.6.1.3	Constant communication between worker and pilot to be maintained	S4				
463	ANSI/IEEE Std 516	5.9.6.1.4	Pilot and worker to use conductive clothing	P4				
464	ANSI/IEEE Std 516	5.9.6.1.5	Pilot to be responsible for all decisions regarding safe flying conditions	S1	S2	T2		
465	ANSI/IEEE Std 516	5.9.6.1.6	Approved work platform to be used by worker	P4				
466	ANSI/IEEE Std 516	5.9.6.1.7	Pull-away bonding clamps to be used	P4				
467	ANSI/IEEE Std 516	5.9.6.1.8	Worker to be safetied to helicopter, platform, or both by safety harness and lanyard	P4	G1			
468	ANSI/IEEE Std 516	6.3.1.1	Absolute limit of approach distance (definition)	T1	P3			
469	ANSI/IEEE Std 516	6.3.1.2	Distances do not account for accidental and unplanned movements	T1	T2	P3		
470	ANSI/IEEE Std 516	6.3.2	Working limit of approach (definition)	T1				
471	ANSI/IEEE Std 516	6.4.1.1	General precautions for work clearance limits	T1	T2			
472	ANSI/IEEE Std 516	6.4.1.2	Extreme care to be taken to ensure the safety of all workers	G1				
473	ANSI/IEEE Std 516	6.4.1.3	Precautions when wearing conductive shoes in vicinity of switchgear etc	T2				
474	ANSI/IEEE Std 516	6.4.2.1	Add distance for unplanned movement to absolute limits to get working distances	P3				
475	ANSI/IEEE Std 516	6.4.2.2	Maintain proscribed distances at all times	P3				
476	ANSI/IEEE Std 516	6.4.2.3	Conductive clothing to be worn whenever field strengths warrant	P4				
477	ANSI/IEEE Std 516	6.5.1	Intro to step and touch potential hazards	T1	T2			
478	ANSI/IEEE Std 516	6.5.2.1	Typical ground potential distribution	T2				
479	ANSI/IEEE Std 516	6.5.2.2	Components subject to step and touch potential	T2				
480	ANSI/IEEE Std 516	6.5.3.1	Use of metal mat to reduce step or touch potential	G1	G2	T2		
481	ANSI/IEEE Std 516	6.5.3.2	Minimization of contact with structures to reduce hazard of step or touch	T2	G1			
482	ANSI/IEEE Std 516	6.6.1.1	Vehicles with aerial equipment near conductors to be grounded or isolated	G1				
483	ANSI/IEEE Std 516	6.6.1.2	Persons on ground not to contact boom in motion near energized wires	G1	P6	P3		
484	ANSI/IEEE Std 516	6.6.2.1	Maintain safe clearances when adjusting load	G1	C1			
485	ANSI/IEEE Std 516	6.6.2.2	Procedure to protect ground operator of aerial device	G1	P4	C1		
486	IEEE Std 957	11.1	Each company should establish its own rules and operating practices (insulator washing)	T1				
487	IEEE Std 957	11.1.1	Minimum distances for safe washing	P3	S1			
488	IEEE Std 957	11.2.1	Bonding of wash nozzle	D3				
489	IEEE Std 957	11.2.2	Water to full pressure before contacting insulation	C3				
490	IEEE Std 957	11.2.3	Monitoring resistivity of water	P4	G1			
491	IEEE Std 957	11.2.4	Make adjustments with water turned off or directed away from energized wires	G1				
492	IEEE Std 957	11.2.5	Ground washing equipment, ensure that public stays clear of equipment in operation	D6	P2			
493	IEEE Std 957	11.2.6	Wash in direction of wind	C3				
494	IEEE Std 957	11.2.7	Inspect insulators, crossarms, hardware prior to washing	C2	G1			
495	IEEE Std 957	11.2.8	Procedure for suspension-type insulators	C3				
496	IEEE Std 957	11.2.9	Procedure for stacked insulators	C3				
497	IEEE Std 957	11.2.10	Procedure for pin or post type insulators	C3				
498	IEEE Std 957	11.2.11	Do not wash damaged insulation	C3	P1			
499	IEEE Std 957	11.2.12	Wash lower insulators first	C3				
500	IEEE Std 957	11.2.13	Direct water stream into any arc developing to reduce damage	C3	C4			
501	IEEE Std 957	11.2.14	Consider overspray pattern in stations to reduce flashover possibility	C3	C4			
502	IEEE Std 957	11.2.15	Protective equipment to be worn by hose operator	S1	P4			
503	IEEE Std 957	11.2.16	Base operator procedure	S1	C3			
504	IEEE Std 957	11.2.17	Presence of corona discharge during/after washing	T1				
505	IEEE Std 957	11.2.18	Individual company rules apply when washing any facilities	T1				
506	IEEE Std 957	11.3.1	Equipment for cleaning insulators to be designed for this purpose	P4				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
507	IEEE Std 957	11.3.2	Company grounding practices apply for de-energized washing	D8	T1			
508	IEEE Std 957	11.4	Consider public safety in washing operations	S2				
509	IEEE Std 1048	3.1	Sources of voltage	T2				
510	IEEE Std 1048	3.2	hazardous voltages at work site	T2				
511	IEEE Std 1048	3.3	Safe body current limits	T2				
512	IEEE Std 1048	3.3.1	Body resistance	T2				
513	IEEE Std 1048	3.3.2	Clothing and footwear resistance	T2				
514	IEEE Std 1048	3.3.3	Ground resistance	T2				
515	IEEE Std 1048	3.4	Fault currents	T2				
516	IEEE Std 1048	3.4.1	Fault current magnitude	T2				
517	IEEE Std 1048	3.4.2	Fault current duration	T2				
518	IEEE Std 1048	3.4.3	DC offset and mechanical force from fault current	T2				
519	IEEE Std 1048	3.5	Rating of grounding sets	T2	P4			
520	IEEE Std 1048	3.5.1	Cable rating	T2	P4			
521	IEEE Std 1048	3.5.2	Clamp rating	T2	P4			
522	IEEE Std 1048	3.5.3	Clamp connection to prevent blowoff	T2	P4	C3		
523	IEEE Std 1048	3.5.4	Circuit configuration effect on forces encountered	T2				
524	IEEE Std 1048	3.5.5	Resistance of ground	T2				
525	IEEE Std 1048	3.6	Inductive coupling	T2				
526	IEEE Std 1048	3.6.1	Capacitive coupling	T2				
527	IEEE Std 1048	3.6.2	Magnetic coupling	T2				
528	IEEE Std 1048	3.7	Lightning	T2				
529	IEEE Std 1048	4.1	Intro to grounding practices	T1				
530	IEEE Std 1048	4.2	Theoretical considerations of grounding	T1				
531	IEEE Std 1048	4.2.1	Work site vs bracketed grounding	T1	T2			
532	IEEE Std 1048	4.2.2	Single phase vs three-phase grounding	T1	T2			
533	IEEE Std 1048	4.2.3	Bonding	T1	T2			
534	IEEE Std 1048	4.2.4	Ground electrode and hazards associated with multiple grounds	T1	T2			
535	IEEE Std 1048	4.3	Distribution line grounding practices	T1				
536	IEEE Std 1048	4.4	Transmission line grounding	T1				
537	IEEE Std 1048	6.2	Voltage detection methods	T1				
538	IEEE Std 1048	6.2.1	Buzzing	T2	D2			
539	IEEE Std 1048	6.2.2	Live line tool method	T2	D2			
540	IEEE Std 1048	6.2.3	Noisy tester method	T2	D2			
541	IEEE Std 1048	6.2.4.1	Neon 'Voltage detectors	C2	D2			
542	IEEE Std 1048	6.2.4.2	Hot horn or noisy tester	C2	D2			
543	IEEE Std 1048	6.2.4.3	Multiple-range voltage detector	C2	D2			
544	IEEE Std 1048	6.3.1	Advantages/disadvantages of neon indicator	T2	P4			
545	IEEE Std 1048	6.3.2	Advantages/disadvantages of noisy tester	T2	P4			
546	IEEE Std 1048	6.3.4	Advantages/disadvantages of multiple range voltage detector	T2	P4			
547	IEEE Std 1048	6.4.2.1	Wire brushing cleaning for connections	T1				
548	IEEE Std 1048	6.4.2.2	Self cleaning clamps	T1				
549	IEEE Std 1048	6.4.2.3	Weathering steel and painted steel tubular structures	T1				
550	IEEE Std 1048	6.5.1	Tool for live line ground installation	T1	C3	P4		
551	IEEE Std 1048	6.5.2	Method of use of live line ground installation	C3				
552	IEEE Std 1048	6.5.3	Voltage rating of tools	P4				

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	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
553	IEEE Std 1048	6.5.4	Problems of control of heavy grounding cables	C3	P7			
554	IEEE Std 1048	6.6.1	Placement of grounds for safety	T2	C3	D6		
555	IEEE Std 1048	6.7.1	Grounding cluster method for steel structures	T2	C3	D6		
556	IEEE Std 1048	6.7.2	Grounding cluster method for wood structures	T2	C3	D6		
557	IEEE Std 1048	6.8	Length of grounding conductors	P4	D6			
558	IEEE Std 1048	6.9.1	Method of removing grounds	T2	C3	D6		
559	IEEE Std 1048	6.9.2	Precautions for removing grounds	T2	C3	D6		
560	IEEE Std 1048	7.1	Grounding of aerial devices and hazards	T2	C3	D6		
561	IEEE Std 1048	7.2	Grounding of equipment	T2	C3	D6		
562	IEEE Std 1048	8.1	equipment for grounding de-energized power lines	P4				
563	IEEE Std 1048	8.2.1	Clamps inspection size and cleaning	C3	C2	P4		
564	IEEE Std 1048	8.2.2	Cable Inspection, length, rigging	C3	C2	P4		
565	IEEE Std 1048	8.2.3	Connections type, inspections, installation	C3	C2	P4		
566	IEEE Std 1048	8.2.4	Installation sequence for grounding	T2	C3	C4		
567	IEEE Std 1048	8.2.5	Wye or star configuration for short-circuiting grounds	T2	C3			
568	IEEE Std 1048	9.1	Pole grounds	T2	P4			
569	IEEE Std 1048	9.2	System neutral	T2	P4			
570	IEEE Std 1048	9.3	Overhead groundwire	T2	P4			
571	IEEE Std 1048	9.4	Ground rods	T2	P4			
572	IEEE Std 1048	9.5	Measuring devices for ground resistance	T2	P4	C2		
573	NYCTA SOP No 1	7.2	Removal of power may intensify passenger discomfort and may imperil them	T2				
574	NYCTA SOP No 1	10.4.1	After power removal, RTTD Supervisor at scene responsible for determining when emergency is over and requesting restoration of power	S4	D4			
575	NYCTA SOP No 1	10.4.3	When power has been removed and several agencies involved, Power Restoration Team responsible for decision to restore power	S4	D4			
576	NYCTA SOP No 1	10.4.4	Power restoration team to perform joint walk-through before declaring safe to restore power	S4	C4	D4		
577	NYCTA SOP No 1	12.2.5	Hose stream should be directed way from any possible source of electricity when adjusting	T2	G1	P6		
578	NYCTA SOP No 1	12.3.2	Avoid use of water-type fire extinguishers around live electrical conductors and equipment	T2	P4			
579	NYCTA SOP No 1	12.3.4	Dry chemical extinguishers safe to use on electrical equipment	P4				
580	NYCTA SOP No 1	12.6	Electrical power should be removed before fighting fire with electrical equipment involved.	T2	C1	D1		
581	NYCTA SOP No 1	13.2.1.5	NYCFD personnel won't enter electrified railroad property until power is off	T2	C1	P6		
582	NYCTA SOP No 1	13.2.1.8	Time extensions allowed before power removal by Desk Trainmaster to clear trains from area	C1	D1			
583	NYCTA SOP No 1	13.2.1.10	Procedure for handling request for power off by fire department	C1	D4			
584	NYCTA SOP No 1	13.2.1.11	Procedure for restoring power after initial restoration results in circuit breaker opening	C1	D4	C4		
585	NYCTA SOP No 1	13.2.1.13	Procedure for confirming request for restoral of power by original requester of removal	D4				
586	NYCTA SOP No 1	13.2.4.2	Loads on feeders to be monitored during emergency	C1	C4			
587	NYCTA SOP No 1	13.2.4.3	Procedure to de-energize sections with abnormal loads, auto circuit breakers to be left out	C1	C4			
588	NYCTA SOP No 1	13.2.4.4	System operator to restore power only after repair of any damaged equipment	C1	C4			
589	NYCTA SOP No 1	13.2.7.5	RTTD supervisor at NYCTA command post may remove power using emergency alarm box	D1				
590	NYCTA SOP No 1	13.2.7.6	If power reported off, RTTD supervisor in charge to confirm with dispatcher	D1	D2	S2		
591	NYCTA SOP No 1	13.2.7.7	Interagency procedure for restoral of power and coordination	D4				
592	NYCTA SOP No 1	13.3.4.1	Procedure for power removal on request from desk trainmaster (fire or smoke on train)	D4	C4			
593	NYCTA SOP No 1	13.3.4.2	Procedure after tripping of emergency alarm circuit	D4	C4			
594	NYCTA SOP No 1	13.3.7.6	If power reported off on arrival of NYCFD, NYCFD Borough Dispatcher to confirm prior to entry	D2	S2			
595	NYCTA SOP No 1	13.3.7.7	Coordination of restoral of power after smoke/fire emergency	D4				
596	NYCTA SOP No 1	13.4.1.6	Procedure for NYCFD to request power off while fighting fire on adjacent structure	D1	S3	D4		
597	NYCTA SOP No 1	13.4.1.7	Procedure for restoring power after NYCFD request for adjacent structure fire	D4				
598	NYCTA SOP No 1	13.4.2.4	Signal division to remove power from equipment in jeopardy	C4	D1			

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	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS			
599	NYCTA SOP No 1	13.4.3.1	System operator to dispatch power department emergency vehicle to scene for direct report	C1	S4		
600	NYCTA SOP No 1	13.4.3.2	System operator to determine what equipment is affected and alert personnel for alternate operations	C1	C4	S3	S4
601	NYCTA SOP No 1	13.4.3.3	System Operator to notify Desk Trainmaster of effect on train operations	C1			
602	NYCTA SOP No 1	13.4.3.4	System operator to direct inspection of equipment after emergency	C1	S4	S3	
603	NYCTA SOP No 1	13.4.3.5	System operator to remove power on request of Desk Trainmaster for use of structure by NYCFD	S2	S3	D1	
604	NYCTA SOP No 1	13.4.3.6	System operator to direct restoral of power after emergency at request of Desk Trainmaster	C1	D4		
605	NYCTA SOP No 1	13.4.6.6	NYCFD to confirm power removal through Borough Dispatcher if power reported off on arrival	D2	S4	D4	
606	NYCTA SOP No 1	13.4.6.7	Procedure for NYCFD to notify that power off condition no longer needed	D4	S4		
607	NYCTA SOP No 1	13.5.1.4	Procedure for RTTD to remove power if mass passenger evacuation required	D1	S2	P6	
608	NYCTA SOP No 1	13.5.1.13	If passengers must descend to roadbed, or if gas, fire, smoke present power removal required	D1			
609	NYCTA SOP No 1	13.5.1.13	Procedure for RTTD to request restoral of power	D4			
610	NYCTA SOP No 1	13.5.4.1	System operator to dispatch power department emergency vehicle to evacuation scene for direct report	C1			
611	Amtrak NRPC- 1910	3	Warning for 480 V power in baggage/dormitory cars	T2			
612	Amtrak NRPC- 1910	4	Warning for 480 V power in heritage cars	T2			
613	Amtrak NRPC- 1910	5	Warning for 480 V power in Amfleet cars	T2			
614	Amtrak NRPC- 1910	6	Warning for 480 V power in multi-level cars	T2			
615	Amtrak NRPC- 1910	7	Warning for 480 V power in heritage cars	T2			
616	Amtrak NRPC- 1910	8	Warning for 480 V power in Viewliner cars	T2			
617	Amtrak NRPC- 1910	9	Warnings for 480 V power in Turbotrain power cars	T2			
618	Amtrak NRPC- 1910	9	Precaution that shutting down turbine power does not remove third rail 600 VDC power	T2			
619	Amtrak NRPC- 1910	9	Precautions that Captoliner cars are electrically connected by jumpers	T2			
620	Amtrak NRPC- 1910	9	Precautions that pantographs on Captoliner cars should be considered electrified	T2			
621	Amtrak NRPC- 1910	9	Precautions that diesel-electric locomotives produce high voltage AC and DC power	T2			
622	Amtrak NRPC- 1910	9	Precautions that shutting down diesel engine on FL-9 does not guarantee that third rail power is shut down	T2			
623	Amtrak NRPC- 1910	9	Precautions for 11000 VAC pantographs on E60 locomotives	T2			
624	Amtrak NRPC- 1910	9	Do not walk on top of any locomotive or car in electrified territory (WAS-New Haven and PHL -HAR)	T2			
625	Amtrak NRPC- 1910	9	Procedure to lower pantographs and ground locomotive	T2			
626	Amtrak NRPC- 1910	9	Precautions for 11000 VAC pantographs on AEM-7 locomotives	T2			
627	Amtrak NRPC- 1910	10.5	Precautions for electric power sources in Amtrak tunnels	T2			
628	Amtrak NRPC- 1910	10.5	Procedure to de-energize electric equipment used by Amtrak	T2			
629	Amtrak NRPC- 1910	10.5	Procedure to lower pantographs and cutting out emergency batteries on Amtrak equipment	T2			
630	Amtrak NRPC- 1910	10.8	Procedure to request removal of electric power from Amtrak Power Director for Union Station Tunnel	T2			
631	Amtrak NRPC- 1910	11	Details of catenary voltages and construction details	T2			
632	Amtrak NRPC- 1910	11	...no person or object to approach within 8 feet of the 138000 V or 3 feet of the 11000 V catenary or 6600 V signal power lines	P3			
633	Amtrak NRPC- 1910	11	No one except qualified persons to enter substations	T2			
634	Amtrak NRPC- 1910	11	Procedure to deactivate third rail by calling power director or activating emergency switch boxes	D1			
635	NFPA 70E	1.H.2	Installations for > 600 V to be accessible only by lock and key to qualified persons	P1			
636	NFPA 70E	1.H.2.a	Installation with exposed live parts to be accessible to qualified persons only	P1			
637	NFPA 70E	1.H.2.b	Metal enclosed equipment or locked enclosures to be used if accessible to unqualified persons	P1			
638	NFPA 70E	II,1,A	Employees to be trained in safety related work practices, safety procedures, and other safety requirements in this standard	G1			
639	NFPA 70E	II,1,A	Employees not to be permitted to work in an area of electrical hazards until trained	G1			
640	NFPA 70E	II,1,B,1	Employers to implement lockout-tagout procedures for working on de-energized equipment	D4			
641	NFPA 70E	II,1,B,2-1	Employees shall be instructed to consider all exposed conductors energized and dangerous	P3			
642	NFPA 70E	II,1,B,2-2	Energized parts to be safeguarded to prevent direct contact by conductive apparel or tools	P2			
643	NFPA 70E	II,1,B,2,a	Employees shall be instructed to be alert at all times where exposed hazards may exist	T2			
644	NFPA 70E	II,1,B,2,a-2	Employees shall not reach blindly into areas that may contain energized parts	G1	P3		

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
645	NFPA 70E	II,1,B,2,a-3	Employees shall not be permitted to work while alertness is imparted due to illness, fatigue etc	G1	S2			
646	NFPA 70E	II,1,B,2,b-1	Employees shall not be permitted to enter spaces with energized parts unless adequate illumination is provided	G1	G2			
647	NFPA 70E	II,1,B,2,b-2	Where lack of illumination precludes observation of the work, functions requiring proximity with energized parts shall not be permitted	G2	P3			
648	NFPA 70E	II,1,B,2,c	Conductive articles of jewelry, cloth with conductive thread, or metal headgear shall not be worn near energized parts	P3				
649	NFPA 70E	II,1,B,2,d	Conductive materials in contact with employees body shall be handled to prevent accidental contact with energized conductors	P3				
650	NFPA 70E	II,1,B,2,e	Employees shall use insulated tools and equipment near exposed conductors	P4				
651	NFPA 70E	II,1,B,2,f	Protective shields barriers or insulating materials shall be used to protect employees from accidental contact	P4	P3			
652	NFPA 70E	II,1,B,2,g	Portable metal ladders shall not be used when working on or near exposed energized conductors	P4				
653	NFPA 70E	II,1,B,2,h	Precautions shall be taken when working in confined or enclosed work spaces	G1				
654	NFPA 70E	II,1,B,2,i	When work is performed on overhead lines, not guarded, insulated or protected, precautions shall be taken to prevent employees from contacting such lines	P3				
655	NFPA 70E	II,1,B,2,i,i	When working in elevated positions near energized lines not guarded or insulated employees shall maintain a safe distance from the conductors	P3				
656	NFPA 70E	II,1,B,2,i,ii	Vehicles capable of having parts of their structure elevated shall maintain minimum distance from energized conductors	P3				
657	NFPA 70E	II,1,B,2,j	Housekeeping and janitorial duties shall not be performed adjacent to energized parts presenting a contact hazard unless safeguards are provided	P3	G1			
658	NFPA 70E	II,1,B,3	Safety work practices shall be used to prevent electric shock or injuries when employees work on energized parts	G1	G2	P3		
659	NFPA 70E	II,2,A	Employees working in situations with potential electrical hazards shall use protective equipment	P4	T3			
660	NFPA 70E	II,2,B	Nonconductive head protection shall be worn with danger of electric shock, burns, or falling objects	P4	T3			
661	NFPA 70E	II,2,C	Protective equipment for the face shall be worn with danger of electric arcs, flashes, or falling objects	P4	T3			
662	NFPA 70E	II,2,D	Insulating rubber gloves or other goods shall be used to protect the hands from contact with electrified parts	P4	P3			
663	NFPA 70E	II,2,E	Protective equipment shall comply with designated standards	P4				
664	NFPA 70E	II,3,A	Only qualified employees trained to work with test equipment shall use test equipment	T2	T1			
665	NFPA 70E	II,3,A,1	Test instruments shall be visually inspected before use on each shift, defective equipment not to be used	C2	P4			
666	NFPA 70E	II,3,A,2	Test instruments to be rated for the circuits and equipment to be used	P4	T3			
667	NFPA 70E	II,3,B	Appropriate alerting techniques shall be used to warn and protect employees	G2				
668	NFPA 70E	II,3,B,1	Safety signs, symbols, or accident prevention tags to be used to warn employees of electrical hazards	G2	T2			
669	NFPA 70E	II,3,B,2	Barricades to be used in conjunction with signs when necessary to prevent employee access to work areas	P2				
670	NFPA 70E	II,3,B,3	When work areas do not permit signing or barricades, manual signaling shall be used for protection	P2				
671	NFPA 70E	.II.3.D.1	Routine opening and closing of circuits shall use loadbreak rated equipment	C4	T3			
672	NFPA 70E	II,3,D,2	Circuits not to be re-energized until it has been determined that it is safe to do so	D4				
673	NFPA 70E	II,3,E	Overcurrent protection modifications shall not be done in a manner that could cause injury	C4				
674	NFPA 70E	II,4,A	Each employer shall document and implement a lockout-tagout procedure	D4				
675	NFPA 70E	II,4,A,1	The employer shall be responsible for implementation and employee training	D4				
676	NFPA 70E	II,4,A,2	The employer shall provide training for all employees assigned to work on or near de-energized circuits with a possibility of re-energizing	T1	T2			
677	NFPA 70E	II,4,A,3	The electrical lockout-tagout procedure shall be coordinated with procedures isolating other energy systems	D4				
678	NFPA 70E	II,4,A,4	The locks, tags, and other hardware shall be standardized, and designed to deter accidental or unauthorized removal	D4				
679	NFPA 70E	II,4,B	Lockout-tagout procedure shall be documented by the employer and contain requirements to safeguard employees near de-energized circuits	D4				
680	NFPA 70E	II,4,B,1	The scope purpose and areas of application of the lockout tagout procedure shall be defined	D4				
681	NFPA 70E	II,4,B,2	Procedures shall assure that circuits and equipment are isolated from all sources of electrical energy	D4	D1			
682	NFPA 70E	II,4,B,2,a	Procedures shall require preplanning to determine safe ways to disconnect power from equipment to be worked on	D4				
683	NFPA 70E	II,4,B,2,b	Equipment shutdown procedures shall be included so equipment is shut down safely before circuits are de-energized	D4	C4			
684	NFPA 70E	II,4,B,2,c	Procedures shall require that circuits are disconnected from all sources of power and disconnecting devices operated only by authorized employees	D1	D4			
685	NFPA 70E	II,4,B,2,d	The procedure shall include requirements for releasing stored energy which might endanger personnel	D1	D4			
686	NFPA 70E	II,4,B,3	Procedure shall include using locks or tags or both to prevent restoration of power	D4				
687	NFPA 70E	II,4,B,4	The lockout tagout procedure shall require certain actions to verify removal of power	D2	D4			
688	NFPA 70E	II,4,B,4,a	Equipment controls shall be operated to verify that the equipment cannot be restarted	D2	D4			
689	NFPA 70E	II,4,B,4,b	Circuits to be tested by appropriate equipment. Test equipment to be checked before and after test	D2				
690	NFPA 70E	II,4,B,5	Procedures shall be included to assure coordination of lockout-tagout procedures during shift changes or changes in employee assignment	D4				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS
691	NFPA 70E	II,4,B,6	Procedures for restoral of electric power to be included in the lockout-tagout procedure	D4
692	NFPA 70E	II,4,B,6,a	Before restoration, verify that tools, mechanical restraints, jumpers, shorts, etc are removed	D4 C4
693	NFPA 70E	II,4,B,6,b	Notify all employees that circuits are being re-energized and verify employees in clear	T2 D4
694	NFPA 70E	II,4,B,6,c	Locks or tags to be removed by the employee who applied the device	D4
695	NFPA 70E	II,4,B,6,d	Employees responsible for operating equipment to be notified when circuits to the equipment are re-energized	D4
696	NFPA 70E	II,4,B,7,a	Before temporary restoration, verify that tools, mechanical restraints, jumpers, shorts, etc are removed	D4 C4
697	NFPA 70E	II,4,B,7,b	Notify all employees that circuits are being re-energized temporarily and verify employees in clear	D4 T2
698	NFPA 70E	II,4,B,7,c	Locks or tags to be temporarily removed by the employee who applied the device	D4
699	NFPA 70E	II,7,A	Safety and protective equipment to be maintained in a safe working condition	P4
700	NFPA 70E	II,7,B,1	Safety and protective equipment to be visually inspected before initial use and at intervals	C2
701	NFPA 70E	II,7,B,2	The insulation of protective equipment shall be verified by test or inspection before initial use and at intervals	C2
702	NFPA 70E	II,7,B,3	Prior to return to service, repaired equipment shall be tested for insulating capability	C2
703	OSHA 29 CFR	1910.331.a	Work rules apply to both qualified and unqualified persons for wiring work	G1 T1
704	OSHA 29 CFR	1910.331.b	Work rules apply to unqualified persons working in transmission, communications, installations in vehicles, and railways	G1 T1
705	OSHA 29 CFR	1910.332.a	Training requirements apply to employees who face a risk of electric shock not reduced to safe levels by design	T1
706	OSHA 29 CFR	1910.332.b	Employees shall be trained in the safety-related work practices that pertain to their respective job assignments	T1 G1
707	OSHA 29 CFR	1910.332.b.2	Unqualified persons shall also be trained in electrically related safety practices	T1 G1
708	OSHA 29 CFR	1910.332.b.3	Qualified persons shall receive additional training	T1
709	OSHA 29 CFR	1910.332.b.3.I	Qualified persons shall be trained in techniques to distinguish live parts from other parts	T1 T2
710	OSHA 29 CFR	1910.332.b.3.II	Qualified persons shall be trained to determine voltages of exposed live parts	T1 T2
711	OSHA 29 CFR	1910.332.b.3.III	Qualified persons shall be trained in the clearance distances and corresponding voltages	T1 T2 P3
712	OSHA 29 CFR	1910.332.c	Training may be classroom or on-the-job	G1
713	OSHA 29 CFR	1910.333.a	Safety related work practices shall be used when working near or on circuits that are or may be energized	G1 T1
714	OSHA 29 CFR	1910.333.a.1	Live parts must be de-energized if possible before working	D1
715	OSHA 29 CFR	1910.333.a.2	If parts cannot be de-energized, work practices shall be used to protect employees from direct or indirect contact	P5 P3
716	OSHA 29 CFR	1910.333.b.1	Lockout tagout rules to apply to work near enough to conductors to be a hazard if they are energized	D4
717	OSHA 29 CFR	1910.333.b.2	When an employees is exposed to contact to parts, they shall be locked out or tagged out or both	D4 P6
718	OSHA 29 CFR	1910.333.b.2.I	Employer shall maintain a written copy of the lockout tagout procedures	D4 G1
719	OSHA 29 CFR	1910.333.b.2.II.A	Safe procedures for de-energizing equipment shall be determined in advance	D4 G1 C4
720	OSHA 29 CFR	1910.333.b.2.II.B	Circuits shall be disconnected from all sources of energy, Interlocks not to be used as a substitute for lockout tagout	D1 D4
721	OSHA 29 CFR	1910.333.b.2.II.C	Stored electrical energy shall be released, Capacitors shall be discharged and short circuited and grounded	D1 D6
722	OSHA 29 CFR	1910.333.b.2.II.D	Stored non-electrical energy in devices that could re-energize electrical circuits shall be blocked or relieved	D1
723	OSHA 29 CFR	1910.333.b.2.III.A	A lock and a tag shall be placed on each disconnecting means used to de-energize circuits to prevent operating the disconnecting means	D4
724	OSHA 29 CFR	1910.333.b.2.III.B	Each tag shall contain a statement prohibiting unauthorized operation of the disconnect and removal of the tag	D4
725	OSHA 29 CFR	1910.333.b.2.III.C	If a lock cannot be applied, tagging procedure must be demonstrated to have equivalent safety as a lock	D4
726	OSHA 29 CFR	1910.333.b.2.III.D	A tag used without a lock shall be supplemented by at least one additional safety measure	D4
727	OSHA 29 CFR	1910.333.b.2.III.E	A lock may be placed without a tag under some circumstances	D4
728	OSHA 29 CFR	1910.333.b.2.III E.(1)	Locks may be used without tags for one piece of equipment or circuit, and	D4
729	OSHA 29 CFR	1910.333.b.2.III.E.(2)	Locks may be placed without tags for one shift, and	D4
730	OSHA 29 CFR	1910.333.b.2.III.E.(3)	Locks may be placed without tags if all employees exposed to the hazard are familiar with the procedure	D4
731	OSHA 29 CFR	1910.333.b.2.iv	Removal of power to circuits shall be verified prior to work	D2
732	OSHA 29 CFR	1910.333.b.iv.A	Qualified persons shall operate the operating controls to verify that equipment can't be restarted	D2 T2
733	OSHA 29 CFR	1910.333.b.iv.B	A qualified person shall use test equipment to verify removal of power, test equipment to be checked before and after test	D2 T2
734	OSHA 29 CFR	1910.333.b.v	Certain requirements must be met before re-energizing equipment	G1 D4
735	OSHA 29 CFR	1910.333.b.v.A	Qualified person shall conductor tests and visual inspections to verify that circuits are safe to re-energize	G1 T2
736	OSHA 29 CFR	1910.333.b.v.B	Employees shall be warned to stay clear of the circuits before re-energizing them	G1 T3 D4

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
737	OSHA 29 CFR	1910.333.b.v.C	Each lock and tag shall be removed by the employee that installed it, or another authorized persons if:	D4				
738	OSHA 29 CFR	1910.333.b.v.C.(1)	The employer ensures that the employee that applied the lock and tag is not available at the workplace and	D4				
739	OSHA 29 CFR	1910.333.b.v.C.(2)	The employer ensures that the employee is aware that the lock and tag have been removed before he resumes work	D4				
740	OSHA 29 CFR	1910.333.b.v.D	There shall be a visual determination that all employees are clear of the circuits and equipment	D4	P6			
741	OSHA 29 CFR	1910.333.c.1	Special work rules apply to employees working on exposed live parts near enough to present a hazard	G1	P6	P3		
742	OSHA 29 CFR	1910.333.c.2	Only qualified employees shall work on energized equipment and shall be familiar with techniques , protective equipment, and shielding material	G1	T2			
743	OSHA 29 CFR	1910.333.c.3	If work is to be performed near overhead lines, the lines shall be de-energized and grounded or other protection provided	G1	P6	D1	D6	
744	OSHA 29 CFR	1910.333.c.3.I.A	Unqualified persons working in elevated positions shall be placed so that they and longest conductive object in use maintain safe clearance from conductors	G1	P6			
745	OSHA 29 CFR	1910.333.c.3.I.B	Unqualified persons working on the ground may not bring any conductive object within safe clearance distance	G1	P6			
746	OSHA 29 CFR	1910.333.c.II	Qualified persons may approach with conductive objects with certain precautions	P6				
747	OSHA 29 CFR	1910.333.c.II.A	If qualified person is insulated from the energized part by protective clothing and equipment or	P4				
748	OSHA 29 CFR	1910.333.c.II.B	The energized part is insulated from all conductive objects at different potential and the person or	P6	P4			
749	OSHA 29 CFR	1910.333.c.II.C	The person is insulated from all conductive objects at a potential different from the energized part	P6	P4			
750	OSHA 29 CFR	1910.333.c.III.A	Any vehicle capable of elevating part of its structure shall be operated with 10 ft clearance minimum from conductors	P6	P3			
751	OSHA 29 CFR	1910.333.c.III.A.1	If vehicle is in transit with structure lowered, clearance may be reduced to 4 ft for 50 KV	P6	P3			
752	OSHA 29 CFR	1910.333.c.III.A.2	If insulating barriers are installed rated for the voltage, the clearance may be reduced to working clearance	P4	P3			
753	OSHA 29 CFR	1910.333.c,III.A.3	If the equipment is an insulated aerial lift operated by qualified employees, the clearance may be reduced	P4	P3			
754	OSHA 29 CFR	1910.333.c.III.B	Employees standing on the ground may not contact the vehicle unless properly equipped	P6				
755	OSHA 29 CFR	1910.333.c.III.B.1	Employees may contact vehicle if wearing protective clothing rated appropriately	P6	P4			
756	OSHA 29 CFR	1910.333.c.III.B.2	Employees may contact vehicle if the non insulated parts of the structure are outside safe clearances	P6	P3			
757	OSHA 29 CFR	1910.333.c.III.C	Employees may not stand near the grounding location of a vehicle with elevated parts. Barriers should be used for hazardous ground potentials	D6	P6			
758	OSHA 29 CFR	1910.333.c.4.I	Employees may not enter spaces containing exposed energized parts unless illumination is provided	P6	P5	G2		
759	OSHA 29 CFR	1910.333.c.4.II	Where lack of illumination or obstructions prohibit observation of the work, employees may not perform tasks near exposed energized parts	P6	P5	G2		
760	OSHA 29 CFR	1910.333.c.5	When employees work in confined spaces that contain exposed energized parts, protective shields, barriers, or insulating materials shall be used	P6	P7	P3	G2	
761	OSHA 29 CFR	1910.333.c.6	Conductive materials and equipment in contact with the employee shall be handled to prevent contacting exposed energized parts.	P6				
762	OSHA 29 CFR	1910.333.c.7	Portable ladders shall have nonconductive siderails if used where energized conductors could be contacted	P6	P4			
763	OSHA 29 CFR	1910.333.c.8	Conductive jewelry or cloth with conductive thread shall not be worn unless insulated	P6	P4			
764	OSHA 29 CFR	1910.333.c.9	Housekeeping duties shall not be performed at close distances to energized parts	P6	G1			
765	OSHA 29 CFR	1910.333.c.10	Only qualified persons may defeat electrical safety Interlocks temporarily while working on the system, interlock to be restored after work	P6	P2			
766	OSHA 29 CFR	1910.335.a.1.I	Employees working in areas of potential electric hazard shall be provided with and use protective equipment	P4				
767	OSHA 29 CFR	1910.335.a.1.II	Protective equipment shall be maintained in a safe reliable condition and test or inspected periodically	P4				
768	OSHA 29 CFR	1910.335.a.1.III	If the insulating capability may be subject to damage during use, the insulating material shall be protected	P4				
769	OSHA 29 CFR	1910.335.a.1.iv	Employees shall wear nonconductive head protection where there is a danger of injury from electric shock or burns	P4				
770	OSHA 29 CFR	1910.335.a.1.v	Employees shall wear face protection when there is danger of injury from electric arcs, flashes or electrical explosion	P4				
771	OSHA 29 CFR	1910.335.a.2.I	When working near exposed energized conductors, employees shall use insulated tools or handling equipment	P4	P6			
772	OSHA 29 CFR	1910.335.a.2.I.A	Fuse handling equipment shall be used to install fuses when the terminals are energized	P4				
773	OSHA 29 CFR	1910.335.a.2.I.B	Ropes and handlines used near exposed parts shall be non conductive	P6				
774	OSHA 29 CFR	1910.335.a.2.B.ii	Protective shields, barriers, or insulating materials shall be used to protect employees working near exposed energized conductors or if there is danger of electric heating o	P6	P3	P4		
775	OSHA 29 CFR	1910.335.b	Alerting techniques shall be used to warn and protect employees from hazards of shock, burns, or failure of electric equipment	P2	G1			
776	OSHA 29 CFR	1910.335.b.1	Safety signs and tags shall be used when necessary to warn employees of electrical hazards	P2	G1			
777	OSHA 29 CFR	1910.335.b.2	Barricades shall be used in conjunction with signs to prevent or limit access to work areas with exposed conductors, conductive barricades not to be used	P2				
778	OSHA 29 CFR	1910.335.b.3	If signs and barricades do not provide sufficient warning, employees shall be stationed to warn and protect employees	P2				
779	OSHA 29 CFR	1926.416.a.1	No employer shall permit an employee to work in proximity to energized circuits unless de-energized and grounded or insulated	P6	D6	D1		
780	OSHA 29 CFR	1926.416.a.2	In work areas where exact location of underground electric power is unknown, insulated gloves shall be provided to jackhammer operators or other workers	P6				
781	OSHA 29 CFR	1926.416.a.3	Before work is begun, employer shall determine whether any energized part or circuit is located so that any tool, person, or machine may contact it	P6	T2			
782	OSHA 29 CFR	1926.416.a.3-2	Employer shall post warning signs where such circuits exist and advise employees of hazards locations and protective means	P2	T2			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
783	OSHA 29 CFR	1926.416.b.1	Barriers or guards shall be provided to ensure that workspace for electrical equipment shall not be used as a passage way when energized circuits or parts are exposed	P2				
784	OSHA 29 CFR	1926.416.b.2	Work spaces walkways etc to be kept clear of cords so not to create a hazard	P5	G2			
785	OSHA 29 CFR	1926.416.c	No changes in circuit protection shall be made to increase the load in excess of the load rating of the wiring	C4				
786	OSHA 29 CFR	1926.416.d	When fuses are installed with one or both terminal energized, special tools insulated for the voltage shall be used	P4				
787	OSHA 29 CFR	1926.416.e	Worn or frayed cords or electric cables shall not be used	P4				
788	OSHA 29 CFR	1926.417.a	Controls that are to be deactivated on energized or de-energized equipment shall be tagged	D4				
789	OSHA 29 CFR	1926.417.b	Equipment and circuits that are de-energized shall be rendered inoperative and shall have tags attached at all points where such equipment can be energized	D4				
790	OSHA 29 CFR	1926.417.c	Tags shall be placed to identify plainly the equipment or circuits being worked on	D4				
791	OSHA 29 CFR	1926.431	Maintenance of equipment	C3				
792	OSHA 29 CFR	1910.269.a.2.i	Employees shall be trained with safety-related work practices that pertain to their job assignments and emergency procedures related to their work	T1	T2			
793	OSHA 29 CFR	1910.269.a.2.ii.A	Qualified employees shall be trained in skills and techniques to distinguish live circuits	T2				
794	OSHA 29 CFR	1910.269.a.2.ii.B	Qualified employees shall be trained in skills and techniques to determine the voltage of exposed live parts	T2				
795	OSHA 29 CFR	1910.269.a.2.ii.C	Qualified employees shall be trained in the minimum approach distances for voltages they will be exposed to	T2	P3			
796	OSHA 29 CFR	1910.269.a.2.ii.D	Qualified employees shall be trained in specials precautionary techniques, personal protective equipment, and insulated tools for work on or near exposed live parts	T2	P4			
797	OSHA 29 CFR	1910.269.a.2.iii	Employers shall determine through supervision and annual inspections, that each employee is complying with safety-related work practices	G1	S3			
798	OSHA 29 CFR	1910.269.a.2.iv	Employees shall receive additional retraining under certain conditions including new technology equipment, or on practices not normally used during regular job duties	G1	T1			
799	OSHA 29 CFR	1910.269.a.2.v	Training shall be classroom or on the job	G1				
800	OSHA 29 CFR	1910.269.a.2.vi	Training shall establish employee proficiency in the work practices required by regulations	G1	T1			
801	OSHA 29 CFR	1910.269.a.2.vii	Employers shall certify that each employee has received training upon reaching proficiency	G1				
802	OSHA 29 CFR	1910.269.a.3	Existing conditions related to safety are to be determined before work near electric lines is started	T2	G1	G2		
803	OSHA 29 CFR	1910.269.b	Employers shall provide medical services and first aid per 1910.151	G2				
804	OSHA 29 CFR	1910.269.b.1.i	CPR trained employees to be available for field work	G2				
805	OSHA 29 CFR	1910.269.b..1.ii	For fixed installations sufficient employees to be CPR trained to reach any employee within 4 minutes	G2				
806	OSHA 29 CFR	1910.269.b.2	First aid supplies to be placed in weatherproof container if required	G2				
807	OSHA 29 CFR	1910.269.b.3	First aid kits to be maintained, readily available for use, and inspected frequently	G2	P4			
808	OSHA 29 CFR	1910.269.c	Employees to conduct a job briefing before starting each job covering hazards, work procedures, special precautions, energy source controls, and personal protective requ	G1	G2	T1	T2	
809	OSHA 29 CFR	1910.269.c.1	At least one briefing per shift, additional briefings if significant changes occur during work	G1	G2	T1	T2	
810	OSHA 29 CFR	1910.269.c.2	Brief discussion for routine work for safety briefing	G1	G2	T1	T2	
811	OSHA 29 CFR	1910.269.c.2.i	More extensive briefing required if work in complicated or particularly hazardous	G1	G2	T1	T2	
812	OSHA 29 CFR	1910.269.c.2.ii	More extensive briefing if employee cannot be expected to recognize and avoid the hazards on the job	G1	G2	T1	T2	
813	OSHA 29 CFR	1910.269.c.3	Employees working alone need not conduct a briefing but employer shall ensure that work is performed as if a briefing were required	G1	G2	T1	T2	
814	OSHA 29 CFR	1910.269.d.1	Lockout-tagout procedures shall apply	D4				
815	OSHA 29 CFR	1910.269.d.2	Employer shall establish a lockout tagout program including training and periodic inspections	D4				
816	OSHA 29 CFR	1910.269.d.2.A	If energy isolating device is not capable of being locked out a tagout system shall be used	D4				
817	OSHA 29 CFR	1910.269.d.2.B	If capable of lockout , lockout shall be used unless employer can demonstrate tagout to provide full protection	D4				
818	OSHA 29 CFR	1910.269.d.2.C	Whenever energy control devices are replaced or modified they shall be designed for lockout	D4	P4			
819	OSHA 29 CFR	1910.269.d..2.iii	Procedures shall be developed documented and used for lockout tagout of potentially hazardous energy	D4				
820	OSHA 29 CFR	1910.269.d.2.iv	Procedure shall outline the scope,purpose,responsibility, rules, and techniques to be used for lockout tagout	D4	G1			
821	OSHA 29 CFR	1910.269.d.2.v	Employer shall conduct a periodic inspection at least annually to ensure that lockout tagout procedures are being followed	G1				
822	OSHA 29 CFR	1910.269.d.2.vi	Employer shall provide training to ensure that functions of lockout tagout are understood and skills required are acquired	T1				
823	OSHA 29 CFR	1910.269.d.2.vii	Employees shall be trained for tagout systems including limitations for safe use of such a system	T1	T2			
824	OSHA 29 CFR	1910.269.d.2.viii	Employers shall provide retraining in certain situations on lockout tagout procedures	T1				
825	OSHA 29 CFR	1910.269.d.2.ix	Employer shall certify that employees are trained in lockout tagout procedure and training is up to date	G1	T1			
826	OSHA 29 CFR	1910.269.d.3.i	Employer shall provide hardware to be used for lockout and tagout	P4				
827	OSHA 29 CFR	1910.269.d.3.ii	Lockout and tagout devices to be identified and used solely for controlling energy and be of proper material and construction	D4				
828	OSHA 29 CFR	1910.269.d.4	Lockout and tagout device application and removal shall be performed only by authorized employees performing the work	D4				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
829	OSHA 29 CFR	1910.269.d.5	Affected employees shall be notified by the employer of the application and removal of lockout tagout devices	D4	T2			
830	OSHA 29 CFR	1910.269.d.6	Procedures for application of lockout tagout devices shall follow a specific sequence	D4				
831	OSHA 29 CFR	1910.269.d.6.i	Before de-energizing a system the authorized employee shall have knowledge of the hazards and means to control the energy	D4	T2	S1		
832	OSHA 29 CFR	1910.269.d.6.ii	Machines or equipment shall be shut down using procedures established to avoid any additional hazards	D4	C4			
833	OSHA 29 CFR	1910.269.d.6.iii	All energy isolating devices needed to control the energy to the system shall be located and operated to remove power	D4				
834	OSHA 29 CFR	1910.269.d.6.iv	Lockout or tagout devices shall be affixed to each energy isolating device by authorized employees using specific procedures	D4				
835	OSHA 29 CFR	1910.269.d.6.v	Following isolation, all potentially hazardous stored or residual energy is to be relieved, disconnected, or otherwise rendered safe.	D1	D4			
836	OSHA 29 CFR	1910.269.d.6.vi	If there is a possibility of reaccumulation of stored energy to a hazardous level, verification of isolation shall be continued during work	D1	D4			
837	OSHA 29 CFR	1910.269.d.6.vii	Before starting work on de-energized equipment, employee shall verify that isolation and de-energizing has been accomplished, tests to be performed before contacting pa	D2				
838	OSHA 29 CFR	1910.269.d.7	Procedures are to be followed for re-energizing circuits and equipment	D4	C4			
839	OSHA 29 CFR	1910.269.d.7.i	The work area to be inspected for equipment safety and normal operability	D4	C4	C1		
840	OSHA 29 CFR	1910.269.d.7.ii	The work area shall be checked to ensure that employees are in a position of safety	D4	P6			
841	OSHA 29 CFR	1910.269.d.7.iii	After lockout tagout devices are removed, employees shall be notified	D4	S3	S4		
842	OSHA 29 CFR	1910.269.d.7.iv	Each lockout tagout device shall be removed by the authorized employee who installed it or specific procedures to be used :	D4				
843	OSHA 29 CFR	1910.269.d.7.iv.A	Employer to verify that employee applying device is not at the facility	D4				
844	OSHA 29 CFR	1910.269.d.7.iv.B	Employer to make reasonable efforts to contact the authorized employee to inform him that lockout tagout device has been removed	D4				
845	OSHA 29 CFR	1910.269.d.7.iv.C	Ensure that the authorized employee has knowledge that lockout tagout has been removed before he resumes work	D4	T2			
846	OSHA 29 CFR	1910.269.d.8	When equipment is to be temporarily re-energized, same procedures to apply as for final re-energizing	D4				
847	OSHA 29 CFR	1910.269.e	Specific work practices, training, equipment and evaluation of potential hazards required for work in enclosed spaces	T2	S3	S4		
848	OSHA 29 CFR	1910.269.g.1	Personal protective equipment shall meet specific requirements	P4				
849	OSHA 29 CFR	1910.269.g.2	Fall arrest equipment shall meet certain requirements and will be inspected before use each day	P4				
850	OSHA 29 CFR	1910.269.h	ladders platforms and steps shall be secured properly and not overloaded, and shall be used only for the applications they were designed for	G1				
851	OSHA 29 CFR	1910.269.j	Live line tools shall be designed to specific standards, inspected for defects each day, and retested after any repairs	P4				
852	OSHA 29 CFR	1910.269.k	Material may not be stored or handled closer than specified clearance limits to energized conductors	P6	P5	G2		
853	OSHA 29 CFR	1910.269.1.1	Only qualified employees may work on exposed live parts or in areas containing unguarded live parts	T2	P6			
854	OSHA 29 CFR	1910.269.1.i	Two employees shall be present during work on live lines above 600 V	G1				
855	OSHA 29 CFR	1910.269.1.ii	Two employees not required for certain work demonstrated to be safely performed by one person	G1				
856	OSHA 29 CFR	1910.269.2	Employer shall ensure that no employee approaches energized parts within specified approach distances	P3				
857	OSHA 29 CFR	1910.269.2.i	Employees may approach live parts using insulated gloves and sleeves	P4				
858	OSHA 29 CFR	1910.269.2.ii	Employees may approach live parts if the parts are insulated from employee and other different potentials	P6				
859	OSHA 29 CFR	1910.269.2.iii	Employees may perform bare hand work if insulated from any other exposed conductive object	P1				
860	OSHA 29 CFR	1910.269.3	Employees to use gloves and sleeves are required unless equivalent protective insulation is used	P4	P1			
861	OSHA 29 CFR	1910.269.4	Employer shall ensure that employee's working position will not cause contact with exposed live parts after a slip or shock	P5				
862	OSHA 29 CFR	1910.269.5.1	Connections to be made first to de-energized parts, then to energized	P6	C4			
863	OSHA 29 CFR	1910.269.5.ii	Disconnecting to begin at the energized parts	P6	C4			
864	OSHA 29 CFR	1910.269.5.iii	Disconnected lines or equipment to be kept away from exposed energized parts	P6				
865	OSHA 29 CFR	1910.269.6.i	Employer shall ensure that employees remove or render nonconductive all exposed articles	P6				
866	OSHA 29 CFR	1910.269.6.ii	Employer shall train each employee in hazards of flames or electric arcs	T2				
867	OSHA 29 CFR	1910.269.6.iii	Employees shall wear protective clothing when exposed to flames or electric arcs	P4				
868	OSHA 29 CFR	1910.269.7	Fuses shall be handled with gloves and tools rated for the appropriate voltage	P4				
869	OSHA 29 CFR	1910.269.8	Covered wires (non insulated) are to be treated as exposed live wires	G1				
870	OSHA 29 CFR	1910.269.9	Noncurrent carrying parts such a cases and housings are to be treated as energized unless inspected to verify they are grounded before working	G1				
871	OSHA 29 CFR	1910.269.m.	Rules for de-energizing lines and equipment by system operators	D4				
872	OSHA 29 CFR	1910.269.m.3.i	A designated employee shall make request for de-energizing a particular section of line, this employee becomes employee in charge	D4				
873	OSHA 29 CFR	1910.269.m.3.ii	All switches disconnects jumpers, taps etc through which electric energy may be supplied to the section shall be opened, locked and tagged	D4				
874	OSHA 29 CFR	1910.269.m.3.iii	Automatic and remote controlled switches shall also be tagged at the point of control and rendered inoperable if possible	D4				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
875	OSHA 29 CFR	1910.269.m.3.iv	Tags shall prohibit operation of the disconnecting means and shall indicate that employees are at work	D4				
876	OSHA 29 CFR	1910.269.m.v	After all sources are disconnected by the system operator, the employee in charge to be notified and lines checked to verify no power	D4	D2			
877	OSHA 29 CFR	1910.269.m.vi	Protective grounds are to be installed	D6				
878	OSHA 29 CFR	1910.269.m.vii	After preceding has been accomplished, lines may be worked as de-energized	D4				
879	OSHA 29 CFR	1910.269.m.viii	If two or more crews are working, each crew will independently comply with these requirements	D4				
880	OSHA 29 CFR	1910.269.m.ix	To transfer the clearance, the system operator shall be notified of the new employee in charge of the clearance	D4				
881	OSHA 29 CFR	1910.269.m.x	To release a clearance, the employee in charge shall make proper notifications	D4				
882	OSHA 29 CFR	1910.269.m.x.A	Employees under the charge of the employee in charge shall be notified	D4				
883	OSHA 29 CFR	1910.269.m.x.B	Employee in charge shall determine that all employees are clear of lines and equipment	D4	S2			
884	OSHA 29 CFR	1910.269.m.x.C	Employee in charge shall determine that all protective grounds are removed	D4	S2	C4		
885	OSHA 29 CFR	1910.269.m.x.A	Employee in charge shall report to the system operator this information and release the clearance	D4				
886	OSHA 29 CFR	1910.269.m.xi	The person releasing a clearance shall be the same person who requested it unless responsibility has been transferred	D4				
887	OSHA 29 CFR	1910.269.m.xii	Tags may not be removed unless the associated clearance has been released	D4				
888	OSHA 29 CFR	1910.269.m.xiii	After grounds have been removed, clearance released by all employees, and protective tags removed, action to re-energize may begin	D4				
889	OSHA 29 CFR	1910.269.n.1	Protective grounding shall be used for protection employees working on transmission and distribution lines	D6				
890	OSHA 29 CFR	1910.269.n.2	If installation of grounds is not practical, work may proceed if lines are de-energized, no possibility of contact with live lines, and no induced voltage hazards exist	D1				
891	OSHA 29 CFR	1910.269.n.3	Temporary protective grounds shall be placed to protect employees from hazardous differences in electrical potential	D6	D3			
892	OSHA 29 CFR	1910.269.n.4	Protective grounding equipment shall be capable of conducting the maximum fault current possible at the point of ground for time necessary to clear the fault	P4	D6			
893	OSHA 29 CFR	1910.269.n.5	Protective ground shall have low enough impedance to cause operation of protective devices in case of accidental re-energization	P4	D6			
894	OSHA 29 CFR	1910.269.n.6	Grounds to be attached to ground first then to line with a live line tool	P4	D6			
895	OSHA 29 CFR	1910.269.n.7	Grounds to be removed first from the line, then from ground	G1	C4			
896	OSHA 29 CFR	1910.269.n.8	Cables not to be grounded at terminals remote from work site if potential for hazardous transfer of potential due to a fault	D6				
897	OSHA 29 CFR	1910.269.n.9	Grounds may be removed temporarily during tests if employees are insulated and other precautions are taken	D6	G1			
898	OSHA 29 CFR	1910.269.o	Procedures and requirements for electrical system test facilities	G1				
899	OSHA 29 CFR	1910.269.p.i	Critical safety components of elevating and rotating equipment shall be inspected thoroughly before use on each shift	G2	C2			
900	OSHA 29 CFR	1910.269.p.ii	Vehicles with restricted view to the rear to be used only when observer present or audible alarm used	G2				
901	OSHA 29 CFR	1910.269.p.iii	Operator not to leave position with suspended load unless demonstrated to be safe	G2				
902	OSHA 29 CFR	1910.269.p.iv	Rubber tired equipment to have rollover protective structures	G2				
903	OSHA 29 CFR	1910.269.p.iv.4	Mechanical equipment to be operated outside minimum approach distances specified	G1	P3	P6		
904	OSHA 29 CFR	1910.269.p.iv.4.ii	Designated employee to observe approach distance of equipment to energized lines and give timely warning	P3	S2			
905	OSHA 29 CFR	1910.269.p.iv.4.iii	If contact with energized parts occurs, special procedures apply for insulation, grounding and bonding	D6				
906	OSHA 29 CFR	1910.269.q.1.i	Elevated structures to be ascertained as capable of sustaining additional stresses before work begins	G2				
907	OSHA 29 CFR	1910.269.q.1.ii	Poles to be set are not to contact energized conductors	G1				
908	OSHA 29 CFR	1910.269.q.1.iii	Protective clothing and equipment to be used when handling poles near energized lines	P4				
909	OSHA 29 CFR	1910.269.q.1.iv	Holes to be attended to prevent falls when setting poles	G2				
910	OSHA 29 CFR	1910.269.q.2.i	Tension stringing method to be used to prevent installed cables from contacting energized lines	P6				
911	OSHA 29 CFR	1910.269.q.2.ii	Protective measures to be applied to conductors, cables, and stringing equipment	P6				
912	OSHA 29 CFR	1910.269.q.2.iii	Automatic reclosers on crossing lines to be made inoperative during stringing operation	P6				
913	OSHA 29 CFR	1910.269.q.2.iv	When stringing lines parallel to energized conductors, precautions shall be taken for induced voltages	P6				
914	OSHA 29 CFR	1910.269.q.2.v	Reel handling equipment to be in safe operating condition	G2	P4			
915	OSHA 29 CFR	1910.269.q.2.vi	Load rating of reel handling equipment not to be exceeded	G2	P4			
916	OSHA 29 CFR	1910.269.q.2.vii	Pulling lines and accessories to be repaired or replaced if defective	P4				
917	OSHA 29 CFR	1910.269.q.2.viii	Conductor grips to be specifically designed for that purpose	P4				
918	OSHA 29 CFR	1910.269.q.2.ix	Reliable communication via radio etc to be maintained during stringing	G1				
919	OSHA 29 CFR	1910.269.q.2.x	Pulling rig to be operated only when safe to do so	G2				
920	OSHA 29 CFR	1910.269.q.2.xi	Employees not to be directly under overhead operations during pulling except as necessary	G2				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
921	OSHA 29 CFR	1910.269.q.3.i	Before using or supervising bare hand work, employees shall be trained in technique and safety requirements	T1	T2			
922	OSHA 29 CFR	1910.269.q.3.ii	Information required on voltages, approach distances and limitations of equipment before starting barehand work	T2				
923	OSHA 29 CFR	1910.269.q.3.iii	Insulated equipment to be designed for such work and kept in proper condition	P4				
924	OSHA 29 CFR	1910.269.q.3.iv	Automatic reclosers to be made inoperative during barehand work	P6				
925	OSHA 29 CFR	1910.269.q.3.v	Bare hand work not permitted during hazardous weather conditions	G2				
926	OSHA 29 CFR	1910.269.q.3.vi	Conductive bucket liner to be provided for bonding the insulated aerial device to the energized line	D6				
927	OSHA 29 CFR	1910.269.q.3.vi.A	Employee to be connected to bucket liner with conductive devices	D6				
928	OSHA 29 CFR	1910.269.q.3.vi.B	Electrostatic shielding to be used if hazardous potential differences exist	P6				
929	OSHA 29 CFR	1910.269.q.3.vii	Conductive bucket liner to be bonded to energized conductor during work	D6				
930	OSHA 29 CFR	1910.269.q.3.viii	Aerial lifts shall have dual controls	G2				
931	OSHA 29 CFR	1910.269.q.3.ix	Lower controls not to be operated when lift is manned except in an emergency	G1				
932	OSHA 29 CFR	1910.269.q.3.x	Controls to be checked before elevating to working position	G1				
933	OSHA 29 CFR	1910.269.q.3.xi	Body of truck to be grounded before elevating boom	G2	D6			
934	OSHA 29 CFR	1910.269.q.3.xii	Boom current test to be conducted prior to work each day or if conditions warrant	C2				
935	OSHA 29 CFR	1910.269.q.3.xiii	Minimum approach distances to be maintained unless insulated by guards	P3	P6			
936	OSHA 29 CFR	1910.269.q.3.xiv	Minimum approach distances to be maintained when approaching, bonding to and energized circuit or grounded parts of the truck	P3				
937	OSHA 29 CFR	1910.269.q.3.xv	Minimum distances to be maintained between bucket and insulator string or bushing	P3				
938	OSHA 29 CFR	1910.269.q.3.xvi	Hand lines not to be used from bucket to ground	P6				
939	OSHA 29 CFR	1910.269.q.3.xvii	Uninsulated equipment not to be passed between pole or structure when employee is bonded to energized line	P6				
940	OSHA 29 CFR	1910.269.q.3.xviii	Minimum approach distances to be printed on nonconductive material visible to boom operator	P3				
941	OSHA 29 CFR	1910.269.q.3.xix	Nonconductive measure device to be available for determining approach distances	P4				
942	OSHA 29 CFR	1910.269.q.4.i	Employer to ensure that no employees are under a tower or structure when work is in progress	G1	G2			
943	OSHA 29 CFR	1910.269.q.4.ii	Tag lines to be used unless they would create a greater hazard	G1				
944	OSHA 29 CFR	1910.269.q.4.iii	Load line not to be detached unless load is safely secured	G1				
945	OSHA 29 CFR	1910.269.q.4.iv	Work to be discontinued under adverse conditions	G1				
946	OSHA 29 CFR	1910.147	Lockout tagout procedures apply to control of energy during servicing and maintenance of equipment	D4				
947	PANYNJ High Tension Administrative Rules	1	The High Tension System Operator is responsible for making all areas safe in which work is to be performed on or near high tension electrical equipment	D4	S3			
948	PANYNJ High Tension Administrative Rules	2	No work is to be performed withou t the specific approval of the High Tension System Operator	S3				
949	PANYNJ High Tension Administrative Rules	3	Numbered keys tags and grounds are to be used, numbers recorded and retained by High Tension System Operator until feeder is back in service	D4				
950	PANYNJ High Tension Administrative Rules	4	In absence from the facility, the High Tension System Operator may authorize by telephone switching of loads providing this does not conflict with any rules and regulation	D4				
951	PANYNJ High Tension Administrative Rules	5	When work in an high tension are is required a electrical work permit shall be completed by the requesting agency	D4				
952	PANYNJ High Tension Administrative Rules	5-2	All necessary work to de-energize, isolate, tag, and ground feeders and install barriers performed under direction of the High Tension System Operator	D4	D1	D6		
953	PANYNJ High Tension Administrative Rules	5-3	The High Tension System Operator shall make certain that appropriate personnel protective equipment is used or worn during de-energizing, isolating, and grounding	P4				
954	PANYNJ High Tension Administrative Rules	6	Original and 6 copies of each Electrical Work Permit to be filled out, detached portion of tags to be filed with High Tension System Operator's copy after work is complete	D4				
955	PANYNJ High Tension Administrative Rules	7	The requesting agency shall assure itself of safe conditions prior to starting work by:	D4				
956	PANYNJ High Tension Administrative Rules	7.a	All equipment has been isolated with locking and tagging disconnect devices, contacts visually checked open	D4				
957	PANYNJ High Tension Administrative Rules	7.b	The feeder cable has been identified properly grounded and cut if it is to be worked on	D4	D1	D6		
958	PANYNJ High Tension Administrative Rules	7.c	All electrical equipment with exposed conductors within the work area is grounded if de-energized or protected by a barrier approved by the High Tension System Operator	D1	P2			
959	PANYNJ High Tension Administrative Rules	7.d	The work area has been identified with approved markers	P2				
960	PANYNJ High Tension Administrative Rules	7.e	Parts 1,2,3 of all copies of the Electrical Work Permit have been completed	D4				
961	PANYNJ High Tension Administrative Rules	7.f	All men working in the work area have initialed part 4A of the Electrical Work Permit	D4	T2			
962	PANYNJ High Tension Administrative Rules	7.g	The work area shall be suitable protected against access by unauthorized persons	P2				
963	PANYNJ High Tension Administrative Rules	8	No work other than that detailed in the Electrical Work Permit shall be performed within the work area unless covered by another electrical work permit	D4				
964	PANYNJ High Tension Administrative Rules	9	After all work is completed, all men shall sign off at the end of the work day on the electrical work permit	D4				
965	PANYNJ High Tension Administrative Rules	10	After completion of the signoff portion, preparation for re-energizing may begin under supervision of the High Tension System Operator	D4				
966	PANYNJ High Tension Administrative Rules	10-2	No switching shall take place until checking that no uncompleted work permits pertain to work on this feeder or equipment or other feeders in the area	D4				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
967	PANYNJ High Tension Administrative Rules	10-3	Prior to re-energizing the feeder, a physical determination shall be made by the High Tension Systems Operator together with the requesting agency to assure that all area	D4	C4			
968	PANYNJ High Tension Safety Rules	1	No work is to be performed without specific approval of the High Tension Systems Operator	D4				
969	PANYNJ High Tension Safety Rules	2	Before any work commences, an electrical work permit and appropriate diagrams SHALL be prepared to assure safe execution of the operation and reviewed	D4				
970	PANYNJ High Tension Safety Rules	3	The person to work on the equipment or cable must be personally satisfied that all safety precautions have been taken	D4	S1			
971	PANYNJ High Tension Safety Rules	4	When work is to be done at least two persons must be present	G1				
972	PANYNJ High Tension Safety Rules	5	Key interlocks shall be operated as designed	D4				
973	PANYNJ High Tension Safety Rules	6	All safety and test equipment must be of approved type and properly maintained and periodically tested	P4	C2			
974	PANYNJ High Tension Safety Rules	7	All electrical equipment in the work area that has exposed conductors must either be grounded or provided with a protective barrier must provide minimum clearance as sp	D1	P6	P2		
975	PANYNJ High Tension Safety Rules	8	All work areas in the work permit must be marked off with approved markers	P2				
976	PANYNJ High Tension Safety Rules	8-2	Only the High Tension System Operator and men who have signed on to the work permit are allowed in the work area	G1				
977	PANYNJ High Tension Safety Rules	9	Protective equipment shall be used or worn by personnel working until all systems have been de-energized, isolated and grounded	P4				
978	PANYNJ High Tension Safety Rules	10	A circuit shall be visually checked by the High Tension Systems Operator to assure that it is isolated	D2				
979	PANYNJ High Tension Safety Rules	10-2	The isolating device shall then be locked open and tagged by the High Tension System Operator	D4				
980	PANYNJ High Tension Safety Rules	10-3	When disconnect potheads, fuse cutouts, or positects are used they shall not be operated until the feeder has been de-energized	P6	C4			
981	PANYNJ High Tension Safety Rules	10-4	At oil switch locations the air break device shall be opened first witnessed and tested to ensure that the circuit is not energized before operating oil switch	C4	G1			
982	PANYNJ High Tension Safety Rules	11	Cables and capacitors shall be treated as energized until discharged and grounded	P6	D1	D6		
983	PANYNJ High Tension Safety Rules	12	Grounding breakers shall be closed only electrically by the High Tension Systems operator	D6	C4			
984	PANYNJ High Tension Safety Rules	13	The secondary side of energized current transformers shall not be worked on until the immediate supervisor has short circuited it between the transformer and the work loc	D1	D6			
985	PANYNJ High Tension Safety Rules	14	Grounds of proper size shall be placed on both sides and as close as practical to the work location under supervision	D6	P4			
986	PANYNJ High Tension Safety Rules	15	Manholes shall be tested for the presence of harmful gas prior to being pumped or entered They shall be ventilated while in use	G2				
987	PANYNJ High Tension Safety Rules	16	Open manholes shall be barricaded or guarded by railings and not left unattended Personnel shall be stationed at the opening to render help and notify of emergencies	G2				
988	PANYNJ High Tension Safety Rules	17	Slight changes in the position of a cable may be made within the scope of a work permit at the Discretion of the High Tension System Operator, rubber gloves and face ma	P4				
989	PANYNJ High Tension Safety Rules	18	Feeder cables to be positively identified by the High Tension System Operator prior to work and suitably tagged	D2				
990	PANYNJ High Tension Safety Rules	19	Cables shall be cut only after positive signal or other identification is made under direct supervision of the High Tension Systems Operator and ident tags are attached	D2				
991	PANYNJ High Tension Safety Rules	20	Before restoring power, the High Tension System Operator shall verify that all short circuits and grounds have been removed and all personnel have been cleared	D4	C4	P6		
992	AMTRAK NRPC-1908	4480	Climb pole only when qualified and authorized to do so	G1				
993	AMTRAK NRPC-1908	4481	Use standard body belt and safety strap adjust for slack only in certain situations	G1				
994	AMTRAK NRPC-1908	4482	Before climbing pole be sure that person above is in position , before descending be sure that persons below are clear	G1				
995	AMTRAK NRPC-1908	4483	Inspect climber, skate, strap ,body belt and safety strap before use if defective it must be marked	P4				
996	AMTRAK NRPC-1908	4484	Use climbing equipment only if not defective	P4				
997	AMTRAK NRPC-1908	4485	Wood pole climbers to be used with caution on the ground	P4				
998	AMTRAK NRPC-1908	4486	Climb painted poles only when paint is dry	G1				
999	AMTRAK NRPC-1908	4487	Safety precautions for general pole climbing	G1				
1000	AMTRAK NRPC-1908	4488	Observe conditions of poles before climbing	G1				
1001	AMTRAK NRPC-1908	4489	Test doubtful poles before climbing	G1				
1002	AMTRAK NRPC-1908	4490	If pole tests unsafe use bracing or guys	G1				
1003	AMTRAK NRPC-1908	4491	Use bracing or guys on crossarms before certain work	G1				
1004	AMTRAK NRPC-1908	4492	when pulling wire around curves keep it on the outside if possible	G1				
1005	AMTRAK NRPC-1908	4493	Tie new catenary wire to each hanger locations to prevent fouling adjacent track	G1				
1006	AMTRAK NRPC-1908	4494	Securely fasten catenary wire after stringing before working on it	G1				
1007	AMTRAK NRPC-1908	4495	Before riding inspect messenger strand, if unsafe use emergency stand and report condition to supervisor	G1				
1008	AMTRAK NRPC-1908	4496	When pulling catenary and auxiliary wire attach clamp to each wire	G1				
1009	AMTRAK NRPC-1908	4497-4499	Rules for safe wire pulling	G1	T1			
1010	AMTRAK NRPC-1908	4510-4518	Rules for safe erecting and removal of poles	G1	T1			
1011	AMTRAK NRPC-1908	4530	Work on electrical equipment only if qualified and only when authorized to do so	G1				
1012	AMTRAK NRPC-1908	4531	Use equipment only if it is approved for use in maintenance and operation of the circuit used on	P4				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1013	AMTRAK NRPC-1908	4532	Insulation or weatherproofing on wire not to be depended upon to avoid shock	P6				
1014	AMTRAK NRPC-1908	4533	Proper protective clothing and equipment to be used for specific voltages	P4				
1015	AMTRAK NRPC-1908	4534	Approach distances for specific voltages	P3				
1016	AMTRAK NRPC-1908	4535	Keep self and any object handled 8 feet from any dangling wire or object in contact with energized circuit	P3				
1017	AMTRAK NRPC-1908	4536	Wire wet rope steel or linen tape line with metallic reinforcement not to be used around energized equipment	P4				
1018	AMTRAK NRPC-1908	4537	Enter electrical substation or power plant only if authorized to do so	G1	T2			
1019	AMTRAK NRPC-1908	4538	Before drilling locate hole to avoid contact with wire or electric equipment	G1	P6			
1020	AMTRAK NRPC-1908	4539	Before excavating foreman must ascertain if any underground wires or equipment are in the area	G1	P6			
1021	AMTRAK NRPC-1908	4540	Specific rules for fire fighting near energized electrical equipment	G1				
1022	AMTRAK NRPC-1908	4541	Employee must report to supervisor and receive authority to work on any circuit > 480 V	G1				
1023	AMTRAK NRPC-1908	4542	Work not to be performed on aerial equipment during electrical storms unless properly grounded	G1	D6			
1024	AMTRAK NRPC-1908	4543	Inspect structure to determine if it is energized due to abnormal conditions, if in doubt deenergize circuit	D2				
1025	AMTRAK NRPC-1908	4544	Position self proper distance from wire when using nonconductive stick to position it	G1	P3			
1026	AMTRAK NRPC-1908	4545	Before riding messenger strand determine that proper clearance from energized circuits will exist	G1				
1027	AMTRAK NRPC-1908	4546	Inspect cable ties when riding messenger strand over energized wire, secure loose cable before proceeding	G1				
1028	AMTRAK NRPC-1908	4547	Place standard wiring tags on switch set to de-energize line or equipment	D4				
1029	AMTRAK NRPC-1908	4548	Employee completing clearance must obtain signatures of all workers and inform them which circuits are covered and which are energized	D4				
1030	AMTRAK NRPC-1908	4549	Before releasing clearance, check that catenary wires are in safe condition for electric operation and all employee and grounding devices are clear	D4	P6	C4		
1031	AMTRAK NRPC-1908	4550	Before operating switch ensure that it does not bear a DO NOT OPERATE tag	D4				
1032	AMTRAK NRPC-1908	4551	Before authorizing removal of tags check that all workmen are clear and have perceived notice that ground shave been removed	D4	P6	C4		
1033	AMTRAK NRPC-1908	4552	Remove or replace fuses > 175 V using only rubber gloves and insulated tongs	P4				
1034	AMTRAK NRPC-1908	4553	Switch pole may be used only on circuits < 15000 V	P4				
1035	AMTRAK NRPC-1908	4554	Before applying grounds to 138000 V line visually check that grounding switch has made contact in substations	C4	T1			
1036	AMTRAK NRPC-1908	4555	Hold switch pole so that max length of pole is between person and circuit	G1				
1037	AMTRAK NRPC-1908	4556	Operate disconnect switch pole using rubber gloves and proper type pole	P4				
1038	AMTRAK NRPC-1908	4557	Close circuit breaker contacts as quickly as possible	G1				
1039	NFPA 130-14	3-4.3.4	The primary hazards presented by the third rail are electrical shock to personnel and the heat and smoke generated by cable or third rail from grounding or arcing	T2				
1040	NFPA 130-14	6-11.1	During an emergency the authority and participating agency personnel shall be carefully supervised so that the minimum number of essential persons operate on the train	S2	G2	P6		
1041	NFPA 130-14	6-11.2	The emergency procedure plan shall have a clearly defined procedure for removing and restoring traction power	D1	D4			
1042	NFPA 130-14	6-11.3	Prior to agency personnel operating on the trainway, the traction power shall be removed	D1	P6			
1043	NFPA 130-14	6-11.4	When traction power is removed the CSS shall be contacted by radio or telephone as given name title and agency of reason for removal of power	D4				
1044	NFPA 130-14	6-11.5	When shutdown of traction power is no longer required, control of such power shall be released to the authority	D4				
1045	BART Emergency Plan (NTSB-RAR-79-5 Appendix G)	11	If there is an actual incident in either the tube or the station, trackway, BREAK GLASS IN PLATFORM TRIP to de-energize the third rail on that side only	D1	T2			
1046	BART Emergency Plan (NTSB-RAR-79-5 Appendix G)	11.a.1	Station control shall confirm with BART central that the power is off	D2				
1047	BART Emergency Plan (NTSB-RAR-79-5 Appendix G)	13	Before entering the tube confirm with BART central that the power is off in that tube. Clearance must be given before entering tubes or electrical enclosures	D1	D2			
1048	BART Emergency Plan (NTSB-RAR-79-5 Appendix G)	15	The forward command officer orders the contact third rail trip to be depressed at the nearest blue light station	D1				
1049	BART Emergency Plan (NTSB-RAR-79-5 Appendix G)	15-2	Confirms with BART central that the power is off in this section, and notifies them that the trip has been depressed.	D2	S2			
1050	BART Emergency Plan (NTSB-RAR-79-5 Appendix G)	17	Department order requires that no operation be conducted below the car floor level until SAFE CLEARANCE has been given	P6				
1051	NFPA 70B	20-1.1	Personnel working on or in close proximity to de-energized lines or conductors should bee protected against shock hazard and flash burns that would occur if inadvertently	P6	G2	P4	C3	
1052	NFPA 70B	20-1.2.1	Deenergize the proper circuit, open the disconnecting device for each source of supply do not consider automatic disconnecting devices for personnel safety	D1	D2	C3		
1053	NFPA 70B	20-1.2.2	Take precaution to prevent accidental re-energization attach tags and locks	D4				
1054	NFPA 70B	20-1.2.3	Test the circuit to confirm that all conductors are de-energized, test detector before and after test	D2				
1055	NFPA 70B	20-1.2.4	Until grounded conductors should be considered energized and personnel should not touch them Ground capacitors	D6	P6			
1056	NFPA 70B	20-1.2.5	Involve all personnel connected with the work each should personally satisfy himself that the necessary steps have been completed	D2	S1			
1057	NFPA 70B	20.1-3	Grounding as means to protect from inadvertent re-energizing	D6				
1058	NFPA 70B	20-1.3.1	Grounding clamps of proper size and capacity	P4	C4	D6		

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1059	NFPA 70B	20-1.3.2	Grounding cables of adequate capacity, size and low resistance	P4	C4	D6		
1060	NFPA 70B	20-1.3.3	Solid metal to metal connections to be made	D6	P4	T3		
1061	NFPA 70B	20-1.3.4	Grounding cables no longer than necessary	D6	P4	T3		
1062	NFPA 70B	20-1.3.5	Grounding cables to be connected between phases to the grounded structure and to the system neutral	D6	T3			
1063	NFPA 70B	20-1.3.5-1	Connect phase conductors together with short cables and clamps	D6	T3			
1064	NFPA 70B	20-1.3.5-2	Inspect grounding equipment prior to use	D6	C2	P4		
1065	NFPA 70B	20-1.3.5-3	Install grounds at each point where work is being performed on de-energized equipment	D6	T3			
1066	NFPA 70B	20-1.3.5-4	Connect one end of ground to metal structure or ground bus before connecting to a conductor	D6	C3			
1067	NFPA 70B	20-1.3.5-5	Remove in reverse order	D6	C3			
1068	NFPA 70B	20-1.3.5-6	Remove protective grounds before re-energizing circuit	D6	C4			
1069	NFPA 70B	20-1.3.5-6.a	Assign identification number to each ground and control all sets and location installed	D6	C4			
1070	NFPA 70B	20-1.3.5-6.b	Before re-energizing circuit account for all sets of grounding equipment	D6	C4			
1071	NFPA 70B	20-1.3.5-6.c	Do not install grounds inside closed switchgear without a highly visible sign or other means	D6	C4			
1072	NFPA 70B	20-1.3.5-6.d	Before re-energizing, have personnel inspect interiors of equipment to verify that all grounding sets have been removed	D6	C4			
1073	NFPA 70B	20-1.3.5-6.e	Before re-energizing test all conductors with a megohmmeter to ascertain if any are grounded	D6	C4			
1074	NFPA 70B	20-1.3.5-6.-2	Use of insulated hot sticks rubber gloves or similar equipment is advisable while installing and removing grounding equipment	D6	C4	P4		
1075	Amtrak NEC Special Instructions	1147-A1.-1	Employees when qualifying must familiarize themselves with the location of all electrified tracks	T2				
1076	Amtrak NEC Special Instructions	1147-A2	When a plate order is in effect trains to be moved in the area must not have raised pantographs	D5				
1077	Amtrak NEC Special Instructions	1147-A2.-1	Signal and switch levers in the area affected must be blocked and blocking devices recorded by operators and train dispatchers	D4				
1078	Amtrak NEC Special Instructions	1147-A5	When necessary to remove control jumpers between electric engines all pantographs must be lowered open generator switch battery switch and air compressor switch	D1	C4			
1079	Amtrak NEC Special Instructions	1147-A6	To change pantographs at any location, raise the down pantograph and then lower the raised pantograph	C4				
1080	Amtrak NEC Special Instructions	1147-A6.-1	Pantographs must not be lowered under low overhead structures until Power Director has been notified and power has been removed	D2				
1081	Amtrak NEC Special Instructions	1147-A6.-2	Pantographs must not be dropped until controller is in the off position and control switches opened or trolley wire is de-energized	C4				
1082	Amtrak NEC Special Instructions	1147-A6.-3	Procedure to change pantographs on bussed couplet Captoliner cars	C4				
1083	Amtrak NEC Special Instructions	1147-A6.-4	Enginemen to know that the changeover switch is in AC DC pantograph locked down and third rail contact shoes raised in Penn station	C4				
1084	Amtrak NEC Special Instructions	1147-A6.-5	Electric engine made dead in eastward trains must be inspected and approved by a class A prior to North river tunnels	C4	S2			
1085	Amtrak NEC Special Instructions	1147-A6.-6	AEM-7 and E60CP may be moved through tunnels dead if pantographs are down but not grounded and vacuum circuit breakers open	C2				
1086	Amtrak NEC Special Instructions	1147-A6.-7	Pantographs not to be dropped in low clearance areas of Harrisburg Station	C4				
1087	Amtrak NEC Special Instructions	1147-A6.-8	Pantographs not to be dropped in low clearance areas of Baltimore Station	C4				
1088	Amtrak NEC Special Instructions	1147-A7	Only one pantograph should be used for each pair of cars with the bus jumper in place	C4				
1089	Amtrak NEC Special Instructions	1147-A8	Operation of more than 2 electric locos other than MU is prohibited	C4				
1090	Amtrak NEC Special Instructions	1147-A9	Employees whose duties are affected by the electrified catenary system must comply with rules of AMT-2	G1	T2			
1091	Amtrak NEC Special Instructions	1147-C1	Location of DC third rail tracks	T2				
1092	Amtrak NEC Special Instructions	1147-W1	Operation of electric engines in Ivy City S&I building to prevent bridging	D5				
1093	SEPTA Blocking Traction Power Feeders	Subway-elevated 1.	Train dispatcher will notify power dispatcher of power out request and state track number direction and location	D1	D4	S3		
1094	SEPTA Blocking Traction Power Feeders	Subway-elevated 2.	Power dispatcher will immediately begin to de-energize the area and report to train dispatcher when complete	D1	D4	S3		
1095	SEPTA Blocking Traction Power Feeders	Subway-elevated 3.	If turn-back or single track code is instituted, train dispatcher will request from power director the nearest crossover to be used	S3				
1096	SEPTA Blocking Traction Power Feeders	Subway-elevated 4.	Power dispatcher will report location of crossover to train dispatcher and stand by for isolation switch operation if required	S3				
1097	SEPTA Blocking Traction Power Feeders	Subway-elevated 5.	At train dispatchers request for turn back power dispatcher will direct manpower to locations as required no partial re-energizing of dead zone allowed until all personnel ar	D4	C2	D6		
1098	SEPTA Blocking Traction Power Feeders	Subway-elevated 6.	At completion of incident, power dispatcher will restore only on request from person who initially requested power off	D4				
1099	SEPTA Blocking Traction Power Feeders	Surface feeders 1.	Controller overhead crew will notify power dispatcher of power out request and state direction and location	D4				
1100	SEPTA Blocking Traction Power Feeders	Surface feeders 2.	Power director will de-energize the section and report back and verify with requester	D4	D2	S3		
1101	SEPTA Blocking Traction Power Feeders	Surface feeders 3.	Power dispatcher will prepare for possible isolation switch, tap switch, or tie switch operation	D1				
1102	SEPTA Blocking Traction Power Feeders	Surface feeders 4.	At conclusion of incident, controller overhead crew will request restoration of power from power director, must be same person.	D5				
1103	SEPTA Blocking Traction Power Feeders	Subway elevated routin	Power foreman will submit a request for planned electrical power interruption 72 hrs in advance to Power dispatcher	S3				
1104	SEPTA Blocking Traction Power Feeders	Subway elevated routin	Request will be reviewed by appropriate departments	C3				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1105	SEPTA Blocking Traction Power Feeders	Subway elevated routin	Copy of form returned to requester with permit number for authorization	C3				
1106	SEPTA Blocking Traction Power Feeders	Subway elevated routin	At time of interruption SEPTA qualified representative will be available to verify that area is de-energized prior to work commencing voltage test witnessed by requester	D1	D4	S2		
1107	SEPTA Blocking Traction Power Feeders	Subway elevated routin	At completion of job a closed out copy of the form will be forwarded to requester	C3				
1108	SEPTA Blocking Traction Power Feeders	Surface Feeder Routin	Power foreman will submit request for planned electrical power interruption 72 hrs prior to power director	S3				
1109	SEPTA Blocking Traction Power Feeders	Surface Feeder Routin	Request will be reviewed by appropriate departments	C3				
1110	SEPTA Blocking Traction Power Feeders	Surface Feeder Routin	Copy of form returned to requester with permit number for authorization	C3				
1111	SEPTA Blocking Traction Power Feeders	Surface Feeder Routin	At completion of job a closed out copy of the form will be forwarded to requester	C3				
1112	NJT TRO-3	2	Safety is of the first importance in the discharge of duty	G1				
1113	NJT TRO-3	3	Employees must know and obey these instructions	G1	T1			
1114	NJT TRO-3	4	Employees must be familiar with department safety rules	G1	T1			
1115	NJT TRO-3	5	Employees in electrified territory to be familiar with location and operation of radios and telephones	G1	T1			
1116	NJT TRO-3	7	All occurrences likely to affect electric operation shall be reported to Power Supervisor or Train dispatcher	S3	C4			
1117	NJT TRO-3	8	Loose or broken impedance bonds to be considered energized	P6	P3			
1118	NJT TRO-3	9	Protect all tracks if overhead wire or third rail failure occurs	G1				
1119	NJT TRO-3	10	Signal approaching electric equipment to drop pantograph if damage is noted on catenary	C4				
1120	NJT TRO-3	11	Crews to be alert to oil leaking from transformers avoid contact with lacking oil	C2				
1121	NJT TRO-3	12	Employees not to enter substations, power plant enclosures, or buildings unless authorized	P2				
1122	NJT TRO-3	13	All overhead wires to be considered live unless known to be de-energized and grounded	P3	P6	D1		
1123	NJT TRO-3	14	Employees working near energized wires to obtain protection and permission from Power Supervisor	P2	P6	S3		
1124	NJT TRO-3	14-2	Conductors etc. must know that employees under their supervision understand and comply with rules	T2	T1	G1		
1125	NJT TRO-3	14-3	Employee in charge must remind inexperienced employees of dangers involved	S2	T2	T1		
1126	NJT TRO-3	15	Approach distances for other than class A to energized wires	P3				
1127	NJT TRO-3	16	Employees not to work near overhead wires unless protected by class A	S2				
1128	NJT TRO-3	17	Authorized and qualified employees must have full knowledge of voltage and service	T2				
1129	NJT TRO-3	18	Employees except class A prohibited from going on top of equipment in electrified territory	P3				
1130	NJT TRO-3	19	Employees must use only tools and equipment approved for type of work	P4				
1131	NJT TRO-3	20	Types of tape not to be used around electrified lines	P4				
1132	NJT TRO-3	21	Employees must not touch dangling wires or foreign objects on wires and protect other persons	P3	T2	S2		
1133	NJT TRO-3	22	Do not depend upon insulation on wires for protection	P3	P6			
1134	NJT TRO-3	23	Notify Power Supervisor to de-energize overhead wires await his instructions	D4	S3			
1135	NJT TRO-3	24	Plate order must be issued to work on catenary prior to de energizing	D4	S3			
1136	NJT TRO-3	25	Trains must not be operated into or out of a de-energized section with raised pantographs	D5				
1137	NJT TRO-3	26	Condition of pantographs to be observed frequently and reported to Train Dispatcher	C2	C4			
1138	NJT TRO-3	27	Pantograph poles carried on all electric engines return poles after use	P4				
1139	NJT TRO-3	27-1	Pantograph poles found on right of way must be cleaned and tested before use	P4	C2			
1140	NJT TRO-3	27.a	Pantograph pole must be clean and dry	P1				
1141	NJT TRO-3	27.b	Hands eight feet from the hook or below warning mark	P3				
1142	NJT TRO-3	27.c	Pole kept clear from clothing and rest of body	G1				
1143	NJT TRO-3	27.d	Pole must be pivoted on roof of car or engine	G1				
1144	NJT TRO-3	28	Only class A can go on roof to remove or secure broken pantograph after	T2	G1			
1145	NJT TRO-3	28.a	overhead wire has been deenergized and grounded	D1	D6			
1146	NJT TRO-3	28.b	Position of adjoining wires noted and wires within 3 feet also deenergized and grounded	D1	D6	T2		
1147	NJT TRO-3	28.c	Standard warning tag applied to handles of all grounding switches	D4				
1148	NJT TRO-3	28.d	All equipment capable of holding a static charge in the main power circuit has been grounded	D4	D6			
1149	NJT TRO-3	29	Pantograph in down position must be considered energized by the up pantograph	P6	T2			
1150	NJT TRO-3	30	MU cars are energized from pantographs through high voltage bus jumpers	P6	T2			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1151	NJT TRO-3	31	Procedure to change operating pantographs	C4				
1152	NJT TRO-3	32	If derailed, consider electric equipment energized	P6	T2			
1153	NJT TRO-3	32-2	drop pantographs and close grounding switches	D1	D6			
1154	NJT TRO-3	32-3	All persons to maintain 3 ft clearance between derailed equipment and the ground until de energized and grounded	P3				
1155	NJT TRO-3	33	Precautions for work near third rail	T2	P6			
1156	NJT TRO-3	34	Contact Amtrak Power director to de energize third rail in an emergency	D4	S3			
1157	NJT TRO-3	35	Consider third rail energized unless known to be de energized and protection by Amtrak class A employee	S2	D1	D2		
1158	NJT TRO-3	36	Never contact third rail and track or rail return system	P6				
1159	NJT TRO-3	37	Ground fire fighting nozzles when fighting fires near electrified zone	D6				
1160	NJT TRO-3	38	Reground nozzle if it needs to be moved beyond limits of first ground	D6				
1161	NJT TRO-3	39	If fire hose to be used near wires deenergize wires and use grounding jumpers	D6				
1162	NJT TRO-3	40	Hand extinguishers should not be used so that stream touches overhead wires	P4				
1163	NJT TRO-3	100	Pilots must promptly notify each member of crew of following:	G1				
1164	NJT TRO-3	100.a	They are operating in electrified territory	T2				
1165	NJT TRO-3	100.b	Crew must keep off of equipment under overhead wires	T2	G1			
1166	NJT TRO-3	100.c	Crew must not let tools material equipment clothing or any part of their body near electrical apparatus	P6				
1167	NJT TRO-3	101	Employees must forbid persons from going on top of high lading or roofs of cars unless catenary is de energized	P6				
1168	NJT TRO-3	101-2	All such persons must be warned to regard all wires as energized and clearances to observe	P3	T2	S2		
1169	NJT TRO-3	102	Pantographs must be dropped before visible obstructions or defects in catenary	C4				
1170	NJT TRO-3	103	Pantographs must be dropped if end horns show indication of being struck	C4				
1171	NJT TRO-3	104	Stop electric equipment if pantographs are damaged and notify dispatcher	C4				
1172	NJT TRO-3	105	Electric equipment not to be moved until damaged pantographs have been removed or secured	C4				
1173	NJT TRO-3	106	IF two trains stop a short distance apart, the following train should wait 30 sec before following.	C1	C4			
1174	NJT TRO-3	107	Take extra precautions in high or low temperatures for inspection of third rail and catenary	C1	C4			
1175	NJT TRO-3	108	Train dispatchers operators conductors and trainmen must not line tracks for movements to unwired or de-energized section unless pantographs are secured with manual	D5				
1176	NJT TRO-3	109	Derailed equipment considered energized drop pantographs immediately and close grounding switch	D1	D6	P6		
1177	NJT TRO-3	109-1	Crew members to inform passengers and employees not to board or discharge until pantograph is lowered or wire is deenergized and grounded	S2	P6	D1	D6	
1178	NJT TRO-3	109-2	Crew members shall not leave equipment making simultaneous contact with equipment and earth and prevent others from doing so	P6				
1179	NJT TRO-3	109-3	Crew members to refer to emergency evacuation procedures	G1				
1180	NJT TRO-3	110	In the event of a traction power shortage operate in P1 or P2 controller positions	C4	C1			
1181	NJT TRO-3	111	P1 or P2 operation to continue until canceled by train dispatcher	C4	C1			
1182	NJT TRO-3	112	Electric engines must not pass AC motor stop signs	C1	C4			
1183	NJT TRO-3	113	Information on phase gap signage	C1				
1184	NJT TRO-3	114	Place controller in off position before entering phase gap	C1	C4			
1185	NJT TRO-3	115.a	MU cars and E60 and ALP-44 engines operating singly must drop pantographs before entering phase gap	C1	C4			
1186	NJT TRO-3	115.b	ALP-44 engines operating singly or coupled with one pantograph up not restricted	C1	C4			
1187	NJT TRO-3	116	Train stopped in phase gap must ensure that pantographs do not bridge the insulated section	C1	C4			
1188	NJT TRO-3	117	Controllers out of off position after passing marker corresponding to number of cars in consist	C1	C4			
1189	NJT TRO-3	118	Pantographs to be manually grounded or tied down on dead electric units	D1	C4	D6		
1190	NJT TRO-3	119	If pantograph not secured, consider movement as an electric train	C1				
1191	NJT TRO-3	120	Secure pantographs before moving electric equipment to/from electrified track to non electrified track	C1	C4			
1192	NJT TRO-3	121	Move dead electric equipment in rear of freight train	C1				
1193	NJT TRO-3	122	Pantographs may be dropped to operate train under damaged catenary after it has been determined that is safe to do so	C1	C4			
1194	NJT TRO-3	123	Pantographs to be tested in the down position prior to reaching drop pantograph zone	C2				
1195	NJT TRO-3	124	Pantograph down switch to be kept in down position throughout limits of drop pantograph order	C1				
1196	NJT TRO-3	125	Controller to off coast or idle position before raising pantograph	C1	C4			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS		
1197	NJT TRO-3	126	Pantograph not to be raised when adjacent to turnout or crossover to prevent bouncing wires over adjacent tracks	C1	C4	
1198	NJT TRO-3	127	Train dispatcher to be notified if electric equipment stops before power is restored	C1	C4	
1199	NJT TRO-3	128	When an MU experiences a power interruption it will be stopped and pantograph and catenary examined for damage	C1	C2	C4
1200	NJT TRO-3	129	If pantograph lower relay has operated pantograph must not be raised	C1	C4	
1201	NJT TRO-3	130	To prevent arcing, the pantograph must not be raised without first operation the pan down control switch	C1	C4	
1202	NJT TRO-3	131	Limits of number of MU cars in trains for each line	C4	C1	
1203	NJT TRO-3	132	If traction motors become inoperative they should be cut out	C1	C3	
1204	NJT TRO-3	133	Cars with traction motors cut out may be placed in trains under certain conditions	C1		
1205	NJT TRO-3	134	Engineer to be alert to sleet conditions and report to train dispatcher	C1	C4	S3
1206	NJT TRO-3	135	Operate engines with both pantographs up in sleet conditions	C1	C4	
1207	NJT TRO-3	136	Electric locos to operate with both pantographs up on lead unit and rear pantograph up on trailing under sleet order	C1	C4	
1208	NJT TRO-3	137	Procedure for sleet order on Arrow III MU cars	C1	C4	
1209	NJT TRO-3	138	Patrol trains with class A to be used under sleet conditions	C1	C4	
1210	NJT TRO-3	139	Speed to be kept below 30 MPH with heavy sleet on wires	C1	C4	
1211	NJT TRO-3	140	Raise and lower pantographs on engines and MU in yards under sleet conditions	C1	C4	
1212	NJT TRO-3	141	Inspect pantograph shoes frequently under sleet conditions	C2		
1213	NJT TRO-3	142	If pantographs lowers from sleet or heavy arcing shut off master controller and raise and lower pantograph several times to remove sleet	C1	C4	
1214	NJT TRO-3	143	Information on remote control boards for traction power	G1	T1	
1215	NJT TRO-3	144	Red light indicates closed switch and green light open on traction control board	G1	T1	
1216	NJT TRO-3	145	Color of target indicates position that control switch was last operated not necessarily position of apparatus controlled	G1	T1	
1217	NJT TRO-3	146	Control switches to be operated only by employees properly instructed	G1	T2	
1218	NJT TRO-3	147	Qualified employees should at beginning of shift check indications and operation of control board and report anomalies	T2	S3	
1219	NJT TRO-3	148	Employees to repeat instructions of power supervisor then operate control switches in the order that instructions were given	G1	D4	
1220	NJT TRO-3	149	Control handles to close position for 3 seconds to obtain red light indication	C1		
1221	NJT TRO-3	150	Control handle to open position for 3 seconds to obtain green light	C1		
1222	NJT TRO-3	151	Employee to notify power supervisor of automatic operation of control panel	G1		
1223	NJT TRO-3	152	When instructed, operate control switch, lock out handle, apply blocking device with standard warning tag with data	D4	C1	
1224	NJT TRO-3	153	Tags and blocking devices not to be removed except as instructed by the power supervisor	D4		
1225	NJT TRO-3	154	Used tags to be forwarded to the power supervisor	D4		
1226	NJT TRO-3	155	Procedure to obtain catenary plate order	D4		
1227	NJT TRO-3	156	blocking devices to be placed on signals or switches providing access to the affected tracks on order of train dispatcher	D4		
1228	NJT TRO-3	157	Plate orders to be written in ink by train dispatcher and underscored as repeated by power director	D4		
1229	NJT TRO-3	158	Plate order to be written in ink by power supervisor and repeated to train dispatcher before de energizing	D4		
1230	NJT TRO-3	159	To cancel plate order power supervisor to coordinate with train dispatcher	D4		
1231	NJT TRO-3	160	Procedure for numbering and recording plate orders	D4		
1232	NJT TRO-3	161	Catenary plate orders remain in effect until canceled	D4		
1233	NJT TRO-3	200	Work not to be done on roof of MU cars unless under supervision of class A or B employee	C3	S2	
1234	NJT TRO-3	201	All electric engines and MU cars considered to be energized unless known that pantographs are down and grounding switches closed or overhead wired deenergized and	T2	D1	D6
1235	NJT TRO-3	202	Work not to be done on any circuit of an energized MU unless switch disconnecting that circuit is open	D1		
1236	NJT TRO-3	203	Employees must know that pantographs are down and grounding switches are closed before and during the time work is done on electrical equipment	D1	D6	S1
1237	NJT TRO-3	204	Obtain permission from class A or B before starting to perform work, class A or B to know all are clear before opening grounding switches	S2		
1238	NJT TRO-3	205	Class A to take charge of tests on energized MU or electric locomotive	S2		
1239	NJT TRO-3	206	No repair work near main circuits on electric equipment until de energized and supervised by class A or B	S2	P6	
1240	NJT TRO-3	207	Inspection and repair work shall be performed according to the following procedure	C4	C2	C3
1241	NJT TRO-3	207.a	Class A or B must lower the pantographs and close grounding switches	D1	D6	S2
1242	NJT TRO-3	207.b	Class A must ensure that pantographs are latched and grounding switches properly closed	D1	D6	S2

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1243	NJT TRO-3	207.c	Instructions applying to maintenance on main circuits or MU cars will apply but each employee to apply his own warning tag	D4	S1			
1244	NJT TRO-3	207.d	Class A or B must know that all warning tags are removed, all persons clear, all tools and materials properly placed before reenergizing	S2				
1245	NJT TRO-3	207.e	Then class A or B may open the grounding switch and raise the pantograph	C3				
1246	NJT TRO-3	207.f	Class A or B is responsible for carrying out these instructions	S2				
1247	NJT TRO-3	208	Pantographs not to be railed until all persons in the vicinity are clear of all circuits and understand that it is to be energized	D6				
1248	NJT TRO-3	209	When defects occur in main circuits, pantographs must be dropped if not done automatically	D1	C4			
1249	NJT TRO-3	210	MU car high voltage fuses not to be removed under energized catenary	P6	C4			
1250	NJT TRO-3	211	Emergency repair work on top of car under energized catenary only by class A or by class B under supervision of class A	S2				
1251	NJT TRO-3	212	MU cars equipped with automatic couplers need not be deenergized or pantographs lowered when interrupting trainline circuits	T2	C3			
1252	NJT TRO-3	213	MU married pairs must have pantograph lowered and grounding switches closed before control and power jumpers are applied or removed	C4	P6	C3		
1253	NJT TRO-3	300	Maint of way equipment with boom must have boom grounded	D6				
1254	NJT TRO-3	300.A	Clearance distances for operation without class A	P3				
1255	NJT TRO-3	300.B	Clearance distance for operation with class A	P3	S2			
1256	NJT TRO-3	300.C.1	Clearance distance for operation without class A under deenergized and grounded wires	P3				
1257	NJT TRO-3	300.C.2	Clearance distance for operation with class A under deenergized and grounded wires	P3	S2			
1258	NJT TRO-3	301	Foreman to request class A if he believes there is a hazard	S2	T2			
1259	NJT TRO-3	302	Mobile cranes etc to be grounded within 8 ft of wires	D6				
1260	NJT TRO-3	303	Equipment other than railroad must not operate <15 ft from wires unless grounded and supervised by class A	P3	S2	D6		
1261	NJT TRO-3	304	Location and working hours of such equipment to be reported to train dispatcher and power supervisor	S4				
1262	NJT TRO-3	305	Class A must be present for work within 3 ft of wires	S2				
1263	NJT TRO-3	306	Class A to be dispatched to wreck derrick	S2				
1264	NJT TRO-3	307	Wreck derrick to be grounded if operated not within 3 ft of wires by wreck foreman without class A	D6				
1265	NJT TRO-3	308	Class A to deenergize and ground wires if derrick must come closer than 3 ft	D6	D1	S2		
1266	NJT TRO-3	309	Wrecking equipment to contact wires only under direction of class A and have cowl on tip	S2	C4			
1267	NJT TRO-3	310	Wires to be drawn out of alignment if necessary only by class A	S2	T2			
1268	NJT TRO-3	311	Method of applying temporary jumpers to work on impedance bond removing both rail connections	C3	P6			
1269	NJT TRO-3	312	Method of applying temporary jumpers to work on impedance bond removing one rail connection	C3	P6			
1270	NJT TRO-3	313	Method of applying temporary jumpers to work in electrified territory to remove rails	C3	P6			
1271	NJT TRO-3	400	Work on circuits apparatus or equipment only if qualified	T2	S1			
1272	NJT TRO-3	401	Power supervisor in charge of the electrical power network, responsible for switching and tagging	S3				
1273	NJT TRO-3	402	Only class A to request electrical protection and be on tagging list	S2	C3			
1274	NJT TRO-3	403	Office of Manager of electric power to distribute switching and tagging list	C1	S3			
1275	NJT TRO-3	404	Wiring diagrams rules and other information must be in possession of class A employees	T2	S2			
1276	NJT TRO-3	405	Safe working clearances must be maintained if not using hot line tools	P3				
1277	NJT TRO-3	406	Approved temporary barriers or rubber goods to be placed between workmen and energized parts if necessary to reduce clearance	P2				
1278	NJT TRO-3	407	All work > 7.2 KV must be de energized or use approved hot line equipment	D1	P4			
1279	NJT TRO-3	408	Colors and method of applying tags	C3	D4			
1280	NJT TRO-3	409	Standard warning tags to be placed in a conspicuous spot	D4				
1281	NJT TRO-3	410	Under no circumstance will lines between red tags be energized	D4				
1282	NJT TRO-3	411	Under no circumstances will a switch bearing a tag be operated	D4				
1283	NJT TRO-3	412	Blue tags not to be attached to switches bearing red tags	D4				
1284	NJT TRO-3	413	Switchgear with red or blue tags not to be operated without consent of power supervisor	D4	S3			
1285	NJT TRO-3	414	Lines between a red and blue or blue and blue can be energized only under direction of employee who requested tags	D4				
1286	NJT TRO-3	415	Reason for yellow tag to be stated on tag	D4				
1287	NJT TRO-3	416	Procedures for following switching orders	D4	S3			
1288	NJT TRO-3	417	De-energized sections must have at least one visible break between all sources of power and the line	D1	S2			

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	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1289	NJT TRO-3	418	Disconnect switches must be opened only after associated circuit breaker has opened	P6	C4			
1290	NJT TRO-3	419	Procedure to open stick switch	T2	C3			
1291	NJT TRO-3	419.a	Use rubber gloves	P4				
1292	NJT TRO-3	419.b	Have max length of pole between circuit and hands	P4	C3			
1293	NJT TRO-3	419.c	Stand to side of disconnect not in line	C3	S1			
1294	NJT TRO-3	419.d	Look away from disconnect when opening or closing	S1	C3			
1295	NJT TRO-3	419.e	Check for proper operation after opening	C2	D1			
1296	NJT TRO-3	420	Manual disconnect switches to be visually checked after opening	C2	D1			
1297	NJT TRO-3	421	Motorized switch to be visually checked open and motor power removed	C2	D1			
1298	NJT TRO-3	422	Cranked out metal clad switchgear is a visible break	D1	C2			
1299	NJT TRO-3	423	Circuit breakers must be verified for operation by mechanical indicators before proceeding with further switching	D1	C2			
1300	NJT TRO-3	424	When operating disconnect or ground switches on SF6 gas insulated bus , switch contacts must be visually checked through portholes	D1	C2			
1301	NJT TRO-3	425	Power supervisor must be notified before any work on or near power	S3				
1302	NJT TRO-3	426	Information required for electrical clearance	S3	D4			
1303	NJT TRO-3	427	Power supervisors role in electrical clearance	S3				
1304	NJT TRO-3	428	Power supervisor will issue switching order to class A	S3				
1305	NJT TRO-3	429	Power supervisor will inform class A of location of lacks and tags	S3				
1306	NJT TRO-3	430	Clearance procedures	S3	D4			
1307	NJT TRO-3	431	Employee receiving clearance responsible for testing circuit to confirm power removal	S2				
1308	NJT TRO-3	432	Notify power supervisor if work cannot be completed in requested time	S3				
1309	NJT TRO-3	433	Additional clearances may be issued with additional sets of tags	S3	D4			
1310	NJT TRO-3	434	Procedure to transfer responsibility for clearance	C3	D4			
1311	NJT TRO-3	435	Class A to release clearance after assuring that all employees are clear	S2				
1312	NJT TRO-3	436	Closing out of clearance after switching is completed	C3	D4			
1313	NJT TRO-3	437	Special conditions for switching without communication from employee	D4				
1314	NJT TRO-3	438	These rules apply to any new construction as soon as it may be energized by operation of a switch	T2				
1315	NJT TRO-3	439	Refer placing of utility co tags to power supervisor	D4				
1316	NJT TRO-3	440	Power supervisor not to order switches to be operated or tagged by persons not on switching list	D4				
1317	NJT TRO-3	441	Consult with manager of electric power distribution or engineer-electric traction if rules cannot be complied with	G1				
1318	NJT TRO-3	442	Before working on line it must be tested for voltage then properly grounded on each side of work site	D2	D6			
1319	NJT TRO-3	443	Attach ground first to ground then line	D6				
1320	NJT TRO-3	444	Remove grounds in reverse order	D6				
1321	NJT TRO-3	445	Rubber gloves and sleeves to be worn when testing or applying grounds from elevated positions	P4				
1322	NJT TRO-3	446	No lines to be grounded without proper clearance from power supervisor unless an emergency	C4	D1			
1323	NJT TRO-3	447	When ground switches are closed for protection, they must be locked and tagged	D6	D4			
1324	NJT TRO-3	500	Class A must have required information and rules in possession when responsible for safety of others	S2	T1			
1325	NJT TRO-3	501	Class A will be responsible for protection of each person to which he is assigned	S2				
1326	NJT TRO-3	502	Class A will instruct foreman and all employees in gang of dangers and hazards surrounding them	S2	T2			
1327	NJT TRO-3	503	Before work is started class A must indicate to all the protected area for work	S2	T2			
1328	NJT TRO-3	504	Class A may not permit anyone who in his opinion does not understand the instructions to work	S2				
1329	NJT TRO-3	505	Class A must be in a position for close observation of all locations near energized wires	S2				
1330	NJT TRO-3	506	The class A will not assume that all employees instructed by him will adhere to the instructions	S2				
1331	NJT TRO-3	507	Class A will indicate to all the location of the grounding devices on the de-energized wires, employees to sign on form they know the limits of safe work	S2	T2			
1332	NJT TRO-3	508	If two class A's on job they will coordinate for full understanding of clearances involved	S2				
1333	NJT TRO-3	509	If class A must leave area gang to stop work and sign that they will not resume until class A returns	S2				
1334	NJT TRO-3	510	When clearances are relapsed the class A will observe that all employees are clear and at safe distance before removing grounds	S2				

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	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1335	NJT TRO-3	511	If class A must protect too many employees he will report circumstances to supervisor or power supervisor	S2	S3			
1336	NJT TRO-3	512	Class A will inform foreman of any employee who is unsafe	S2				
1337	NJT TRO-3	513	When adjacent circuits are energized, class A will take precautions that tools, apparatus and employees are a safe distance from wires	S2	P3			
1338	NJT TRO-3	600.a	Employees issued protective equipment are responsible for care and maintenance	C4				
1339	NJT TRO-3	600.b	Employees issued protective equipment are responsible for inspection and reporting defects for repair	C2	S4			
1340	NJT TRO-3	600.c	Employees issued protective equipment are responsible for having equipment ready for immediate use	S1	P4			
1341	NJT TRO-3	600.d	Employees issued protective equipment are responsible for wearing the equipment in a manner to provide intended protection	S1	P4			
1342	NJT TRO-3	601	Personal protective equipment such as rubber gloves, sleeves, blankets, line hose, hoods must be used in accordance with the rules and not neglected	S1	T1	P4		
1343	NJT TRO-3	602	All rubber protective equipment is marked with color coded labels of class and data of last test	C2				
1344	NJT TRO-3	603	Description of rubber gloves and protective leather glove	T1	P4			
1345	NJT TRO-3	604	Gloves received from stock without acceptance stamp are not to be accepted or used	C2	P4			
1346	NJT TRO-3	605	Gloves to be electrically tested periodically and so marked	C2				
1347	NJT TRO-3	606	Electrical test to be made on gloves every 90 days	C2				
1348	NJT TRO-3	607	Employee must test rubber gloves prior to wearing. Defective gloves to be marked and returned	C2				
1349	NJT TRO-3	608	Gloves not to be accepted if visual inspection proves them defective	C2				
1350	NJT TRO-3	609	Remove oil from hands before using protective gloves	G1				
1351	NJT TRO-3	610	Remove wet leather protectors from rubber gloves until dry	G1	P4			
1352	NJT TRO-3	611	Leather protectors to be used with rubber gloves	P4				
1353	NJT TRO-3	612	Rubber gloves to be worn on live work exceeding 120 V	P4	P6			
1354	NJT TRO-3	613	Rubber gloves and sleeves must be worn for work on or near live wires in elevated position	P4	P6			
1355	NJT TRO-3	613-2	Other live and grounded parts must be protected from hand contact	P2				
1356	NJT TRO-3	614	Rubber sleeves must be electrically inspected every 6 mo.	C2				
1357	NJT TRO-3	615	Rubber gloves and sleeves not to be exposed to sunlight	C3				
1358	NJT TRO-3	616	Upon request, new glove or sleeves must be issued to employee if old ones are unsafe	P4				
1359	NJT TRO-3	617	Rubber gloves and sleeves to be worn when replacing or removing fuses on primary distribution circuit	P4				
1360	NJT TRO-3	618	Rubber gloves must be worn when operating sectionalizing, gang operated, manual throw-over and grounding switches, and all energized substation equipment	P4				
1361	NJT TRO-3	619	No contact using rubber gloves with any conductor in excess of 7.2 KV, must be deenergized and grounded instead	D1	D6			
1362	NJT TRO-3	620	Maintain all rubber goods in safe condition defective goods to be removed from service and replaced	C4				
1363	NJT TRO-3	621	Approved safety hats to be worn	P4				
1364	NJT TRO-3	622	Conditions and procedures for using Hot Line ladders on catenary	P4	P3	P6	C4	P1
1365	NJT TRO-3	623	All hot line tools and protective barriers to be periodically tested, and washed down once per week	C2	P4			
1366	NJT TRO-3	624	Visual inspection of all tools ladders and barriers must be made prior and during use	C2				
1367	NJT TRO-3	625	Class A approved for Hot Stick work may apply insulation line and insulator covers maintaining 3 foot clearance	T2	P3			
1368	NJT TRO-3	626	After line is covered, class A must stay 6 in from line	P3				
1369	NJT TRO-3	700	Upon entering substation or switchhouse report to power supervisor advising him of any alarms or abnormal conditions	S4				
1370	NJT TRO-3	701	Equipment not to be operated except under jurisdiction of the Power supervisor	S3				
1371	NJT TRO-3	702	Only class A on switching and tagging list authorized to perform these tasks	S2	C3			
1372	NJT TRO-3	703	Alert all workmen in area prior to performing any switching	S2	S4			
1373	NJT TRO-3	704	Employee must assure that all energized areas are properly barricaded and working clearances are maintained	P2				
1374	NJT TRO-3	705	Approved safety belts to be worn when practical in elevated positions	G1				
1375	NJT TRO-3	708	All trucks cranes and equipment in substations where there is danger of induced voltage or static charge must be grounded	D6				
1376	NJT TRO-3	709	Proper clothing must be worn at all times in battery rooms	P4				
1377	NJT TRO-3	711	Barricades must be installed if panels are removed from energized metal-enclosed switchgear	P2				
1378	NJT TRO-3	712	Treat all lightning arrestors as if charged to full potential unless disconnected and grounded	P6				
1379	NJT TRO-3	713	Capacitors must not be worked on until discharged, disconnected and grounded	P6	D1	D6		
1380	NJT TRO-3	714	Motor circuit breaker and generator circuit breaker must be opened and tagged during work on signal supply generator	D4	P6			

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	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1381	NJT TRO-3	715	Exercise extreme care if a potential or control transformer is connected to de-energized equipment for possible back feed. Make a voltage test prior to work	D1	D2			
1382	NJT TRO-3	716	Exercise care near supply or power transformers for possible backfeed	P6				
1383	NJT TRO-3	717	Opening secondary circuit of transformer with primary energized is prohibited due to high magnetic flux and induced voltages	P6	C4			
1384	NJT TRO-3	718	Procedures for internal inspection of substation transformers	D1	D6	G1	G2	S1
1385	NJT TRO-3	719	Procedure for safe operation of SF 6 242 KV 2&3 pole breaker	C3				
1386	NJT TRO-3	720	Hazards of arced SF-6	T2				
1387	NJT TRO-3	721	Hazards of SF-6 heavier than air gas	T2				
1388	NJT TRO-3	722	Procedure for inspection of SF-6 breaker	D1	D6	G1	G2	S1
1389	NJT TRO-3	811	Before working on underground cables > 2300 V de-energize iaw tagging rules	D1	D4			
1390	NJT TRO-3	812	All switches must be cleared and tagged wires shorted and grounded	D4	D1	D6		
1391	NJT TRO-3	813	Test wire for de-energization	D2				
1392	NJT TRO-3	814	Identify cable and spike while wearing rubber gloves	P4	D2			
1393	NJT TRO-3	815	Notify power supervisor of improper labels	S4				
1394	NJT TRO-3	816	Apply blue tags for test voltage use. Check circuit for potential and ground for static discharge rubber gloves to be worn	D2				
1395	NJT TRO-3	817	When men safely in clear with grounds removed re-energization may occur	P6	S2			
1396	NJT TRO-3	902	Rubber gloves and sleeves to be donned piror to climbing pole or structure	P4	G1			
1397	NJT TRO-3	910	Rules for setting or removing poles near live conductors	P3	P6	P4		
1398	NJT TRO-3	926	Where wires are being strung or removed and may contact or be in close proximity with live wires the live line should be de-energized and grounded	P7	D1	D6		
1399	NJT TRO-3	928	Where three is danger to employees or public, lines under construction should be grounded and short circuited until placed in service	D1	D6			
1400	NJT TRO-3	929	Necessary precaution must be made when crossing over or under live circuits	P7	P6			
1401	NJT TRO-3	937	When working on pole or structure avoid ground wires, metal pipes etc that may be at ground voltage	P6				
1402	NJT TRO-3	938	When working near live wires > 100 V rubber protective equipment to be used to protect body	P4				
1403	NJT TRO-3	939	Use extreme care working around transformers to prevent backfeed disconnect secondary leads or de-energize secondary circuit	P6				
1404	NJT TRO-3	940	If working on primary lines with parts of body near secondary or ground lines, wires to be covered with rubber protective equipment	P2				
1405	NJT TRO-3	941	Protective equipment to be placed from below wires in order of distance from climbing space	P2				
1406	NJT TRO-3	942	Work on wires >600 V only when de-energized and grounded unless protected by gloves or rubber goods	P4	P2	D1	D6	
1407	NJT TRO-3	943	Before working on catenary cross over section deenergize circuits which men tools or material may contact	D1	P7			
1408	NJT TRO-3	944	Work not to be performed between tower car and energized wires	P6				
1409	NJT TRO-3	945	Do not depend on insulation to prevent shock	P2				
1410	NJT TRO-3	946	Wet rope and improper tapes not to be used near energized equipment	P4	T3			
1411	NJT TRO-3	947	Check structure carrying live wires to see if it is energized by damaged equipment	D2				
1412	NJT TRO-3	948	Position self so as not to touch insulators on adjacent energized wires	P6				
1413	NJT TRO-3	949	Visual inspection of all tools and approved protective barriers must be made prior to and during their use	C2	P4	S1		
1414	NJT TRO-3	950	Man in charge of wire train or hirail truck must know that all employees understand his instructions	S2	T2			
1415	NJT TRO-3	957.a	After receiving clearances class A must explain cesignations of circuits deenergize and extent, get initials of all men	S2	T2			
1416	NJT TRO-3	957.b	After receiving clearances class A must be the first person to ascend to the top of the equipment	S2				
1417	NJT TRO-3	957.c	After receiving clearances class A must personally direct the application of grounds	S2	D6			
1418	NJT TRO-3	957.d	After receiving clearances class A must direct the attention of each man to the energized circuits	S2	T2			
1419	NJT TRO-3	957.e	After receiving clearances class A must locate himself to observe the movements of men on top of the equipment	S2				
1420	NJT TRO-3	957.f	After receiving clearances class A must upon completion, direct the removal of the grounding devices and be last to descend	S2				
1421	NJT TRO-3	957.g	At completion of work class A must advise all men that the circuits are to be energized	S2	T2			
1422	NJT TRO-3	958	All employees must report to class A before going on top of wire train	G1	T2			
1423	NJT TRO-3	959	Work on tower car or wore train only after two grounding devices have been applied to the deenergized circuit work only between the two	D6				
1424	NJT TRO-3	960	Strike hanger clip or messenger to confirm deenergized catenary before attaching ground	D2	D6			
1425	NJT TRO-3	961	Grounding stick must be applied so as not to foul the pantographs of trains on adjacent tracks	D6	C4			
1426	NJT TRO-3	962	All trucks cranes and equipment must be grounded if there is danger of induced voltages	D6				

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1427	NJT TRO-3	963	Person in charge and employees must inspect body belts and safety straps periodically	C2	S2	S1		
1428	NJT TRO-3	964	Body belts and rubber good must be stored properly when not in use	C4				
1429	NJT TRO-3	965	Secure tools in belt so they will not fall	P7	G1			
1430	NJT TRO-3	967	When working in elevated positions all tools and material must be raised and lowered	P7	G1			
1431	NJT TRO-3	968	Do not throw tools from the ground to the working position	P7	G1			
1432	NJT TRO-3	969	Insulation put on tools must never serve as a substitute for rubber gloves	P4				
1433	NJT TRO-3	970	Rope used for hot line work must be kept clean and dry	T3	P4			
1434	NJT TRO-3	971	Use equipment only if it is approved for use in maintenance and operation of the circuits to be used on.	T3				
1435	PATCO "Energized Circuits"	105	Do not enter electrical substation or power plane enclosure unless authorized	G1				
1436	PATCO "Energized Circuits"	106	Do not allow uninsulated tools equipment clothing or any power of the body to contact energized circuits	P6				
1437	PATCO "Energized Circuits"	107	Insulation must not be depended upon for protection against shock	P2				
1438	PATCO "Energized Circuits"	108	Before touching structure determine if it is energized by abnormal conditions	D2				
1439	PATCO "Energized Circuits"	109	Consider damaged impedence bonds as energized	P6				
1440	PATCO "Energized Circuits"	110	Before drilling walls locate wires	P6				
1441	PATCO "Energized Circuits"	111	Do not place unauthorized items on cabinets switch boxes or apparatus	P7				
1442	PATCO "Energized Circuits"	112	Remove handle after manually operating electrically controlled oil or air circuit breaker	C3				
1443	PATCO "Energized Circuits"	113	Keep face turned away and operate open type switch or circuit breaker as quickly as possible	G1				
1444	PATCO "Energized Circuits"	114	Hold insulated pole so max length is between hands and disconnect switch	P4	C3			
1445	PATCO "Energized Circuits"	115	Operate stick type high tension disconnect switch only when wearing approved rubber gloves and insulated pole	P4	C3			
1446	PATCO "Energized Circuits"	116	Protective equipment required for various circuit voltages	P4				
1447	PATCO "Energized Circuits"	117	Clearance distances for various voltages	P3				
1448	PATCO "Energized Circuits"	118	Place DO NOT OPERATE tags on switch when deenergizing circuits	D4				
1449	PATCO "Energized Circuits"	119	Apply grounding devices only after ascertaining that circuit is deenergized, then apply ground to ground then line	D1	D2			
1450	PATCO "Energized Circuits"	120	Keep as far from circuit as practical when installing grounds	P3	D6			
1451	PATCO "Energized Circuits"	121	When removing grounds disconnect line side first	C3				
1452	PATCO "Energized Circuits"	122	Do not open secondary circuit of transformer	C4	P6			
1453	PATCO "Energized Circuits"	123	Do not stand with hands behind back when back is toward high voltage equipment	P6	G1			
1454	PATCO "Energized Circuits"	124	Door or covers of electrical apparatus must be closed except when making inspection or repairs	C3				
1455	PATCO "Energized Circuits"	125	Both sided of circuit must be deenergized before opening or closing a hand operated sectionalizing switch or removing pothead	C4				
1456	FRA CFR 49	217.7a	Before Feb 1, 1975 each railroad shall file with the FRA one copy of its code of operating rules, timetables, and timetable special instructions	T1				
1457	FRA CFR 49	217.7b	Each amendment to operating rules, timetables, and special instructions shall be filed with FRA within 30 days	T1				
1458	FRA CFR 49	217.11	Requires that each railroad employee shall receive training on operating rules, railroad to file training program details with FRA	T1				
1459	LIRR Safety Rules - S-7C	3600-3613	Instructions for work in manhole, trench, sewer, or other excavation	G2	G1			
1460	LIRR Safety Rules - S-7C	3625-3660	Instructions for working on or around a ladder, scaffold, trestle and working at elevated place	G1	S1			
1461	LIRR Safety Rules - S-7C	3670	Climbing pole unless authorized to do so is prohibited	G1	S1			
1462	LIRR Safety Rules - S-7C	3672	Use standard body belt and safety strap adjust for slack only in certain situations	G1	S1	T3		
1463	LIRR Safety Rules - S-7C	3673	Before climbing pole be sure that person above is in position , before descending be sure that persons below are clear	G1	S2			
1464	LIRR Safety Rules - S-7C	3676	Inspect climber, skate, strap ,body belt and safety strap before use if defective it must be marked	G1				
1465	LIRR Safety Rules - S-7C	3680	Safety precautions for general pole climbing	G1				
1466	LIRR Safety Rules - S-7C	3681	Observe conditions of poles before climbing	G1				
1467	LIRR Safety Rules - S-7C	3682	Test doubtful poles before climbing	G1				
1468	LIRR Safety Rules - S-7C	3683	If pole tests unsafe use bracing or guys	G1	S1			
1469	LIRR Safety Rules - S-7C	3685	Securely fasten catenary wire after stringing before working on it	G1				
1470	LIRR Safety Rules - S-7C	3686	Before riding inspect messenger strand, if unsafe use emergency stand and report condition to supervisor	G1				
1471	LIRR Safety Rules - S-7C	3687	When unreeling wire, tend reel from opposite side from which wire is pulled.	G1	T1			
1472	LIRR Safety Rules - S-7C	3700-3707	Rules for safe erecting and removal of poles	G1	T1			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1473	LIRR Safety Rules - S-7C	3715	Work on electrical equipment only if qualified and only when authorized to do so	G1	S4			
1474	LIRR Safety Rules - S-7C	3716	Use equipment only if it is approved for use in maintenance and operation of the circuit used on	P4	T3			
1475	LIRR Safety Rules - S-7C	3717	Proper protective clothing and equipment to be used for specific voltages	P4				
1476	LIRR Safety Rules - S-7C	3717	Approach distances for specific voltages	P3				
1477	LIRR Safety Rules - S-7C	3725	Place standard wiring tags on switch set to de-energize line or equipment	D4				
1478	LIRR Safety Rules - S-7C	3726	Employee completing clearance must obtain signatures of all workers and inform them which circuits are covered and which are energized	D4				
1479	LIRR Safety Rules - S-7C	3727	Before operating switch ensure that it does not bear a DO NOT OPERATE tag	D4				
1480	LIRR Safety Rules - S-7C	3728	Before authorizing removal of tags check that all workmen are clear and have perceived notice that ground shave been removed	D4	P8			
1481	LIRR Safety Rules - S-7C	3729	Remove or replace fuses >= 400 V using only rubber gloves and insulated tongs	P4				
1482	LIRR Safety Rules - S-7C	3730-3735	Switching Instructions for energized equipment	D5	P4	D1	C1	
1483	LIRR Safety Rules - S-7C	3736-3737	Use proper standard grounding devices on line, apparatus or equipment.	D6	T1	S3		
1484	LIRR Safety Rules - S-7C	3738	Use non-metallic barricades when practicable.	P2				
1485	LIRR Safety Rules - S-7C	3740-3748	Instructions and restrictions for switching operations	P4	D6			
1486	LIRR Safety Rules - S-7C	3749	Working on capacitor or lightning arrestor before it is discharged is prohibited.	D1				
1487	LIRR Safety Rules - S-7C	3800-3813	Instructions for use and care of protective gloves	P4				
1488	LIRR - C.T. 290	p. 1	General Instructions	G1	T1	S4		
1489	LIRR - C.T. 290	p.1 thru 3	General definitions	G1	T1	T2		
1490	LIRR - C.T. 290	p. 4	Instructions for energized (LIVE) circuits	G1	P3	P6	S2	
1491	LIRR - C.T. 290	p. 4	Instructions for damaged wires, third rail, attachments, or supports	S4	P3	S2		
1492	LIRR - C.T. 290	p. 5	Description and instructions for third rail systems	S3	S4	G1	D1	
1493	LIRR - C.T. 290	p. 6 - 7	instructions for the operation of electric equipment	D5	G1			
1494	LIRR - C.T. 290	p. 7 - 8	instructions for working near third rail	G1	P4	P8		
1495	LIRR - C.T. 290	p. 8 - 9	instructions for work in and on high equipment and rolling stock in AC territory	G1	P8	D4	D1	S2
1496	LIRR - C.T. 290	p. 9	instructions for the operation of wrecking equipment in AC territory	S3	S4	P3	C3	
1497	LIRR - C.T. 290	p. 10	instructions for the operation of MOW machinery	D1	D6	D5	P3	S4
1498	LIRR - C.T. 290	p. 10 - 12	instructions for employees assigned to protection duties	S2	T1	D4	S3	S4
1499	LIRR - C.T. 290	p. 12	instructions for work near overhead wires	G1	D1	D6	P6	S2
1500	LIRR - C.T. 290	p. 12 - 13	instructions for releasing victim from contact with a live electrical conductor	P1	P6	G1		
1501	LIRR - C.T. 290	p. 13 - 14	instructions for resuscitation from electric shock and apparent death	G1				
1502	LIRR - C.T. 290	p. 14 - 17	instructions for performing artificial respiration	G1				
1503	LIRR - C.T. 290	p. 17	instructions for administering first aid treatment for burns	G1				
1504	LIRR - C.T. 290	p. 17 - 19	instructions for extinguishing fires	S4	D1	P3	G1	
1505	MNCR - MN-290	p. 1 - 6	General Definitions	G1	T1			
1506	MNCR - MN-290	p. 7 - 9	General Instructions	G1	T1	S4	P3	C2
1507	MNCR - MN-290	p. 9 - 12	Instructions for work around third rail system	G1	T2	S4	D5	
1508	MNCR - MN-290	p. 12 - 15	Instructions for work around catenary system	S2	S3	P4	D1	D8
1509	MNCR - MN-290	p. 16	Instruction as to the use and care of electrical protective gloves	G1	P4	S1	P1	
1510	MNCR - MN-290	p. 16 - 17	instructions for the employees assigned to protection duties	S2	S3	D1	D4	S4
1511	MNCR - MN-290	p. 17 - 1 8	instructions for working on wire train or high-rail truck	G1	S2	S1	P3	D4
1512	MNCR - MN-290	p. 18 - 20	Instructions for the operation of remote control boards	T1	D4			
1513	MNCR - MN-290	p. 20 - 22	Instruction for work on electric engines and MU cars	S2	G1	D1	D4	
1514	MNCR - MN-290	p. 22 - 23	Instructions for replacing worn out or defective pantograph shoes	D1	G1	D4	P8	
1515	MNCR - MN-290	p. 23	Instructions for the operation of wreck derricks	S4	S3	C4	P1	
1516	MNCR - MN-290	p. 24	Instructions for the operation of MOW machinery	P3	S2	S3		
1517	MNCR - MN-290	p. 25	Iistructions for the operation of maintenance and construction roadway machinery	D6	P3	S4	S2	
1518	MNCR - MN-290	p. 25 - 30	Rules pertaining to transportation department personnel	D5	D4	S4	P7	

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1519	MNCR - MN-290	p. 31 - 32	instructions for entiguishing fires	S4	D1	P3	G1	
1520	MNCR - MN-290	p. 32 -37	instructions for first aid application	G1				
1521	SEPTA - ET 001	p. 1 - 6	Illustrations of typical equipment - OCS, pantographs, and warning tags	G1	T2	D4		
1522	SEPTA - ET 001	p. 7 - 8	General Definitions	G1	T1			
1523	SEPTA - ET 001	p. 9 , Section 1.1	List of SEPTA Territories	T2				
1524	SEPTA - ET 001	p. 9 , Section 1.2	Work in Amtrak Territories - Follow AMT-2 rules also	T1				
1525	SEPTA - ET 001	p. 9 , Section 1.3	All workers must report occurences and conditions which may affect electrical operation	S4				
1526	SEPTA - ET 001	p. 9 , Section 1.4	Employees must not touch dangling wires/foreign objects	S4	P3	S2		
1527	SEPTA - ET 001	p. 9 , Section 1.5	Broken impedence bonds must be considered energized	S4	P3			
1528	SEPTA - ET 001	p. 9 , Section 1.6	When overhead wire failure occurs, all affected tracks must be protected.	C1	S2			
1529	SEPTA - ET 001	p. 9 , Section 1.7	WHen OCS failure occurs and there is a potential for damage to and by the pantograph, drop pantograph.	C1	S3	T2		
1530	SEPTA - ET 001	p. 10 , Section 1.8	Deenergization of OCS	D1	S3	S4	C1	
1531	SEPTA - ET 001	p. 10 , Section 1.9	Instructions for deenergizing a section of the OCS	D1	S3	S2		
1532	SEPTA - ET 001	p. 10 , Section 1.10	Instructions for the continuous inspection of pantograph shoes.	C2	S4	C1		
1533	SEPTA - ET 001	p. 10 , Section 1.11	Only class A and Class B ET employees and Class B rail equipment employees can work on roof of equipment	T1				
1534	SEPTA - ET 001	p. 10 , Section 1.12	Instructions for working in and around derailed electrical equipment.	P3	D6	D4	D1	S2
1535	SEPTA - ET 001	p. 10 , Section 1.13	instructions for qualified employees woring near overhead wires or apparatus	T3	S2			
1536	SEPTA - ET 001	p. 11, Section 1.14	Maintaining safe distances from energized conductors	P3	D1	D6		
1537	SEPTA - ET 001	p. 11, Section 1.15	Restrictions on what type of employees can work on equipment under catenary wires	T1	S3			
1538	SEPTA - ET 001	p. 11, Section 1.16	The requirement for the use of pantograph poles	T3	P4	P3		
1539	SEPTA - ET 001	p. 11, Section 1.17	Operation of sectionalizing switches and circuit breakers	C1	S3	S4		
1540	SEPTA - ET 001	p. 11, Section 1.18	Responsibility of foremen	S2				
1541	SEPTA - ET 001	p. 11, Section 1.19	Restrictions of train operations in and around deenergized sections	D5				
1542	SEPTA - ET 001	p. 11, Section 1.20	List of items prohibited around energized wires	P7	G1			
1543	SEPTA - ET 001	p. 11, Section 1.21	Restrictions on what class of employee can enter electrical substations	S3				
1544	SEPTA - ET 001	p. 12-16, Section 2	Instructions pertaining to train and engine service personnel	C1	C4	S4	S3	
1545	SEPTA - ET 001	p. 17, Section 3.1	Instructions for arranging for protection of track sections.	S3	S4			
1546	SEPTA - ET 001	p. 17, Section 3.2	Instructions for the use of plate orders	S2	S3	S4	D1	D4
1547	SEPTA - ET 001	p. 17, Section 3.3	Instructions for the use of movement permit	D1	D4	P2	D6	S4
1548	SEPTA - ET 001	p. 18, Section 4.1	Instructions for operating MOW machines - boom equipped	D6	P4	P3	S3	
1549	SEPTA - ET 001	p. 18, Section 4.2	instructions for operation of maintenance and construction roadway machinery	D6	P3	P4	S3	
1550	SEPTA - ET 001	p. 18-19, Section 4.3	Instructions for the operation of wreck derricks	S3	S4	D1	D6	C4
1551	SEPTA - ET 001	p. 19-20, Section 4.4	Instrcutions for the renewing of impedence bonds	P6	D6			
1552	SEPTA - ET 001	p. 21, Section 5.1	Restrictions on what type of employees can work on equipment under overhead wires	D1	D6	D4	S1	
1553	SEPTA - ET 001	p. 21, Section 5.2	General electrical work on MU cars	D1	D4	S2		
1554	SEPTA - ET 001	p. 21, Section 5.3	Repair work on or near main power circuits/use of standard warning tags	D4	D1	D6		
1555	SEPTA - ET 001	p. 21-22, Section 5.4	Instructions for the inspection and repair work in yards	D1	D6			
1556	SEPTA - ET 001	p. 22, Section 5.5	Instructions for the removal of fuses on silverliner IV pantograph assembly	C3	C4			
1557	SEPTA - ET 001	p. 22, Section 5.6	Instructions for the removal of control and power jumpers	C1				
1558	SEPTA - ET 001	p. 22, Section 5.7	Instructions for MU automatic coupler removal	C1				
1559	SEPTA - ET 001	p. 22, Section 5.8	Instructions for emergency repair work	T1	S3			
1560	SEPTA - ET 001	p. 22, Section 5.9	Instructions for work on roof of equipment in tunnels	D1	D6	D4		
1561	SEPTA - ET 001	p. 22-23, Section 5.10	Instructions for work on equipment to secure / remove broken pantograph	D1	D6	D4		
1562	SEPTA - ET 001	p. 23, Section 5.11	Instructions when occupying roof of equipment under energized/ungrounded wire	D4				
1563	SEPTA - ET 001	p. 23, Section 5.12	Instructions for renewing pantograph shoes in an emergency	P3	D4			
1564	SEPTA - ET 001	p. 23-24, Section 5.13	instructions for renewing pantograph shoes when 5 feet clearance is available	D4	P6			

TABLE B.1 - DETAILED REVIEW OF APPLICABLE SAFETY RULES, REGULATIONS, STANDARDS AND RECOMMENDED PRACTICES

	RULE SOURCE	RULE NO.	DESCRIPTION	RISK REDUCTION METHODS				
1565	SEPTA - ET 001	p. 24, Section 5.14	instructions for renewing pantograph shoes when 5 feet clearance is not available	D1	D4	D6		
1566	SEPTA - ET 001	p. 24, Section 5.15	Instructions for reporting power failure in yard	S4				
1567	SEPTA - ET 001	p. 24, Section 5.16-17	General information - causes of failures	T2				
1568	SEPTA - ET 001	p. 25-26, Section 5.18	Procedures to be followed in cases of power failure	S4	C1	C2	S3	D4
1569	SEPTA - ET 001	p. 26, Section 5.19	Instructions for reoving sleet from pantograph	S2	C4			
1570	SEPTA - ET 001	p. 26-27, Section 5.20	Safety Instructions	T2	P4	D1	D6	S2
1571	SEPTA - ET 001	p. 28, Section 6.1	Instructions for the use of fire extinguishers - general	G1	G2			
1572	SEPTA - ET 001	p. 28, Section 6.2	Instructions for fire fighting near electrical wires	S4	D1	D6		
1573	SEPTA - ET 001	p. 28, Section 6.3	Fire on electrical equipment and apparatus	D1	D6	S4		
1574	SEPTA - ET 001	p. 28, Section 6.4	High voltage conductors and fire fighting	P3	P6			
1575	SEPTA - ET 001	p. 28, Section 6.5	Instructions for using fire extinguishers	G1	G2	P6	D2	
1576	SEPTA - ET 001	p. 28, Section 6.6	Use of approved fire extinguishers	G1	G2			
1577	SEPTA - ET 001	p. 28, Section 6.7	Precautions for fires involving oil from circuit breakers or transformers	G1				
1578	SEPTA - ET 001	p. 29-33, Section 7	Catenary to Rail clearances at bridges	P3				
1579	SEPTA - ET 001	p. 35-40, Section 8	instructions for applying first aid	T1	T2			

APPENDIX C. CHARACTERISTICS OF LIGHTNING STROKES

The relative severity to electrical systems of the hazard from lightning is dependent on the magnitude of the overvoltage which results from a direct or induced lightning stroke current into the system. A lightning stroke is the discharge of current which results when a lightning flash strikes an object. In addition to its magnitude, the severity of a stroke current discharge also depends on the frequency of occurrence of the discharge event. Frequency of occurrence here is meant to be the number of observed lightning strike events where it is understood that the single event itself may consist of many lightning stroke discharges which could occur over very brief intervals of time. When visually observed, multiple stroke discharges are usually seen as a single lightning flash.

The magnitude of the overvoltage is directly related to the magnitude of the surge current that results from the strike. Stroke current magnitude as well as its probability of occurrence has been a subject of extensive investigation in the electric utility industry [1]. Data on the characteristics and properties of lightning is continually being updated and refined. For example, Reference [1] provides more than 20 recently published texts and papers on the subject.

C.1 Probability of Occurrence of a Lightning Stroke

One measure of the magnitude of the severity of a lightning stroke is given by what is called the lightning stroke current probability curve. Lightning stroke probability curves are generally given as the percentage of strokes that exceed a given value of stroke current. The probability $P(I_o)$ that the crest value magnitude of the stroke current (I_o) will equal or exceed I_o (for I_o in kA) can be estimated from the following empirical relation [2]:

$$P(I_o) = \frac{1}{1+(I_o/31)^{2.6}} \qquad \text{(C-1)}$$

Figure C.1 and Table C.1 show the resultant values for the probability $P(I_o)$, for a range of stroke currents (I_o). From these results we see that about 95% of all stroke currents would have expected values of the order 10 kA or more. About 50% of the stroke currents would have expected values not exceeding about 30 kA, and less than 5% of all stroke currents would be expected to have a crest value exceeding 100 kA.

C.2 Frequency of Occurrence of a Lightning Stroke

The annual relative frequency of occurrence of lightning strokes within a given area can be specified by the ground flash density (N_g). Ground flash density is usually given as the number of lightning flashes per km^2. However, data on the average annual value of N_g in the continental U.S. (CONUS) has not been generally available. In North America keraunic levels, or the number of thunderstorm days per year, has been the traditional means for estimating lightning strokes. The flash density can be estimated from a known keraunic level (K). An approximate relationship between ground flash density and keraunic level has been developed [3] where:

$$N_g = CK^a \qquad \text{(C-2)}$$

The exponent (a), in equation (C-2) has been empirically determined to lie in the range of 1.25 to 1.35. The constant (C), in this equation varies from 0.023 to 0.040 and its value is based on geographic region. For the North American continent a value of C of 0.04 is normally used. Figure C.2 and Table C.2 show the approximate relationship of N_g to K, for the keraunic value (K) varying between 5 to 160 and for the exponent (a), set equal to 1.3. The ranges of K for CONUS are from a K of 10 typical of the West Coast, to a value of K exceeding 80, typical for the Florida region. Using a K of 40 as the average keraunic value for CONUS, the ground flash density is about 5 flashes per km^2 (about 13 ground flashes per square mile). For most of the Northeast where the value of K is 30, the flash density is between 3 and 4 flashes per km^2 (about 9 strokes per square mile per year).

C.3 Induced Surge Voltage

The induced surge voltage which results from the stroke current discharge can be estimated with the following equation [4]:

$$V_s = \frac{I_o H Z_o}{Y_o} \cdot \left\{ 1 + \frac{\beta}{(2-\beta^2)^{1/2}} \right\} \qquad \text{(C-3)}$$

In equation (C-3), Z_o is called the wave impedance and is related to the permeability and permittivity of free space and is approximately 30 Ω, H is the vertical height of the transmission line, Y_o is the closest distance between a location on the transmission line and the lightning flash, and β is the ratio of the return stroke velocity to the speed of light. Note that in free space the bracketed term in equation (C-3) will vary from 2 to 1 as β varies from unity to zero. As seen from equation (C-3), the surge voltage depends on several physical parameters as well as the characteristics of the lightning flash.

Table C.1 shows the expected surge voltage (V_s) as a function of stroke or surge current (I_o). This data is based on a transmission line height of 20 m (66 ft), for a Y_o of 5 m, and for the bracketed term of equation (C-3) set equal to a mean value of 1.5. As expected the surge voltage magnitude is proportional to the surge current magnitude. Using this data we can estimate expected overvoltages for specfic lines. For a surge current of 30 kA and for a line having a nominal voltage of 25 kV, which would be a typical catenary voltage level, the surge voltage would result in a voltage rise of about 22% above the nominal 25 kV. For the same line and for a surge current of 60 kA, the voltage rise would nearly double to about 43% above the nominal value. These values are for the case where Y_o equals a distance of 5 m. The magnitude of the induced voltage will approach infinity as Y_o approaches zero and will of course become relatively small for large distances from the point of contact of the lightning strike.

Also apparent from Table C.1 is one apparent advantage of operating the line at a higher voltage. The surge voltage is a function of only the surge current for all other factors held constant. Therefore, the percentage voltage rise decreases as the line voltage is increased. For a 50-kV line and for a surge current of 60-kA, the voltage rise is about 22% compared to the 43% value that would be expected for a 25-kV line.

The surge voltage-surge current relationship for the specfic set of conditions given here is shown in Figure C-3. The linear relationship is readily apparent.

C.4 Lightning Flash Density for Transmission Lines

For transmission lines the measure of lightning flash density is sometimes given as the number of strokes per year for a given distance of transmission line. This density measure N_s, is related to the ground flash density for a given transmission line of length L, and can be estimated from [5] as:

$$N_s = 0.001 N_g L \cdot (b + 2R_a) \qquad \text{(C-4)}$$

$$R_a = 10H^{0.7} \qquad \text{(C-5)}$$

The terms (b) and (R_a) in these equations are related to the physical characteristics of the line. The term b is the width of the line measured at the shield wires or between the outer conductors whichever width is the greater. The term R_a is called the attractive distance or shadow height and is a measure of the exposure of the line to a lightning strike. It can be estimated from equation (C-5) where H is the height of the line. Figure C.4 and Table C.3 show the relationship between transmission line flash density and keraunic level. For a keraunic level of 30 which is the typical value for the northeastern CONUS, about 96 flashes per year of direct strokes would be expected to occur for each 100 miles of line, or an average of about 8 flashes a month to a 100-mile line. For south central Florida which has a keraunic level of 100, about 460 flashes per year would occur for each 100 miles of line or about 38 direct strike flashes a month.

Most of the historical data found in the literature which uses this type of density measure, has been based on an isokeraunic level of 30, which is again the level found in most of the northeastern CONUS. Line density estimates can be made for the other keraunic levels. This could be accomplished by using the level 30 density as a base level reference and then by simple ratioing of the isokeraunic levels obtain a density measure for the keraunic level of interest. The relative accuracy of this straight line approximation for extrapolating to other keraunic levels can be seen in Figure C.4.

For additional analysis, the above equations can be used in a computer spreadsheet program or an equation solving program similar to that shown here, which is from a TK Solver program file [6] listed at the end of this appendix. The curves and tables shown here have been produced using this particular program. The table titled Variable Sheet lists all of the variables and allows the physical characteristics of the transmission line to be adjusted in order to assess the impact of lightning stroke current magnitude and the location of the strike on the transmission line.

As seen from the equations discussed above, the induced surge voltage and the linear flash density of the transmission line, or in the case of an electrified railway the catenary system, are functions of both the surge current and the physical parameters of the transmission line. These equations are shown on the Rule Sheet listing.

FIG C.1 STROKE PROBABILITY CURRENT
(Probability that Io(kA)
Equals or Exceeds P)

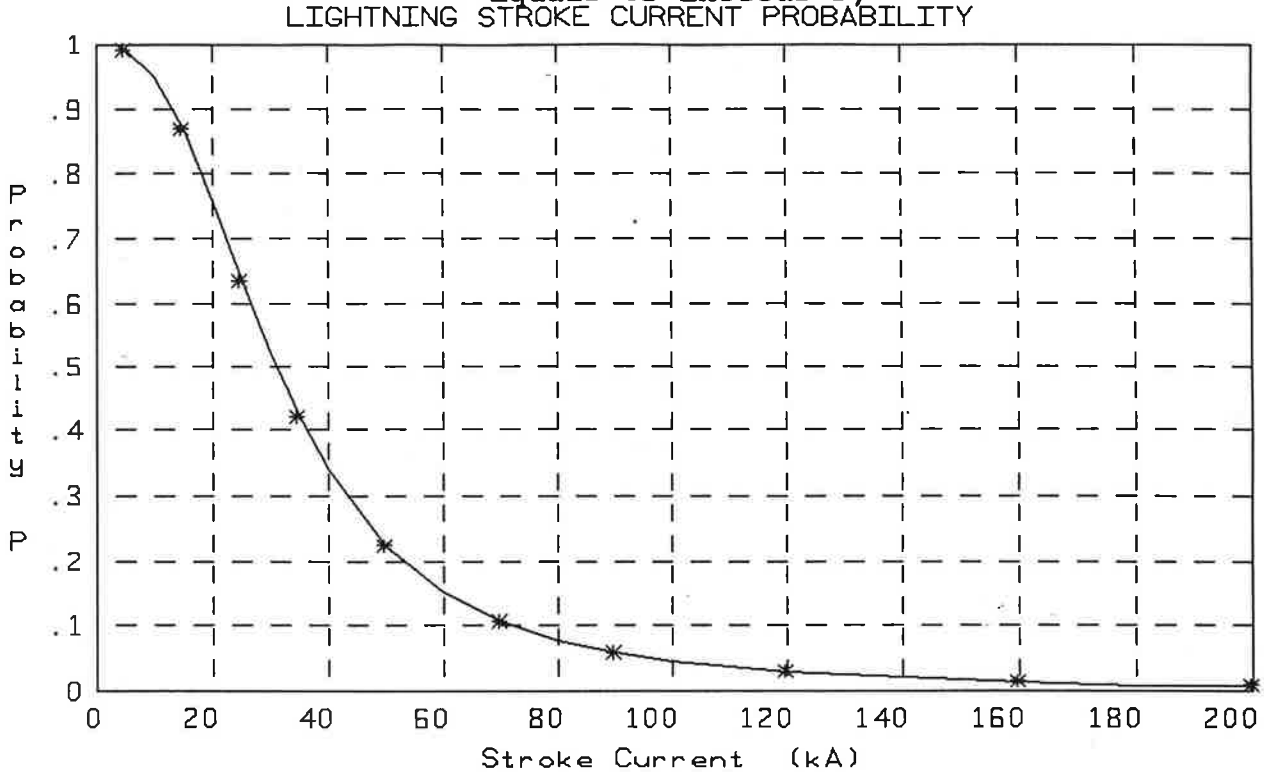

TABLE C.1 LIGHTNING STROKE CHARACTERISTICS.

Io(kA)	P(Io)	Vs(V)
5	0.9914	900
10	0.9499	1800
15	0.8685	2700
20	0.7576	3601
25	0.6363	4501
30	0.5213	5401
35	0.4218	6301
40	0.3401	7201
50	0.2239	9002
60	0.1523	10802
70	0.1074	12602
80	0.0784	14403
90	0.0589	16203
100	0.0454	18003
120	0.0288	21604
140	0.0195	25204
160	0.0138	28805
180	0.0102	32406
200	0.0078	36006

FIG C.2 GROUND FLASH DENSITY
(Flashes per SqKm)

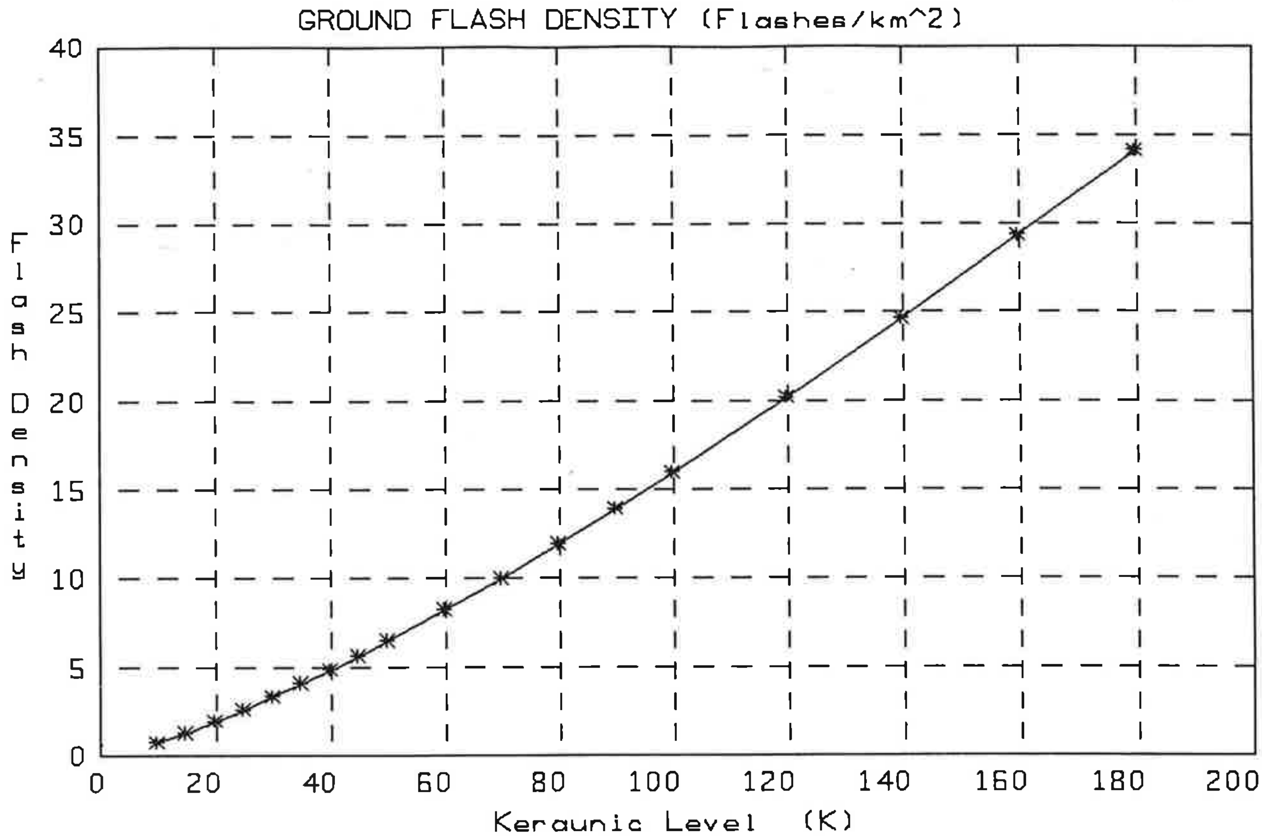

TABLE C.2 GROUND FLASH DENSITY.

Keraunic Level	Keraunic Region	Flash(F/km^2)
5		0.32
10	West_Coast	0.80
15		1.35
20	N_New_England	1.97
25		2.63
30	Northeast	3.33
35		4.07
40	N_Mid_CONUS	4.84
45		5.64
50	S_Mid_CONUS	6.47
60	Southeast	8.20
70	Gulf_Coast	10.02
80	N_Florida	11.91
90	SW_Florida	13.89
100	SC_Florida	15.92
120		20.18
140		24.66
160		29.34

FIG C.3 INDUCED SURGE VOLTAGE

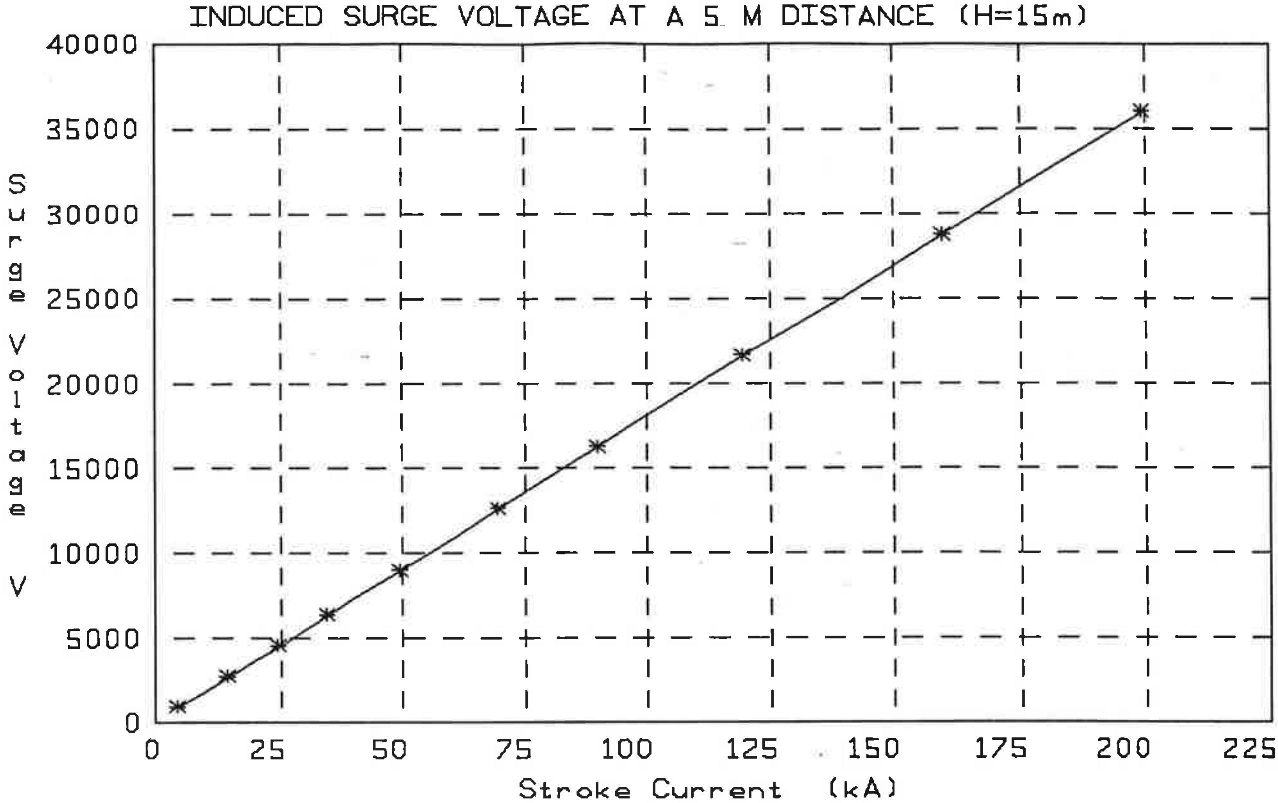

FIG C.4 TRANSMISSION LINE FLASHES
(Flashes per 100 miles of line)

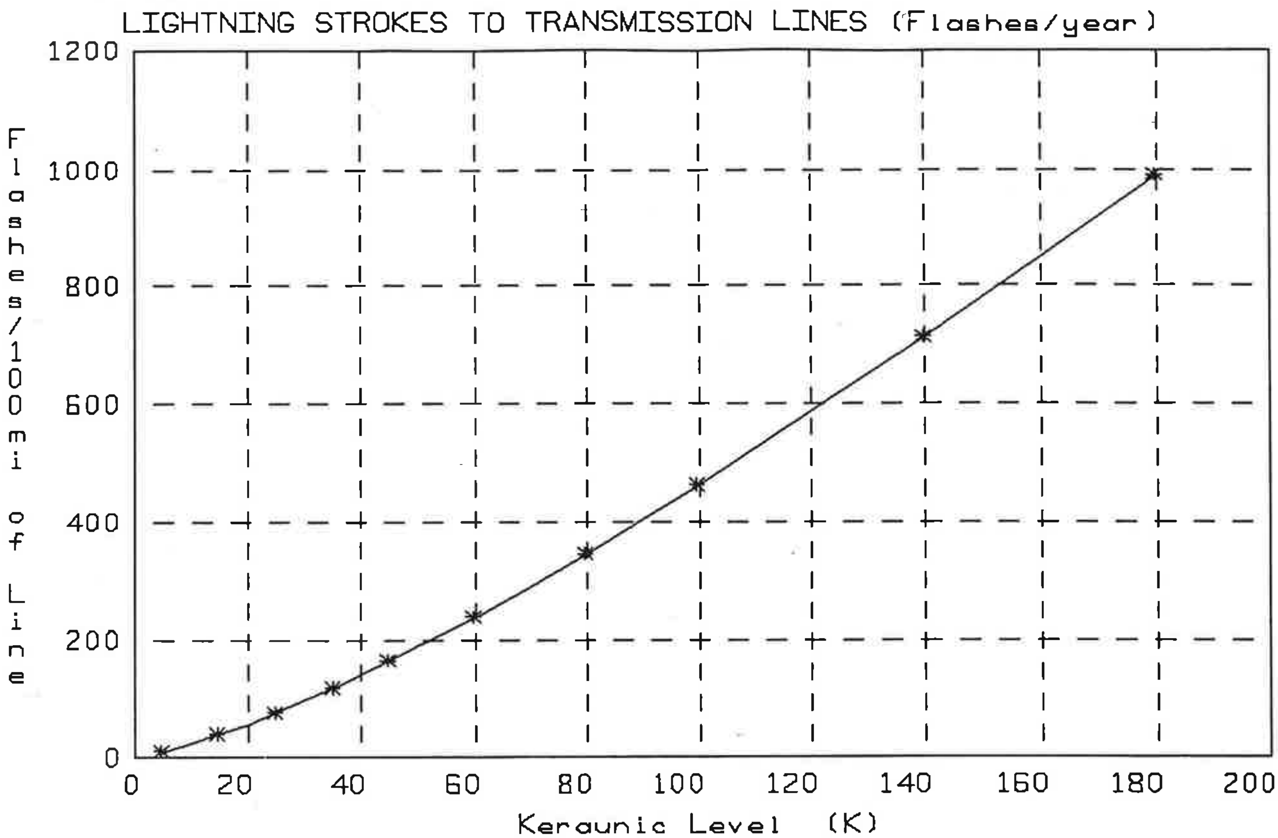

TABLE C.3 LIGHTNING STROKES TO TRANSMISSION LINES.

K(K Level)	Keraunic Region	Ns(F/yr/100km)	Ns(F/mi/100mi)
5		5.83	9.38
10	West_Coast	14.35	23.09
15		24.31	39.12
20	N_New_England	35.34	56.86
25		47.23	76.00
30	Northeast	59.87	96.33
35		73.15	117.70
40	N_Mid_CONUS	87.02	140.01
45		101.42	163.18
50	S_Mid_CONUS	116.30	187.13
60	Southeast	147.41	237.19
70	Gulf_Coast	180.12	289.81
80	N_Florida	214.27	344.75
90	SW_Florida	249.72	401.80
100	SC_Florida	286.38	460.78
120		362.97	584.02
140		443.51	713.61
160		527.59	848.89

C.5 References

1. Uman, M. and Rubinstein, M., "Lightning," The Electrical Engineering Handbook, Chapter 38, CRC Press, Boca Raton, FL, 1993, p.935.

2. Institute of Electrical and Electronics Engineers, Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems, Std. C62.2-1987, New York, NY, 1988, p.14.

3. Institute of Electrical and Electronics Engineers, Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations, Std 487-1992, New York, NY, 1992, p.20.

4. Rusck, S. "The Protection of Distribution Lines," Lightning Volume 2, Chapter 23, Academic Press, New York, NY, 1977, p.760.

5. Eriksson, A. and Meal, D.,"The Incidence of Direct Lightning Strikes to Structures and Overhead Lines," IEEE Conference on Lightning and Power Systems, London, June 1984.

6. Universal Technical Systems, Inc.,"TK Solver Release 2.0," Rockford, IL, 1992.

APPENDIX D. STATIC ELECTRICTY

Static electricity results when electric charge accumulates on an object resulting in an electrostatic field about that charged object. Electric current in the form of a spark is the result of the discharge of an electrostatic field that has accumulated. Static electricity is a very common occurrence and exists almost everywhere in nature. Lightning is one form of static electricity and probably represents the extreme condition of an electrostatic discharge.

D.1 Energy Storage and Electrostatic Voltage

The magnitude of the electrostatic voltage V, that can exist on a charged object is determined by the amount of energy W_e, that exists on or that can be accumulated on that object. This energy can be estimated with an equivalent capacitance model. The relationships between energy storage and electrostatic voltage are given by equations (D-1) and (D-2) as:

$$W_e = \frac{1}{2} CV^2 \qquad \text{(D-1)}$$

$$W_e = \frac{1}{2} qV \qquad \text{(D-2)}$$

The energy W_e is given in joules (J), when the electrostatic voltage of the object with respect to a ground reference is measured in volts, C is the equivalent capacitance given in farads, and q is the accumulated charge in coulombs. In air the amount of charge that can be accumulated on the object is based on the maximum voltage that can be supported before breakdown of the air dielectric occurs. The maximum electric field E, that can be sustained in air before breakdown is of the order of $3x10^6$ V/m [1]. This means that for a discharge gap of 0.01 m (about 0.4 in), the expected breakdown voltage would be about 30,000 V.

D.2 Capacitance Model For a Human

A person who is well insulated from ground can acquire sufficient charge to reach an electrostatic potential of several thousand volts. A relatively simple equivalent circuit model for the human is shown in Figure D.1 [2]. This model uses an equivalent capacitance, resistance and spark gap to describe the electrostatic properties of a human.

In the model, R_1 represents the skin contact resistance, R_2 is the equivalent leakage resistance to ground of the person, C is the contact capacitance of the skin, and I is the charging current from a source of static electricity. Typical ranges for R_1, R_2, and C are; R_1 can vary from 0 to 40 kΩ, R_2 can exceed 100,000 kΩ and C can vary from 100 to 300 pF.

A static discharge occurs when the accumulated voltage across C exceeds the breakdown voltage of the spark gap shown in the left hand side of the model. When discharge occurs a portion of the stored energy is dissipated across the skin contact resistance R_1, and the remainder of the stored energy is discharged as a spark across the gap.

It is not uncommon for static charge on a human to build to voltage levels of 10 kV or more. The voltage level reached depends mainly on the electrostatic charge current and on the leakage resistance to ground. In certain industrial operations electrostatic voltages of about 50 kV have been observed [2]. Antistatic footwear is one method used in industrial operations to limit the magnitude of voltage and charge that can be accumulated. The leakage resistance to ground can be reduced to ranges varying from 50 kΩ to 50,000 kΩ through the use of antistatic footwear. With the above circuit model it can be shown that the lower the leakage resistance the lower the accumulated voltage for a given value of charging current. Also, it can be shown that once the source of charging current has been removed the lower the leakage resistance the faster the decay time of the stored charge.

D.3 Spark Ignition Energies

Using the above parameter values in equations (D-1) and (D-2), the charge storage on a human can be of the order of 1.25 mJ to 375 mJ. The spark ignition energy for certain gas mixtures is of the order of 2 mJ [3]. Note that this is at the lower range of the charge storage on a human.

Depending on the gas mixture and environmental conditions the ignition energy can become as low as 0.4 mJ [2]. Reference [2] also reports that the majority of gas ignition incidents recorded have occurred at an energy level of about 25 mJ. This energy value corresponds to an electrostatic voltage of about 13 kV when a capacitance value of C equal to 300 pF is used in conjunction with equation (D-1). Electrostatic voltage levels of the order of 20 kV with a corresponding energy level of 35 mJ on humans have been reported. Energy levels of this magnitude are considered to be very hazardous for many petrochemical operations [4] and special precautions are required such as antistatic clothing and footwear.

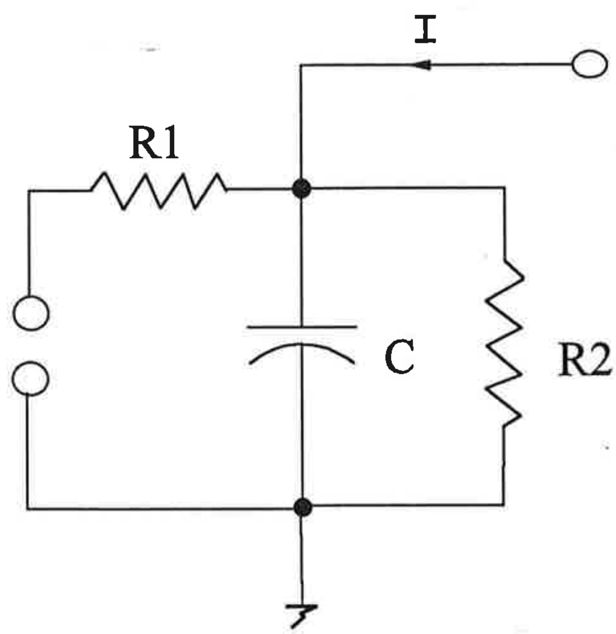

Figure D.1 Capacitance Model For A Human

D.4 References

1. Haase, H., Electrostatic Hazards, Their Evaluation and Control, Verlag Chemie, Weinheim, Germany, 1977.

2. Cross, J., Electrostatics, Principles, Problems and Applications, Adam Hilger, Bristol, England, 1987.

3. Schmieg, G., "Static Electricity: Causes, Analysis and Prevention," Electrical Hazards and Accidents, Van Nostrand Reinhold, New York, NY, 1991.

4. Shell Safety Committee, Static Electricity, Technical and Safety Aspects, Shell Oil Company, The Hague, Netherlands, June 1988.

APPENDIX E. AN ANALYSIS OF DIFFERENT METHODS FOR ESTIMATING THE RISK OF A LIGHTNING STRIKE

E.1 Introduction

There are several methods for quantitatively assessing the magnitude of the risk of a lightning strike to a structure or facility. The risk assessment method considered and discussed here is that of determining the relative susceptibility of a structure or facility being struck by lightning with subsequent damage to the facility and/or injuries to its occupants.

Common to many of the risk assessment methods is the use of keraunic levels. The keraunic level is the number of thunderstorm days in a given area for a specified interval of time, usually given on a per year basis. Keraunic level is used as a basis for estimating the probable number of lightning strokes to a given area, since lightning is related to thunderstorm activity. Maps of thunderstorm activity have been developed for most geographical regions of the earth and these are called isokeraunic maps.

One method of risk assessment found in U.S. standards is that contained in the National Fire Protection Association (NFPA) Standard, Lightning Protection Code, 1992 Edition, NFPA 780 [1]. The method discussed in this standard makes use of a derived risk value. This risk value is related to the keraunic level that surrounds the structure and to a set of index values assigned to certain characteristics of the structure or facility. These characteristics include categories which describe the use of the structure, its type of construction, its contents and/or consequential effects, its degree of isolation with respect to its surroundings and the type of terrain that the structure is located in. The lightning risk value determined from these factors is a relative risk rating.

Alternative methods can be found in European standards such as the British Standards Institute (BSI), Protection of Structures Against Lightning, BS 6651:1992 [2]. The method found in the British standard is a more quantitative method which involves first determining the probability of a strike. The probability value determined is then also modified by a set of index values assigned to the type and use of the structure in a general manner similar to the NFPA standard. The risk value determined with this method can be expressed as the probable number of strikes per year.

A more detailed discussion of each of these methods follows starting with a review of the BSI method first.

E.2 British Standard BS 6651: 1992

BSI BS 6651: 1992, contains several calculation procedures for assessing the risk of a lightning strike. Several tables of weighting index factors also are given in the standard for different types of structures as well as for the relative location of a particular structure. These factors are to be used in conjunction with its recommended risk assessment calculation procedure. Different factors are given for ordinary structures and for those facilities that contain sensitive electrical and electronic equipment. Facilities containing sensitive electrical and electronic equipment would be those considered to be highly susceptible to damage or malfunction from a direct or nearby lightning strike.

The assessment of risk is obtained by comparing the calculated risk assessment values to minimally acceptable threshold values. If these threshold values are exceeded, the standard recommends specific actions be taken on the structure for achieving the desired level of lightning protection.

E.2.1 Risk Assessment Calculation Methodology

A lightning strike probability factor (PF) is first determined using the lightning flash density (N_g) and the coverage area (A_c) of the structure or facility. The BSI standard contains a lightning flash density table which would appear to be relevant to the conditions of the United Kingdom. The lightning strike probability factor is given by:

$$PF = N_g \cdot A_c \qquad \text{(E-1)}$$

The collection area of a structure is related to its cross sectional area as well as its height above the ground. For a structure of finite area, such as a traction substation, the collection area can be estimated as:

$$A_c = (L \cdot W) + 2H(L+W) + \pi H^2 \qquad \text{(E-2)}$$

where L and W are the length and width respectively of the structure and H is its height including any aerial or overhead conductors.

For a structure such as a railroad right-of-way, the collection area can be estimated as:

$$A_c = (L \cdot W) + H(2L+W) + 2H^2 \qquad \text{(E-3)}$$

where L and W are the length and width of the right-of-way and H is the height of the catenary or highest overhead transmission conductor above the ground.

For critical electrical and electronic facilities the surrounding ground area and the projected area of all incoming and outgoing power and signal lines must also be included in the coverage area. This will be further discussed in section E.2.4.

The overall risk factor (R) is then obtained by combining the probability factor with a weighting factor (W_f) The overall risk factor is determined as:

$$R = PF \cdot W_f \tag{E-4}$$

The weighting factor itself is a combination of the individual index factors discussed above. In the British standard, the weighting factor itself, W_f, is the product of several other factors that define the structure or facility from a lightning risk perspective.

The overall risk factor determined from equation (E-4) is then used to determine whether or not mitigation against a lightning strike is necessary. The British standard suggests that with a value of R very much less than 10^{-5} (a value of R less than 1 in 100,000) protection would not be necessary unless there are other overriding considerations. The standard also suggests that a value of R of the order of 10^{-4} would require that additional protective measures be taken or sound reasoning be made for not providing such protection.

No additional rationale is given in the standard for the recommendation for these ranges. However, a comparative probability of death for many activities is listed in Table 7 of the British standard as a means for putting the above values in some type of context. For example; a moderate smoker has a 1 in 400 probability of death by that risk, death in traffic accidents have a probability of 1 in 8,000, natural disasters of probability of death of 1 in 500,000 and death by being struck by lightning has a 1 in 2,000,000 probability.

For critical structures a different threshold value is used and will be discussed in section E.2.4.

E.2.2 Risk Assessment Factors For Ordinary Structures and Facilities

The BSI standard lists five physical categories that are to be used when performing a lightning risk assessment to ordinary facilities and structures. These categories are; the use to which a structure is put, the type of construction used for the facility, its contents or consequential effects, its relative degree of isolation with respect to its surroundings, and the type of terrain that the structure resides in. Within each of the categories there are detailed descriptions for differentiating risk among the different elements that make up a category.

The following tables list these categories and the recommended index factors. The weighting factor W_f discussed above for ordinary facilities, is the product of the index factor values listed in Tables E.1 through E.5, that is $W_f = A*B*C*D*E$.

TABLE E.1 USE OF STRUCTURE - FACTOR A

Use to Which Structure is Put	Value of Factor A
Houses, and buildings of comparable size	0.3
Houses and other buildings of comparable size with outside aerial	0.7
Factories, workshops and other laboratories	1.0
Office blocks, hotels, blocks of flats and other residential buildings other than those included below	1.2
Places of assembly, e.g. churches, halls, theatres, museums, exhibitions, department stores, post offices, stations, airports, and stadium structures	1.3
Schools, hospitals, children's and other homes	1.7

TABLE E.2 TYPE OF CONSTRUCTION - FACTOR B

Type of Construction	Value of B
Steel frame encased with any roof other than metal*	0.2
Reinforced concrete with any roof other than metal	0.4
Steel frame encased or reinforced concrete with metal roof	0.8
Brick, plain concrete or masonry with any roof other than metal or thatch	1.0
Timber framed or clad with any roof other than metal or thatch	1.4
Brick, plain concrete or masonry, timber framed but with metal roofing	1.7
Any building with a thatched roof	2.0

* An exposed and continuous metal structure is excluded from the table as it requires no lightning protection beyond adequate earthing arrangements.

TABLE E.3 CONTENTS OR CONSEQUENTIAL EFFECTS - FACTOR C

Contents or Consequential Effects	Value of C
Ordinary domestic or office buildings, factories and workshops not containing valuable or specially susceptible contents	0.3
Industrial and agricultural buildings with specially susceptible* contents	0.8
Power stations, gas installations, telephone exchanges, radio stations	1.0
Key industrial plants, ancient monuments and historic buildings, museums, art galleries or other buildings with specially valuable contents	1.3
Schools, hospitals, children's and other Homes, places of assembly	1.7

* This means specially valuable plant or materials vulnerable to fire or the results of fire.

TABLE E.4 DEGREE OF ISOLATION - FACTOR D

Degree of Isolation	Value of Factor D
Structure located in a large area of structures or trees of the same or greater height, e.g. in a large town or forest	0.4
Structure located in an area with few other structures or trees of similar height	1.0
Structure completely isolated or exceeding at least twice the height of surrounding structures or trees	2.0

TABLE E.5 TYPE OF TERRAIN - FACTOR E

Type of Country	Value of Factor E
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300 m and 900 m	1.3
Mountain country above 900 m	1.7

E.2.3 Risk Assesment Factors for Facilities Containing Sensitive Equipment

For facilities which contain sensitive electrical and electronic equipment, the BSI standard has three special tables for use in the lightning strike risk assessment. The categories include, the type of construction, the degree of isolation of the facility with respect to its surroundings and the type of terrain that the facility is located in. For the type of construction category the standard recognizes that because of the nature of the installation, its construction features will be in accordance with lightning protection standards. The remaining two tables, namely the degree of isolation and the type of terrain categories, use the same elements and values as that used for ordinary facilities and structures.

The factor index tables to be used for facilities containing sensitive equipment are given below. For facilities of this type the weighting factor W_f, is then given by $W_f = F*G*H$.

TABLE E.6 TYPE OF CONSTRUCTION - FACTOR F

Type of Structure	Value of Factor F
Buildings with lightning protection and equipotential bonding to BS 6651 or equivalent standard.	1.0
Buildings with lightning protection and equipotential bonding to CP 326 or equivalent standard.	1.2
Buildings where equipotential bonding for electrical and electronic equipment reference may be difficult(e.g. buildings over 100 m long)	2.0

TABLE E.7 DEGREE OF ISOLATION - FACTOR G

Degree of Isolation	Value of Factor G
Structure located in large area of structures or trees of the same or greater height, e.g. in a large town or forest	0.4
Structure located in an area with few other structures or trees of similar height	1.0
Structure completely isolated or exceeding at least twice the height of surrounding structures or trees	2.0
NOTE. Table E.7 has the same weighting factors as Table E.4.	

TABLE E.8 TYPE OF TERRAIN - FACTOR H

Type of Country	Value of Factor H
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300 m and 900 m	1.3
Mountain country above 900 m	1.7
NOTE. Table E.8 has the same weigthing factors as Table E.5.	

E.2.4 Lightning Risk Assessment Methodology for Special Structures

In a manner similar to that used for ordinary structures, the above tables are combined with the lightning strike probability value (the probable number of strikes per year to a structure) to obtain an overall risk (R). Again, this overall risk value is obtained from the product of the lightning flash density and the exposure area of the facility and the weighting factor, W_f.

The exposure area of the facility must also include the surrounding ground area and the projected area of all incoming and outgoing lines. This additional exposure area accounts for the probability of a nearby strike adversely impacting the sensitive equipment contained within the facility. These adverse impacts could be a result of either a ground potential rise (GPR) or from destructively high voltages being induced on the incoming or outgoing lines or both. The exposure area for sensitive facilities be estimated as:

$$A_c=2(L\cdot D)+2(W\cdot D)+\pi D^2+A_{ms}+A_{dl} \qquad \text{(E-5)}$$

where L and W are the length and width of the facility, D is the ground collection distance, A_{ms} is the effective collection area of the incoming mains service, and A_{dl} is the effective collection area of the outgoing data lines. The ground collection distance accounts for the likelihood of a GPR from a nearby strike and the value of D depends on soil resistivity. For typical soil resistivity of 100 Ω·m, the BSI standard recommends that D be taken as 100 m.

The values for A_{ms} and A_{dl} depend on line voltage and line materials and construction. Typical values are summarized in the following tables.

Effective Collection Area of Mains Services

Type of Mains Service	A_{ms}
High voltage overhead cable	$4 \cdot D_m \cdot L_m$
High voltage underground cable	$0.1 \cdot D_m \cdot L_m$
Low voltage overhead cable	$10 \cdot D_m \cdot L_m$
Low voltage underground cable	$2 \cdot D_m \cdot L_m$

Effective Collection Area of Data Lines

Type of Data Line	A_{dl}
Overhead signal line	$10 \cdot D_d \cdot L_d$
Underground signal line	$2 \cdot D_d \cdot L_d$
Fiber optic cable without a conductive metallic shield or core	0

In the above tables D_m, L_m and D_d, L_d are the collection distances and lengths of each of the mains and data lines, respectively.

Additional information is required to assess the calculated overall risk factor for critical facilities. The usage of the structure and the consequences of damage to its contents must be known. Furthermore, quantitative exposure level thresholds are required to assess the calculated overall risk factor against certain criteria.

Table E.9 lists the classification criteria for critical structures and Table E.10 classifies the exposure level as a function of the overall risk factor R. As seen from Table E.10, exposure level is given as one of four classes which are listed as negligible, low, medium, and high. Dependent on the consequential loss rating and the R value determined from the risk assessment, a facility will fall into one of these four classes.

TABLE E.9 CLASSIFICATION OF STRUCTURES AND CONTENTS

Structure Usage and Consequential Effects of Damage to Contents	Consequential Loss Rating
Domestic dwellings and structures with electronic equipment of low value and small cost penalty due to loss of operation	1.0
Commercial and industrial buildings with essential computer data processing where equipment damage and downtime could cause significant disruption	2.0
Commercial or industrial applications where loss of data or computer process control could have severe financial costs	3.0
Highly critical processes where loss of plant control or computer operation may lead to severe environmental or human cost(e.g. nuclear plant, chemical works, etc.)	4.0

TABLE E.10 CLASSIFICATION OF EXPOSURE LEVEL

Consequential Loss Rating	Exposure Level			
	R<0.005	0.005=R<0.0499	0.05=R<0.499	R>0.5
1	Negligible	Negligible	Low	Medium
2	Negligible	Low	Medium	High
3	Low	Medium	High	High
4	Medium	High	High	High

NOTE. Exposure level categories in this table are based on a lightning risk assessment only. If transients of other origins are present, consideration should be given to upgrading protectors. For example, if the risk assessment suggests a surge protection device suitable for medium exposure level is appropriate, the presence of inductive switching transients may make the selection of a high exposure device more appropriate.

E.3 National Fire Protection Association NFPA 780

NFPA 780 contains a procedure in its Appendix I for assessing the risk of a lightning strike. The scope of this standard restricts itself to ordinary structures. Its assessment procedure does not explicitly differentiate between critical and noncritical facilities as far as sensitive electronic and electrical equipment are concerned.

Five tables, which are referred to as index values, are given for use with its recommended method for assessing the risk of a lightning strike. The index values given in the NFPA standard are used to obtain a weighting factor. The NFPA standard uses a comprehensive breakdown of the elements within a particular factor category. For example, in the types or uses of structures, the NFPA standard uses 18 distinct categories for assigning an index value for this item.

A sixth table is given in the NFPA standard which relates keraunic level to a keraunic factor value. The factor value assigned to a kernaunic level of 0 to 5 is a value of 9. It declines to an index value of 1 for keraunic levels greater than 70.

The assessment of risk is obtained by comparing the calculated risk index to a list of qualitative criteria. As in the British standard the recommendation for providing specific measures of lightning protection are based on the comparision results.

E.3.1 Risk Assessment Calculation Methodology

The NFPA lightning strike risk assessment is called a risk index (RI). This index is obtained by dividing the weighting factor (W_n), by the keraunic index factor (K_i) as:

$$RI = W_n / K_i \tag{6}$$

For the NFPA standard methodology, the weighting factor is obtained by summing the individual index values for the five categories given.

The risk index determined above is then compared to the relative risk ratings in order to arrive at an assessment of risk (AR). The assessment of risk is a set of qualitative ratings which are shown in the following table.

Assessment of Risk (AR)

RI Value	Risk Value
0-2	Light
2-3	Light to Moderate
3-4	Moderate
4-7	Moderate to Severe
Over 7	Severe

E.3.2 Risk Assessment Factors

Appendix I of the NFPA standard contains five tables of risk assessment factors. These tables consist of physical structure related categories which include type of structure, its type of construction, relative location of the structure compared to its surroundings, type of topography that the structure resides in, and type of occupancy and contents of the structure. These tables are listed below as Table E.11 through Table E.15.

The sixth table in the appendix of the NFPA standard is shown as Table E.16 below. This table relates keraunic level (K) to the keraunic index factor (K_i). As shown in the table, the keraunic index factors are given for ranges of keraunic level.

TABLE E.11 TYPE OF STRUCTURE - INDEX A

Structure	Index Value A
Single family residence less than 5000 sq ft	1
Single family residence over 5000 sq ft	2
Residential office, or factory building less than 50 ft in height: -Covering less than 25000 sq ft of ground area -Covering more than 25000 sq ft of ground area	 3 5
Residential, office or factory building from 50 to 75 ft high	4
Residential, office or factory building from 75 to 150 ft high	5
Residential, office or factory building from 150 ft or higher	8
Municipal services buildings, fire, police, water, sewer, etc.	7
Hangers	7
Power generating stations, central telephone exchanges	8
Water towers and cooling towers	8
Libraries, museums, historical structures	8
Farm buildings	9
Golf shelters and other recreational shelters	9
Places of public assembly such as schools, churches, theaters, stadiums	9
Slender structures, such as smokestacks, church steeples and spires, control towers, lighthouses, etc.	10
Hospitals, nursing homes, housing for the elderly or handicapped	10
Buildings housing the manufacture, handling of storage of hazardous materials	10

TABLE E.12 TYPE OF CONSTRUCTION - INDEX B

Structural Framework	Roof Type	Index Value B
Nonmetallic (Other than wood)	Wood Composition Metal-not continuous Metal-electrically continuous	5 3 4 1
Wood	Wood Composition Metal-not continuous Metal-electrically continuous	5 3 4 2
Reinforced concrete	Wood Composition Metal-not continuous Metal-electrically continuous	5 3 4 1
Structural steel	Wood Composition Metal-not continuous Metal-electrically continuous	4 3 3 1
Note:Composition roofs include asphalt, tar, tile, slate, etc.		

TABLE E.13 RELATIVE LOCATION - INDEX C

Location	Index Value C
Structures in areas of higher structures: Small structures - covering ground areas of less than 10000 sq ft Large structures - covering ground areas of more than 10000 sq ft	 1 2
Structures in areas of lower structures: Small structures - covering ground areas of less than 10000 sq ft Large structures - covering ground areas of more than 10000 sq ft	 4 5
Structures extending up to 50 ft above adjacent structures or terrain	7
Structures extending more than 50 ft above adjacent structures and terrain	10

TABLE E.14 TOPOGRAPHY - INDEX D

Location	Index Value D
On flat land	1
On hillside	2
On hilltop	4
On mountain top	5

TABLE E.15 OCCUPANCY AND CONTENTS - INDEX E

Occupancy and Contents	Index Value E
Noncombustible materials - unoccupied	1
Residential furnishings	2
Ordinary furnishings or equipment	2
Cattle and livestock	3
Small assembly of people - less than 50	4
Combustible materials	5
Large assembly of people - 50 or more	6
High value materials or equipment	7
Essential services - police, fire, etc	8
Immobile or bedfast persons	8
Flammable liquids or gases - gasoline, hydrogen, etc	8
Critical operating equipment	9
Historic contents	10
Explosives and explosive ingredients	10

TABLE E.16 LIGHTNING FREQUENCY ISOKERAUNIC LEVEL - INDEX F

Isokeraunic Level	Index Value F
0 - 5	9
6 - 10	8
11 - 20	7
21 - 30	6
31 - 40	5
41 - 50	4
51 - 60	3
61 - 70	2
Over 70	1

E.4 Comments on the BSI and NFPA Calculation Methodologies

As seen above, the BSI calculation method arrives at a quantitative measure for the assessment of the risk of a lightning strike. The final result of the calculation is an estimate of the probable number of strikes, or expected value of strikes, in a year to the area exposed by the structure or facility in question. The NFPA calculation method of determining risk is to determine a numerical index which is related in an indirect manner to isokeraunic levels. The calculation result of the NFPA method is a dimensionless value which is then compared to qualitative descriptors for determining the significance of the risk. Although both methods each yield an assessment of risk, the BSI method with its quantitative probability estimate, would appear to be the more preferred approach.

Both methods use an index value approach to evaluate the many different factors associated with the risk assessment. The index values given in the NFPA standard are used in the same manner to obtain the weighting factor as the British standard uses its factor values. The primary difference between the two methods is that the NFPA method is based on a summation of its index values and the BSI method in based on a multiplication of its factor values. As one would expect the numerical values given for each of the indices for the listed categories is different in the NFPA standard when compared to those given in the BSI standard. A cursory examination has shown that one could obtain an approximate equivalent set of index values that could be commonly used with both calculation methods.

The NFPA standard uses a more comprehensive breakdown of the elements within a particular index factor category. For example, the "Types or Uses of Structures" category in the British standard is subdivided into only six elements, whereas the NFPA standard uses 18 elements for assigning its index values. Further, many of the elements given in the BSI standard appear to be unique to British type structures and installations. For example, the possible use of thatched roof structures would be unique to British installations.

The BSI standard enables the explicit risk assessement of critical facilities of the type that would be part of an electrified railway. In the NFPA standard these types of facilities are not explicitly addressed. As such the NFPA standard would appear to have limited utility for estimating the risk of a lightning strike for those facilities that contain sensitive electrical and electronic equipment.

E.5 Recommended Lightning Risk Assessment Methodology

The approach recommended for estimating the risk of a lightning strike is based on the British method of determining the probable number of a lightning strikes to an area per year. Again, this method makes use of lightning flash density, structure/facility exposure area and a set of weighting factors related to construction, structure or facility usage, and locale including its relationship to its surroundings. Although intended for critical structures only, preliminary analysis has indicated that the classification of exposure level approach (see Table E.10) could be extended to cover all types of structures and facilities.

E.5.1 Index Value Table Revisions

The tables listed in NFPA 780, Appendix I, Risk Assessment Guide, have been revised to reflect the weighting factors that would be applicable for use with the BSI 6651 calculation methodology for the risk assessment of a lightning strike. These revised tables are shown below.

The BSI calculation methodology requires lightning flash density be specified rather than keraunic level. Accordingly, Table E.17 shown below makes use of ground flash density, rather than the isokeraunic level weighting factors listed in the NFPA standard. It can be shown that lightning flash density (N_g), is approximately related to keraunic level (K) as [3]:

$$N_g = C \cdot K^{1.3} \qquad \text{(E-7)}$$

where C is a constant that ranges from 0.023 to 0.04. For the North American continent, the value of 0.04 is typically used. The exponent term can vary from 1.25 to 1.35 and the value shown in equation (E-7) is the average value. The relationship between keraunic level and flash density is shown in Table E.17. Ground flash density is given in metric units to agree with the BSI calculation approach of expressing coverage area in m^2 and ground flash density as the number of flashes per km^2.

It should be noted that the BSI standard has ordered and weighted its index values different from the NFPA approach. The revised tables shown here maintain the original order of the elements as given in the NFPA standard. The revised index values shown may or may not be in ascending order since they have been based on interpolations made from the BSI standard.

TABLE E.17 TYPE OF STRUCTURE - INDEX A

Structure	Index Value A
Single family residence less than 5000 sq ft	0.3
Single family residence over 5000 sq ft	0.5
Residential office, or factory building less than 50 ft in height: Covering less than 25000 sq ft of ground area Covering more than 25000 sq ft of ground area	 0.6 1.1
Residential, office or factory building from 50 to 75 ft high	1.0
Residential, office or factory building from 75 to 150 ft high	1.1
Residential, office or factory building from 150 ft or higher	1.2
Municipal services buildings, fire, police, water, sewer, etc.	1.2
Hangers	1.2
Power generating stations, central telephone exchanges	1.2
Water towers and cooling towers	1.2
Libraries, museums, historical structures	1.2
Farm buildings	1.3
Golf shelters and other recreational shelters	1.3
Places of public assembly such as schools, churches, theaters, stadiums	1.3
Slender structures, such as smokestacks, church steeples and spires, control towers, lighthouses, etc.	1.7
Hospitals, nursing homes, housing ior the elderly or handicapped	1.7
Buildings housing the manufacture, handling of storage of hazardous materials	1.7

TABLE E.18 TYPE OF CONSTRUCTION - INDEX B

Structural Framework	Roof Type	Index Value B
Nonmetallic (Other than wood)	Wood Composition Metal-not continuous Metal-electrically continuous	0.5 0.3 0.4 0.1
Wood	Wood Composition Metal-not continuous Metal-electrically continuous	0.5 0.3 0.4 0.2
Reinforced concrete	Wood Composition Metal-not continuous Metal-electrically continuous	0.5 0.3 0.4 0.1
Structural steel	Wood Composition Metal-not continuous Metal-electrically continuous	0.4 0.3 0.3 0.1
Note:Composition roofs include asphalt, tar, tile, slate, etc.		

TABLE E.19 RELATIVE LOCATION - INDEX C

Location	Index Value C
Structures in areas of higher structures:	
Small structures - covering ground areas of less than 10000 sq ft	0.4
Large structures - covering ground areas of more than 10000 sq ft	0.6
Structures in areas of lower structures:	
Small structures - covering ground areas of less than 10000 sq ft	1.0
Large structures - covering ground areas of more than 10000 sq ft	1.2
Structures extending up to 50 ft above adjacent structures or terrain	1.5
Structures extending more than 50 ft above adjacent structures and terrain	2.0

TABLE E.20 TOPOGRAPHY - INDEX D

Location	Index Value D
On flat land	0.3
On hillside	1.0
On hilltop	1.3
On mountain top	1.7

TABLE E.21 OCCUPANCY AND CONTENTS - INDEX E

Occupancy and Contents	Index Value E
Noncombustible materials - unoccupied	0.1
Residential furnishings	0.3
Ordinary furnishings or equipment	0.3
Cattle and livestock	0.4
Small assembly of people - less than 50	0.6
Combustible materials	0.8
Large assembly of people - 50 or more	1.7
High value materials or equipment	1.3
Essential services - police, fire, etc	1.0
Immobile or bedfast persons	1.7
Flammable liquids or gases - gasoline, hydrogen, etc	1.7
Critical operating equipment	1.7
Historic contents	1.7
Explosives and explosive ingredients	1.7

TABLE E.22 GROUND FLASH DENSITY

Keraunic Level	CONUS Region	Flash Density (F/km^2)
5		0.32
10	West Coast	0.80
15		1.35
20	Northern New England	1.97
25		2.63
30	Northeast	3.33
35		4.07
40	Northern Mid CONUS	4.84
50	Southern Mid CONUS	6.47
60	Southeast	8.20
70	Gulf Coast	10.02
80	North Florida	11.91
90	Southwest Florida	13.89
100	South Central Florida	15.92

Flash density calculation method in accordance with IEEE Std 487-1992, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations.

The values given in Table E.22 are different from and are larger than those given in the British standard. Note that the values in the above table are based on an IEEE recommended practice. These higher values reflect the North American continent and do reflect the geographical differences of North America compared to the British Isles.

E.5.2 Sample Risk Assessment Results

Several sample test cases were run to evaluate the use of the recommended risk assessment calculation methodology. The cases considered included at grade and elevated track in both urban and rural areas and traction substations installed in both urban and rural areas for a variety of terrain conditions. The specific cases considered were:

- Traction substation in an urban location on flat terrain
- Traction substation in a rural location on flat terrain
- Traction substation in a rural location on hilly terrain

- Railway route in an urban location and at grade
- Railway route in a urban location and elevated
- Railway route in a rural location and at grade
- Railway route in a rural location and elevated.

The test cases used keraunic level as the parameter to determine the overall risk factor (R). The lightning risk exposure level following the suggested breakdown given in Table E.10 was then determined. The exposure levels listed in Table E.10 are again; negligible, low, medium and high. The consequential loss rating category selected was category 2 which is the significant disruption category.

The results of the sample test cases are shown in the attached curves and tables. These cases were developed using the spreadsheet calculator discussed in Appendix C. As can be seen from the tables, operating in an urban environment would have exposure levels varying from negligible to medium. Operating in a rural or open environment the exposure levels would vary from low to high. Using a keraunic level of 40 which would describe large portions of the CONUS, operating in a urban environment would result in exposure levels of low to medium. Operating in a rural or open area the exposure levels then become medium to high. As expected the elevated track and hilly location for substation conditions results in a high exposure risk to a lightning strike for most of the keraunic levels expected to be found in the CONUS. Except for the relatively narrow coastal region in the West, where the keraunic level is 10, lightning protection would appear to be warranted.

FIGURE E.1
RISK FACTOR FOR TRACTION SUBSTATION
URBAN FLAT LOCATION
File Name: Lrisksuf

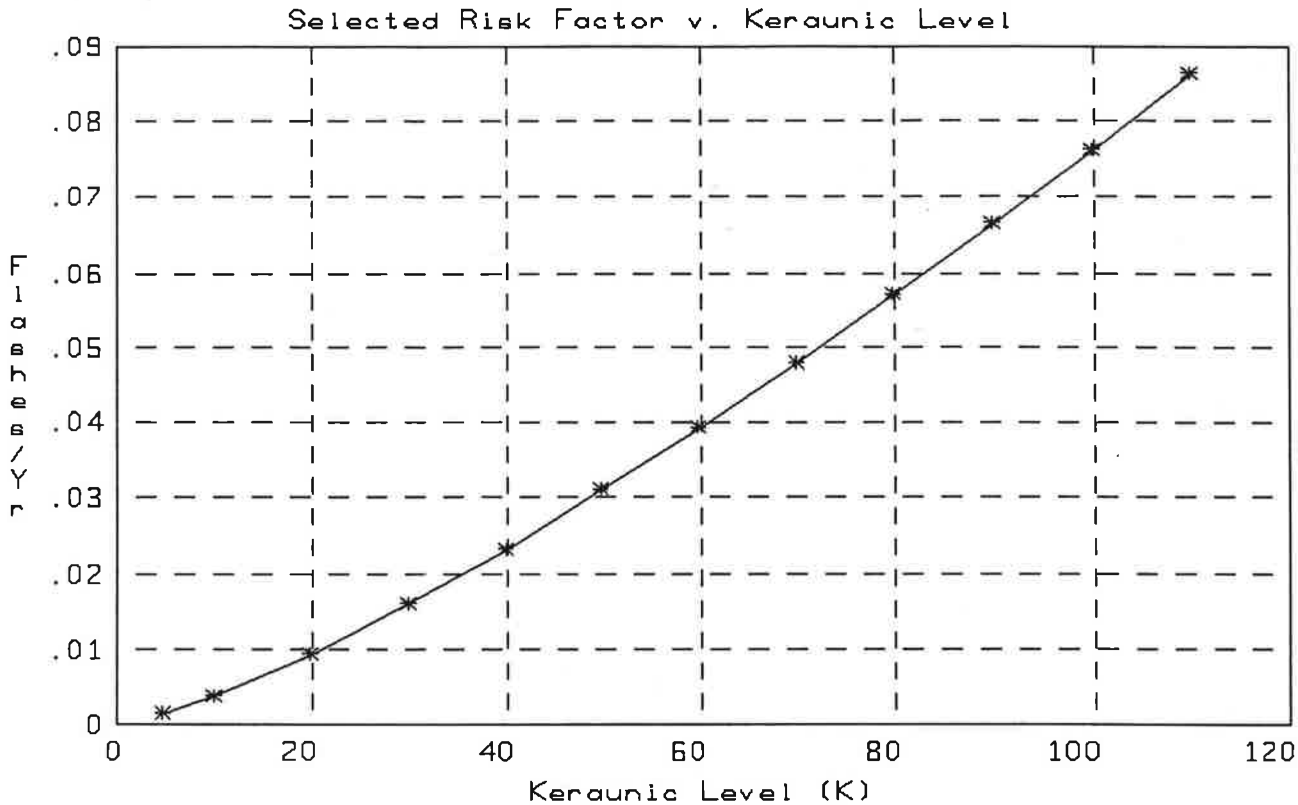

TABLE E.23 TRACTION SUBSTATION URBAN FLAT LOCATION

Keraunic	F/km^2	F/yr	Level1	Level2	Level3	Level4
5	0.32	0.002	Negligible			
10	0.80	0.004	Negligible			
20	1.97	0.009		Low		
30	3.33	0.016		Low		
40	4.84	0.023		Low		
50	6.47	0.031		Low		
60	8.20	0.039		Low		
70	10.02	0.048		Low		
80	11.91	0.057			Medium	
90	13.89	0.067			Medium	
100	15.92	0.076			Medium	
110	18.02	0.086			Medium	

FIGURE E.2
RISK FACTOR FOR TRACTION SUBSTATION
RURAL FLAT LOCATION
File Name: Lrisksrf

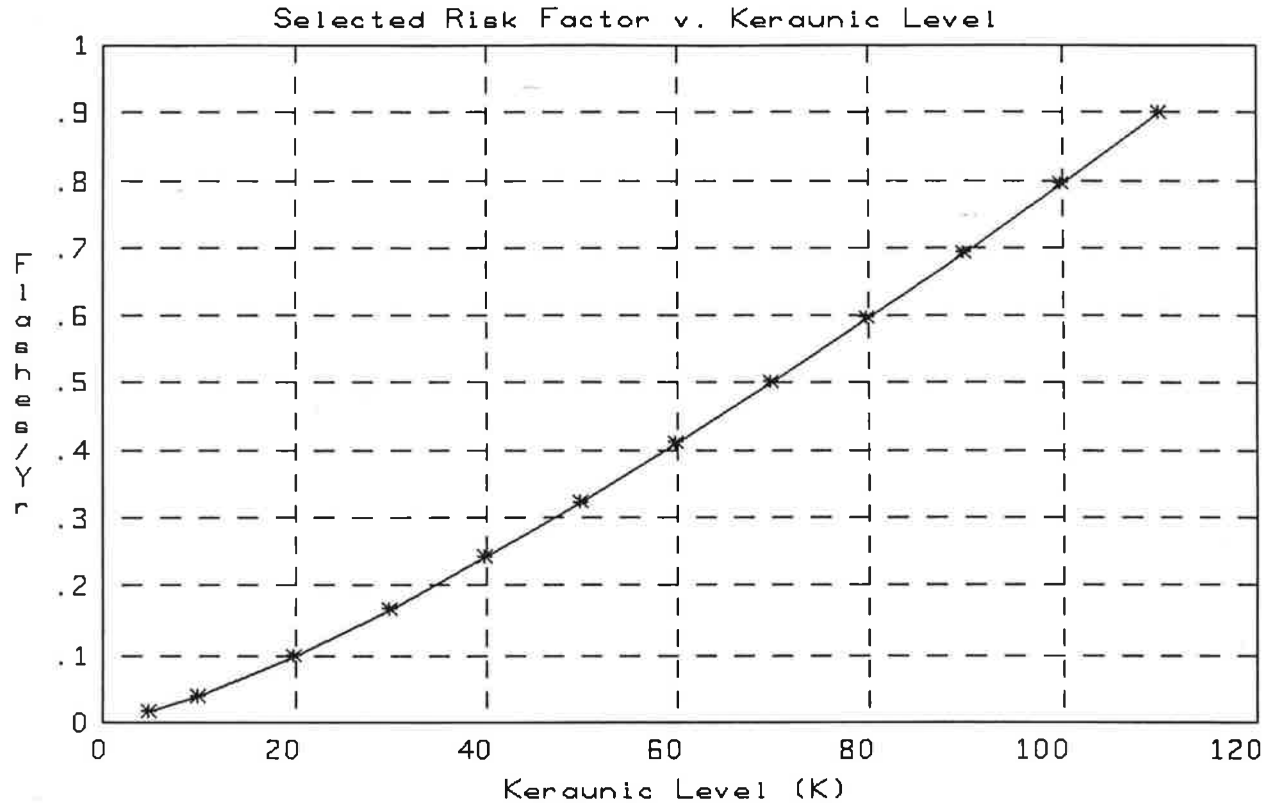

TABLE E.24 TRACTION SUBSTATION RURAL FLAT LOCATION

Keraunic	F/km^2	F/yr	Level1	Level2	Level3	Level4
5	0.32	0.016		Low		
10	0.80	0.040		Low		
20	1.97	0.098			Medium	
30	3.33	0.167			Medium	
40	4.84	0.242			Medium	
50	6.47	0.324			Medium	
60	8.20	0.410			Medium	
70	10.02	0.501				High
80	11.91	0.596				High
90	13.89	0.695				High
100	15.92	0.797				High
110	18.02	0.902				High

FIGURE E.3
RISK FACTOR FOR TRACTION SUBSTATION
RURAL HILL TOP LOCATION
File Name: Lrisksrh

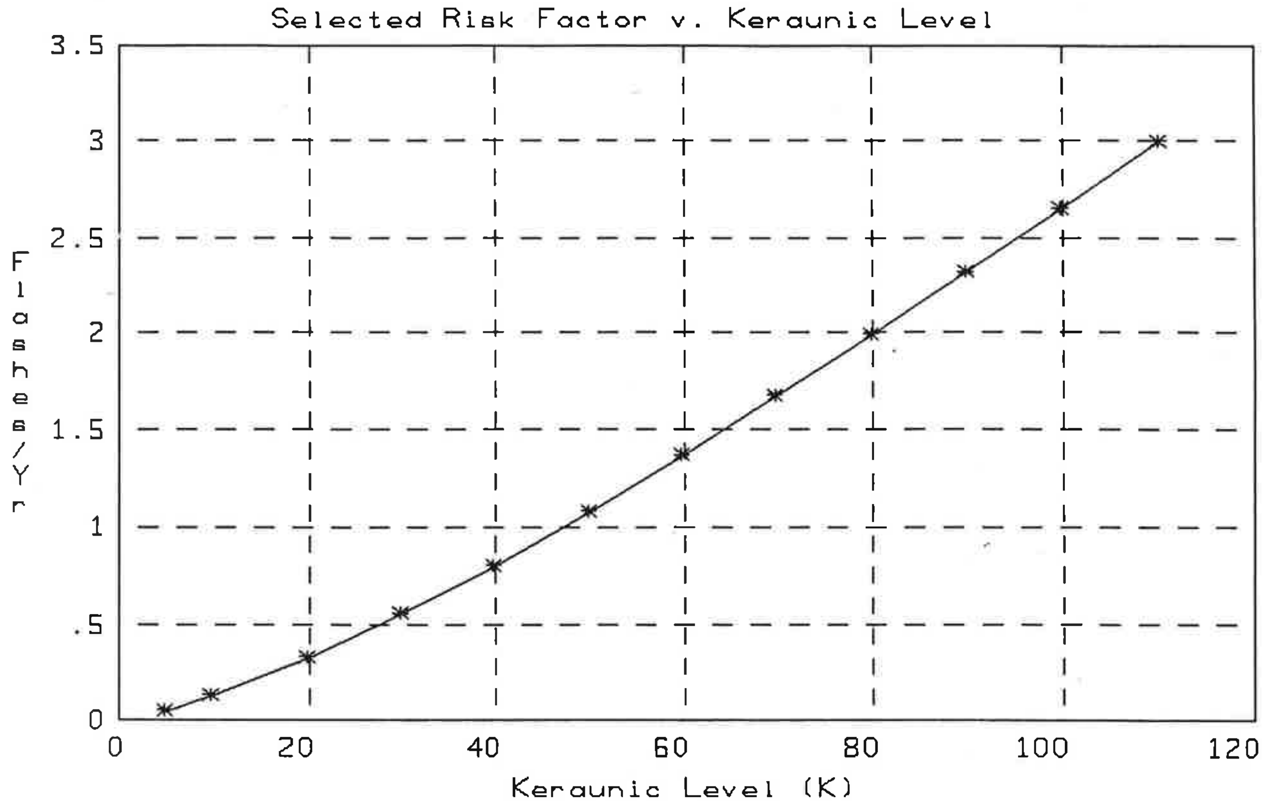

TABLE E.25 TRACTION SUBSTATION RURAL HILLY LOCATION

Keraunic	F/km^2	F/yr	Level1	Level2	Level3	Level4
5	0.32	0.054			Medium	
10	0.80	0.133			Medium	
20	1.97	0.328			Medium	
30	3.33	0.555				High
40	4.84	0.807				High
50	6.47	1.079				High
60	8.20	1.368				High
70	10.02	1.671				High
80	11.91	1.988				High
90	13.89	2.317				High
100	15.92	2.657				High
110	18.02	3.007				High

FIGURE E.4
RISK FACTOR FOR RAILWAY ROUTE
URBAN AT GRADE
File Name: Lrisktug

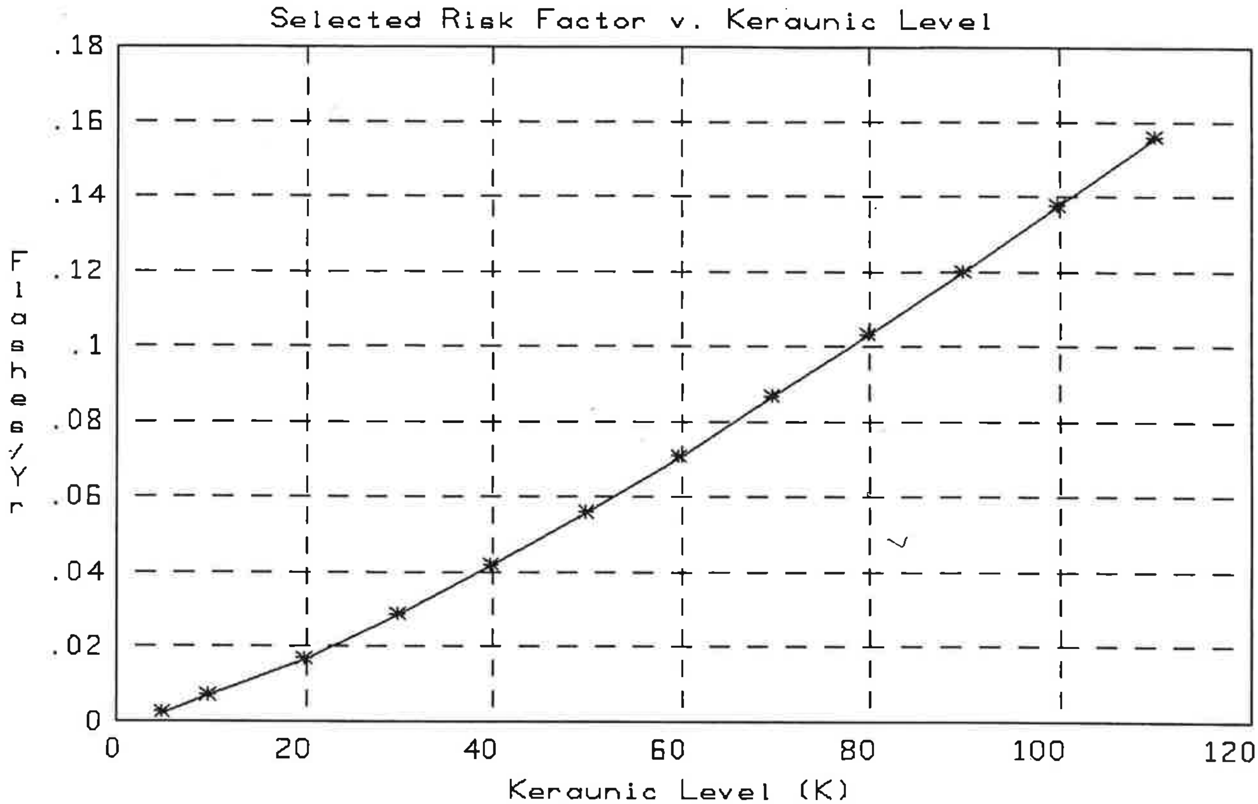

TABLE E.26 RAILWAY ROUTE IN URBAN FLAT LOCATION

Keraunic	F/km^2	F/yr	Level1	Level2	Level3	Level4
5	0.32	0.003	Negligible			
10	0.80	0.007		Low		
20	1.97	0.017		Low		
30	3.33	0.029		Low		
40	4.84	0.042		Low		
50	6.47	0.056			Medium	
60	8.20	0.071			Medium	
70	10.02	0.087			Medium	
80	11.91	0.103			Medium	
90	13.89	0.120			Medium	
100	15.92	0.138			Medium	
110	18.02	0.156			Medium	

FIGURE E.5
RISK FACTOR FOR RAILWAY ROUTE
URBAN ELEVATED TRACK
File Name: Lrisktue

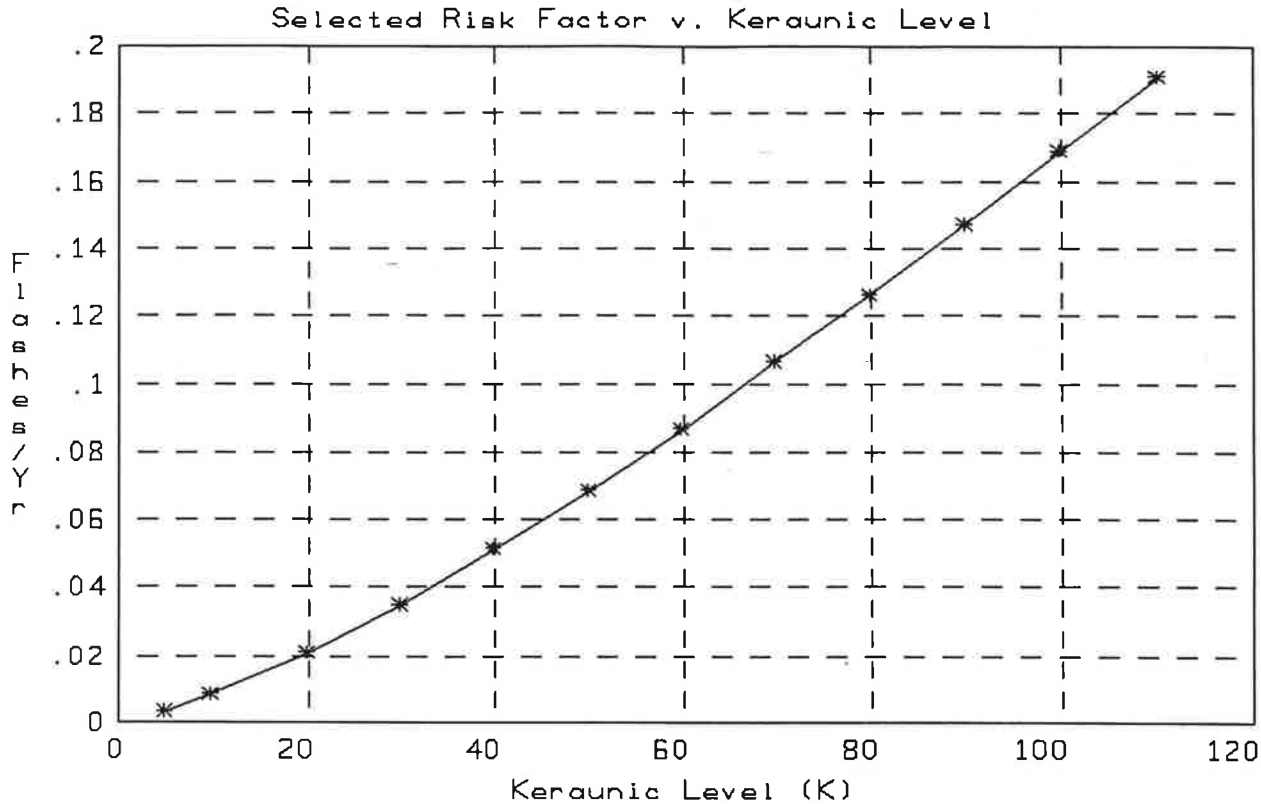

TABLE E.27 RAILWAY ROUTE URBAN ELEVATED TRACK

Keraunic	F/km^2	F/yr	Level1	Level2	Level3	Level4
5	0.32	0.003	Negligible			
10	0.80	0.008		Low		
20	1.97	0.021		Low		
30	3.33	0.035		Low		
40	4.84	0.051			Medium	
50	6.47	0.069			Medium	
60	8.20	0.087			Medium	
70	10.02	0.106			Medium	
80	11.91	0.126			Medium	
90	13.89	0.147			Medium	
100	15.92	0.169			Medium	
110	18.02	0.191			Medium	

FIGURE E.6
RISK FACTOR FOR RAILWAY ROUTE
RURAL AT GRADE TRACK
File Name: Lrisktrg

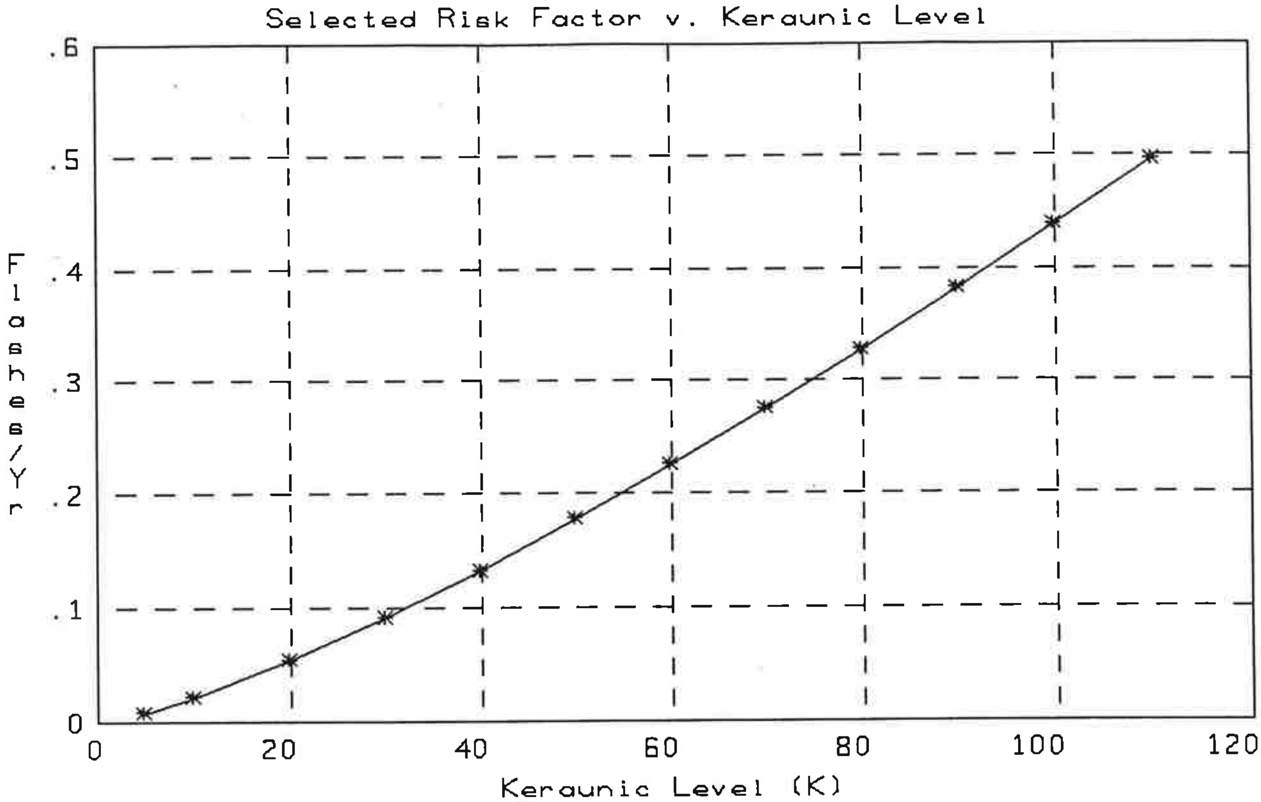

TABLE E.28 AT GRADE RAILWAY ROUTE IN RURAL HILLY TERRAIN

Keraunic	F/km^2	F/yr	Level1	Level2	Level3	Level4
5	0.32	0.009		Low		
10	0.80	0.022		Low		
20	1.97	0.054			Medium	
30	3.33	0.092			Medium	
40	4.84	0.133			Medium	
50	6.47	0.178			Medium	
60	8.20	0.225			Medium	
70	10.02	0.275			Medium	
80	11.91	0.328			Medium	
90	13.89	0.382			Medium	
100	15.92	0.438			Medium	
110	18.02	0.496			Medium	

FIGURE E.7
RISK FACTOR FOR RAILWAY ROUTE
RURAL ELEVATED TRACK
File Name: Lrisktre

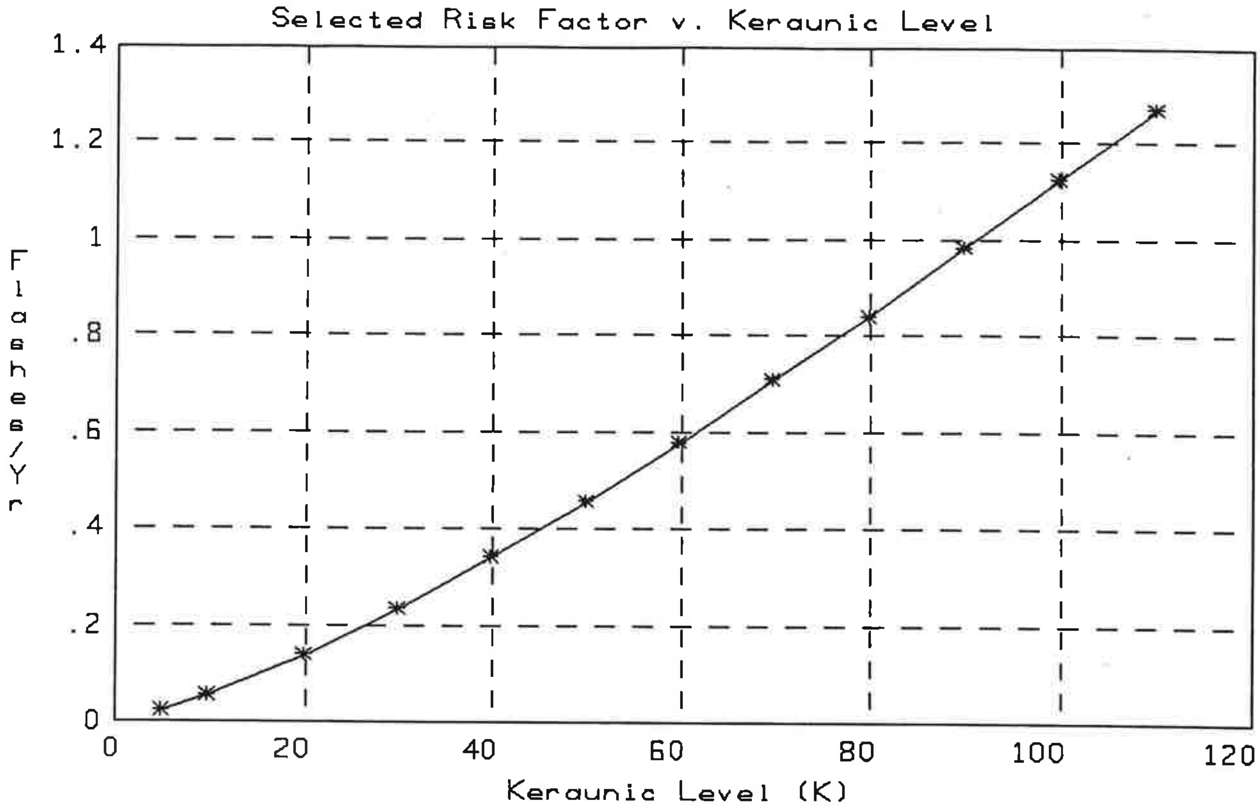

TABLE E.29 ELEVATED RAILWAY ROUTE IN RURAL HILLY TERRAIN

Keraunic	F/km^2	F/yr	Level1	Level2	Level3	Level4
5	0.32	0.023		Low		
10	0.80	0.056			Medium	
20	1.97	0.139			Medium	
30	3.33	0.235			Medium	
40	4.84	0.342			Medium	
50	6.47	0.457			Medium	
60	8.20	0.580				High
70	10.02	0.708				High
80	11.91	0.843				High
90	13.89	0.982				High
100	15.92	1.126				High
110	18.02	1.275				High

E.6 References

1. National Fire Protection Association, Lightning Protection Code, NFPA 780, Batterymarch Park, Quincy, MA. August 14, 1992.

2. British Standards Institute, Code of Practice for Protection of Structures Against Lightning, BS 6651, December 15, 1992.

3. Institute of Electrical and Electronics Engineers, Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations, Std 487-1992, New York, NY, November 4, 1992.