1.0 Executive Summary

Network reliability has been impacted by a variety of causes, one of which is fire. Although service affecting fires have been rare in the telecommunications industry, a few serious fires have occurred in the last 5-7 years that have received national attention. In general, when major fires occur in telecommunications facilities, they have a severe impact on service and require a significant amount of time to fully restore telecommunications capability. The efforts of the Fire Prevention Focus Team have concentrated on assessing the current state of the industry regarding fire prevention systems and examining the specific aspects of each fire reported to the Focus Team in the past 5 years. Common issues have been identified and will be shared with the industry, by providing appropriate countermeasures that are addressed by material and design standards or by "Best Practices" that were submitted by respondents to the survey or provided by Focus Team members and experts in fire prevention research and operations.

The Quality Improvement Process was used by this Focus Team to analyze the data received and ultimately segregate findings into seven (7) root cause categories. The study results point up the need to formulate strong action plans relating to the areas of power, employee and vendor management in telecommunications buildings, switching and transmission equipment standards and telco employee emergency response training. Based on the specific findings, countermeasures are proposed in this paper that have the potential to improve the overall fire safety characteristics of telecommunications type facilities to the degree that service affecting fires could be reduced by as much as 25%.

2.0 Background:

The Network Reliability Steering Team (NO REST) formulated the following problem and issues statements relating to the matter of fire prevention. **" Fire is potentially a serious threat to our ability to provide reliable telecommunications service to the community. Telecommunications Service Providers must maintain, and in some cases improve their capabilities in fire prevention, detection, suppression and containment to help assure a high level of service reliability."** See exhibit 19.0 for copy of Issue Statement.

The Fire Prevention Focus Team organized its effort to not only understand the current state of fire prevention deployment in the telecommunications industry but to acquire knowledge specific to the fire prevention "Best Practices" involving fire detection, suppression, containment, smoke control, alarm strategies and new materials available to reduce flammability and corrosive smoke emissions. Monthly meetings were devoted to learning from subject matter experts, who presented the latest information on fire prevention strategies and the latest new technology that is expected to impact the telecommunications industry in the near future. Specific information generated from these technical sessions are incorporated in this Team's final recommendations to the industry.

The Fire Prevention Focus Team established as its theme - **Improve network reliability by reducing the likelihood of occurrence and resulting service impact from fires and related events.** The basis for improvement would be the measured reduction of service affecting fire events, and service impact as collected from the industry by a standardized reporting process. The baseline for improvement should be established following the first full year after standardized reporting begins. Reporting guidelines will be made available to the telecommunications industry early in 1993.

The lack of consistent reporting standards, and/or record retention concerning fire related events in the past 5 years in telecommunication facilities, has likely resulted in some level of under reporting. Thus, no good benchmark information exists to accurately measure future progress. As a result it is quite possible that events in the fire category may reflect an initial increase over what has been described in the report once the formal reporting structure is adopted by the industry.

In some sections of this report, recommendations will be made for industry action. References to "the industry" are generic and do not indicate or imply any specific forum, association, etc. The Fire Prevention Focus Team believes that there are several National Standards organizations that should take action on recommendations made in this report. Further action relating to tracking of future fire events is addressed in section 14.3.

3.0 Fire Prevention Focus Team Members

James Eibel	Illinois Bell - Chairman
Charles Clos	New York Telephone
Marshall Cochrane	Pacific Bell
George Crump	ALLTEL

G

Cliff Harvey	Boulder, Colorado - Fire Department
Dimitrios Karydas	Factory Mutual Research
Larry McKenna	AT&T
Barbara Reagor	Bellcore
Rick Shores	GTE
Steve Messer	Telecommunications Consultant
Ross Ireland	Pacific Bell - NO REST Committee - Chairman

4.0 Data Collection and Analysis Process

4.1 To understand the fire events that occurred in the telecommunications industry during the past 5 years and the level of fire protection capability each company currently had in place, the Fire Prevention Focus Team developed questionnaires to address several areas of concern.

Questionnaire #1 requested information on the number of switching/transmission entities, repeater stations, controlled environmental vaults (CEV's), satellite earth stations etc., that each company operated in their network. The data requested, reflected current capabilities regarding smoke detection, alarming, smoke control, fire department access and automatic suppression system deployment. The questionnaire is shown in exhibit 19.1

Questionnaire # 2 requested specific information regarding the actual fire events that occurred during the past 5 years including detection status, fire department response, extinguishing process and material used, location within structure, extent of service and equipment damage and finally, root cause analysis of the event. The data collection concentrated on the period 1988 - 1992, but we had several major fire events reported for a few years prior to the survey period. The questionnaire is comprehensive and is shown in exhibit 19.2.

Questionnaire #3 - The "Best Practices" that responding companies had established dealing with fire prevention and response to an actual fire event was requested in this questionnaire. This data was projected to be used, in part, to develop the countermeasures that are an integral part of the Total Quality Process that this team was to use in developing its final recommendations.

4.2 Following the team approval of the three questionnaires, Bellcore assumed the role of distribution and data assembly for the Fire Prevention Focus Team, under a non disclosure agreement. The questionnaires were mailed to sixty five (65) companies which included the fifty (50) largest Local Exchange Carriers, Interexchange Carriers, several equipment vendors and many smaller telephone companies. Responses were received from twenty seven (27) companies representing approximately 93% of the U.S. access lines in service. Therefore, the findings are representative of the telecommunications industry in the United States.

The data collected from questionnaires 1 and 2 was stripped of company identity by Bellcore and assembled in a generic data base for statistical manipulation. These data were used by the Focus Team, Data and Analysis Sub-Committee. This sub-committee had as its charter the requirement to determine:

1. The degree to which fires disrupt service.
2. Fire protection measures in place in telecommunication facilities.
3. Major contributing factors causing service or potentially service affecting fires.

4.3 The team used a variety of tools such as graphs, histograms, Pareto diagrams and checklists to establish seven (7) root cause categories for telecommunication facility fires. Analysis was confined to the information provided in the questionnaires and could not be supplemented by verbal clarification with responding companies because of the non-disclosure agreement.

After compiling the data in presentation format, which reflected the most significant root cause findings, recommendations for countermeasures were made by the Focus Team. A flow diagram depicting the work activity of the Data and Analysis Sub-Committee is shown as exhibit 19.3.

4.4 Responding companies reported 195 fire events. The total number of fire events reported in the 5 year period from 1988 to 1992 was 189. This equates to approximately 38 incidents per year with 8 per year indicated as service affecting (see exhibit 19.4). The telecommunications facilities of the companies reporting these fires represented approximately 52,000 physical switching, transmission, CEV or radio relay entities (see exhibit 19.5). Most fires occurred within normal business hours with approximately 80% occurring while the sites were occupied. Although smoke or other detection capability was shown to exist in 90% of the fire locations, in 49% of the cases the occupants discovered the fire first. Fire department

G

response time to the fire site was 6 minutes or less in 57% of the reported cases. Response time exceeding 15 minutes was reported in thirteen (13) events. Extinguishment of fires was dominated by occupants, with 49% of reported fires cared for by telco employees or their contractors. Fire departments extinguised 25% and automatic fire suppression systems extinguised 6% of the fires.

5.0. Types and Causes of Fires

5.1 The analysis of the survey data initially used physical location within the telecommunications facility environment as a method for analysis. This proved interesting but did not entirely correlate with fire root cause data. Examination of these root causes led to the identification of 7 fundamental categories.

1. Within telco equipment and peripheral equipment (test set, micro processors, etc.)
2. Power equipment (AC/DC, Batteries, Diesel Generators, etc.)
3. Vendor/Contractor initiated
4. Telco personnel initiated
5. Natural - (Lightning, Wind & Flood)
6. Fire outside facility (Dumpsters, Landscaping, etc.)
7. Building Systems (Elevators, HVAC Systems, Lighting, Heaters, Fans and Motors)

Exhibit 19.6 depicts the total number of fire events reported by root cause for the total reporting period. Also attached (exhibit 19.7) is a trend chart for each root cause for the period 88 - 92. The chart shows a general increase in fire incidents in the year 1989. The Focus Team believes that the increase in reported incidents may have resulted from the increased attention by the telecommunications industry following the detailed industry report on the Hinsdale, Illinois major service outage and fire incident. Following 1989 most root cause reports remained relatively flat.

5.2 Root Cause Summary

As stated earlier in this paper, the fire events reported were categorized into seven (7) root causes. Exhibits 19.8 thru 19.18 represent specific information within each root cause category. Detailed analysis of fire causes were virtually identical for both service affecting and non service affecting fire events. Therefore, service affecting and non service affecting categories were combined when addressing countermeasures and "Best Practices".

The most significant fire causes under each root cause category are listed below.

Root Cause #1 - Within Telco or Peripheral Equipment

During the time period investigated in this study, nineteen (19) fires were reported in telco or peripheral equipment of which 47% (9) were service affecting. The high level of service impact is expected when fires occur within equipment frames or associated peripherals and no redundancy is present. Although specific suppliers' equipment was not identified, the types of equipment involved in these events could be categorized into circuit packs and back planes associated with adjunct frames, computer power boards and other peripheral equipment like teletype machines.

Root Cause #2 - AC/DC, Batteries and Diesels

In this category sixty-three (63) fires were reported of which, thirteen (13) were service affecting. As expected, only those fires which directly disrupted telecommunications equipment resulted in a service outage. Some of the largest fires encountered have this root cause, and potentially, all the fires in this category have the ability to produce service outages. The predominant areas affected were rectifiers eleven (11), cable shorts and arcs eleven (11), transformers eight (8) and batteries nine (9). Twenty-four (24) other events were associated with connectors, motors, air compressors, diesels and other power equipment.

Root Cause #3 - Vendor/Contractor initiated

Of the thirty-four (34) events reported in this category, nine (9) were service affecting. Vendors/Contractors were found to be in violation of safe working practices within the telecommunication facility environment. Events involving lack of bus bar protection when working above power equipment, welding or use of gas torches, and cable mining and equipment removal activities accounted for the majority of vendor/contractor caused fires. All service affecting fires were related to work involving powered telco equipment or building electrical contractors.

G

Root Cause #4 - Telco personnel

This category represented nineteen (19) fire events with one(1) creating a service outage. This single event was the result of the improper use of a soldering iron. The majority of these fires occurred within the lounge or kitchen area of a telecommunications facility and were largely attributed to faulty or improperly used appliances. Smoking in the telecommunications building also was a major contributor to fire events in this category since it represented six (6) of the nineteen (19) events.

Root Cause #5 - Natural

Only ten (10) fire events resulted from natural causes, seven (7) of which were service affecting. Lightning and wind related events were responsible for the majority of these reports. Storms were responsible for transient voltages entering the telco buildings through AC service cables or telco disribution cables as a result of lightning or wind initiated wire crosses.

Root Cause #6 - Building - External

Twelve (12) fires resulted from activities external to the telecommunications facility. The dominant causes for fires in this category were dumpster fires and the ignition of landscape materials that surround the buildings. These fires have the potential to generate large amounts of soot and/or corrosive smoke which can enter the building through the ventilation system and affect equipment performance.

Root Cause #7 - Building Systems

Of the thirty five (35) fires recorded in this category, motors contributed to nineteen (19) fires with two (2) impacting service. Fourteen (14) motor fires were concentrated in building elevator equipment or HVAC equipment. Other contributing elements in this category were space and water heaters five (5), control panels four (4) and lighting fixtures three (3).

6.0 Countermeasures and Recommended Best Practices

Listed below are countermeasures and "Best Practices" that are recommended for each of the seven (7) root causes previously described. Also included is information and recommendations on fire prevention planning, strategies and future development not directly related to root causes.

Unless otherwise stated, implementation of these countermeasures and "Best Practices" shall be the responsibility of the company who owns the telecommunications facility. However, some recommendations will require action by manufacturers who supply equipment to these companies.

"Best Practices" are those countermeasures (but not the only countermeasures) which go furthest in eliminating the root cause(s) of outages. None of the practices are construed to be mandatory; however, a very small number of countermeasures that are deemed by the Focus Team, and concurred by the Network Reliability Steering Team (NO REST), to be especially effective countermeasures will be designated as *"recommended"*.

Service providers and suppliers are strongly encouraged to study and assess the applicability of all countermeasures for implementation in their companies and products, respectively. It is understood that all countermeasures, including those designated as *"recommended"* may not be applied universally.

6.1 Root Cause #1 - Within telco equipment and peripheral equipment.

Analysis of the fire data has shown that power board failures and both circuit pack and back plane shorting are responsible for many of the events. Countermeasures are discussed below which address this area. In addition, the need for better fire standards for adjunct, computer and peripheral equipment was clearly shown by the types of equipment fires encountered.

6.1.1 Vendors should perform and document equipment shelf power distribution tests that ensure:

- power supplies/converters are provided with overload protection and limit power or remove power during short circuit conditions,
- shelf back plane printed circuit runs, connectors, and wires that provide and return power are protected from overcurrent conditions (associated with the appropriate power source),
- power outputs are divided/redundant so that total shelf function is not lost and the value of protection devices can be lowered to prevent electrical ignition (each divided path has current limiting or protection).

G

6.1.2 All equipment frame outside plant interfaces should be designed to resist over-voltage conditions on outside plant lines (ANSI-T1 316 - 1992).

6.1.3 Vendors should control contamination during the manufacturing process of multi-layer boards and insure adherence to NEBS and other applicable industrial standards regarding the flammmability of PC board, electrical/mechanical components and sub-assemblies (TR NWT 000078, TR NWT 000063 & UL - 94).

6.1.4 The industry should continue to develop improved materials and standards that relate to reducing flammability and corrosive smoke emissions. During the early stages of a fire, corrosive smoke emissions can have major impact on electronic equipment. Preventing or reducing this impact requires a higher level of attention by Standards Bodies to prescribe improved changes to materials and prevention/control techniques for the telecommunication industry.

6.1.5 Buyers of telecommunication equipment should subject adjunct and peripheral equipment, collocated with network equipment, to identical product approval requirements including NEBS and applicable industrial standards. Review of equipment frame/shelf power distribution and protection is advisable.

6.2 Root Cause #2 - Power equipment

Several Best Practices can be found to address the four major areas associated with fires in this category (rectifier fires, cable shorts/arcs, transformers and batteries). Below we have listed many of the areas that can help to reduce these fires.

The Fire Prevention Focus Team strongly recommends the immediate adoption of the following two countermeasures.

6.2.1 Develop pre-plans with local fire agencies which address the specific telecommunications environment, with special attention devoted to understanding of telecommunications power plants and the necessary de-powering instructions should the fire department require power removal for effective fire control. The Ameritech Power Zone Marking and De-Powering Plan (AM770 300-950 issue A, April 93) provides a simplified method of marking equipment areas for understandable de-powering by local fire agencies and local personnel under fire conditions.

6.2.2 Verify smoke/heat detection capability in each zone of a telecommunication facility for sensitivity and alarm receipt by local forces and/or fire agency.

The following countermeasures are recommended to prevent or reduce fires involving DC power distribution and equipment. The focus group recommends that these countermeasures be implemented on a going forward basis as part of power plant modernization programs, normal maintenance procedures, new equipment installations and pre/post conditioning and removal projects.

6.2.3A Power wire and cables and communications cables that meet NEBS should be required in all telecommunications locations. These cables are rated by physical properties relating to abrasion, compression and flammability. Selection of cables should be based upon user understanding of risks provided with each product.

6.2.3B As new installations are added, consideration should be made not to reuse existing cables unless they meet NEBS requirements. Remove non-compliant cable to the degree it is economically feasible and safe to do so.

6.2.4 Use of Standard for Telecommunications Environmental Protection, DC Power Systems covered in American National Standards Institute document ANSI T1.311-1991 is recommended. This standard covers power configuration, grounding protection and wiring methods for telecommunications Central Offices and similar type facilities.

6.2.5A Re-emphasize need for adequate ventilation and air exchange in battery areas to avoid build up of hydrogen gas. Where inadequate, ensure that proper gas detection is installed (TR-NWT-000063, T1-311-1991).

6.2.5B Provide regular inspection and battery maintenance to identify leaking cells, corroded terminals and loose inter-cell connectors and ensure timely replacement of batteries. Aging properties of batteries can lead to thermal runaway which may result in fire.

6.2.5C A large variation in battery capacity shown during testing of pre-1989 Valve Regulated Lead Acid (VRLA) batteries is evident. The batteries have been in the field perhaps 50 to 70% of their expected lives and their capacity should have been higher and more closely grouped. It is

G

recommended that all pre 1989 batteries be tested using impedance instruments (SR-NWT-001307).

6.2.6A Wherever possible, DC power cables, AC power cables and telecommunications cables should not be mixed. New installations of switching, transmission and power equipment should provide for separation of power and signaling cables through the use of layered racks, dividers or other means designed to accomplish this purpose. Existing DC primary distribution runs should be assessed, to the degree possible, to insure insulation integrity of the DC power cable and prevent contact between the DC power cable and metallic components of the cable rack such as horns etc., and commingled armored cable. Cable horns should be insulated or removed where exposure exists for contact with power cables.

Removal of power cables or armored cable from mixed use cable routes should be scheduled to coincide with a major equipment removal order unless these cables are easily accessible in the top surface layer of a cable run or in the event cable degradation (cracked, damaged) has occurred. All power should be removed from the cables to be mined. A New York telephone procedure relating to the Pre/Post conditioning process to prevent electrical ignition in racks should be considered for review prior to any major cable removal activity.

6.2.6B Verify DC fusing levels, especially at the primary (main) distribution board to avoid overfusing on significantly underutilized circuits or primary distribution feeds assessed as having damaged or deteriorated insulation, being commingled with armored cable, or feeding manufactured discontinued fuse bays. A primary distribution feed with suspected or known damaged or deteriorated insulation is considered compromised. To minimize fire caused by an arcing or conductive fault involving a compromised or underutilized DC primary distribution feeder, it is recommended that they be fused at a level not to exceed the smallest conductor used in the feed or 200% of the maximal consumption, whichever is smaller. Regarding the latter, a more conservative approach would consider fusing at a level consistent with the in-rush current or current drain of the equipment powered. Remember to consider fuse coordination requirements with downstream fuses and fuse interrupt capacity when applying this countermeasure. The closer the fuse value approaches the operating current, the greater the likelihood that the fuse will operate when a conductive or arcing fault occurs.

6.2.6C For compromised and underutilized primary distribution runs, circuit rearrangements or power transitions should be utilized to de-energize the DC power cables if economically feasible and safe to do so.

6.2.6D Arc fault detection equipment should be investigated as it becomes commercially available in the next one to two years. This topic is fully addressed in section 11.0.

6.2.7A Rectifier fires represent a large component of the surveyed base. Power plant modernization programs should consider replacement of units with a history of component failures and degradation of internal insulation systems or if the units are at an age where replacement by a more energy efficient unit can be cost justified. Replacement may also be warranted before rectifiers reach the end of their design life or when replacement parts and technical support are no longer available. The same consideration should be applied to converters and invertors in bulk power applications.

It is recommended that a case history file, by equipment category, be established to identify failure trends. Prompt attention should be given to the application of engineering change notices related to each manufacturers' product. Most manufacturers also make projections for life expectancy of these products. This may assist with the orderly removal and replacement as part of a power plant modernization program. The Focus Team also recommends the establishment of a joint industry effort to develop a risk assessment model that, through use of easily identified parameters, would allow telecommunications companies to assess rectifiers that have the highest potential for failure and prioritize those that would become part of a power plant modernization program.

6.2.7B Providing smaller power plants closer to the load as part of modernization or new installation programs will reduce the risk of ignition in cable racks and create zones for localized or selective disconnect if necessary.

6.2.8 Thermography should be utilized to inspect power boards, rectifiers, batteries, power room buss connections, switch gear (includes AC) and primary distribution runs.

The following countermeasures are recommended to prevent or reduce fires involving AC Power distribution and equipment:

6.2.9 Whenever practical, electric utility transformers should be located external to the building to minimize the possibility of fire damage to telecommunication equipment. Proper ventilation and good housekeeping practices should be maintained in all transformer space. Appropriate local/national building codes should be consulted regarding special requirements such as compartmentation, etc. For transformers utilizing oil as a coolant, a gas and oil analysis can detect the presence of internal arcing. Insure adherence to Local/National Electric Code primary and secondary protection requirements.

6.2.10 Motors should be regularly inspected for unusual noise, excessive bearing housing heat, and proper shaft and coupling lubrication. On an annual basis clean external surfaces including design plates and verify that proper thermal protection and winding protection according to Local/National Electric Code is in place based on motor design plate data. Where visible, inspect internal surface for dirt accumulation and bearing lubricant overflow. Check motor mountings and alignment. Check electrical connections for tightness to prevent single phasing. Provide proper maintenance of driven equipment such as compressors, pumps, air handling fans and air dryers.

6.2.11 Follow manufacturers recommendations regarding the exercising and calibration of circuit breakers to assure against failure in crisis conditions. Industry data shows a higher probability for failure when circuit breakers are not exercised regularly.

The increased use of non-linear AC loads such as electronic ballasts in lighting fixtures, computers, and office equipment has caused the creation of harmonics which can flow back into other parts of the building AC power distribution system. Harmonics can generate an overcurrent condition in shared neutrals associated with 3-phase, 4-wire systems or primary windings of transformers. They can cause currents to flow in 3-phase motors which oppose the direction of rotation and in peak sensing electronic trip circuit breakers. These breakers may operate prematurely or fail to operate depending on the harmonic distortion present in the phase conductor. If harmonics are suspected, companies may wish to institute a survey process to identify possible corrective action such as de-rating transformers (ANSI/IEEE standard C57,110), running extra neutrals etc.

No correlation could be made between reported fires and the presence of harmonics but the Fire Prevention Focus Team believes the industry should be alerted.

6.3 Root Cause #3 - Vendor/Contractor initiated

Of the thirty-four (34) events reported in this category, nine (9) were service affecting. Vendors were found to be in violation of safe working practices within the telecommunications facility environment.

Issues involving lack of bus bar protection when working above power equipment, welding or use of gas torches and cable mining and equipment removal activities accounted for the majority of vendor caused fires.

Many good practices and recommendations can be implemented to greatly reduce problems identified under this root cause. They are listed below.

6.3.1 Require use of a defined practice or procedure for cable mining and equipment removal operations within telecommunications buildings. Consideration should be given to the review and use of the Ameritech Guidelines for Method of Procedure, Installation and Removal Projects - AM 790-100-421LB. This practice provides guidance for establishing formal Method of Procedure (MOP) agreements with certified vendors for equipment installation, equipment removal and cable mining activity within telecommunications buildings.

6.3.2 Implement a vendor and contractor certification and training program for telco and building type contractors to assure each understands continuity and protection of telco service and all safety requirements enforced within the facility including housekeeping, use of flammable products and smoking. Several telecommunications practices dealing with vendor management have been reviewed. Those viewed as meeting the requirements of this countermeasure exist in New York Telephone and in the Pacific Bell Installation Job Acceptance Handbook.

6.3.3 All work performed in or external to the telecommunications facility should require a standard signed Method of Procedure (MOP), indicating full understanding of work processes including, service and safety precautions. The Pacific Bell Installation and Job Acceptance Handbook provides guidance for this specific recommendation as does the Ameritech Guidelines for Method of Procedure (MOP), Installation and Removal Projects.

G

6.3.4 Welding and use of torches within central office buildings should be avoided whenever possible. When welding or flame use is required, a second individual certified on the use of a fire extinguisher, should be required to observe and man a portable extinguisher.

6.4 Root Cause #4 - Telco personnel initiated

This category represented nineteen (19) fire events with one (1) reported service outage. The majority of these fires occurred within the lounge or kitchen area of a telecommunications facility and were largely attributed to faulty or improperly used appliances.

Smoking in telecommunications buildings was also a major contributor to fire events in this category representing six (6) of the nineteen (19) events.

Recommendations related to this root cause are listed below.

6.4.1 A comprehensive site management and building certification program is recommended to verify proper placement and operation of electrical appliances in telecommunications buildings. The Pacific Bell Site Assessment Program is quite comprehensive and warrants review for possible use in all telco's.

6.4.2 Implement periodic reviews of work process and safety practices on the use of soldering irons in telecommunications facilities.

6.4.3 Prohibit smoking in telecommunications buildings.

6.5 Root Cause #5 - Natural

Fires from Natural Causes are the hardest to protect from since they in most part are not predictable. However, as shown by the event analysis protection of facilities from foreign voltages can possibly reduce these fires. Practices and recommendations that address this are discussed below.

6.5.1 Verify with power company, with joint ride along aerial feed serving telecommunications facilities, that no obvious conflicts exist with trees or other hazards that could then trigger a failure under high wind or ice storm conditions.

6.5.2 Provide AC surge protection at service entrances to minimize or prevent effects from lightning or extreme voltage fluctuations (ANSI/IEEE C62.41, ANSI T1.313-1991 and TR-NWT-001011).

6.5.3 Verify telecommunications grounding arrangements within each service element in the building along with approved general building grounds, including any external structures, such as radio towers (ANSI T1.313-1991, Electrical Protection for telecommunications Central Offices and Similar Type Facilities).

6.5.4 Assure that a program exists to test all environmental alarms on a regular basis.

6.6 Root Cause #6 - Building - External

Many of the fires in this category were associated with smoking paraphernalia igniting garbage and landscape materials. Although none of these fires impacted service, they do have the potential to produce contamination (soot and smoke) which can impact equipment performance. Several improved building practices and recommendations that can help greatly reduce these fires are discussed below.

6.6.1 Establish a comprehensive building certification program which addresses conditions within and external to a building dealing with aspects of safety, local training, housekeeping and operational aspects of the specific building. Pacific Bell and New York Telephone have comprehensive building certification programs which provide a formal structure to assure uniform compliance with fire safety measures. The "Best Practices" reference section 18.0 lists available practices

6.6.2 Avoid the use of combustible landscape material adjacent to the telecommunications structure.

6.6.3 Dumpsters should not be located in close proximity to the building and air intake systems. Where neighborhood conditions warrant, consider use of a lock.

6.6.4 Insure proper outside air filtration and damper control to prevent smoke from entering the telecommunications facility. (Smoke-Handling Strategies suitable for Central Office Equipment Protection, Bellcore SR-NWT-D01833,ISS 1, December 1990 and Ventilation of Central Office Buildings, BR 781-810-885, ISS 1, July 1991).

6.7 Root Cause #7 - Building Systems

Although this category had next to the lowest number of service impacting fires, there are many

G

practices and recommendations that can help to reduce and prevent fires in this category. Many are outlined below that address the major categories of elevators, HVAC systems, and motors. The Focus Group recommends the following action relating to this root cause category.

6.7.1 A comprehensive building certification program should be considered for use which addresses the proper aspects of housekeeping within the elevator environment. (See previous reference to Pacific Bell and New York Telephone Building Certification programs).

6.7.2 Assure that required elevator safety and maintenance routines are administered per manufacturers recommendations and local codes.

6.7.3 Verify that elevator defined building compartments comply with building codes.

6.7.4 Provide smoke detection capability and adequate ventilation in the motor room environment. (Bellcore Special Report SR-NWT-001833, ISS. 1, December 1990).

6.7.5 Recommend use of over-current protection devices and verification of all fusing arrangements.

6.7.6 Require regular inspection and maintenance of HVAC equipment areas.

6.7.7 Restrict use of all space heaters in the telecommunications environment and other areas of the building.

6.7.8 Establish an effective building equipment maintenance program.

6.7.9 Recommend certified inspection programs for boilers, fuel storage and pressure vessels.

6.8 Fire Prevention Planning, Strategies and Future Developments

The following six topics are viewed as having the potential to generate overall improvements in the area of telecommunications fire protection. This material will supplement material previously described as countermeasures for defined root causes to reported fires. The recommendations provided under this section represent the most significant "Best Practices" submitted by surveyed companies and the latest technical information in the industry relating to fire protection in the telecommunications environment.

7.0 RISK ASSESSMENT - A MANAGEMENT TOOL FOR FIRE PREVENTION STRATEGIES

Introduction

Modern fire risk assessment combines both qualitative and quantitative models to assess both the fire hazard and fire risk of a given event. Fire hazard can be defined as the severity of loss for a given situation or event while fire risk is defined as the probability an event will happen. Since the assessment process can fail when the measure of the severity and/or the determination of the probabilities fail to match the needs of a given situation, it has not found extensive application in the telecommunications area. However, in recent years following several large fire events, researchers have turned to developing more accurate risk assessment tools that can be applied with predictable benefits to telecommunications facilities. In addition, today there is a growing emphasis on examination of the costs versus benefits for any fire prevention strategy. **The availability of an accurate risk assessment tool that can compare strategies and determine which meet the fire risk needs of the company for a given expenditure is greatly needed by the telecommunications industry.** In this paper we review what fire risk assessment is and discuss some of the new tools soon to be available.

Objective of Fire Protection/Prevention

The objective of risk management in telecommunications companies is to provide a fire safe work place for their employees and assure uninterrupted telecommunications service for their customers. In achieving this goal, companies strive to: a) comply with all applicable laws governing fire protection; b) ensure the public safety, service continuity, and protection of company assets; c) protect employees and telecommunications equipment from generally recognized fire hazards; d) include fire safety considerations in the design operation and installation of all company facilities; e) use the most advanced information and state-of-the-art fire risk assessment methodologies; and finally, f) support and contribute to the development and implementation of rational fire safety measures.

Background

Today, there are more than 65 fire risk models that can be applied to a variety of fire scenarios. A great deal of research is aimed at understanding and quantifying the probabilities associated with a given

G

fire scenario in order to better match fire hazards and fire risks which in turn improves the fire risk assessment models Over the last 5 years a much greater understanding for the need to have multiple fire risk tools in order to assure minimum risk to life and property has developed in the telecommunications industry.

One set of tools known as "Fire Risk Rating Schedules", or FRRS provide the basis for the models being developed today. The FRRS integrate various processes of modeling and scoring fire hazards and other risk parameters to produce a rapid and simple estimate of relative risk. They are referred to as index systems, numerical gradings and point schemes. Originally they were developed for the insurance industry, but today are providing the basis for more complex models.

In addition to the development of FRRS for given fire risk assessment tools, fire risk analysis categories are also combined in the process. Generally, four types of fire risk analyses are used.

- Narratives are used to describe existing fire conditions and address ways to reduce them. This is a qualitative approach that helps identify the problems or situations to be addressed.

- Checklists are generalized tools that help to identify existing fire hazards. Here, no weighting is provided that would rank what is observed.

- Schedules are developed which assign negative or positive values for assessing risk comparisons. (For example - a fire rated door would add negative risk)

- Emulations provide for the analysis of fire risk through computer modeling and network analysis.

For fire risk analysis to be effective it must reflect accurate measures of the severity and scenarios of a given fire event and develop accurate probability distribution of the event. It is in achieving this goal that a large amount of research has occurred over the last few years. Many groups have addressed fire risk analysis by quantifying the different aspects that contribute to the fire scenario.

Factory Mutual Research (FMR) Corporation has conducted both small scale and large scale fire tests to develop improved probabilistic models for given fire scenarios for commercial (storage facilities), industrial (manufacturing) and telecommunications (switching rooms/equipment). These tests have contributed to the development of multi-state models that provide for extensive comparison of experimental and simulated data, knowledge of materials, configuration and airflow, and temperature gradients that combine to contribute to a viable assessment of a fire scenario. Currently, they are applying these tools to many of their insurance customers in order to further validate and improve them.

The Australian risk assessment models combine the impact of the building subsystems with these probabilistic models to achieve a requisite level of safety. They are currently being used in major commercial buildings. A similar tool has been developed for use by Telecom Australia.

The Canadian Building Code Assessment Framework (BCAF) adds an impact analysis and addresses trade offs between fire risk increase or reduction and cost increase or reduction in order to assess the cost benefit of fire risk management. This tool is currently being applied to new construction.

In 1992, the National Fire Protection Association published NFPA 101M "Manual on Alternative Approaches to Life Safety". This manual combines the four concepts of fire risk analysis (narratives, check lists, schedules and emulation's) with building design considerations, population distributions and knowledge of materials and configuration to assess strategies for life safety. It brings to bear the concept that fire scenarios and fire impacts are different and need to be assessed with different approaches. The manual is used by many local and state fire prevention engineers is assessing fire risk as defined in NFPA standard 101, Life Safety Code.

Many of the models discussed above are now being modified and expanded to address the fire risk associated in telecommunication facilities.

A quantitative method for the systematic assessment of fire risk associated with telecommunication facilities has been developed in a joint research study between Bellcore and AT&T corporate Staff. The results of this study are to be published before the end of 1993. This "Fire Risk Assessment Methodology" (FRAM) combines an understanding of fire hazards and impacts on service continuity and personnel safety. It uses a numerical approach through checklists and computer simulation combined with elements of the NFPA 101M Alternate Approaches to Life Safety. Through matrix management, it addresses the cross

G

correlation between Fire Safety (preventing ignition, control of fire growth and management and protection of exposed assets [people and equipment]) with Fire Impact (equipment loss, facilities damage, service interruption). As with the Australian and Canadian efforts it goes further to design in fire prevention strategies from a cost to benefit standpoint. Use of this model would allow for an observed change in the fire risk index as a function of capital investment/improvement. One could then readily examine multiple strategies and design site specific improvements that provide the lowest risk (best fire protection) for the best use of capital investment.

Practical Benefits

Since the advantages of risk assessment tools are largely conjecture to those who have not been exposed to them before, they can best be illustrated by an example. For this example, consider a typical central office in a mid-sized city. The risk assessment begins with a site survey, during which a great deal of information is collected. The actual questions vary depending on the methodology being used, and typical survey inputs include:

- building/space geometry,
- construction materials
- building/space use
- type, age, and condition of telecommunications equipment present in the building/space,
- compartmentation present,
- HVAC system design, including smoke removal or management functions
- fire detection system design, type, condition, and function
- fire suppression system design, type, condition, and function
- presence of recognized fire hazards (i.e., combustible materials, flammable liquids, etc.)
- emergency planning (i. e., employee training, evacuation plans, fire department familiarization, power shut down, etc.), and
- management attitudes towards loss prevention and emergency planning.

Once the requisite data has been collected, it is entered into the calculation routine, which yields a value for the fire risk present in the space/building. If the value falls within the range of acceptable values, as defined by the owner, the insurer, and/or the public authority, the space/building has an acceptable level of fire risk. A series of such calculations, combined with accurate cost estimates, can be very useful in determining which changes will result in the greatest improvement in risk at the least cost. Future enhancements to the risk assessment methodologies may well include routines which automatically perform these "what if?" calculations, and offer a series of suggested remedies when a space/building is found to be defective. The utility of a risk assessment methodology becomes very clear when a cost-benefit analysis such as this can be readily performed.

Summary

In summary, all of the models being developed today for telecommunications require a firm understanding of the materials, configuration and impacts on people, equipment and service. The information obtained by the NRC - FCC Fire Prevention Team is a Delphi approach to provide risk managers with the needed real world data to make Fire Risk Assessment effective for telecommunication companies.

Conclusions and Recommendations

Up until this time the fire protection strategies within a telecommunication company have been largely based on technology and conditions that were viewed to be acceptable in the electromechanical era. New detection devices, new materials for cables and hardware, and smoke control arrangements now offer companies an opportunity to evaluate fire protection vs. benefit for capital dollars expended.

The Risk Assessment models soon to be ready for commercial use in the telecommunications industry will allow the companies to maximize fire protection alternatives for a specific site, and for a defined capital outlay. These tools should be used to help each company maximize fire protection levels that correlate with capital availability while continuing to improve assurance of life safety, asset protection and service continuity.

G

References

- "Fire Hazard and Fire Risk Assessment" ASTM STP 1:50, M. M. Hirschler, ed., ASTM: Philadelphia, PA, June 1992
- Proceedings of "International Symposium on Fire Protection for the Telecommunications Industry, New Orleans, LA, May 1992
- NFPA 101M "Manual on Alternative Approaches to Life Safety" NFPA, February 1992
- "Fire Risk Assessment Methodology" Bellcore and AT&T Corporate Staff, to be published

8.0 DETECTION

Introduction

Early detection of a fire is necessary to ensure response by trained personnel prior to the onset of service interrupting damage. The survey showed that 89% of central offices have an automatic fire detection system installed. The survey also showed that the predominant detection technology employed is point-type ionization detectors located at the ceiling of the room.

Research has shown that the use of **point-type detectors at the ceiling of a room containing modern telecommunications equipment will not ensure detection of a fire early enough to prevent service interrupting damage.** This is due largely to changes in the design of the telecommunications equipment and corresponding changes to the room air conditioning systems. Recent advancements in fire detection technology have led to the introduction of new products which have the demonstrated capability of detecting a fire in a modern telecommunications equipment room early enough to allow intervention before the onset of service interruption.

The Fire Prevention Focus Team recommends that all important telecommunications equipment be protected with smoke detection systems employing one of these new technologies. The group also recommends changes in the design of detection systems to compensate for the challenging air flow conditions present in modern facilities.

Discussion

The survey also showed that several of the companies are in the process of upgrading their fire detection systems. The Study Team contacted those companies to determine the reasons for upgrading their systems. The team also contacted noted international experts in the field of fire detection to determine the current state of the art, and to gain additional insight into the unique problems of fire detection in telecommunications facilities.

The initial research which led to the selection of the point-type ionization detector strategy was conducted some 20 years ago, and was based in large part on protecting high-bay (11'6" frames) analog equipment. The fundamental basis for that research included:

- the size of fire which was considered to be "tolerable" in such equipment,
- the number of customers served by typical equipment installations,
- the predominate method of gravity cooling of the equipment, supplemented with room air conditioning, and
- the materials (including a considerable quantity of cellulosic materials) which were used in the construction of the equipment, which would be the fuel for a fire in the equipment.

All of these fundamental bases have all changed: Modern telecommunications facilities are significantly different from the facilities present when the early smoke detector research was conducted: The equipment is manufactured with different materials, which have very different burning characteristics and burning rates. The compactness of the equipment generates considerably more heat per cubic foot, which requires a great deal of forced cooling, by both internal cooling fans, and by very robust room air conditioning systems. Coincidentally, the compactness of the equipment concentrates more service in ever decreasing floor areas. The net effect of these changes in equipment design and installation is that a fire of a given size will cause a larger service outage today than it would have caused ten or fifteen years ago.

Recent research conducted by AT&T, Bellcore and independent researchers has shown clearly that point-type ionization detectors mounted at the ceiling, are not adequate to ensure detection of a fire

G

in a modern telecommunications equipment environment early enough to preclude a service interrupting fire.

Exhibit 19.19 shows an elevation view of a typical early 1970's central office which was the basis for this research. Exhibit 19.20 shows the path which the smoke from a typical fire in this equipment will follow.

In contrast, exhibit 19.21 shows an elevation view of a typical digital central office, with four smoke plumes which are characteristic of possible fires in this equipment. These smoke plumes are not affected by the HVAC system, which is assumed to be not operating in this figure. In a typical circuit board fire in a frame with little induced ventilation the smoke will rise a short distance and then stratify in a low level "cloud" as seen in smoke plume # 1. This stratification occurs because the fire is of very low intensity, and is not releasing a great deal of heat (the typical condition for NEBS compliant digital equipment). As the heated smoke rises, it mixes with cooler air in the room air. Once this occurs, the smoke is no longer buoyant, and it will not rise any farther unless driven by fans, or unless the fire grows in size.

As the fire grows in size, the quantity of smoke liberated increases, and the heat contained in it is greater. Smoke plume # 2 shows the next stage of smoke plume development, in which the plume has sufficient thermal buoyancy, or mechanical assistance, to rise above the equipment. As the plume reaches the cable trays, it again tends to stratify as a cloud. In this case, the same dilution cooling discussed earlier is enhanced by both the mechanical barrier presented by the trays, and by the cooling effect that the mass of metal trays and copper cables exerts. By this stage in a fire, more than one circuit pack is involved, and service interruption will have probably occurred.

As the fire continues to grow, a plume similar to that shown in smoke plume #3 extends to the ceiling of the room, where most current detection systems are located. In a similar fashion a fire in an elevated cable tray will have a smoke plume such as that shown in smoke plume #4. Since this fire source is closer to the ceiling, the plume will reach the ceiling mounted detectors much sooner than a lower level fire, despite the effect of dilution cooling.

Exhibit 19.22 shows the probable effect of room HVAC systems on the same four smoke plumes. Note that the dilution and cooling effect are both greatly enhanced. The smoke plumes quickly become so diluted that they disappear and the smoke is soon nearly evenly distributed throughout the room. In this case, a very large quantity of smoke is necessary to raise the room concentrations enough to activate a standard ionization detector at the ceiling.

This discussion has so far focused on the thermal effects which a fire can cause (i.e. damage from direct contact with flame or excessive heat). Over the last fire to eight years, the impact of non-thermal effects has been highlighted by a number of fires in the telecommunications industry and in other high technology industries. Non-thermal effects are those types of damage caused by corrosive and/or conductive gases, chemicals, or particulates which are typically released during the combustion process as smoke.

These fire events and related research have shown that non-thermal damages caused by a fire in or near electronic equipment often can account for as much as 95% of the total fire damage. Because these non-thermal affects are caused by agents borne in the smoke, the damages which they cause will occur wherever the smoke spreads. In several cases, these damages have spread throughout the building.

Given the long time periods necessary to replace major equipment systems, it is clear that improvements in fire detection technologies and/or strategies (methods to install the technologies) are necessary. The research indicated that newer fire detection strategies and/or technologies can achieve the early detection necessary to permit intervention prior to the onset of serious service interruption. Current fire detection technology offers the telecommunications industry system designs which can detect a fire before it reaches the service-affecting stage, despite the high air flows which dilute the smoke and can often prevent it from ever reaching ceiling mounted point-type detectors.

Engineering Approach to Smoke Detection Design

The science of fire protection engineering is sufficiently advanced that a true engineering approach can be used for smoke detection design and installation. Such an approach requires careful consideration of the key issues which are fundamental to the process. The most critical of these is the determination of the critical size of a fire in the space to be protected. Once this is known, it is a relatively straightforward process to design a detection system which will detect a

G

fireearly enough to permit response and corrective action before the fire grows to this size.

Exhibit 19.23 gives a schematic representation of the design process. The figure shows a typical fire growth curve, which plots fire severity (typically expressed as either temperature, heat released, or heat release rate) against time. Such plots are developed from actual fire tests, and are different for each fuel type and configuration. The practical use of this information is given in the following example, which is illustrated in the exhibit.

In a telecommunications equipment area, critical fire size has often been defined as the size of fire at which service interruptions first occur. This is sometimes determined from actual fire tests, but is more often derived from a combination of expert judgment and the results of fire tests not designed to measure this directly. Once the critical fire size has been determined, the critical time can be determined from a fire growth curve(s) for the equipment in the space.

After determining the critical time, t_c, subtract the smoke travel time, t_t ,(the time required for the smoke to travel from the fire source to the detector), the detector operating time, t_o, (the time required for the detector to operate once the smoke is present in sufficient quantities inside of the detector), the personnel response time, t_p, and an appropriate safety factor, t_s, to arrive at the time of required detection, t_r. From the required time of detector activation, the maximum permissible fire size, S_m, can be determined. In the general case of telecommunications equipment spaces, the required detector response time can be several minutes less than critical time.

The smoke travel time is a function of the room HVAC design, the location of the fire, the fuel source, the rate of heat release, and the mode of combustion. It is generally expressed as a range of time, since the variables of fire location and air currents in the room cannot be absolutely fixed. The detector operating time can be directly measured. The personnel response time includes time for the facility staff to recognize that an alarm has sounded, time to determine what their reaction should be, time to take the actions required by the preplan (i.e. call the fire department), time to travel to the room where the alarm is activated, and time to take appropriate extinguishing actions. The safety factor is included principally to factor in the variances in personnel response, which can be expressed as a range of time.

Given the research findings described above, the calculation procedure outlined, the Fire prevention Focus Team makes the following recommendations:

Recommendations

All critical and important telecommunications facilities should be provided with modern smoke detection systems. These systems should be designed for the conditions present in the space, and must specifically consider the air flow patterns present, the potential for stratification of the smoke, the criticality of the equipment and the service which it provides.

<u>For telecommunications equipment areas,</u> **the team recommends the use of the following fire detection technologies, either alone or in some combination, based on the using company's risk management protocol: Air sampling detection systems; programmable, adjustable sensitivity detection systems having a early alert sensitivity of .2 percent per foot obstruction; and corrosive gas (hydrogen chloride, HCl) detectors.**

The team further recommends that smoke detection systems be designed to monitor the environmental conditions at more than one level in telecommunications equipment areas.

All telecommunications facilities containing critical and important equipment and/or services should be protected by an automatic smoke detection system throughout the entire facility. <u>For non-equipment areas in telecommunications facilities</u>, conventional point-type ionization or photoelectir detectors, or air sampling type detection systems are recommended.

<u>9.0 FIRE ALARMS</u>

Introduction

Preplanning, fire detection systems, employee training, and fire department familiarization are all of little use if there is inadequate transmission of a fire alarm. Past fire events have shown that the consequences of a delayed alarm transmission will lengthen the duration of a service outage, and can result in a minor fire growing into a catastrophic failure. The Fire Prevention Focus Team recommends that the fire detection and alarm systems in all important telecommunications facilities be connected directly to the local fire department, a telco alarm center or to a third party alarm monitoring service which will notify the fire department immediately upon receipt of an alarm.

Discussion

Immediate response to fire alarms by both telephone company personnel and the local fire department is essential if the detrimental effects of smoke and heat are to be minimized. The trend in the industry towards reduced staffing and/or unstaffed facilities increases the importance of immediate notification of the local fire department. Remote monitoring of fire alarm signals, and automatic notification of the local fire department, is the best method to ensure prompt response and corrective action by the appropriate agencies.

The survey showed that only 2% of all surveyed facilities, and 5% of central offices, have their fire alarm system directly connected to the local fire department. The survey also showed that fire alarm signals were remotely monitored by either a third party or by the telephone company in 49% of all telecommunications facilities. Included in this were nearly all (93%) of the central office buildings covered by the survey. These figures appear to reflect a conscious decision by many companies to provide a greater level of protection for their more important facilities than that provided for those facilities where redundancies in the network would permit re-routing of service.

Direct connection of fire alarms for important facilities to the local fire department is desirable, but most fire departments do not offer this service. In those instances, telephone company remote monitoring or independent alarm monitoring agencies can be used. Whatever monitoring method is selected, care must be taken to ensure that the operators have current information regarding who to notify, and how to notify them, when an alarm occurs.

Automatic alarm response, when combined with prearranged methods for fire department access to a facility, will assure the minimum delay in initiation of corrective actions.

Recommendations

All critical or important telecommunications facilities should have their fire detection and alarm systems arranged to automatically notify the local fire department upon discovery of a fire.

For those facilities located in remote areas, or areas where a timely response by a fire department is not possible, the alarms should be monitored remotely by the telecommunications company.

10.0 SMOKE MANAGEMENT SYSTEMS - FOR THE TELECOMMUNICATIONS INDUSTRY

Introduction

In today's environment telecommunications systems are expensive, complex, and closely grouped in frames. The smoke damage associated with the combustion products of fires in telephone Central Offices has recently been addressed[1,2,3] and, in most cases, it is more severe than the thermal damage. It is estimated that ninety-five percent of the fire damage in Telephone Central Offices is attributed to the smoke products and only five percent is caused by the thermal effect of fires. Even early detection and suppression of fires cannot eliminate the generation and transport of smoke. There are instances where smoldering fires did not activate the fire suppression system, still the smoke damage was substantial In any fire accident there is a quantity of combustion products generated before the complete suppression of the fire, which may cause short- or long-term damage to sensitive equipment. This report deals with the management of smoke and combustion products associated with fires in telecommunication facilities. It summarizes an engineering approach for the management of smoke in telecommunication facilities housing sensitive equipment. The objective of such smoke management systems is the rapid elimination of the products of combustion. Therefore, the design parameters of smoke management systems are driven by equipment vulnerability criteria and the respective smoke generation rate and transport patterns. This subject is extremely important to the industry since results of this Focus Group survey indicates that the majority of the 21,000 reported central offices do not have smoke removal systems today and are subject to the impacting corrosive smoke, should a fire occur.

The hazards associated with materials involved in fires can be defined and quantified by the heat release rate during their combustion, the rate of generation of fire products (gases, liquids and solids), and the total amount of heat and fire products generated. The rate of smoke generation is proportional to the heat release and mass loss rate of these materials and it can be linked with the flame growth and spread. The flame growth and spread can be described by empirical data, or, alternatively, by physical models based on fundamental flammability and thermal properties of materials and their geometric configurations. This fire source information is necessary input to smoke movement and transport models. Information about the heat release rates and smoke yields of materials and commodities is catalogued, and methods for obtaining these values have been reported in the SFPE handbook[4,5]. Pyrolysis and combustion models that simulate fire spread and growth have also been developed[6,7,8,9]. They may be used in combination with computer models that predict the smoke movement (e.g., models for smoke detection and models predicting the descent of smoke from the ceiling to the floor, or the transport of smoke to adjacent spaces).

Smoke Movement and Distribution

The design of effective smoke management and control systems is addressed through the analysis of basic concepts of smoke movement and smoke layer growth within the compartment of the fire origin and smoke distribution mechanisms in spaces connected to it. Important elements of this analysis include: smoke rise criteria based on linear smoke temperature stratification[10]; smoke ceiling jet development and movement[11, 12, 13]; development of an upper hot layer of smoke in the room where the fire starts[14]; smoke migration to adjacent spaces based on transport mechanisms. Driving forces, including stack effects, buoyancy and expansion of combustion gases, wind effects, elevator movement, and interaction with forced ventilation systems[15].

This approach is necessary for the evaluation of the smoke detection time if temperature stratification and interactions with forced ventilation systems allow for such detection[16]. It is also necessary for the quantification of smoke concentrations in the rooms filled with smoke, as a function of time. The fire source is responsible for the formation of dynamic layers (zones) of smoke within the room of origin and the connecting spaces. The dimensions and smoke concentration of the zone increase with time as a function of the intensity of the smoke source, the geometry of the room including such elements as room openings, vents, type of ventilation, and thermal losses.

Smoke Deposition

The space filled with smoke is the theater of the dynamic interaction of the combustion elements among each other and with the surfaces contained in this volume or bounding it. The size of the smoke particles is dynamically modified by the coagulation and aging phenomena involved. Settling and deposition mechanisms of particles by agglomeration, gravitational or aerodynamic forces, and diffusion processes describe the rate of deposition on the surfaces exposed to the combustion products[17]. The cumulative quantity of the collected smoke, as a function of time and source intensity, is used to assess the damage inflicted on sensitive equipment.

Damage Criteria

The deposition of corrosive substances on surfaces of electronic components creates the potential for damage. Quantification of this hazardous condition requires information about the type and quantity of smoke products, equipment vulnerability criteria, exposure time to contaminants, ambient temperature, and relative humidity.

Exhibit 19.24 includes a comprehensive set of criteria and conditions of smoke concentrations causing damage to sensitive surfaces and equipment[18, 19]. It is worth noting that the sensitivity of electronic devices becomes substantial at the level of 16 $\mu g/cm^2$ of smoke chloride deposition. This level corresponds to approximately 30 years of cumulative indoor depositions of outdoor generated ionic species for average locations in the United States, or 10 years for the worst case location[20]. Analytical expressions for the prediction of smoke damage probability as a function of concentration, humidity, and temperature are given in appendix 1.

Smoke Management Systems

The goal of any smoke management solution in a telecommunications facility is the mitigation of possible service interruption consequences by reducing smoke damage to acceptable levels. The following steps are required to evaluate the potential damage caused by a fire, and to establish quantitative criteria and objectives for any engineered solution averting smoke damage:

- Determination of detection time.

G

- Determination of smoke control system activation.
- Determination of the distribution of smoke spatial concentration.
- Calculation of deposition rate of smoke products on vulnerable surfaces.
- Calculation of total deposition of smoke products from fire initiation until final smoke control.

Currently available tools and methods provide the vehicle for the computation of these five parameters. The next step is the selection of the most appropriate and feasible smoke management strategy that i) minimizes the total smoke deposition (parameter 5) and ii) reflects the realistic conditions of the facility. Such conditions include considerations for the design for a totally new installation, or upgrade of the facility along with other planned equipment retrofits, or remodeling of a facility when no other equipment or building upgrade is planned.

There are several strategies that may accomplish both requirements [15]. **The most appropriate considerations for telecommunications facilities are i) compartmentation, ii) early and reliable detection of smoke from flaming and non flaming fires, iii) automatic and reliable activation of smoke removal systems at the early stages of the fire (small flame size). iv) measures limiting migration of smoke into connecting spaces in combination with passive smoke barriers, opposing airflow, and pressurization of surrounding space.**

Recommendations

The most attractive smoke strategy for existing facilities that are not scheduled for any other retrofit is the early smoke detection with automatic activation of smoke exhaust system. For early stage fires that do not exceed 100 kW and a distance of the fire source to the upper hot gas layer of 15 ft., (i.e., the fire is on the floor) the exhaust air flow requirements are in the range of 6700 cfm: for elevated fire sources, e.g. cable trays of the same size (100 kW) separated from the hot gas interface by a distance of 5 ft, the exhaust air flow requirements are limited to 1300 cfm. These exhaust air flows can be materialized by reverse flow actuation of existing ventilation systems with the addition of an appropriate control system.

For systems that will undergo planned equipment changes, compartmentation combined with early detection and automatic exhaust system actuation may be a desirable and feasible smoke control strategy. The addition of displacement ventilation, i.e., introduction of low velocity air flow directed from the floor of the compartment toward the ceiling will facilitate the early detection and will constrain the smoke layer at the upper zone of the space. If dispacement ventilation is not possible, bi-level smoke detection systems are recommended.

For new facilities (new designs), in particular multistory, multi-occupant buildings, compartmentation (passive or active) and automatic pressurization of adjacent spaces connected with the room of the fire origin would be a recommended strategy. Displacement ventilation with very early detection systems should also be part of new designs.

It is very important for any strategy and any facility, that the engineered solution to be reliable. Formal qualitative (e.g., Failure Modes and Effect Analysis, FMEA) and quantitative methods (e.g., Fault Tree Analysis, Reliability Block Diagrams) are available and should be employed by qualified personnel for the selection and operation of the appropriate equipment. Inspection and maintenance policies should also be based on formal reliability principles.

References

- 1. Reagor, B., "Smoke Corrosivity: Generation, Impact, Detection and Protection Colloquium on Smoke Corrosivity, (The Journal of Fire Sciences, Baltimore, MD, November 7-8, 1991)
- 2. Nowlen, S. P., "A Review of Research at Sandia national Laboratories Associated with the Problem of Smoke Corrositvity" (Fire Safety Journal 15, 1989 pp. 403-413)
- 3 Karydas, D. M., "A Probabilistic Methodology for The Fire-Smoke Hazard Analysis of Electomic Equipment" (Interflam 93, University of Oxford, U.K., April 1, 1993)
- 4. Babrauskas, V., "Burning Rates" (The SFPE Handbook of Fire Protection Engineering,

G

National Fire Protection Association, Section 2-1, Quincy Massachusetts, 1988)

- 5. Tewarson, A., "Generation of Heat and Chemical Compounds in Fires", (The SFPE Handbook of Fire Protection Engineering, National Fire Protection Association, Section 1-13, Quincy, Massachusetts, 1988)

- 6. Fernandez-Pello, A. C. and Hirano, T., (Comb. Scie., Tech. 32, 1, 1983)

- 7. Quintiere, J.G., "The Application of Flame Spread Theory to Predict Material Performance",(Journal of Research of the National Bureau of Standards, vol 93, No1, January-February 1988)

- 8. Chen, Y., Motevalli V., Delichatsios, M. A., "Development of an Integral Model for Prediction of Flame Spread on Horizontal Surfaces", Joint Meeting of the Eastern and Central States Comb. Inst., New Orleans, March 1993)

- 9. Quintiere, J.G., "A Simulation Model for Fire Growth on Materials Subject to a Room-Corner Test" (Fire Retardant Chemicals Association, Spring Conference, March 29-April 1, 1992, Orlando Fl.)

- 10. Morton, B. R., G. Taylor, J. S. Turner, "Tirbi;emt gravotatopma; cpmvectopm frp, ,aomtaomed amd omstatamepis spirces." (Proc. Royal Society A(234): 1-23, 1956)

- 11. Thomas, P. H., "The Distribution of Temperature and Velocity Due to Fire Beneath Ceilings, " (Fire Research Station, Boreham Wood, Herts F.R., Note 141, 1955

- 12. Alpert, R. L., "Fire Induced Turbulent Ceiling Jet," (Factory Mutual Research Corporation, Norwood, Massachusetts, Report 19722-2, 1971)

- 13. Heskestad, G., Delichatsios, M.A., "The Initial Convective Flow in Fire," (Seventeenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, p. 1113, 1979)

- 14. Friedman, R. " Survey of Computer Models for Fire and Smoke" (second edition, Factory Mutual Research Corporation, Norwood, MA, December 1991)

- 15. Klote, J.H., Milke, J. A., "Design of Smoke Management Systems" (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlant GA, 1992

- 16. Kushler, B.D., Parks, L. L., Simpson, J., "Smoke Detector Behavior Under Low Energy Fire Conditions" (Bellcore ?????? August 1992)

- 17. Gelbard F., "Multicomponent Aerosol Code, MAEROS 2" (Sandia National Laboratories, Containment Modeling Division, 6429, Albuquerque, New Mexico, 1989)

- 18. Reagor, B., Bell Communicatins Research, Inc. "Impact of Smoke Corrosivity on Post Fire Restoration Rates in Telephone Offices" (personnal notes from a seminar presentation at Factory Mutual Research Corportation, July 12, 1988)

- 19. Greenough, K.F., Restoration Technologies Inc., (private correspondence, June 14, 1988)

- 20. Sinclair, J. D.,"Corrosion of Electronics: The Role of Ionic Substances" (Journal of The Electorchemical Society, vol 135, No 3, pp.89c-95c, March 1988)

Appendix

Vulnerabilities of electrical and electronic devices exposed to products generated during the combustion of composite materials have been examined experimentally and analytically[20]. Based on this work the exponential law of failure probability has been found to describe satisfactorily and rather conservatively the likelihood of the exposure damage. The analytical formulation of this law applied for the surface accumulation criteria of exhibit 19.24 is given by the following equation:

$$P = 1 - e^{-[(c - 3)/c_o)]}$$

where, c = the concentration of contaminants, in µg/cm²

c_o = the average concentration of contaminants causing damage, i.e., 16 µg/cm²

A more appropriate analytical expression for the exposure damage, as a function of the exposure time, and other conditions, such as the ambient relative humidity and the reaction rates of the contaminants with the affected surfaces is the

G

following probit equation, currently under investigation[20].

$$Pr = a + b_1 \ln c + b_2 \ln t$$

where, c = the surface concentration of contaminants, in $\mu g/cm^2$

t = the exposure time of vulnerable surfaces to contaminants causing damage, in s

a, bl, b2 = parameters describing factors, such as R.H., and corrosion rates

Pr = Probit value, which after a statistical transformation defines the damage likelihood

11.0 ARC DETECTION/DE-POWERING STRATEGY

Introduction

Occurrence of arcing faults in low voltage electrical power distribution is a well-known phenomenon (1). According to the survey conducted by the Fire Prevention Focus Team of the Network Reliability Council (NRC), eleven fires, of which three were service-affecting, occurred over the past five years. The experience in the telecommunications industry indicates that when a fire involves electrical insulation corrosive smoke can be produced. This smoke can lead to damage to the telecommunications equipment and subsequent loss of service. The recovery from such an event can be difficult. Therefore, reduction in the risk of fire ignition from electrical faults is an important element in improving the reliability of the telecommunications network.

The existing overcurrent protection device (fuses and circuit breakers) were not intended to protect against arcing faults. Therefore, an important part of the effort to reduce the risk of electrical fire ignition is the development of capability to detect and possibly de-energize arcing faults. This subsection will describe the challenges facing the implementation of this technology in existing and future DC power distribution systems. Finally, this subsection will speculate on novel fire-prevention approaches that might take full advantage of this technology.

This subsection will describe the properties of arcing faults and overcurrent protection devices. It will explain the need for arc detection in DC power distribution systems. It will describe the challenges facing the development of the arc detection capability. Then it will review the status of the effort to develop this technology. The subsection will describe the challenges facing the implementation of this technology in existing and future DC power distribution systems. Finally, this subsection will speculate on novel fire prevention approaches that might take full advantage of this technology.

Properties of Arcing Faults and Overcurrent Protection

A The Nature of Faults

A fault is an unintended electrical contact between two conducting objects at different potentials. To prevent faults, energized conductors are insulated (for example, power wire and cable) or firmly fixed in place(for example, busbar) or often both. Two of the ways that a fault can occur are the following:

- The insulation of a power wire is damaged severely enough to expose the metal conductor, which comes in contact with an uninsulated conducting object (for example, cable rack) at a different potential.

- Uninsulated conductors at different potentials are bridged by a metal object.

If the fault conductors form solid, prolonged, low-resistance contact, then the fault is a *bolted* (conductive) fault. If hot plasma forms between the fault conductors, then it is an *arcing* fault. The conduction of fault current through this plasma, rather than through a direct contact between the conductors as in *bolted* fault, gives the arcing fault its physical properties.

Appendix I contains a detailed discussion of the physical properties of arcing faults. The salient features of the arcing faults are the following:

- The probability of sustaining an arcing fault depends on the system voltage

- Arcing faults can occur in 48 volt DC systems.

- In AC systems, arcing faults are more likely in 480/277-volt AC systems than in 208/120-volt AC systems

G

- Arcing faults can reduce the rms value of the fault current by 50 - 60 percent in both 48-volt DC and 480/277 - volt AC systems as compared to bolted faults.

- Arcing faults can either self-extinguish or they can form a self-sustaining cycle in which the surrounding materials ignite, cause more arcing faults and ignite again.

- Arcing faults can ignite surrounding materials quickly.

In addition, an important parameter of the fault is the impedance of the circuit carrying the fault current. For a bolted fault, the fault current depends on the source voltage and the impedance of this fault-current path. For arcing faults, the fault current is reduced by 50-60 percent from its bolted fault value.

B Overcurrent Protection

Overcurrent protection devices (fuses and circuit breakers) protect the distribution system against bolted faults to return paths of sufficiently low resistance. The fuses operate when the fault current heats the thermal element beyond its melting point. The thermal circuit breakers have a bi-metallic strip that opens the circuit. The heat generated by these thermal elements is proportional to the duration of the fault and the square of the fault current value (i^2t).

Because arcing faults generate a low fault current and last a short time, they usually do not generate sufficient heat in these thermal elements to operate overcurrent protection devices. Even overcurrent protection devices that do not operate by a thermal mechanism, often utilize a built-in time-delay to avoid nuisance tripping from transients, inrush currents, etc. The probability that an overcurrent protection device will operate on an arcing fault depends on its time-current characteristics. In general, although not intended for this purpose, faster-acting or lower ampacity-rated devices have a better chance of operating on an arcing fault.

The Need for Arc Detection in DC Power Distribution

There is a need for arc detection capability because existing overcurrent protection devices (fuses and circuit breakers) were not intended to protect against arcing faults. However arcing faults are rare. Thus, although it is desirable to employ arc detection in all telecommunications power circuits, the need is most urgent in the DC power distribution system. The reasons are the following.

- DC power distribution systems tend to employ large ampacity fuses for overcurrent protection. These fuses have a smaller chance of operating on arcing faults.

- Arcing faults can cause fire ignition of surrounding materials. In the telecommunications environment, a serious threat to service arises from fire ignition of polymeric materials and subsequent corrosive smoke. DC power distribution wire and cable often resides in racks filled with wire and cable with polymeric insulation.

- Removal and installation activity in cable racks filled with DC power wire and cable can damage their insulation and increase the probability of arcing faults.

Exhibit 19.25 shows a typical DC power system. The purpose of the DC distribution system is to provide energy to the telecommunications equipment with minimal power losses, regardless of the state of commercial AC power. The typical power architecture is described below.

Incoming commercial AC power supplies the rectifiers. The rectifiers provide the power for the telecommunications equipment and maintain the charge (float) of the batteries. The batteries and the back-up engine provide the energy in case of interruption of commercial AC power. The DC power distribution system transmits the energy from the rectifiers or batteries to the telecommunications load equipment. The distribution system can be divided into the primary and secondary distribution.

The primary distribution system contains the overcurrent protection devices and the wire and cable to connect the output voltage from the batteries and rectifiers to the secondary distribution system. The overcurrent protection devices provide the fault and isolation protection when a short or overload condition occurs on the wire or cable between the primary and secondary distribution systems. The secondary distribution system contains the overcurrent protection devices (fuses and circuit breakers) and the wire and cable to connect the output voltage from the rectifiers and the primary distribution system to the telecommunications load equipment. The overcurrent protection devices in the secondary

G

distribution system are intended to protect the wire and cable from faults in the secondary distribution system. Equipment faults are normally protected by overcurrent protection devices within the telecommunications load equipment or the frames that contain the telecommunications load equipment.

Because the primary distribution delivers energy to multiple secondary distribution systems (see exhibit 19.25) the primary distribution often uses larger ampacity wire protected by larger ampacity rated overcurrent protection devices. Also, cable mining and removal activity is more difficult in cable racks with large ampacity cables. Thus there is greater immediate need for use of arc detection in the primary DC distribution.

The Arc Detection Concept

Because existing overcurrent protection devices do not provide reasonable protection against arcing faults, an arc detector is needed. The need is especially urgent for the primary DC distribution system.

The basic concept is to detect arcing faults using some properties of their current. Exhibit 19.26 shows a simplified DC power distribution circuit that illustrates this concept. The arc detector monitors the current flowing from the power source. The arc detector ignores the normal (non-arcing) load current. If an arcing fault occurs, the fault current adds to the load current. The arc detector recognizes the fault current as coming from an arcing fault and outputs an alarm.

In order for the arc detector to be useful in reducing the probability of electrical ignition it must possess the following properties:

- Nearly total detection efficiency

- Because each arcing fault has the possibility to seriously affect service, every one should be detected.

- Avoidance of false alarms

  False indications of arcing can lead to unnecessary power shutdowns or unneeded troubleshooting efforts by the personnel.

- Fault location

  The detector should indicate the wire or cable involved in the arcing fault so that appropriate action can be taken. Since action may need to be taken with respect to the arcing cable, a mere indication that an arcing fault is taking place within a telecommunications facility is not usually sufficient.

- Constant availability

  Arcing events are rare. According to the survey by the NRC Fire Prevention Focus Group, there were 11 fires caused by arcing faults in the past five years. The actual number of arcing faults is probable higher, since many arcs self-extinguish and do not cause fire ignition. Nevertheless, this is an indication of the need for constant availability of detection.

Uses for Arc Detection

The previous discussion has demonstrated the need for the ability to detect arcing faults in DC power distribution systems. The following discussion will focus on how such capability might be used if it was available. The two areas to consider are the strategy for deploying arc detection into the telecommunications network and the utilization of information provided by arc detection devices. The deployment and the utilization strategy of arc detection technology would depend upon the cost-benefits analysis of its application.

There are various strategies for deploying the arc detection capability. Some possible ways are the following:

- In high priority offices

  One strategy would be to deploy arc detectors in high priority telecommunications facilities.

- During cable mining, removal or installation operations

  Many arcing faults in DC power distribution systems are probably caused by cable mining and removal operations. Wire insulation can be damaged during cable work leading to arcing faults. It may be prudent to employ arc detection during such work.

- In possible problem offices

  Another strategy is to concentrate on problem offices, for example, offices that have a history of cable mining or have cables with vintage insulation.

G

- In all installations

  The last strategy mentioned here is to deploy arc detection in all telecommunications facilities.

Besides different ways of deploying arc detection capability, there are different ways to utilize the information provided by arc detection devices. One possibility is to identify problem cables and then react manually. The other is to install automatic disconnect devices to automatically de-energize problem cables upon receiving the arc detection alarm.

A Manual Response

Manual reaction is feasible because not all arcing faults cause immediate ignition and fire. Some self-extinguish without causing ignition. However, they may reoccur later and cause ignition eventually. The numerical ratio of faults that cause ignition to those that don't is unknown.

The basic idea behind this strategy, is that the detection of an arcing fault indicates a possible problem with a particular cable. Personnel can take appropriate action such as inspection of the wire, repair of the wire or removal of the wire from service at an advantageous time. The advantages of manual reaction strategy are the following:

- inadvertent loss of DC power and the accompanying loss of service is minimized.

- problems may be repaired without loss of service and

- personnel decide about the need and timing of removing power.

The principle disadvantage of this strategy is that, if an arcing fault causes ignition and fire, it is unlikely that telco personnel can react in time to prevent ignition. However, the early warning provided by an arc detection alarm may help to significantly reduce fire damage.

The manual reaction strategy is probably most appropriate in the early stage of deployment of the arc detection capability. The accuracy of arc detection alarms will not be known when the arc detection capability is first deployed. The manual reaction strategy will help to insure against inadvertent loss of service until the reliability and accuracy of arc detection is proven by widespread deployment. The manual response strategy is also useful when used during cable mining or removal operations. In these cases, the personnel are already on the scene and can respond to an arcing fault alarm.

B Automatic Response

An automatic response strategy involves combining arc detection with automatic disconnect devices. An arc detection alarm would operate a disconnect device that would automatically de-power the arcing cable. Successful implementation of this strategy requires the availability of reliable and accurate arc detection devices and reliable disconnect means.

The main advantages of the automatic disconnect strategy are that the fire ignition from arcing faults can be prevented. The disadvantages are the following:

- inadvertent loss of service may occur if there are false alarms from the arc detector,

- power may be removed from an arcing cable when the arcing fault did not cause fire ignition, and

- additional reliability concerns exist with the introduction of automatic disconnect devices (single-point failure mechanisms) into the DC power distribution system. They are the following:

  - disconnect devices may fail in an open state disrupting service or

  - disconnect devices may fail to open when needed

  These concerns can be alleviated by:

- obtaining sufficient experience and gaining confidence in the arc detection technology,

- developing sufficiently reliable disconnect devices, and

- increasing use of redundant power architectures that permit de-powering of a particular feeder without losing service.

The automatic response strategy might be most applicable to new telecommunications equipment installation where all of the above items are available. Development of means to automatically operate installed overcurrent protection devices may also be feasible, but is very difficult. Later

G

discussion will focus on possible future applications of arc detection and automatic disconnect technology.

Status

Recent advances in electronics have made possible the effort to develop arc detection technology. Presently, the Fire Prevention Focus Team is aware of at least two efforts to develop arc detection for low voltage power distribution. Hendry Telephone Products, and Bell Communications Research, Inc, (Bellcore) have independently shown the feasibility of arc detection. Both companies are currently field-testing prototype arc detectors. Both companies still face challenges in developing an implementation that meets all of the criteria outlines in Subsection 4.

Future Possibilities

This discussion will speculate about the future possibilities of using arc detection and other emerging technologies to reduce the possibility of service loss from fires caused by arcing faults. In the future, some or all of the following may be available:

- Arc detection capability,
- Reliable disconnect devices,
- Improved fire or smoke sensors,
- Sensors for corrosive gases,
- Sophisticated microprocessor-controller algorithms for power plants, and
- Redundant power system architectures.

The combination of these emerging technologies and architectures may make possible robust automatic fire or smoke prevention systems that would be able to take action to prevent fire ignition and smoke contamination without disrupting service. The following speculative discussion will look at some of the possible developments in more detail.

One avenue is the wider use of robust DC power distribution architectures. These architectures could allow individuals cables to be de-energized without loss of service. This could be done, for example, by using parallel (A/B) feeders with individual overcurrent and disconnect devices.

Another possibility is utilizing smaller-capacity power plants closer to the loads. This would reduce the need for extensive DC power distribution systems. Also, this would reduce the available fault current easing the requirements on the disconnect devices. In addition, the feeders would serve smaller sections of the load, so that, de-energizing an individual feeder would affect a smaller portion of the telecommunications capability.

Another avenue is the development of reliable DC power disconnect devices. Such devices must have the high reliability needed for telecommunications power systems. They must be able to interrupt safely the high fault currents that would occur in DC power distribution systems. These devices might be best employed in redundant power architectures, that would enable de-powering of individual feeders without loss of service.

Another area is the development of algorithms for microprocessor-controllers that would attempt to prevent fire ignition and smoke contamination. These algorithms would receive inputs from various sensors, including arc detectors, smoke and fire detectors, corrosive gas detectors, fuse and power alarms, environmental sensors, etc. and make decisions regarding the state of the power system. The microprocessor-controller could take into consideration the relative priority of loads. The microprocessor-controller would make decisions about operating the disconnects, controlling fans, etc. and the most opportune time to do this. In addition to fire-prevention, such systems could assist in other tasks relating to power systems management.

Summary

Arcing faults have occurred in telecommunications DC power distribution systems. The corrosive smoke and fire resulting from these faults have caused severe service outages. The physical properties of arcing faults is such, that the arcing faults produce low fault current and last a short time, yet can ignite the surrounding materials quickly. Therefore overcurrent protection devices are not likely to protect against arcing faults. To reduce the probability of electrical fire ignition and the accompanying service loss, an arc detection capability is needed.

Presently, the Fire Prevention Focus Team is aware that at least two companies have shown the feasibility of arc detection and are field-testing experimental-prototype arc detectors. In the near term, arc detection capability could be used to identify problem cables for manual intervention. As technology matures and redundant power architectures are employed, automatic de-powering may become feasible. Future development of arc detection, automatic disconnects, power architectures, and microprocessor-control technologies should enable the creation of robust fire and smoke prevention systems.

Appendix 1

This appendix will discuss the physical properties of arcing faults in more detail. The physical properties of arcing faults arise from the conduction of the fault current by the plasma that develops between the fault conductors.

Arc Voltage

There are two distinct types of voltage pertinent to an arc. One is the voltage across the arc while it is conducting unidirectional current, the other is the voltage needed to restart the arc across a gap after it extinguishes. The former is usually called the *arc voltage*, the latter is called the *re-strike* voltage.

The arc voltage supplies the electric field needed to maintain the plasma. The arc voltage usually consists of three components: the voltage drop between the positive conductor and the plasma, the voltage drop across the plasma and the voltage drop between the plasma and the negative conductor. Thus, the arc voltage is typically given by the formula $V_{arc} = A + Bl$, where A and B are parameters that depend on arc current, and l is the arc length (separation between conductors) [2]. For typical fault current values, A is about 20 volts and B was measured at between 20 and 50 volts/inch [3]. This implies that usually a minimum of 20 volts is needed to maintain the arc. Larger voltage is needed to maintain arcs of greater length.

The re-strike voltage is the voltage needed to start the arc when there is an air gap between the electrodes. The re-strike voltage probably has the same form of length dependence as the arc voltage but is an order of magnitude larger. Usually, about a minimum of 375 volts is needed to re-strike the arc. Greater voltage is needed to re-strike across longer separations. The re-strike voltage can become considerably lower if the gap between the conductors is filled with ionized gas.

Arc Initiation

Since considerable voltage is required to start an arc across an air gap, how can an arc begin? There are several ways. One is if the voltage across the conductors exceeds the threshold level needed to breakdown (ionize) the air gap. Once the gap is ionized and the plasma is created, the arc can continue as long as the source voltage exceeds the arc voltage. Another way is if the conductors first touch together at a narrow spot (point contact). The current that flows through this narrow contact point can heat the contact and vaporize the contact creating the arc plasma. Also, an arc can develop if a conductive path (for example, carbonized insulation) develops between the fault conductors. The current can flow through this path, heat the path and vaporize it creating the arc plasma.

Arc Duration

The arc plasma is supplied by the evaporation of the fault conductors, which cause an increase in the separation between the conductors and an increase in the arc voltage. This tends to extinguish the arc quickly, especially in 48-volt DC systems. However, the arc can restart later, either because the conductors move, or because a conductive path is created in the wire insulation. If a series of arcs happen rapidly in succession, a sustained arc is occurring. This sustained arc is probably the most damaging type in the telecommunications environment.

In AC systems, the arc extinguishes every time the current passes through a zero crossing. For the arcing fault to continue, the arc has to re-strike in each half-cycle. The higher value of the re-strike voltage explains why there is a higher probability of a sustained arcing fault in 480/277-volt AC systems than in the 208/110-volt AC systems.

Ignition

The hot plasma of the arcing fault can ignite surrounding materials quickly, often in less than one second. However, in some cases, the arc may vaporize a portion of the arcing conductors and self-extinguish without causing immediate ignition or disrupting service. However, there is the possibility that the arc can occur again in the future. In some cases, the ignition of electrical insulation creates conductive paths that lead to further arcs, creating a sequence of arcs that can produce considerable amount of smoke and ignite the insulation materials.

Arc Current

The voltage drop across the arcing fault significantly reduces the fault current as compared to a bolted fault. In a DC circuit, the current is given by the difference between source voltage and the arc voltage divided by the resistance of the fault path. Thus, the fault current in a 48-volt DC system is generally reduced by about 50 percent. In an AC system the mechanism responsible for fault current reduction is more complicated. During every cycle the fault current extinguishes at zero crossing and then re-ignites when the voltage reaches the arc re-strike value. Thus the current rms value can be reduced by as much as 60 percent.

References

- 1. J. R. Dunki-Jacobs, The Effects of Arcing Ground Faults on Low-Voltage System Design, IEEE Transaction on Industry Application (Vol. 1A-3 May/June 1972)
- 2. Undin. Welding Engineering
- 3. A. P. Strom, Long 60-Cycle Arcs in Air, AIEE Transaction (Vol. 65, March 1946)

12.0 SUPPRESSION SYSTEMS STATUS

Introduction

The telecommunications industry today is divided in its view of the effectiveness of various forms of fire suppression for telecommunications switch-rooms, transmission areas and power rooms that house critical electronic equipment. There are a number of elements and events that must be considered involving the installation of suppression systems in telecommunication equipment areas.

These elements or events are

- Halon 1301 will no longer be manufactured after January 1, 1994.
- There are at least five substitute products for Halon 1301. these substitutes for Halon 1301 generally solve ozone depletion problems but create an environmental global warming problem that is of concern. There are also other factors to be evaluated concerning the safe use of these substitutes.
- When water is used as a suppression agent in telecommunications areas with powered electronic equipment, corrosive damage to equipment and the resulting service outage can be as extensive as that of a fire and/or corrosive smoke.
- Water suppression systems do not activate until the temperature at the detection head reaches a minimum of 160°F. According to research by Factory Mutual Research Company, damage from corrosive smoke and heat would be extensive by the time of the suppressant discharge at 160°F.
- Research is currently underway in GTE on a canisterized water mist system that may be attractive to the industry, providing power to equipment can be removed prior to activation.

This technical paper will provide detailed information about the above conclusions.

The typical telephone exchange facility today is unattended and has an ionization fire detection system that reports to a remote monitoring station. In the event of a fire the detection of the fire may not be discovered until sufficient smoke has been generated and air currents transport the smoke to the detector. The fire detector activates, sounding the local alarm, and transmits a signal to the remote monitoring station. If the telephone exchange facility is attended, the local fire department will be requested, and employees will respond to the fire alarm and manually suppress the fire. If unattended, the local fire department will be requested to respond and employees will be dispatched to the facility to check out the fire alarm.

The Hinsdale, Illinois fire of 1988 affected more than one-half million residential and business customers and drew much attention to the need for fire prevention in the telecommunications industry. The Illinois Commerce Commission and many metropolitan building codes are, and will be in the future, placing strict fire protection regulations to control fire and smoke damage and prevent or significantly reduce service outages. So, the question is "What do we do about fire protection"?

Listed below is the status of fire suppression systems currently used and those being developed for future use in the telecommunications industry.

Halon 1301

Halon 1301 was deployed in the early seventies as a fire suppression agent by several telephone companies. Halon 1301 is a chemical agent generally known for its ability to extinguish

G

electrical fires, then evaporate and minimize cleanup. However, in recent years, it has been discovered that secondary corrosion damage has occurred when Halon 1301 systems were discharged within telecommunications facilities. Large amounts of corrosive gases can be generated when hot metal surfaces are present. Upwards of 5,000 ppm of hydrogen bromide can form during a ten minute soak after dumping. Hydrogen fluoride, hydrogen bromide and hydrogen chloride gases in varying amounts are generated during Halon 1301 decomposition. All these gases will corrode telecommunication equipment. Exposures of 5000 ppm of hydrogen bromide to telecommunications equipment will cause non-recoverable equipment damage. This can lead to a large service outage.

The Montreal Protocol of Substances that Deplete the Ozone layer, in effect, wrote the death warrant for Halon 1301. Halon 1301 was cited as one of the substances adversely affecting the earth's ozone layer. The US Environmental Protection Agency's Clean Air Act of 1990 has limited the manufacture of Halon 1301 and in the recent Montreal Protocol follow-up meeting in Copenhagen, the US agreed to phase out production of Halon 1301 by January 1, 1994. Most telephone companies have already made plans to stop installing Halon 1301 and begin removing the systems over time to meet the EPA regulations.

Alternatives for Halon 1301

Halon Alternatives Research Corporation, better known as HARC, was established in 1989 to provide a focus for development of replacement extinguishing agents. HARC is made up of manufacturers such as 3M, DuPont, and ICI Americas. Their goal is to find alternative extinguishing agents that posses Halon's positive features: absence of residues, low toxicity, and electrical non-conductivity.

When considering alternative gases to replace Halon 1301, the main driver is finding a gas that has a low ozone depletion potential (ODP) and low global warming potential (GWP). But at the same time, this replacement must be a good extinguishing agent with low toxicity, without causing damage to electrical equipment. Therein lies the problem. To date, an acceptable replacement has not been discovered.

Water

While automatic fire sprinklers are more that 98% effective in controlling or extinguishing most fires, the use of water on powered telephone equipment results in the immediate creation of a continuous leakage pathway from the battery system to ground points on boards and cable runs. This can lead to the start of electrolytic corrosion. Electrolytic corrosion will continue until the power is eliminated. The continuance of electrolytic corrosion can result is non-repairable damage to circuitry. This leads to a service outage. The use of water as a fire extinguishing agent is only effective in a controlled manner, after the removable of all AC and DC power from the equipment.

Water Mist Fire Suppression Technology

Water mist as a fire suppression agent has surfaced as a potential replacement for Halon in many industrial uses. There have been two basic approaches: total flooding and local application. The total flooding approach has been basically ruled out in the telecommunications industry because of the high potential for electrolytic corrosion within the telephone switching equipment. However, research is moving forward on the local application of a water mist fire suppression technology within switch gear cabinets. It must be stressed that electrolytic corrosion danger exists with both the water mist systems and regular sprinkler systems until the power source has been removed.

GTE in conjunction with Kidde-Fenwal and Factory Mutual Engineering and Research has conducted preliminary tests using water mist to extinguish a localized fire within a telephone switch gear cabinet. The tests used water with a droplet size of 40 microns. A container holding 0.5 liter of water pressurized with GN2 to 1000 psi was discharged through a straight nozzle inside the cabinet. Conclusions: effective in extinguishing the fire within three minutes, caused localized and minimal electrolytic corrosive damage to the telephone switch equipment, and is environmentally friendly.

Is it practical? Much more research and development will be required to prove if water mist fire suppressing technology can be applied to the telecommunications industry.

The National Institute of Standards and Technology (NIST), part of the US Department of Commerce's Technology Administration, conducts basic and applied research in the physical sciences and engineering. With the imminent lack of availability of Halon fire suppressants, NIST researchers are pursuing the potential application of water mist systems. One of their projects includes the application of the water mist technology in the

G

telecommunications industry. It is still in the visionary stage at this time and there are few known applications and or pilots in place at this time. NIST is continuing to facilitate the process of commercializing the water mist technology through its conferences and workshops.

Future Planning, Strategies and Countermeasures

The NRC Focus Team on fire prevention not only assessed the current status of what fire prevention systems were being used throughout the industry, but the focus group also looked at "Best Practices" being used to prevent fire in the telecommunication industry. It is generally accepted that there are five basic components to a telecommunications industry fire safety program: compartmentalization, firestopping, detection, manual suppression and occupant responsibilities. The NRC Focus Team found these five components were inadequate and future strategies, in addition to the basic five, would require adding the following

- More control over the composition of materials used in cable, wiring and cards,
- earlier and quicker fire detection capabilities,
- quicker response by employees and local fire departments to fire alarms,
- control of smoke in the event of fire to limit spread to other areas; and
- a means to quickly remove electrical power from elements or areas of the central office.

A simple solution for a fire suppression system for the telecommunications industry is not around the corner. Halon 1301 has been discovered to create secondary corrosion when discharged into a heated environment and it harms the earth's ozone layer. Water fire sprinklers would extinguish the fire and save the building, but will start electrolytic corrosion when water is sprayed on powered telephone equipment leading to non-reversible damage.

Recommendations

Based on information provided the Focus Team concerning existing suppression systems, it can be concluded that none of the currently used or available suppression systems can acceptably answer the fire suppression and equipment and service protection needs for central office telecommunication equipment areas. The use of any suppression system should provide for a reliable solution for automatic removal of power from the affected telecommunications equipment. Automatic removal of power from telecommunications equipment is addressed in section 11.0 of this technical paper.

References

- V.J. Hession, "Summary Evaluation of Automatic Suppression of Central Office Equipment Areas" (Bellcore, November 1988)
- B. T. Reagor, "The Contamination Impacts of Fire Suppression Material" (Bellcore, September 1992)
- Factory Mutual Engineering Corp., "Protecting Telephone Central Offices" (FMRC Update, Vol. 6, No. 3, 1992)
- US Department of Commerce, "Water Mist Fire Suppression Workshop",(National Institute of Standards and Technology, 1993)
- T.O. Duyck, "Recovery from Fire in a Central Office" (Northern Telecom, May, 1992)
- J. Provost, "Fire Protection Policy" (MT&T, April, 1992)

13.0 MEASURING IIMPROVEMENTS

The Focus Team's effort to acquire the best and most accurate data available regarding fire events met the Focus Team's initial expectations. Recognizing that all telephone companies and interconnect carriers were operating under no standard plan for recording service affecting or potentially service affecting fire events prior to the time of this survey, we have indications that the data received for this analysis may be somewhat under reported. The Fire Prevention Focus Team has received approval from the Network Reliability Council (NRC) for a new industry fire reporting process. This process requires all telecommunications companies in the United States to report to the Exchange Carriers Standards Association (ECSA) any telecommunications fire event that causes a service affecting outage to 100 lines or more for 30 minutes or more. It is highly likely that service affecting fires will rise to a level of 20-30 per year once these new reporting standards are imposed upon the industry. The

G

Focus Team believes service affecting fires can be reduced by as much as 25%, once telecommunications companies read and begin implementing the recommendations made in this report. The 25% improvement goal will be related to the information received by this new reporting process.

14.0 Maintenance of this Focus Team Effort

This Focus Team strongly believes that a decline in service affecting fires impacting telecommunications facilities can be achieved with the implementation of recommendations presented in this paper. To be able to demonstrate this, and to discover other fire causes which might be eliminated with a change in use or policy, however, it is imperative that some form of mandatory reporting be implemented. The reporting process involving service affecting fires is largely voluntary at the present time, thus resulting in perhaps some level of under-reporting of fire events.

14.1 Probability vs. Potential

As one can readily see when reading this Focus Team report, the incidence of service affecting fires in the telecommunications industry is extremely small. It is also apparent, however, that a high percentage of fires, when they do occur, cause some level of service disruption. Although the probability is low, the potential is extremely high. When disruption occurs, restoral takes a great deal of both time and money. Clearly, it is in the best interest of the industry to document the problems experienced, with an eye toward correcting the problems which cause that disruption.

14.2 What Makes an Acceptable Reporting System?

In order for any reporting system to be beneficial, certain criteria need to be addressed. First, the reporting medium needs to be easy to understand and quick to fill out, ideally limited to a one page form. The report should gather information not only about the fire itself, the number of service lines affected and for how long, but also about the dynamics of the fire, the contents of the area of fire origin, the size and configuration of the building, the quality of the fire department response and, based on total fire, smoke and water damage, the value of any built-in fire alarm, detection and protection equipment. The reporting form should allow the manager to use his/her own words to describe the event, but should also provide a "generic" numbering system to "code" the answers to the questions. This coding will allow the fast entry and easy retrieval of information, which in turn will allow a quick review of the fire problems being experienced. From this data base of information, management can readily see what the problems are and, generally, what is causing those problems. Armed with this information, "conscious" management decisions for equipment and policy changes can be made quickly, while taking the most effective and economical approach.

14.3 Recommendations

While it is strongly recommended that information concerning all fires with the potential for being service affecting be documented and gathered at the local level, the base for reporting will include all fires that impact 100 service lines or more, for a period of 30 minutes or longer. To effectively measure industry improvement in this category, this Focus Team recommends the establishment of a common reporting process. It is important to capture all events that result from design problems, procedural errors (telco/vendor), natural disasters and acts of violence. These reports will be monitored and tracked by the Exchange Carriers Standards Association (ECSA), on an on-going basis. Service affecting fires, impacting 100 or more lines for 30 minutes or longer, will be reported to the ECSA within 24 hours. The ECSA will then mail a one page report form and a users manual to the person designated, by the telecommunications company, to prepare such forms. The assembly of this information will be handled under a non-disclosure agreement, which will protect the reporting company from public identification. The ECSA will analyze these reports to determine if proposed Focus Team countermeasures ultimately accomplish a 25% improvement in service affecting fires. ECSA will be responsible for tracking fire trends, and for the interface with the various Standards Making Bodies, when technical changes are recommended. Exhibit 19.27 reflects current assignments of study topics and identifies the industry group responsible for generating appropriate Standards. Should tracking reveal new problems or ineffective countermeasures, the matter will be referred to the appropriate committee or forum for further analysis or resolution. To establish the initial baseline by which improvement will be tracked, all telecommunications companies are requested to collect fire data beginning in the year 1993, based upon criteria outlined in this section and in exhibit 19.28. A Users manual for completing the form shown in exhibit 19.28 is currently available.

G

15.0 Conclusion

Service impacting fires within the telecommunications industry occur at an extremely low frequency. This is a credit to the reliability of the many types of equipment used in the industry as well as the strong commitment to safety and emergency preparedness. On those few occasions when a fire has struck a critical communications facility, the result has been devastating and has raised the question of the need to improve prevention across the entire telecommunications industry. Fires and their causes cannot be dismissed because the occurrence is rare. This industry takes pride in the fact that service quality in this country is the best in the world. However, we must learn from each tragic fire event and share specific findings and recommendations. Action must then be taken to prevent similar occurrences in the industry.

The current condition of fire protection capability within the telecommunications industry, as shown in exhibit 19.5, shows a wide range of capability across the 51,800 entities to be monitored. As each company moves to add additional fire protection capability, it is also important to stress the need for formal pre-planning effort with the local fire agency. This effort will assure familiarity with the facility and an understanding of service impact for each extinguishing action used.

The contents of this technical paper including findings, recommendations and general information resulted from specific information and "Best Practices" submitted by companies responding to the Fire Prevention Focus Team survey. The Fire Prevention Focus Team itself includes industry experts on fire prevention and their contribution to this report was very significant. Many national standards already exist which address recommendations included in this report. Additional work is required of Standards Bodies to develop requirements that will lead to safer and more fire and corrosive smoke resistant products that will be deployed within the network. The Focus Team recommends continued emphasis of standards toward the goal of fire prevention.

16.0 Acknowledgments

The Fire Prevention Focus Team is grateful to all of the contributing companies for their assistance in acquiring and assembling the data that was so essential in preparing this paper.

ALLTEL
ALTS
American Express Company
Ameritech
Anchorage Telephone Utility
AT&T
Bell Atlantic
Bell South
Bellcore
C-Tec Corporation
Cable and Wireless Communcations
Centel Corporation
Century Telephone Enterprise
Chilicothe Telephone Company
Citizen Utilties Company
Clifton Forge - Waynesboro Telephone Company
Concord Telephone Company
Conestoga Telephone and Telegraph Company
CWA
Denver and Ephrata Telephone and Telegraph
DSC Communications Corporation
Ericsson Network Systems
Exchange Carriers Standards Association
Fail Engineering Company
Farmers Telephone Coop., Inc.
Great Plains Communications
GTE
Gulf Telephone Company
Hargray Telephone Company
Horry Telephone Coop., Inc.
Illinois Consolidated Telephone Company
Independent Telecommunications Network
Lexington Telephone Company
Lincoln Telephone and Telegraph Company
Lufkin-Conroe Telephone Exchange
Mankato Citizens Telephone Company
Matonuaka Telephone Association, Inc.
McCaw Cellular, Inc.
MCI
NARUC (Tennesse Public Service Commission)
National Communications System
New York Clearing House
North Pittsburgh Telephone Company
North State Telephone Company
Northern Telecom
NYNEX
Pacific Bell
Pioneer Telephone Company
PTI Communications
Puerto Rico Communications Authority
Puerto Rico Telephone Company
Rochester Telephone Company
Rock Hill Telphone Company
Roseville Telephone
Siemens Stromberg-Carlson
SLT Communications
Southern New England Telephone Company

G

Southwestern Bell Telephone Corporation
SPRINT
Standard Telephone Company
Stentor Canadian Network Management
Telephone and Data Systems
Teleport Communications Group
Twin Lakes Telephone Coop
United Telecommunications
US West Communications
Virgin Island Telephone Corp.
Wiltel, Inc.

17.0 References The following listing represents a partial summary of technical references which address a number of fire prevention countermeasures proposed in this paper.

- Smoke-Handling Strategies Suitable for Central Office Equipment Protection (SR-NWT-001833, ISS, 1, 1990)
- Ventilation of Central Office Buildings (BR 781-810-885, ISS. 1, July 1991)
- Electrical Protection for Telecommunications Central Offices and Similar type Facilities (ANSI T1. 313-1991)
- Network Equipment-Building System (NEBS) Generic Equipment Requirements Bellcore (TR-NWT-000063, ISS. 4, July 1991)
- National Electrical Safety Code (ANSI C2-1990)
- Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Ground System (ANSI/IEEE 81-1983)
- The IEEE recommended practice for determining the electric power station ground potential rise and induced voltage from a power fault (ANSI/IEEE 367-1987)
- Gas Tube Surge Arrestors on Wire Line Telephone Circuits (ANSI/IEEE C62.61 -1985)
- National Electrical Code (ANSI/NFPA 70-1990)
- Lightning Protection Code (ANSI/NFPA 78-1989)
- Guide for Surge Voltages in Low-Voltage AC Power Circuits (ANSI/IEEE C62.41-1980)
- Standards for surge protective devices for low voltage AC power circuits (IEEE C62-62)
- Generic Requirement Surge Protective Devices (SPDS) on AC Power circuits, , Bellcore, TR-NWT-001011, issue 1, February - 1992)
- Electrical protection for telecommunications Outside Plant (ANSI T1.316-1992)
- Isolated Ground Planes: Definition and Application to Telephone Central Offices (TR-NWT-000295, ISS. 2, July 1992)

18.0 "Best Practices "Reference

- Ameritech Guideline for Method of Procedure, Installation and Removal Projects (AM 790-100-421LB)
- Pacific Bell Installation and Job Acceptance Handbook
- Pacific Bell Building Certification Practice
- New York Telephone Building Certification Practice
- New York Telephone Company, Pre/Post Conditioning Process to Prevent Electrical Ignition in Cable Racks
- Ameritech Power Zone Marking and De-Powering Plan - (AM 770 300-950, issue A, April 93)
- Rectifier Fire Risk Assessment