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Evaluating Data and Voice Signals in Pathway Survivable Cables for Life Safety Systems

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Final Report by:

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Foreword

Many life safety systems require pathway survivability. Pathway survivability is defined in NFPA 72, *National Fire Alarm and Signaling Code®* as the ability of any conductor, optic fiber, radio carrier, or other means for transmitting system information to remain operational during fire conditions. An example of a life safety system that requires pathway survivability includes emergency voice/alarm communication systems (EVACS), which are one-way systems. In buildings with partial evacuation or relocation plans, EVACS are required to have a Level 2 or Level 3 survivability pathway. Pathway survivability Level 2 requires at least one of the following four conditions: (1) 2-hour fire-rated circuit integrity (CI) or fire-resistive cable (2) 2-hour fire-rated cable system (electrical circuit protective system(s)) (3) 2-hour fire-rated enclosure or protected area (4) Performance alternatives approved by the Authority Having Jurisdiction (AHJ). Pathway survivability Level 3 requires at least one of the conditions above and be installed in a building fully protected by an automatic sprinkler system in accordance with NFPA 13, Standard for the Installation of Sprinkler Systems.

Other examples of life safety systems that require protection are in-building wired emergency services communications systems and Emergency Responder Communications Enhancement Systems (ERCES), which are two-way systems. First responders depend on two-way communication to protect people and property in emergencies. Fire department radio systems may not operate properly when signal strength inside buildings is impaired by building materials such as steel and concrete, obstructions, and by radio frequency interference. ERCES provides radio coverage in buildings to ensure the performance of public safety radio systems. ERCES functions by boosting the signal from the public safety radio repeater with a signal booster, commonly referred to as a Bi-Directional Amplifier (BDA). The signal booster receives and amplifies transmissions from radios inside to the repeater antenna outside.

There are several types of life safety systems that require pathway survivability. The overall goal of this project is to determine if temperature impacts the transmission and the functional and operational quality of alarm/data signals and voice messages in a fire rated and non-fire rated environment. If temperature does have an impact, identify the critical temperature and time at which the transmission of alarm/data signals and voice messages are no longer understandable to provide technical basis for any changes to NFPA 72 and NFPA 1225, *Standard for Emergency Services Communications*.

This project comprised of three tasks: a literature review, a research plan, and a final report. The purpose of the literature review is to document types of life safety systems requiring pathway survivability, identify incidents of cables failures for life safety systems, review the technical substantiations for pathway survivability provisions in existing codes, and review relevant technical literature on the transmission and functional and operational quality of alarm/data signals for specific conditions. To fill the knowledge gaps and identify proposed fire testing, a research plan was developed. The final report includes the research plan and summary of findings and review from the first two tasks.

The Fire Protection Research Foundation expresses gratitude to the report authors: Patrick van Hees, Joakim Åström, and Petra Anderson, who are with Lund University located in Lund, Sweden and Brian Meacham of Meacham Associates, located in Shrewsbury, MA. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsors, and all others that contributed to this research effort.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

NFPA's membership totals more than 65,000 individuals around the world.

Keywords: Cable, Emergency Responder Communication Enhancement Systems, ERCES, Emergency Services Communications Systems, Emergency Voice/Alarm Communication Systems, EVACS, Degradation, Fire, Functional Performance, Life Safety Systems, NFPA, NFPA 72, NFPA 1225, Pathway Survivability, public Safety, Radio Systems, Reliability

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Executive Summary

Many life safety systems require pathway survivability. Pathway survivability is defined in *NFPA 72, National Fire Alarm and Signaling Code®*[1], as the ability of any conductor, optic fiber, radio carrier, or other means for transmitting system information to remain operational during fire conditions. An example of a life safety system that requires pathway survivability includes emergency voice/alarm communication systems (EVACS), which are one-way systems.

Other examples of life safety systems that require protection are in-building wired emergency services communications systems and Emergency Responder Communications Enhancement Systems (ERCES), which are two-way systems. First responders depend on two-way communication to protect people and property in emergencies. *NFPA 1221, Standard for the Installation Maintenance and Use of Emergency Services Communication Systems®*¸ requires backbone cables of two-way ERCES to be routed through an enclosure that matches the building's fire rating. As part of the Emergency Response and Responder Safety Document Consolidation Project, this content is being moved to *NFPA 1225, Standard for Emergency Services Communications®*. Recently, new language was proposed as a second revision in NFPA 1225 to maintain the requirement for backbone cables in two-way ERCES in high rise structures, while recognizing that other types of building structures may not need the same level of survivability.

Although cables including but not limited to co-ax, fiber, ethernet and fire alarm signaling circuits are required to be protected from heat and physical damage, there are questions related to the impact of elevated temperature on alarm/data signals, and voice messages utilizing radio frequency (RF) transmitted across these cables and circuits and if that results in less reliable communications. A research project was therefore initiated by the Fire Protections Research Foundation

The research goal of the project was to determine if elevated temperature impacts the transmission and the functional and operational quality of alarm/data signals and voice messages in a fire rated and non-fire rated environment. If temperature does have an impact, identify the critical temperature and time at which the transmission of alarm/data signals and voice messages are no longer understandable to provide technical basis for any changes to NFPA 72 and NFPA 1225.

The project was conducted through a literature review assisted by a survey. The literature review contained items such as a study on Life Safety Systems (LSS) Requiring Pathway Survivability, a search to identify incidents of cable failures for LSS, a study of the appropriate NFPA standards, a study of the literature on transmission, functional and operational quality of signals and was concluded with a review of manufacturer literature on best practices. Supplementary to the literature review a small survey was conducted to gather data of incidents as the literature review was resulting in very limited data.

The outcome of these reviews and the survey were analyzed in order to define the knowledge gaps and the research needs. As a general observation, it is difficult to clearly follow, and understand the specific intents of the numerous NFPA provisions on critical circuits and pathway survivability. The analysis showed namely that very scarce data is available on malfunctioning of life safety systems

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during fire apart from a few cases. Consideration might be given to try to clarify and make more concise the requirements in NFPA 72 and NFPA 1225.

The core findings from the literature review are summarized as follows:

- The potential for fire-related impacts exists, but evidence of impacts in EVACS or ERCES was not found, and therefore it is unknown whether there is a serious potential problem. However, this could be investigated through testing under controlled environments and different data- and communication transmission modes and media.
- No scientific studies were found which illustrate that fire-rated enclosures or building fire sprinkler systems specifically mitigate thermal-induced data or voice signal degradation in cables. However, fire-rated enclosures and/or building fire sprinkler systems can reduce the temperature to which cables are exposed, which could be expected to help, but the extent to which is unknown.
- While no evidence was found specifically on ERCES systems and components, it seems likely that the amplifier is more at risk than the signal itself. This too can be explored through testing.
- Inspection, testing and maintenance (ITM) are important.
- As little evidence for an actual problem during the fire situation was found, the research needs are focused on obtaining data to show that problems can occur.

The final outcomes of the study have resulted in a research plan with the following research areas:

- Research Area 1. Testing series to investigate the potential for thermal effects on signal degradation
- Research Area 2. Impact from other factors such as mechanical stress and water impact on communication systems
- Research Area 3. Evaluating different test method(s) for pathway protection and suggest improvements.
- Research Area 4. Engineering models for performance-based approaches
- Research Area 5. Packaging research outcomes for standardization and dissemination

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Introduction

Background

The background of this project originates from the call for proposals.[2] Many life safety systems require pathway survivability. Pathway survivability is defined in *NFPA 72, National Fire Alarm and Signaling Code*®[3],as the ability of any conductor, optic fiber, radio carrier, or other means for transmitting system information to remain operational during fire conditions. An example of a life safety system that requires pathway survivability includes emergency voice/alarm communication systems (EVACS), which are one-way systems.

Other examples of life safety systems that require protection are in-building wired emergency services communications systems and Emergency Responder Communications Enhancement Systems (ERCES), which are two-way systems. First responders depend on two-way communication to protect people and property in emergencies. *NFPA 1221, Standard for the Installation Maintenance and Use of Emergency Services Communication Systems*, requires backbone cables of two-way ERCES to be routed through an enclosure that matches the building's fire rating. As part of the Emergency Response and Responder Safety Document Consolidation Project, this content is being moved to *NFPA 1225, Standard for Emergency Services Communications*. Recently, new language was proposed as a second revision in NFPA 1225 to maintain the requirement for backbone cables in two-way ERCES in high rise structures, while recognizing that other types of building structures may not need the same level of survivability.

Although cables including but not limited to co-ax, fiber, ethernet and fire alarm signaling circuits are required to be protected from heat and physical damage, there are questions related to the impact of elevated temperature on alarm/data signals, and voice messages utilizing radio frequency (RF) transmitted across these cables and circuits and if that results in less reliable communications.

Research Goal

The research goal[1] is to determine if elevated temperature impacts the transmission and the functional and operational quality of alarm/data signals and voice messages in a fire rated and non-fire rated environment. If temperature does have an impact, identify the critical temperature and time at which the transmission of alarm/data signals and voice messages are no longer understandable to provide technical basis for any changes to NFPA 72 and NFPA 1225.

Project Tasks

The project consists of the following tasks[2]:

Task 1: Literature Review

Task 2: Gap Analysis and Research Plan

Task 3: Final Report

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[2] Excerpted from FPRF Call for Proposals, Evaluating Data and Voice Signals in Pathway Survivable Cables for Life Safety Systems, 22 July 2021

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Approach

For the literature review, traditional search tools have been used, such as Web of Science, Google Scholar and Lund University libraries. In addition, various standards were consulted, such as from NFPA, UL, ISO and CEN.

The following keywords were used in different areas listed below in the table

AREA	KEY WORDS
FIRE ALARM SYSTEM	Pathway survivability, Cable, functional performance, Mont Blanc fire ventilation system
THERMAL DAMAGE TO CABLE	Reliability, functional criterion, heating, fire
SIGNALS	Reliability, voice, data, data corruption, degradation, fire, copper, fibre, fibre Bragg
INCIDENTS	WTC, Grenfell, New York phone exchange, Fire and Cable failure

1. Task 1: Literature Review

A summary of the outcome of the literature review conducted for this effort is provided below.

Task 1.1 Life Safety Systems (LSS) Requiring Pathway Survivability

1.1.1 Life Safety Systems (LSS)

In terms of building safety, life safety systems (LSS) are any systems that are intended to provide protection and preservation of human life during an emergency or failure of a critical building system. LSS can include passive and active fire protection systems, emergency communications systems, emergency lighting systems, and the like. In the broader sense, the following representative examples could be considered LSS:

- Building fire suppression system (built-in system in which a fire suppressant (e.g., water, foam, gas) is delivered to the area of fire origin upon activation of an initiating device).
- Egress system (system of exit access, exit, and exit discharge components).
- Emergency communication system (a system for the protection of life by indicating the existence of an emergency situation and communicating information necessary to facilitate an appropriate response and action).
- Emergency communication systems – combination (emergency communications systems such as fire alarm, mass notification, fire fighter communications, area of refuge communications, elevator communications, or others that can be served through a single control system or through an interconnection of several control systems[2]).
- Emergency lighting systems (battery or hard-wired lights which illuminate on loss of building power for a defined period of time).
- (In-building) Emergency responder communications enhancement systems (a combination of components, RF-emitting devices, antennas, cables, power supplies, control circuitry, and programming installed at a specific location to improve wireless communications within the building and between on-scene first responders and communications centers.).

- Emergency services communication system (a communications system dedicated to the receipt of events, the coordination and dispatch of first responder resources, and the management of resources and activities post-dispatch).
- Fire alarm systems (a system or portion of a combination system that consists of components and circuits arranged to monitor and annunciate the status of fire alarm or supervisory signal-initiating devices and to initiate the appropriate response to those signals).
- Fire emergency voice/alarm communications system (in-building) (dedicated manual or automatic equipment for originating and distributing voice instructions, as well as alert and evacuation signals pertaining to a fire emergency, to the occupants of a building[2]).
- Smoke alarms (standalone devices, generally for residential use, perhaps with electrical interconnections between devices for general alarm notification).
- Smoke control system (mechanically-assisted system for removing or exhausting smoke from a defined space).

Based on the scope of the research project as defined, for the purpose of this study, LSS are limited to those systems and components used for transmitting signals / information (analog or digital) for the purpose of facilitating a life safety system function (e.g., detection of a fire, notification of building occupants by non-voice alarm signal, activation of a LSS such as smoke exhaust, emergency voice communication system (one- or two-way; occupant and emergency responder). In particular, the focus is on those LSS for which survivability of the communication pathway is defined and/or required. This derives from the state research goal to determine if there are temperature effects that render messages no longer understandable. (It should be noted that future consideration might be given to assessment of pathways by which other than voice/data message signals are transmitted.)

1.1.2 Life Safety Systems (LSS) Requiring Pathway Survivability

Given the focus of this research on LSS in which signals (data, information) are transmitted for purposes of communication, the primary LSS of concern are identified as follows (derived from above list and scope of work):

- Emergency communication system – ECS
- Emergency communication systems – combination – ECSC
- Emergency responder communications enhancement systems (in-building) – ERCES
- Emergency services communication system – ESCS
- Fire alarm systems – FAS
- Fire emergency voice/alarm communications system (in-building) – EVACS

Following the language of the RFP, the focus is on ERCES and EVACS. Requirements for pathway survivability as associated with these systems are described in *NFPA 72, National Fire Alarm and Signaling Code*®, and *NFPA 1225, Standard for Emergency Services Communications*. More detail on the related provisions within these standards is presented under Task 1.3 below.

Task 1.2 Identify Incidents of Cable Failures for LSS

In this part of the study, accidents / incident reports, surveys, and related investigation approaches have been used with a primary aim to identify failures in which elevated temperatures (thermal impact) from a fire was a factor, and if so, how and what the resulting impacts were.

1.2.1 Incidents Identified by Literature Review

Some fires that triggered research by the National Fire Protection Association (NFPA), the U.S. Nuclear Regulatory Commission (NRC) and Factory Mutual (FM) in USA in the 1970s/80s on control/communication cables include:

- The New York Telephone Exchange fire in 1975 (Lathrop 1975a)
- The World Trade Center Fire in 1975 (Lathrop 1975b)
- The Browns Ferry Nuclear Plant Fire, (Pryor, 1976)

The fire in the New York Telephone Exchange in February 1975 was started by an arc and then spread along the cable vaults. The fire was difficult to extinguish as it was difficult to access. The fire resulted in replacement of a large number of cables, which were either burnt or affected by soot. There is no specific note on problems due to thermal damage in the paper by Lathrop (Lathrop 1975a), with the major damage reported as being due to the soot. Another fire in a telephone exchange building is the Hinsdale Central Office fire in 1990 where the actual burn area was limited but the smoke and soot resulted in large damage and half a million customers were affected (Appendix B: Historic Industrial Fires). This fire started due to a short circuit between damaged cables that resulted in increased heat but not any blown fuses. Due to poor weather conditions at the time, the alarm was interpreted as typical of alarms due to loss of power that result from bad weather, and diesel generators were started. When staff came to the site to check status, they observed considerable smoke coming out of the building. Staff attempted to call the fire department, but this was not possible as the phone lines were inoperable due to the fire. Extinguishment of the fire was difficult as the cables were energized from battery power. It was not possible to disconnect the power until the fuses were removed. The number of cables which were ultimately replaced was significant, and required a long period of time.

The World Trade Center (WTC) in New York City suffered a fire in 1975 due to a telephone cable igniting. Other cable fires include Zurich-Hottingen in 1970 (Appendix B: Historic Industrial Fires). As a result of such fires, research and testing was focused on fire properties of cable (ignition, combustion, fire spread) and the ability to produce acidic/corrosive smoke. In order to limit fire spread in cables and cable trays, requirements such as physical separation have been developed.

The Browns Ferry Nuclear Plant fire in March 1975 was reported to have started by a lit candle used for checking for air leaks igniting a temporary polyurethane cable penetration seal in the cable spreading room below the control room for unit 1 and 2 of the reactors (NUREG/KM-0002). The fire spread quickly into the seal and cables and resulted in significant damage. It also had an impact on the communication and control systems, and all the emergency core cooling systems for unit 1 and 2 were disabled. In the end, the staff were able to use non-emergency components to do a manual shut-down of the reactor and prevent core meltdown. The Browns Ferry fire resulted in a large research effort on control cables and their survivability in fires. Research was conducted by the newly started Nuclear Regulatory Commission (NRC) together with different research organizations.

In 1993, the WTC in New York City was severely damaged due to a terrorist bomb. The evacuation and rescue efforts suffered from limited emergency lighting and communication as a result of main vertical trunk lines being destroyed in the blast. The communications were further hampered due to incompatibility between the rescue services communications system and the buildings' communication systems. As a result of this incident NIST conducted research on how the rescue services can use systems already in place in the building (Holmberg et.al.)

In the fire following the attacks on the WTC in 2001, all communication was lost above the level of airplane impact, despite the presence of several vertical trunk risers. To overcome this situation in the future, NIST advised having a riser be located in the central part of the building (core) and to protect the core both structurally and from fire (Keough, R., Grill, R.). They also advised to invest more in repeaters for the fire service radio communication systems instead of installing dedicated telephones, as it was found that these were not used during the event. Keough and Grill also mention the differences in requirements on telephone circuits compared with fire alarm circuits, and the fact that a short circuit causes a signal for a fire alarm, but not for telephone lines, in the result being that there will be no message in case of an alarm if the telephone line experiences a short circuit. Other areas for improvement that were noted include storing alarm information in another location and giving notification for evacuation automatically rather than requiring a person on site to do so. There was significant impact to the fire alarm and communication systems but it has not determined whether this was due to heat or mechanical impact in this very severe fire.

A more recent fire is the Grenfell fire in 2017. In this fire the rescue services had large problems with communications (Johnson 2020). All communications were made through the radio system during the fire, but all personnel did not have radios that could be used together with their breathing apparatus gear (BARIE Breathing Apparatus Radio Interface Equipment) and had to remove their masks for communication. In addition, as so many rescue service units were on site, the limited number of available channels became too congested and communication was not possible. As a result, runners were used for some communication, i.e. people running around relaying messages, and mobile phones were also used. Leaky feeders for the radio communication system were not used as it was deemed resource demanding to distribute the cables in the building and also introduce further hazards in narrow stairwells. There were also doubts raised after the fire concerning as to whether the radio signals would be strong enough even under normal circumstances. This is something not tested during building inspection as the outcome of such a test is very dependent on environmental conditions (weather etc.).

1.2.2 Incidents Identified by Survey and Other Methods

In order to expand the search to other resources, the project team reached out to various persons by email and other means. The aim was to try to identify more related incidents and outcomes. Unfortunately, no additional incidents pertinent to this study were identified through email outreach. Therefore, a survey was conducted in cooperation with the FPRF and the NFPA to try and collect more data. The survey is presented in Annex B. In brief, the survey resulted in 10 answers, but no particularly useful data. Three of the 10 respondents answered ‘yes’ to Q1 (Are you aware of any operational cable (defined as any conductor, optical fibre, radio carrier, or other means for transmitting system information to remain operational during fire conditions) for life safety systems that failed due to fire/fire effects?). However, no data on the incidents was provided. The other 7 responded ‘no’ which means that they were not aware of incidents. For the 3 that answered yes to the first question, only one answered that they had experienced more than 1 operational cable failure.

After the survey, contact was also made with Dr. Stephen Kerber (Kerber 2022) from UL, who in turn sent a request to UL’s fire service advisory board. From the answers provided, it can be concluded that there have been several occasions where the communications systems clearly did not function, especially during inspection. Very few incidents, however, occurred during fire, with one clear example where the voice signal was disturbed most likely due to water from the sprinklers.

Task 1.3 Review Codes & Standards for LSS Requiring Pathway Survivability

The stated objective of this task is to review existing codes and standards for life safety systems requiring pathway survivability and identify the scientific substantiations for those requirements. A review of various building and fire codes and standards and test standards was conducted. Excerpts of codes and standards provisions is provided are Annex A.

In brief, no direct requirement for pathway survivability / circuit integrity for purposes of emergency communication of voice or data signals was identified in the ICC (International Code Council) *International Building Code®* (IBC)[4], *ICC International Fire Code®* (IFC)[5], *NFPA 101® Life Safety Code®* (LSC)[6], or *NFPA 5000®, Building and Construction Safety Code®*[7]. However, each of these codes refers to NFPA 72 and NFPA 70®, *National Electrical Code® (NEC®),*[8] for requirements associated with emergency communication of voice or data signals. NFPA 72 in turn refers to NFPA 1225 for emergency services communications. NFPA 72 also refers to *UL 2196®, Fire Test for Circuit Integrity of Fire-Resistive Power, Instrumentation, Control and Data Cables®*, for fire tests for circuit integrity of a specific class of cables: fire-resistive power, instrumentation, control and data cables. No particular circuit integrity fire test requirements were identified for coaxial cables.

During the review of the draft interim report by the Project Technical Panel (PTP), it was requested to explore when the requirement for pathway survivability was introduced into NFPA 72 and NFPA 1221, and whether any scientific justification was provided at the time of introduction. To assist in this, FPRF project manager Jacqueline Wilmot, reached out to the NFPA Library staff for assistance in this matter. NFPA Digital Asset & Records Manager, Joy Rodowicz, pointed to the Origin and Development pages of the 2022 edition of NFPA 72 as a starting point. The following is excerpted from this section. Pertinent text is italicized by the authors.

"The 2010 edition of the Code presented a major change in the scope and organization of the document. This was reflected in the new title, National Fire Alarm and Signaling Code. *The broader scope of the Code included emergency communications systems in addition to the traditional scope of fire alarm systems. A new chapter on emergency communications systems (ECS) was added to provide requirements for a variety of systems used for communication of information in various emergency situations. The ECS chapter included new systems such as in-building mass notification systems, wide area mass notification systems, distributed recipient mass notifications systems, two-way radio communications enhancement systems, and area of refuge emergency communications systems. The ECS chapter also included two systems formerly in the chapter on protected premises fire alarm systems: (in-building fire) emergency voice/alarm communications systems and two-way in-building wired (telephone) emergency services communication systems.*

Two other new chapters were added in the 2010 edition. The new chapter on circuits and pathways included requirements and information formerly from the chapters on fundamentals of fire alarm

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systems and from the chapter on protected premises fire alarm systems. *This new chapter provided circuit and pathway performance (class) designations and pathway survivability level designations as well as general wiring requirements presented in a format that allowed use by any type of system covered in the Code*. The new chapter on emergency control functions and interfaces included requirements and information formerly contained in the chapter of protected premises fire alarm systems. In this chapter the term fire safety function generally was replaced with the term emergency control function to reflect the potentially broader application beyond just fire alarm systems. This new chapter also included new provisions for first-responder-use elevators and elevators for occupant-controlled evacuation."

To further assist with the review, Ms Rodowicz provided excerpts from the NFPA Report on Comments (ROC) and Report on Proposals (ROP) for the 2010 edition of NFPA 72 in which pathway survivability proposals and comments were presented. Research by Ms Rodowicz found reference to pathway survivability being added to NFPA 72 to better align with the provisions of NFPA 70 at the time. Further research by the project team noted this as well, For example:

"Additionally, the NEC has changed over the last 2 cycles to require a dedicated shaft for the protection of critical circuits in Articles 695 and 700. These changes were a result of hotel fires that left buildings without emergency power or communications. One such event was in 2004 at the Bellagio Hotel when an electrical short circuit within the common shaft led to a complete shutdown of the normal and emergency systems." (72-242 Log #290 SIG-PRO: 72-A2009-ROC) This example is provided since it reflects a fire event.

However, a search of the ROC and ROP documents did not find particular substantiation for adopting the requirements of the National Electrical Code (NEC 2005), and in some cases, noted examples of where lack of substantiation was noted as a concern. In particular, in the ROP a proposal was made to introduce a new chapter entitled "Pathway Interconnections", which included pathway survivability. The substantiation is as follows: "*Substantiation: At the direction of the Technical Correlating Committee a new chapter covering pathway interconnections and survivability has been drafted. Technical changes include: 1. Class designations have been revised and can be applied to other circuits that are not SLCs, IDCs or NACs, 2. Levels of survivability have been created that can be referenced by other chapters in NFPA 72 and by other codes and standards, 3. The performance characteristics for pathways have been defined. The intent of the committee is to define the performance characteristics and leave the application (where and when) to other chapters of NFPA 72 or other codes and standard*s. While this was accepted, a comment on an affirmative vote noted: "*HAMMERBERG, T.: The substantiation does not explain why it was necessary to make all these changes. This will be confusing to the users. It is okay as a first pass, but it needs work.*

This reflects the feeling of some at the time that while adding pathway survivability made sense, it was not clear why all the specific items were included. This can be seen in other comments as well, in particular in attempts to clarify how the provisions around 'fully sprinklered building' may or may not have been adequate and/or technically justified. For example: "*Although circuits installed in metal raceways in fully sprinklered buildings was a choice for 6.9.10.4.3 in the 2006 ROP, that same choice was added to 6.9.10.4.2 by the Technical Committee. The TC "revised the requirements for protection of systems and circuits to provide consistent application of methods for protection against attack by fire." (Wording from the TC statement in the 2006 ROP) The committee added this requirement with no technical justification to do so. There is a lot of difference in the requirements of 6.9.10.4.2 and 6.9.10.4.3. If there is no water where the wiring is installed, how does it provide the equivalent* *protection as a replacement for CI cable or cable systems? Maybe the NFPA FPRF should consider doing a study of this*." (72-243 Log #339 SIG-PRO: 72-A2009-ROC)

Furthermore, on this topic in particular, other action highlighted a need for research. For example: "*CLARY, S.: I agree with the intent of Chapter 13 to provide a "menu" of choices for survivability levels. I further support that the choice of the appropriate level is up to other chapters and codes. While I agree that sprinkler do offer a level of protection in buildings, I do not agree that a fully sprinklered building is a substitute for the use of two-hour rated cables, cable systems or enclosures unless the sprinklers are installed in the area of the cables. I simply cannot agree with the committee statement that it is not the intent to provide "wetting" of the conductors. The Automatic Fire Alarm Association (AFAA) has contacted the NFPA Research Foundation to consider doing tests to either validate or invalidate the opinion that a fully sprinklered building is an acceptable substitute of other technologies in lieu of providing sprinklers at the area to be protected*." and "*HAMMERBERG, T.: We agree with the intent of Chapter 13 to provide a "menu" of choices for survivability levels. We agree that the choice of the appropriate level is up to other chapters and codes. We agree that sprinkler do offer a level of protection in buildings. However, we do not agree that a fully sprinklered building is a substitute for the use of two-hour rated cables, cable systems or enclosures unless the sprinklers are installed in the area of the cables. We do not agree with the committee statement that it is not the intent to provide "wetting" of the conductors. We have contacted the NFPA Research Foundation to consider doing tests to either validate or invalidate the opinion that a fully sprinklered building is an acceptable substitute of other technologies in lieu of providing sprinklers at the area to be protected*." (72-240 Log #111 SIG-PRO: 72-A2009-ROC)

In brief, it appears requirements were added to the 2010 edition of NFPA 72 regarding pathway survivability to address previous changes in NFPA 70 (as early as 2002 and modified in 2005). These codes and associated ROP and ROC have not been reviewed. At the time, questions were raised about technical justification of some provisions, including the extent of applicability of the 'fully sprinklered building' option, and calls for research in this area were noted. It was not found that any reference to fire impact on the integrity of voice or data communication signals was considered. In part, this could be because the baseline NEC provisions did not consider this. Again, the NEC history was not explored at this time.

1.3.1 National Fire Protection Association

NFPA 72, *National Fire Alarm and Signaling Code*®[9]

NFPA 72, National Fire Alarm and Signaling Code®, Chapter 3 – Definitions, defines 'pathway survivability' as *the ability of any conductor, optic fiber, radio carrier, or other means for transmitting system information to remain operational during fire conditions.*

Pathway survivability is addressed in NFPA 72, Chapter 12, Circuits and Pathways, which identifies performance characteristics to be achieved. However, Chapter 12 does not require a specific level of survivability, but it provides options when other chapters, codes, standards, or authorities having jurisdiction require survivability. Prescriptive requirements for pathway survivability appear in the

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NFPA 72 for pathways included as a part of emergency communications systems) (24.3.14 and 24.4.8.6.4) and a part of public emergency alarm reporting systems (27.6.3.1.3).

Reference is made to 'circuit integrity cable,' which is defined in NFPA 70 (725.179(F) - cables that are used for survivability of critical circuits under fire conditions shall meet the requirements of either 725.179(F)(1) or (F)(2)). Critical circuits are not defined in NFPA 72 nor referred to in NFPA 101 or NFPA 5000. Critical circuits are defined in the IBC and IFC, but not in relation to emergency communications.

In NFPA 72, 24.3.14.4.1, it is noted that for systems that do not employ relocation or partial evacuation, a Level 0, Level 1, Level 2, Level 3, or Level 4 pathway survivability shall be permitted. In brief, this means essentially some fire resistance requirements in some cases, but no requirements for circuit integrity (CI) cable to be used.

As such, the only requirement for pathway survivability (for emergency communication to occupants) is in NFPA 72, 24.3.14.4.2 for systems employing relocation or partial evacuation, and only applies to the communication and control circuit pathways between a room or rated enclosure containing fire alarm equipment and other room(s) or rated enclosure(s) containing fire alarm equipment required for occupant notification, where the separation of in-building fire emergency voice/alarm control equipment locations results in the portions of the system controlled by one location being dependent upon the control equipment in other locations (24.4.8.6.4).

NFPA 1225, *Standard for Emergency Services Communications*[10]

NFPA 1225, *Standard for Emergency Services Communications*, addresses two-way first responder communication systems, including radio systems. This standard incorporates requirements previously located in NFPA 1221, *Standard for the Installation Maintenance and Use of Emergency Services Communication Systems*, which was relocated as part of a consolidation effort. With respect to radio frequency transmitting systems, there is concern that fire department radio systems may not operate properly when signal strength inside buildings is impaired by building materials such as steel and concrete, obstructions, and by radio frequency interference. For such contingencies, ERCES includes provisions for boosting the signal from the public safety radio repeater with a signal booster, commonly referred to as a Bi-Directional Amplifier (BDA), which receives and amplifies transmissions from radios inside to the repeater antenna outside. These systems are referred to as 'backbone' systems (3.3.10*).

With respect to survivability, NFPA 1225 requires backbone cables of two-way ERCES to be routed through an enclosure that matches the building's fire rating. More specifically, backbone cables and backbone cable components installed in nonsprinklered buildings, in buildings that are partially protected by a sprinkler system, or in high-rise buildings shall be protected from attack by fire in accordance with one of the following (18.12.3.4):

(1) Use a cable with a listed fire-resistance rating in accordance with the following:

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(1) Where the primary structural frame of a building is required to have a fire-resistance rating of 2 hours or more or is classified as heavy timber construction, the minimum fire-resistance rating shall be 2 hours.

(2) Where the primary structural frame of a building is required to have a fire-resistance rating of less than 2 hours, the minimum fire resistance rating shall be 1 hour.

(3) Where the primary structural frame of a building does not require a fire-resistance rating, a fire resistance rating shall not be required.

(2) A protected enclosure or area shall have a fire-resistance rating in accordance with the following:

(a) Where the primary structural frame of a building is required to have a fire-resistance rating of 2 hours or more or is classified as heavy timber construction, the minimum fire-resistance rating shall be 2 hours.

(b) Where the primary structural frame of a building is required to have a fire-resistance rating of less than 2 hours, the minimum fire resistance rating shall be 1 hour.

(c) Where the primary structural frame of a building does not require a fire-resistance rating, a fire resistance rating shall not be required.

NFPA 70®, *National Electrical Code®*.[11]

The National Electrical Code provides requirements for test, installation and performance of wiring, cables and circuits. Fire alarm system wiring and equipment, including all circuits controlled and powered by the fire alarm system, must be installed in accordance with the requirements of Article 760. Optical fiber cables installed as part of the fire alarm system must meet the requirements of Article 770 and be protected against physical damage in accordance with Article 760. Optical fiber cables entering from outside the building or structure must also comply with NFPA 70 Article 840. Requirements for circuit integrity cable or electrical protection systems are found in 725.179(F), 760.24(B), 760.179(G), 770.179(E) and 805.179(C).

1.3.2 Underwriters Laboratories Inc.

UL 2196, Fire Test for Circuit Integrity of Fire-Resistive Power, Instrumentation, Control and Data Cables

In brief, this standard tests for continuity of signal to a cable exposed to fire by means of the standard fire-resistant test and a hose stream test after the experiment. For control circuits activated by particular voltage and current, those must be maintained during the test. For circuits transmitting data, a bit error rate (BER) check is applied. No specific requirements around voice signal transmission and signal integrity were noted.

1.3.3. Scientific Substantiation for Pathway Survivability or CI Cable Requirements

No particular scientific substantiation for pathway survivability or circuit integrity cable requirements or performance were identified in a review of the codes and standards identified above. This does not necessarily mean that there is not scientific substantiation, but rather, that it is not reported.

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Also, it is not particularly easy or straightforward to identify requirements, as compared with options, nor differences between some of the options, for pathway survivability or circuit integrity cable for use associated with emergency communication. In part, this is because there are associations with fire resistive construction and installation of automatic sprinklers, which presumably reflect an overall expectation of building survivability, including circuits and pathways within those protected spaces. There is also different terminology used between applicable documents. It is suggested that much could be done to simplify and clarify intents, requirements and guidance.

In addition, it seems to be assumed that a particular resistance to fire will provide adequate protection of information that is being transmitted. However, it seems that this is a drastic extrapolation based probably only on a limited test by Lukens (1982), for limited circuits and cable type, under limited fire conditions. It is not readily determinable from this review of codes and standards that integrity of voice communications and data in EVACS and ERCES will be achieved in all cases where it is desired. Further research could be warranted.

Task 1.4 Review Literature on Transmission, Functional and Operational Quality of Signals

Functional performance of items which are part of an alarm system as indicated in the Background consists of several components and several data transmission modes. Cables are of course one component, but other components, such as transmitter, switches etc., are part of the system and must be considered too. When it comes to signal quality there must first be an understanding of how signals are being transmitted in cables. There are two ways to transport a signal through a cable, the use of electrical currents through conductors and light pulses transported through optical fibers (Åström and Lindahl 2021). An electrical conductor such as a copper cable transports a current which can have different purposes, either deliver a certain voltage correlating to a measurement output from an instrument or deliver a current to power a motor or other mechanical work (Taylor, 2012).

1.4.1. Failure modes of electrical circuits

In a NUREG (U.S. Nuclear Regulatory Commission) report from 2003 (LaChance et al, 2003) there is a list of ways that cables fail and what effects that can have on the circuit. Being a NUREG report this list was comprised in the setting of an NPP (Nuclear Power Plant). Cable failure can be: open circuit, conductor short to external ground, conductor to conductor short, hot short and leakage. If a cable fails the circuit can be affected in ways such as, loss of power/control, lost/inaccurate readings on instruments, spurious operation and so on (LaChance et al, 2003). The ways that the circuit reacts is dependent on the function of the individual circuit (LaChance et al, 2003). Since the faults are circuit dependent it is difficult to decide on a universal failure criterion.

1.4.2. Functionality models of cables affected by fire

The main failure mode is thermal degradation and melting of the insulator which can lead to current leaking or short circuit (Taylor, 2012). For this reason, the models for predicting functionality of an electrical cable have been based on material properties of the dielectric insulator on the cables. In a report by Valbuena (2007) three such models are evaluated, a kinetic degradation model, a heat transfer model and a model of the Insulation Resistance (IR). Note that the models are used to see when a cable reaches an experimental predetermined functional criterion, such as a critical temperature or decrease in insulation resistance. The three models will be described in the sections below.

1. Kinetic model

The kinetic model was an attempt to carefully model the degradation of the insulation, which would be based on experimental data where a constant describing the transient degradation would be empirically derived (Valbuena G., 2007). But due to lack of data of the kinetic properties of cable insulation this became a theoretical derivation.

2. Heat transfer, THIEF model

The heat transfer model described by Valbuena (2007) was originally derived by (Andersson, van Hees 2000, 2001, 2005). This model is based on heat transfer into the cable using an empirically determined temperature of the core as a functional criterion. The model then utilizes the thermal properties of the insulation to predict the core temperature of a given cable (Andersson, van Hees 2000, 2001, 2005). The model by Andersson and van Hees was included in the CFD model FDS by NIST (McGrattan, 2010). The model has later been validated by the NIST team (Nowlen 2007 a, b) but also by others (Dreisbach et al 2010, Janssens 2012). However other type of cables and transmissions such as optical cables and package data (digital signals etc.) need further attention. Work was also conducted on optical cables (Rosenqvist 2014) to investigate transmission losses over longer lengths of cables.

In the CAROLFIRE project from NIST the THIEF model was validated using both small and intermediate scale experiments (McGrattan, 2008). In the small scale experiments the cables where heated by radiation in a setup named Penlight, this agrees well with the one-dimensional heat transfer upon which the THIEF model is based (McGrattan, 2008). The intermediate scale experiments consisted of cables mounted in a room setup, in conduits, cable trays and air drop configuration. The fire source in the intermediate scale was a 200 kW propane burner. The validation results indicated that the THIEF model would underpredict the time to failure with 3 % in the small-scale experiment and by 15 % in the intermediate scale experiments (McGrattan, 2008), i.e. a result on the conservative side.

3. Insulation Resistant (IR) model

Lastly, Valbuena (2007) describes an IR model that uses the insulation resistance in Ohm as a functional criterion. The proposed model relies on two constants C1 and C2 to be empirically defined for the insulation material to later be used to quantify the damage on the cable. However, different tests have led to a big variation in the determination of C1 and C2 for the same material (Valbuena G., 2007). Instead, each circuit would have to be tested as of how the lowering of the IR would affect the signal in the circuit (Valbuena G., 2007).

Of the three models discussed above the heat transfer model is the one that is most readily used because of the availability of temperature induced failure data for a variety of cables. However, as signal quality in some cases is of more importance than a simple short/no-short criteria the IR model might be worth looking into especially in relation to voice signals.

1.4.3 Use of metal conduit or raceway

The failure of an electrical cable is dependent on the environment surrounding it. By putting the cable within a metal conduit or raceway this environment is effectively changed. However, it becomes important to understand to what extent. The above-described THIEF model has been validated for cables protected by conduits through the test program CAROLFIRE (McGrattan, 2008). Since the model takes a surrounding temperature of the hot gases into account it was easily modified for a conduit by assuming that the cable instead is affected by the heating conduit.

More recently an experimental study by Wang, Shu and Chen (2013) looked at time to failure of cables with PVC insulation with and without a conduit. The goal was to see when the cable no longer could provide power to electrical equipment. Wang, Shu and Chen (2013) specify that they had fire-fighting equipment in mind and that the results might be used to evaluate cable installation and fire protection strategies. The study comprised of two test setups, a cable protected by fire-retardant coating applied directly to the PVC insulation and a cable within a conduit protected with fire-retardant insulation.

The result indicates that a maximum thickness of the fire retardant on the PVC insulation was 1 mm, thicker layers could crack with cable movement (Wang, Shu and Chen, 2013). This limitation gave a time to failure of 226 sec for a fire-retardant protected PVC cable (Wang, Shu and Chen, 2013). When placing the cable in a metal conduit without fire-retardant protection the time to failure was increased to 310 sec in the same test. Further, Wang, Shu and Chen (2013) applied fire-retardant on the metal conduit, the thickest layer applied was 3 mm and resulted in a survivability of 578 sec for the cable. Thus, they concluded that putting an untested cable in a metal conduit is a good way to prolong the time to failure. However, they also point out that for equipment that needs to operate under long time in a fire it is not sufficient to place a common cable in a metal conduit, instead the cable and or the circuit must be specially designed and tested for the intended use (Wang, Shu and Chen, 2013).

1.4.4. Optical signals

Fiber optical cables have not yet been subject to testing in the same extent as electrical cables. Therefore, the optical cables are reviewed in this separate section. Failure of an optical fiber subjected to a fire environment has not been extensively studied. Åström and Lindahl (2021) found that the functionality of an optical fiber was unaffected until the moment when the cable snapped. This is somewhat similar to the unaffected signal in an electric conductor until a short occurs, in the sense that the failure occurs without warning.

The functional criteria of optical signals affected by fire has been measured using either attenuation (Rosenqvist, 2014) or data package loss (Åström and Lindahl, 2021). The first method has also been used to measure functionality of optical cables in non-fire related situations. NASA performed a study on preconditioning of fiber optic cables for space flight (Thomes et al. 2008). In the study by Thomes et al. (2008) fiber optic cables were tested at a temperature span of -50 to 125 °C. For untreated cables they could measure a large disturbance in the signal due to thermal expansion of the cable, this result indicates that the performance of an optical fiber is affected by thermal exposure. This was also noticed in a study by Rosenqvist (2014) who tested cables while subjected to live fire. Even with the measured disturbance Rosenqvist (2014) concluded that it was difficult to translate this to how a fiber optic network would react. Therefore, a study by Åström and Lindahl (2021) was conducted where the fiber was tested in a fire environment whilst data package loss was measured and a method was developed to check integrity of the signal distribution from transmitter to receiver when parts of an optical cable were exposed to heat radiation. While successful, this type of approach needs further research and larger volumes of test data.

1.4.5. Protected by automatic fire sprinklers

Some test methods for cables, such as the UL 2196, incorporate a water spray at the end of the test. This has the potential to short circuit damaged electrical cables and potentially crack brittle optical fibers. However, no direct technical study on the subject was found during this literature review.

1.4.6. Critical temperatures

After the Browns Ferry accident in 1975, there was a number of cable functionality related projects that tried to describe the functional criteria for electrical conductors. Part of this work was the CAROLFIRE project that resulted in the THIEF model originally developed by Andersson and van Hees. After this, the report NUREG/CR-6850/EPRI 1011989 was published in 2005 containing recommendations on how to assess functionality of cables in PRAs (probabilistic risk analysis. The recommendation from this report was to use deterministic values. NUREG grouped cables based on the type of plastic in the insulations. They differed between Thermoplastic (TP) and Thermoset (TS) isolation with the critical temperatures of 205 °C and 330 °C respectively. Other experimental results yield temperatures based on other classifications, for example Lukens (1982) concluded that qualified cables, i.e cables that passed the IEEE 383, could withstand temperatures of 250 °C and un-qualified cables would fail at 130 °C. However, there is a large span based on how you qualify the cables and perhaps even between the different test methods.

More recent research was made in an attempt to broaden the scope of probabilistic risk assessments (PRAs) with respect to the NUREG regulation. Gallucci (2017) looked at the data from a number of large cable test projects, such as CAROLFIRE, DESIREE-Fire (Nowlen et al. 2012) and KATE-Fire (Nowlen and Brown, 2011). From these test samples Gallucci (2017) created three groups of cables and fitted the result to statistical distributions. By doing so the three types of cable insulation would be given a more probabilistic functional criteria to be used in PRAs. Gallucci (2017) concludes that using the distributions in a PRA might yield more conservative values, but at the same time more realistic values, since it is no longer a deterministic criterion.

The above examples of both deterministic values and probability distributions are made for electrical conductors. For fiber optics there has not been that many studies conducted on functionality during fire. However, Åström and Lindahl (2021) conducted a statistical analysis on their samples in a similar manner to what Gallucci did for electric conductors. No deterministic recommendations are made by Åström and Lindahl (2021), but for reference they present a worst-case 5th percentile value of about 350 °C for their fiber optic samples. Note that the temperature measurements for the electrical cables have been more thorough and there seems to be some variation in temperature along the fiber optic cable during the tests conducted by Åström and Lindahl (2021).

1.4.7. Fire alarm system test

To date few data are available for full analysis of the whole system when subjected to higher temperature or thermal radiation (van Hees 2019).

1.4.8. Mechanical impact

It is worth noting that much of the tests are conducted on cables without mechanical stress. Mechanical stress will in many cases have a negative impact on the time to short circuit and survivability of the cable as the conductors come more easily in contact with each other during mechanical stress (bends, cables hanging down etc.). As an example, the European test standard EN 50200 incorporates a pendulum which strikes the cable holder with a standardized force every 5 minutes during the test. The mechanical impact is not tested in UL 2196. The standard incorporates a tensile strength test, but that test is carried out on 5 samples not exposed to fire. The mechanical impact was identified an important parameter by Åström and Lindahl (2021) in their study on fiber optic cables and therefore they incorporated both a striking pendulum and a narrow bend on the cable.

In many real-life installations plastic straps/cable ties are also used to mount cables, straps that will release the cables early in a fire as they melt quickly in a fire. The straps are in general not specified for installations and no requirements are in place.

1.4.9. Conclusions of technical literature review

There have been multiple studies on functionality of electrical cables in a fire environment. There has also been some testing on fiber optic cables but not to the same extent. For electrical cables, the studies have mainly used three functional criteria, degradation of insulation, short circuit and insulation resistance. While all three can characterize a number of electrical faults, they do not take into account the exact impact on the signal. For optical fibers the same thing can be seen, but in this case the main functionality evaluation has been based on measuring the attenuation, with exception of the study of Åström and Lindahl (2021) where the actual data packages were measured. For both types of transfer, it is possible to be more specific in studying the cables for their intended use.

Further, looking at critical temperatures there are two separate approaches. The deterministic and probabilistic approaches. The latter allows for a more analytical solution of fire safety issues but on the other hand might be more difficult to regulate. The deterministic approach allows for an easy to regulate route using specific criteria, but these need to be on the conservative side to guarantee safety.

In addition, it is important how the failure criterion is determined, if impact such as mechanical stress is included or not, what parts of the system is included etc.

Task 1.5 Review Manufacturer Literature to Identify Best Practices for Installation.

An extensive review of internet resources was performed with respect to best practices, but the major outcome was reference to manufacturers datasheets on performance of systems, where they mainly refer to NFPA and state that they comply with the NFPA standards.

2. Task 2: Research Plan

Task 2.1 Analysis, Knowledge Gaps and Research Needs

As a general observation, it is difficult to clearly follow and understand the specific intents of the numerous NFPA provisions on critical circuits and pathway survivability. Life safety systems are undefined, and many systems which support life safety in case of fire seem out of scope of this work, yet may be susceptible to fire impacts (e.g., data communication to smoke exhaust systems). A broader investigation into ‘life safety critical systems and communications modes and media’ may be warranted. Consideration might be given to try to clarify and make more concise the requirements in NFPA 72 and NFPA 1225.

One task in this study was to identify incidents in which thermal damage on cables influenced the outcome. This review did not reveal any clear indication of data or communication failure in EVACS or ERCES due to thermal influence from fires. Many of the incidents in which communication problems had occurred were severe fires in combination with mechanical impact after which large cable damage could be identified. However, due to the combination of heat and mechanical impact the extent of thermal damage to the cables could not be quantified in any of the cases. Also, the communication problems seem in many cases also to have been due to other organizational causes. Many of the fires were historic and have already resulted in research and updated regulations, but not specifically towards the data and voice communication through cables.

The technical literature did reveal that data and communication signals could be impacted by increased temperature. However, most current test methods are often focused on a short circuit criterion which does not indicate a decreasing signal quality, except for the UL 2196. Although, the UL 2196 does incorporate a certain voltage or BER for the circuit no specific criteria for voice signals or voice signal integrity are identified. Therefore, none of the identified test methods is substantial enough to tests for fire-induced (thermal) impacts on data and communications signals as part of EVACS or ERCES.

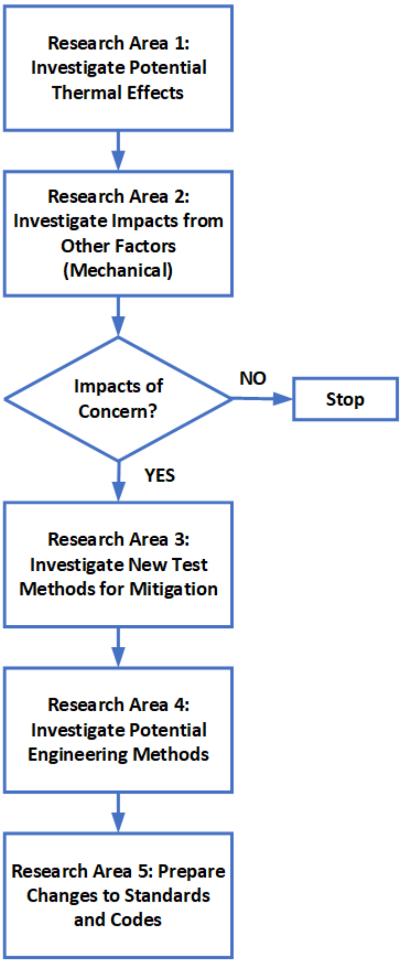
Currently the most common criterion for testing a circuit is to see if it has the integrity to keep a light on. This criterion was mentioned in the literature overview (see task 1.4). The criterion can be considered easy to pass since a lightbulb does not require much power to stay on. However, there has been a few studies conducted in which signal quality has been in focus. One such study was conducted by Åström and Lindahl (2021). They looked at the thermal effects on fiber optic cables by counting data packages that were continuously sent through the cable. In doing so their study looked at the signal quality and not only the cable survivability.

Finally, some of the core findings from the literature review are compressed as bullet points as research needs:

- The potential for fire-related impacts exists, but evidence of impacts in EVACS or ERCES was not found, and therefore whether or not there is a serious potential problem is unknown. However, this could be investigated through testing under controlled environments and different data and communications transmission modes and media.
- No scientific studies were found which illustrate that fire-rated enclosures or building fire sprinkler systems specifically mitigate thermal-induced data or voice signal degradation in cables. However, fire-rated enclosures and/or building fire sprinkler systems can reduce the temperature to which cables are exposed, which could be expected to help, but the extent to which is unknown.
- While no evidence was found specifically on ERCES systems and components, it seems likely that the amplifier is more at risk than the signal itself. This too can be explored through testing.
- Inspection, testing and maintenance (ITM) are important areas as there are uncertainties if many of the systems work even without a fire.

Task 2.2 Research Roadmap

Based on the above analysis and identification of research needs the following research roadmap is proposed for better understanding (1) whether data and voice signals over pathways, and RFI signals / transmitters / repeaters are affected by thermal insult from a fire, (2) whether mechanical damage may likewise impact signal transmission, (3) if so, how might thermal tests be designed to assess such thermal impacts and the potential mitigation strategies, (4) whether engineering methodologies may be developed to help in the mitigation design phase, and (5) preparation of justification for potential changes of standards and codes where deemed appropriate. Schematically it is presented in the figure below.



Schematic of the research roadmap

Research Area 1. Testing series to investigate the potential for thermal effects on signal degradation

Since this study did not find evidence of scientific analysis / testing of the thermal impacts of data and voice signal degradation during transmission via signal pathways during fire, it is not known whether thermal effects are a problem for communication cables with respect to EVACS or ERCES. As such, a first research area would be to define, establish and conduct repeatable test methods for the assessment of thermal impact on data and voice communication transmission by various signal pathways, including RFI transmission. In this research area a test program will be developed to evaluate where the potential for communication failures in cabling due to thermal effects could result. This would begin with determining the thermal boundary conditions and functional performance parameters. Test environments and apparatus would then be analyzed and recommended, ideally using existing test apparatus but proposing new if needed. Tests would then be conducted to assess thermal impacts. Research on different communication protocols will be investigated and a testing campaign will be conducted comprising different types of cables and communication means. It should also be investigated how transfer of the intended data or voice signal is measured and evaluated, rather than simply providing power to a light bulb and/or short circuit evaluation.

In order to investigate if and to what extent there is a danger for thermally induced failures in data and voice transmission in pathway survivable cables the following test schemes is proposed

- The work starts with conducting a test series where the cable is exposed to a constant high temperature for a specified time, e.g., 2 or 4 hours while transmitting voice and data signals respectively. The number of different cables tested could be 6-10, covering different types such as coaxial, non-coaxial, fibre, copper, qualified and non-qualified cables. Cables will be selected together with the FPRF panel.
- While there are methods available to measure data transmission that can be used for the testing, it is unknown which will work best for voice transmission. Therefore, some further investigation is needed to determine a test protocol for this aspect. It will be explored whether a specific test signal can be used sending both audio and data.
- The most recent method was presented by Åström and Lindahl (2021) in which a Local Area Network (LAN) was created to send data packages through the cable. The network consisted of two computers between which communication was established. Each computer was connected to a swich that allowed the connection of the tested cable type. The sample cable was the connection between the switches and was also routed through the exposure area. The data was measured as package loss by sending a known number of data packages and counting when arriving at the second computer. Since some cables might not be able to send digital information, a protocol using analogue signals might need to be established.
- The heat exposures for the testing can be made in a furnace, preferably one where some bending is made of the cable according to the allowed radius, as previous studies have shown that it is very difficult to get an impact on a straight cable without any mechanical tension. Other heat exposures such as thermal radiation and combined radiation and convection will be investigated for a more limited set of cables and conditions. For the latter an apparatus such as the cone calorimeter according to ISO 5660 can be used.
- Testing is conducted until a value for when thermal impact is achieved within a couple of hundred °C, i.e. testing temperatures could be 1100, 900, 700, 500 and 300°C. If no impact is seen at temperatures where fire resistance is tested (1100 °C) the tests are terminated for that specific cable.
- In total a maximum of three heat exposures will be investigated. The approximate amount of testing would be a maximum of 100 combinations of exposure, critical level, type of transmission and type of cable. Experimental planning tools will be used to optimise the number of tests with respect to the possible combinations.

Research Area 2. Impact from other factors such as mechanical stress and water impact on communication systems

This research area will explore different factors besides thermal effects which can have an impact on signal degradation. In much the same process as Research Area 1, this will be followed by an investigation of what factors should be tested, and how, and via what test methods. Factors which were defined in this study include mechanical stress and water. Research on different communication protocols will be investigated and a testing campaign will be conducted comprising different types of cables and communication means. The exact content will depend on the outcome and the experience from Research Area 1. In this research area a number of tests will be conducted utilising mechanical impact and water ingress. Experiences from tests such as UL 2196 (fire resistance exposure and hose stream test) and EN 50200 for mechanical exposure. This will be also under different thermal conditions and with the cables selected in the previous step. The number of expected combination of tests will be less but expected to be a maximum of 50 different combinations.

If Research Areas 1 and 2 suggest that neither thermal impacts or mechanical impacts are a concern, then no further research may be necessary. However, in the case that thermal and/or mechanical impacts are found to influence voice or data signals, next steps would be to explore appropriate mitigation measures and to develop recommend changes as warranted.

Research Area 3. Evaluating different test method(s) for pathway protection and suggest improvements.

Based on outcomes from Research Areas 1 and 2, if failure mechanisms are identified, a set of plausible scenarios for failure due to thermal and/or mechanical impacts will be developed, a set of standardized tests will be proposed to assess mitigation strategies, and a series of tests using the scenarios and test methods will be undertaken to evaluate the efficacy and repeatability of the test methods and mitigation strategies. The scenario analysis will also involve further analysis of specific criteria for different alarm circuits and used during standard tests to expand the applicability.

Whereas Research Areas 1 and 2 focused on fire test methods for evaluating the thermal impacts on signal transmission and functional and operational quality of alarm/data signals and voice messages for different temperature and time exposures, this research area focuses on the evaluation of potential mitigation measures, aimed at preventing unacceptable thermal exposure. In the research area, it is expected that the following mitigation strategies will be evaluated:

- Pathways located within fire rated and non-fire rated enclosures (chases).
- Pathways located within metal conduit or raceway, but not in a fire-rated enclosure, and pathways not located within in a metal conduit or raceway and not within a fire-rated enclosure.
- Pathways without physical protection, but located in a room / enclosure that is protected throughout by an automatic fire sprinkler system.

Development of mitigation strategy test methods is expected to involve items such as:

- Defining fire environments and duration for testing.
- Defining test methods that will provide data on the signal performance throughout the fire test.
- Defining any mechanical strain, water impacts, or other such factors which could impact the performance of the mitigation system.
- Consideration of all parts of the system/circuit. For example, in case of radio amplification the cable might be protected but the amplifier itself might not perform as intended.
- Specific criteria which are created for different fire alarm circuits in the scenario analysis and used during standard tests need to be established.
- Testing of different systems and under different conditions based on the outcome of Research Areas 1 and 2.
- Consideration of the intended data or voice signal, rather than simply providing power to a light bulb. This would build on the study by Åström and Lindahl (2021) so that measurements on the intended signal could be developed. They can then be used to classify a cable and or circuit.

Research Area 4. Engineering models for performance-based approaches

This research area would involve development of engineering models to predict the performance of a whole system based on the performance of each component either by analytical modeling or by using probabilistic methods. Input data and determination models will be established. Further detail as to what these might be is not possible pending outcomes of Research Area 3.

Research Area 5. Packaging research outcomes for standardization and dissemination

In this research area provisions will be given for improvement and changes in current available standards and dissemination of the engineering tools. While not being immediately a strict research area it is an important part of the roadmap and is therefore given a specific area.

3. Conclusions

This study revealed that there is not much scientific evidence that thermal effects are a problem for communication cables with respect to EVACS or ERCES. However, there were several studies found which showed the malfunctioning of cables through short circuit under elevated temperature conditions. Therefore, it is necessary to conduct a testing research program to investigate the conditions under which communication fails in order to provide necessary data for prescriptive and performance-based design of communication systems.

4. Acknowledgements

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Annex A – Excerpts from Codes and Standards

EXCERPTS FROM BUILDING AND FIRE CODES

International Code Council

2021 *International Building Code*® (IBC®)[12]

SECTION 202

"[F]CRITICAL CIRCUIT. A circuit that requires continuous operation to ensure safety of the structure and occupants."

CHAPTER 9

"[F] 913.2.2 Circuits supplying fire pumps.

Cables used for survivability of circuits supplying fire pumps shall be protected using one of the following methods:

1. Cables used for survivability of required critical circuits shall be listed in accordance with UL 2196 and shall have a fire-resistance rating of not less than 1 hour.

2. Electrical circuit protective systems shall have a fire-resistance rating of not less than 1 hour. Electrical circuit protective systems shall be installed in accordance with their listing requirements.

3. Construction having a fire-resistance rating of not less than 1 hour.

4. The cable or raceway is encased in a minimum of 2 inches (51 mm) of concrete.

Exception: This section shall not apply to cables, or portions of cables, located within a fire pump room or generator room which is separated from the remainder of the occupancy with fire-resistance-rated construction."

"909.20.7.1 Ventilation systems.

Smokeproof enclosure ventilation systems shall be independent of other building ventilation systems. The equipment, control wiring, power wiring and ductwork shall comply with one of the following:

1. Equipment, control wiring, power wiring and ductwork shall be located exterior to the building and directly connected to the smokeproof enclosure or connected to the smokeproof enclosure by ductwork enclosed by not less than 2-hour fire barriers constructed in accordance with Section 707 or horizontal assemblies constructed in accordance with Section 711, or both.

2. Equipment, control wiring, power wiring and ductwork shall be located within the smokeproof enclosure with intake or exhaust directly from and to the outside or through ductwork enclosed by not less than 2-hour fire barriers constructed in accordance with Section 707 or horizontal assemblies constructed in accordance with Section 711, or both.

3. Equipment, control wiring, power wiring and ductwork shall be located within the building if separated from the remainder of the building, including other mechanical equipment, by not less than

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2-hour fire barriers constructed in accordance with Section 707 or horizontal assemblies constructed in accordance with Section 711, or both.

Exception:

1. Control wiring and power wiring located outside of a 2-hour fire barrier construction shall be protected using any one of the following methods:

1.1. Cables used for survivability of required critical circuits shall be listed in accordance with UL 2196 and shall have a fire-resistance rating of not less than 2 hours.

1.2. Where encased with not less than 2 inches (51 mm) of concrete.

1.3. Electrical circuit protective systems shall have a fire-resistance rating of not less than 2 hours. Electrical circuit protective systems shall be installed in accordance with their listing requirements."

"[F] 2702.3 Critical circuits.

Required critical circuits shall be protected using one of the following methods:

1. Cables, used for survivability of required critical circuits, that are listed in accordance with UL 2196 and have a fire-resistance rating of not less than 1 hour.

2. Electrical circuit protective systems having a fire-resistance rating of not less than 1 hour. Electrical circuit protective systems are installed in accordance with their listing requirements.

3. Construction having a fire-resistance rating of not less than 1 hour."

"3007.8.1 Protection of wiring or cables.

Wires or cables that are located outside of the elevator hoistway and machine room and that provide normal or standby power, control signals, communication with the car, lighting, heating, air conditioning, ventilation and fire-detecting systems to fire service access elevators shall be protected using one of the following methods:

1. Cables used for survivability of required critical circuits shall be listed in accordance with UL 2196 and shall have a fire-resistance rating of not less than 2 hours.

2. Electrical circuit protective systems shall have a fire-resistance rating of not less than 2 hours. Electrical circuit protective systems shall be installed in accordance with their listing requirements.

3. Construction having a fire-resistance rating of not less than 2 hours.

Exception: Wiring and cables to control signals are not required to be protected provided that wiring and cables do not serve Phase II emergency in-car operations."

"3008.8.2 Protection of wiring or cables.

Wires or cables that are located outside of the elevator hoistway, machine room, control room and control space and that provide normal or standby power, control signals, communication with the car, lighting, heating, air conditioning, ventilation and fire-detecting systems to occupant evacuation elevators shall be protected using one of the following methods:

1. Cables used for survivability of required critical circuits shall be listed in accordance with UL 2196 and shall have a fire-resistance rating of not less than 2 hours.

2. Electrical circuit protective systems shall have a fire-resistance rating of not less than 2 hours. Electrical circuit protective systems shall be installed in accordance with their listing requirements.

3. Construction having a fire-resistance rating of not less than 2 hours.

Exception: Wiring and cables to control signals are not required to be protected provided that wiring and cables do not serve Phase II emergency in-car operation."

2021 *International Fire Code* ® (IFC ®) [13]

SECTION 202

"CRITICAL CIRCUIT. A circuit that requires continuous operation to ensure safety of the structure and occupants."

CHAPTER 9

"[BF] 909.20.6.1 Ventilation systems.

Smokeproof enclosure ventilation systems shall be independent of other building ventilation systems. The equipment, control wiring, power wiring and ductwork shall comply with one of the following:

1. Equipment, control wiring, power wiring and ductwork shall be located exterior to the building and directly connected to the smokeproof enclosure or connected to the smokeproof enclosure by ductwork enclosed by not less than 2-hour fire barriers constructed in accordance with Section 707 of the International Building Code or horizontal assemblies constructed in accordance with Section 711 of the International Building Code, or both.

2. Equipment, control wiring, power wiring and ductwork shall be located within the smokeproof enclosure with intake or exhaust directly from and to the outside or through ductwork enclosed by not less than 2-hour fire barriers constructed in accordance with Section 707 of the International Building Code or horizontal assemblies constructed in accordance with Section 711 of the International Building Code, or both.

3. Equipment, control wiring, power wiring and ductwork shall be located within the building if separated from the remainder of the building, including other mechanical equipment, by not less than 2-hour fire barriers constructed in accordance with Section 707 of the International Building Code or horizontal assemblies constructed in accordance with Section 711 of the International Building Code, or both.

Exception: Control wiring and power wiring located outside of a 2-hour fire barrier construction shall be protected using any one of the following methods:

1. Cables used for survivability of required critical circuits shall be listed in accordance with UL 2196 and shall have a fire-resistance rating of not less than 2 hours.

2. Where encased with not less than 2 inches (51 mm) of concrete.

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3. Electrical circuit protective systems shall have a fire-resistance rating of not less than 2 hours. Electrical circuit protective systems shall be installed in accordance with their listing requirements."

"913.2.2 Circuits supplying fire pumps.

Cables used for survivability of circuits supplying fire pumps shall be protected using one of the following methods:

1. Cables used for survivability of required critical circuits shall be listed in accordance with UL 2196 and shall have a fire-resistance rating of not less than 1 hour.

2. Electrical circuit protective systems shall have a fire-resistance rating of not less than 1 hour. Electrical circuit protective systems shall be installed in accordance with their listing requirements.

3. Construction having a fire-resistance rating of not less than 1 hour.

4. The cable or raceway is encased in a minimum of 2 inches (51 mm) of concrete.

Exception: This section shall not apply to cables, or portions of cables, located within a fire pump room or generator room that is separated from the remainder of the occupancy with fire-resistance-rated construction."

"1203.3 Critical circuits.

Required critical circuits shall be protected using one of the following methods:

1. Cables used for survivability of required critical circuits shall be listed in accordance with UL 2196 and shall have a fire-resistance rating of not less than 1 hour.

2. Electrical circuit protective systems shall have a fire-resistance rating of not less than 1 hour. Electrical circuit protective systems shall be installed in accordance with their listing requirements.

3. Construction having a fire-resistance rating of not less than 1 hour."

National Fire Protection Association

NFPA 1® – *National Fire Code*® (NFC®)[14]

No direct specification / requirement. Reference is made to installation in accordance with NFPA 72 (in Chapter 13).

NFPA 101® – *Life Safety Code*® (LSC®)[15]

No direct specification / requirement. Reference is made to installation in accordance with NFPA 72 (in Chapter 9). Reference is made in Chapter 9 (fire alarm) and 11 (high-rise / special occupancies) to risk analysis for mass notification systems.

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11.8.4.3 Risk Analysis for Mass Notification Systems.

For high-rise buildings with a total occupant load of 5000 or more persons, or where the floor of an occupiable story is greater than 420 ft (128 m) above the lowest level of fire department vehicle access, a risk analysis in accordance with Section 9.14 shall be performed to determine whether a mass notification system is required.

NFPA 5000® – *Building and Construction Safety Code*®[16]

No direct specification / requirement. Reference is made to installation in accordance with NFPA 72 (in Chapter 55). Reference is made in Chapter 33 (high-rise) and 55 (fire protection and life safety systems) to risk analysis for mass notification systems.

55.13 * Risk Analysis for Mass Notification Systems.

55.13.1 Where required by another section of this Code, a risk analysis for mass notification systems shall be provided in accordance with the requirements of Chapter 24 of NFPA 72.

55.13.2 Where a mass notification system is required by the risk analysis in 55.13.1, the system shall be in accordance with the requirements of Chapter 24 of NFPA 72.

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EXCERPTS FROM STANDARDS

National Fire Protection Association

NFPA 70® – National Electrical Code® (NEC®)[17]

725.179 Listing and Marking of Class 2, Class 3, and Type PLTC Cables.

Class 2, Class 3, and Type PLTC cables, installed as wiring methods within buildings, shall be listed as resistant to the spread of fire and other criteria in accordance with 725.179(A) through (I), shall be marked in accordance with 725.179(J), and shall be permitted to be marked in accordance with 725.179(K).

(A) Types CL2P and CL3P. Types CL2P and CL3P plenum cable shall be listed as suitable for use in ducts, plenums, and other space for environmental air and shall be listed as having adequate fire-resistant and low-smoke producing characteristics.

(Informational Note: One method of defining a cable that is low-smoke producing and fire resistant is that the cable exhibits a maximum peak optical density of 0.50 or less, an average optical density of 0.15 or less, and a maximum flame spread distance of 1.52 m (5 ft) or less when tested in accordance with NFPA 262-2019, Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces.)

(F) Circuit Integrity (CI) Cable or Electrical Circuit Protective System. Cables that are used for survivability of critical circuits under fire conditions shall meet the requirements of either 725.179(F)(1) or (F)(2).

(Note: Section 725.179(F) permits the use of circuit integrity (CI) cable for applications where continuity of the operations of critical circuits is needed during a fire. Such circuits could be essential to fire-fighting operations or could be circuits whose interruption could cause a more dangerous condition to occur. A smoke removal system is an example of where it could be necessary to use CI cables for control circuits to ensure that the dampers operate during a fire.)

(1) Circuit Integrity (CI) Cables. Circuit Integrity (CI) cables, specified in 725.179(A), (B), (C), and (E), and used for survivability of critical circuits, shall have the additional classification using the suffix “CI.” Circuit integrity (CI) cables shall only be permitted to be installed in a raceway where specifically listed and marked as part of an electrical circuit protective system as covered in 725.179(F)(2).

(2) Electrical Circuit Protective System. Cables specified in 725.179(A), (B), (C), (E), and (F)(1) that are part of an electrical circuit protective system shall be identified with the protective system number and hourly rating printed on the outer jacket of the cable and installed in accordance with the listing of the protective system.

(Informational Note No. 1: One method of defining circuit integrity (CI) cable or an electrical circuit protective system is by establishing a minimum 2-hour fire-resistive rating when tested in accordance

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with ANSI/UL 2196-2017, Standard for Fire Test for Circuit Integrity of Fire -Resistive Power, Instrumentation, Control and Data Cables.

Informational Note No. 2: UL guide information for electrical circuit protective systems (FHIT) contains information on proper installation requirements to maintain the fire rating.)

728 Fire-Resistive Cable Systems

728.1 Scope. This article covers the installation of fire-resistive cables, fire-resistive conductors, and other system components used for survivability of critical circuits to ensure continued operation during a specified time under fire conditions as required in this Code.

728.2 Definition. The definition in this section shall apply within this article and throughout the Code.

Fire-Resistive Cable System. A cable and components used to ensure survivability of critical circuits for a specified time under fire conditions.

760.24 Mechanical Execution of Work.

(B) Circuit Integrity (CI) Cable. Circuit integrity (CI) cables shall be supported at a distance not exceeding 610 mm (24 in.). Where located within 2.1 m (7 ft) of the floor, as covered in 760.53(A)(1) and 760.130(B)(1), as applicable, the cable shall be fastened in an approved manner at intervals of not more than 450 mm (18 in.). Cable supports and fasteners shall be steel.

760.179 Listing and Marking of PLFA Cables and Insulated Continuous Line-Type Fire Detectors.

PLFA cables installed as wiring within buildings shall be listed as being resistant to the spread of fire and other criteria in accordance with 760.179(A) through (H) and shall be marked in accordance with 760.179(I). Insulated continuous line-type fire detectors shall be listed in accordance with 760.179(J). Cable used in a wet location shall be listed for use in wet locations or have a moisture-impervious metal sheath.

(G) Fire Alarm Circuit Integrity (CI) Cable or Electrical Circuit Protective System. Cables that are used for survivability of critical circuits under fire conditions shall meet either 760.179(G)(1) or (G)(2).

(Informational Note No. 1: Fire alarm circuit integrity (CI) cable and electrical circuit protective systems may be used for fire alarm circuits to comply with the survivability requirements of NFPA 72-2019, National Fire Alarm and Signaling Code, 12.4.3 and 12.4.4, that the circuit maintain its electrical function during fire conditions for a defined period of time.

Informational Note No. 2: One method of defining circuit integrity (CI) cable or an electrical circuit protective system is by establishing a minimum 2-hour fire-resistive rating for the cable when tested in accordance with ANSI/UL 2196-2017, Standard for Fire Test for Circuit Integrity of Fire -Resistive Power, Instrumentation, Control and Data Cables.

Informational Note No. 3: UL guide information for electrical circuit protective systems (FHIT) contains information on proper installation requirements for maintaining the fire rating.)

(1) Circuit Integrity (CI) Cables. Circuit integrity (CI) cables specified in 760.179(D), (E), (F), and (H), and used for survivability of critical circuits, shall have an additional classification using the suffix “CI.” Circuit integrity (CI) cables shall only be permitted to be installed in a raceway where specifically listed and marked as part of an electrical circuit protective system as covered in 760.179(G)(2).

(2) Electrical Circuit Protective System. Cables specified in 760.179(D), (E), (F), (H), and (G)(1), that are part of an electrical circuit protective system, shall be identified with the protective system number and hourly rating printed on the outer jacket of the cable and installed in accordance with the listing of the protective system.

770.179 Optical Fiber Cables.

Optical fiber cables shall be listed and identified in accordance with 770.179(A) through (G) and shall be marked in accordance with Table 770.179. Optical fiber cables shall have a temperature rating of not less than 60°C (140°F). The temperature rating shall be marked on the jacket of optical fiber cables that have a temperature rating exceeding 60°C (140°F).

E) Circuit Integrity (CI) Cable or Electrical Circuit Protective System. Cables that are used for survivability of critical circuits under fire conditions shall meet either 770.179(E)(1) or (E)(2).

(Informational Note: The listing organization provides information for circuit integrity (CI) cable and electrical circuit protective systems, including installation requirements necessary to maintain the fire rating.)

(1) Circuit Integrity (CI) Cables. Circuit integrity (CI) cables specified in 770.179(A) through (D), and used for survivability of critical circuits, shall have an additional classification using the suffix “CI.” In order to maintain its listed fire rating, circuit integrity (CI) cable shall only be installed in free air.

(Informational Note: One method of defining circuit integrity (CI) cable is by establishing a minimum 2-hour fire resistance rating for the cable when tested in accordance with ANSI/UL 2196-2017, Standard for Fire Test for Circuit Integrity of Fire-Resistive Power, Instrumentation, Control and Data Cables.)

(2) Fire-Resistive Cables. Cables specified in 770.179(A) through (D) and 770.179(E)(1) that are part of an electrical circuit protective system shall be fire-resistive cable and identified with the protective system number on the product or on the smallest unit container in which the product is packaged and installed in accordance with the listing of the protective system.

(Informational Note No. 1: One method of defining an electrical circuit protective system is by establishing a minimum 2-hour fire resistance rating for the system when tested in accordance with UL Subject 1724, Outline of Investigation for Fire Tests for Electrical Circuit Protective Systems.

Informational Note No. 2: The listing organization provides information for electrical circuit protective systems (FHIT), including installation requirements for maintaining the fire rating.)

805.179 Communications Wires and Cables.

Communications wires and cables shall be listed in accordance with 805.179(A) through (F) and marked in accordance with Table 805.179 and 805.179(G). Conductors in communications cables, other than in a coaxial cable, shall be copper.

Communications wires and cables shall have a voltage rating of not less than 300 volts. The insulation for the individual conductors, other than the outer conductor of a coaxial cable, shall be rated for 300 volts minimum. The cable voltage rating shall not be marked on the cable or on the under-carpet communications wire.

Exception: Voltage markings shall be permitted where the cable has multiple listings and voltage marking is required for one or more of the listings.

(Informational Note: Voltage markings on cables may be misinterpreted to suggest that the cables may be suitable for Class 1, electric light, and power applications.)

(C) Circuit Integrity (CI) Cable or Electrical Circuit Protective System. Cables that are used for survivability of critical circuits under fire conditions shall be listed and meet either 805.179(C)(1) or 805.179(C)(2).

(Informational Note: The listing organization provides information for circuit integrity (CI) cable and electrical circuit protective systems, including installation requirements required to maintain the fire rating.)

(1) Circuit Integrity (CI) Cables. Circuit integrity (CI) cables specified in 805.179(A) through (D), and used for survivability of critical circuits, shall have an additional classification using the suffix “CI.” In order to maintain its listed fire rating, circuit integrity (CI) cable shall only be installed in free air.

(Informational Note: One method of defining circuit integrity (CI) cable is by establishing a minimum 2-hour fire resistance rating for the cable when tested in accordance with ANSI/UL 2196-2017, Standard for Fire Test for Circuit Integrity of Fire-Resistant Power, Instrumentation, Control, and Data Cables.)

(2) Fire-Resistive Cables. Cables specified in 800.179(A) through (D) and 805.179(C)(1), that are part of an electrical circuit protective system, shall be fire-resistive cable identified with the protective system number on the product, or on the smallest unit container in which the product is packaged, and shall be installed in accordance with the listing of the protective system.

(Informational Note No. 1: One method of defining an electrical circuit protective system is by establishing a minimum 2-hour fire resistance rating for the system when tested in accordance with UL Subject 1724, Outline of Investigation for Fire Tests for Electrical Circuit Protective Systems.

Informational Note No. 2: The listing organization provides information for electrical circuit protective systems (FHIT), including installation requirements for maintaining the fire rating.)

Article 820 Community Antenna Television and Radio Distribution Systems

Part I. General

820.1 Scope. This article covers coaxial cable distribution of radio frequency signals typically employed in community antenna television (CATV) systems.

(Author note: No reference to circuit integrity associated with fire impact.)

NFPA 72® – National Fire Alarm Code®[18]

Chapter 3 – Definitions

3.3.206 Pathway Survivability. The ability of any conductor, optical fiber, radio carrier, or other means for transmitting system information to remain operational during fire conditions. (SIG-ECS)

Chapter 12 – Circuits and Pathways

12.1.1 Pathways (interconnections) shall be designated based on the performance characteristics defined in this chapter.

12.2.1* Performance and survivability of signaling pathways (interconnections) shall comply with the defined designations of this chapter.

12.4* Pathway Survivability. All pathways shall comply with NFPA 70.

*A.12.4 The intent of the pathway survivability designation is to provide options for the protection of the pathway circuits as shown in Table A.12.4 and not to create a hierarchical ranking. Other chapters within *NFPA 72* or other code-making jurisdictions can select the survivability option that best meets their needs.

Table A.12.4

Required Performance Criteria	**Level 0** (12.4.1)	**Level 1** (12.4.2)	**Level 2** (12.4.3)	**Level 3** (12.4.4)	**Level 4** (12.4.5)
Per 12.2.3.3 and Section 12.4 of this Code, all pathways must comply with NFPA 70 applicable requirements.	Yes	Yes	Yes	Yes	Yes
Wiring methods permitted are installed in accordance with manufacturer's published instructions (12.2.3.3).	Yes	Yes	Yes	Yes	Yes
Building is fully protected by an automatic sprinkler system in accordance with NFPA 13.	-	Yes	-	Yes	-
Any interconnecting conductors, cables, or other physical pathways are protected by metal raceways or metal armored cables.	-	Yes	-	-	-
One or more of the following are required:					
(1) 1-hour fire-rated circuit integrity (CI) or fire-resistive cable					

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(2) 1-hour fire-rated cable system [electrical circuit protective system(s)]	-	-	-	-	Yes
(3) 1-hour fire-rated enclosure or protected area					
(4) Performance alternative approved by the AHJ					
One or more of the following are required:					
(1) 2-hour fire-rated circuit integrity (CI) or fire-resistive cable					
(2) 2-hour fire-rated cable system [electrical circuit protective system(s)]	-	-	Yes	Yes	-
(3) 2-hour fire-rated enclosure or protected area					
(4) Performance alternative approved by the AHJ					

Informational notes:

Chapter 12 does not require a specific level of survivability, but it provides options when other chapters, codes, standards, or authorities having jurisdiction require survivability. Prescriptive requirements for pathway survivability appear in the Code for pathways included as a part of emergency communications systems (ECSs) (see 24.3.14 and 24.4.8.6.4) and a part of public emergency alarm reporting systems (see 27.6.3.1.3). Additionally, where survivability of circuits or pathways is required by another section of the Code, equal protection is required to be provided for secondary power supply circuits (see 10.6.11.3.1.3).

The designer is permitted, and in some cases required, to conduct an analysis, document the approach, and provide technical justification for the pathway survivability selected (see 23.10.3, 24.3.14.3, 24.3.14.16, and 24.5.4.2). This approach is similar to other requirements in the Code in which the system designer is responsible for conducting an analysis to determine the level of class of pathways (see 7.3.9.1 and 23.4.3.1).

Although levels of survivability are listed in ascending numerical order, the order does not mean that one level of survivability is preferred over another for a specific application.

Pathway survivability addresses protection from fire events, except for mass notification systems (MNSs), for which the Code specifically cites that the designer is required to consider both fire and non-fire emergencies when determining risk tolerances for survivability (see 24.3.12.2). For the definition of the term pathway survivability, see 3.3.206.

12.4 * Pathway Survivability. All pathways shall comply with NFPA 70.

12.4.1 Pathway Survivability Level 0. Level 0 pathways shall not be required to have any provisions for pathway survivability.

12.4.2 Pathway Survivability Level 1. Pathway survivability Level 1 shall consist of pathways in buildings that are fully protected by an automatic sprinkler system in accordance with NFPA 13 with any interconnecting conductors, cables, or other physical pathways protected by metal raceways or metal armored cables.

12.4.3* Pathway Survivability Level 2. Pathway survivability Level 2 shall consist of one or more of the following:

(1) 2-hour fire-rated circuit integrity (CI) or fire-resistive cable

(2) 2-hour fire-rated cable system [electrical circuit protective system(s)]

(3) 2-hour fire-rated enclosure or protected area

(4)* Performance alternatives approved by the authority having jurisdiction

12.4.4* Pathway Survivability Level 3. Pathway survivability Level 3 shall consist of pathways in buildings that are fully protected by an automatic sprinkler system in accordance with NFPA 13 and one or more of the following:

(1) 2-hour fire-rated circuit integrity (CI) or fire-resistive cable

(2) 2-hour fire-rated cable system [electrical circuit protective system(s)]

(3) 2-hour fire-rated enclosure or protected area

(4)* Performance alternatives approved by the authority having jurisdiction

12.4.5* Pathway Survivability Level 4. Pathway survivability Level 4 shall consist of one or more of the following:

(1) 1-hour fire-rated circuit integrity (CI) or fire-resistive cable

(2) 1-hour fire-rated cable system [electrical circuit protective system(s)]

(3) 1-hour fire-rated enclosure or protected area

(4) Performance alternatives approved by the authority having jurisdiction

<u>24.3.12* Risk Analysis for Mass Notification Systems.</u>

24.3.12.1* Each application of a mass notification system shall be specific to the nature and anticipated risks of each facility for which it is designed.

24.3.12.1.1 When an owner has developed a risk analysis in accordance with 24.3.12, such risk analysis shall be permitted to be used as a baseline in preparing the risk analysis for new or renovated facilities that are similar in nature.

24.3.12.2 The designer shall consider both fire and non-fire emergencies when determining risk tolerances for survivability for the mass notification system.

24.3.12.3 The detail and complexity of the risk analysis shall be commensurate with the complexity of the facility for which the mass notification system is designed.

24.3.12.4 The risk analysis shall be permitted to be limited in scope to address the communication requirements of an existing emergency response plan.

24.3.12.5 The risk analysis shall consider the number of persons, type of occupancy, and perceived peril to occupants.

24.3.12.6 The analysis shall be based on the maximum occupant load calculation for every occupiable room, building, area, space, campus, or region is expected to contain.

24.3.12.7 Occupancy characteristics shall comply with 24.3.12.7.1 and 24.3.12.7.2.

24.3.12.7.1 The risk analysis shall consider characteristics of the buildings, areas, spaces, campuses or regions, equipment, and operations that are not inherent in the design specifications.

24.3.12.7.2 Those elements that are not inherent in the design specifications, but that affect occupant behavior or the rate of hazard development, shall be explicitly identified and included in the risk analysis.

24.3.12.8 The risk analysis shall consider the following types of potential events, which are not all-inclusive but reflect the general categories that shall be considered in the risk analysis:

(1) Natural hazards — Geological events

(2) Natural hazards — Meteorological events

(3) Natural hazards — Biological events

(4) Human caused — Accidental events

(5) Human caused — Intentional events

(6) Technological — Caused events

24.3.12.9 The risk analysis shall include a review of the extent to which occupants and personnel are notified, based on the anticipated event (potential hazard).

24.3.12.10* The risk analysis shall be used as the basis for development of the MNS provisions of the facility emergency response plan.

24.3.12.11 The risk analysis shall consider cybersecurity risks in accordance with Chapter 11.

<u>24.3.14 Pathway Survivability.</u>

24.3.14.1 Pathway survivability levels shall be as described in Section 12.4.

24.3.14.2 Other component survivability shall comply with the provisions of 24.4.8.6.6.

24.3.14.3* The pathway survivability requirements in 24.3.14.4 through 24.3.14.16 shall apply to notification and communications circuits and other circuits necessary to ensure the continued operation of the emergency communications system.

24.3.14.4 In-building fire emergency voice/alarm communications systems shall comply with 24.3.14.4.1 or 24.3.14.4.2.

24.3.14.4.1 For systems that do not employ relocation or partial evacuation, a Level 0, Level 1, Level 2, Level 3, or Level 4 pathway survivability shall be permitted.

24.3.14.4.2* For systems employing relocation or partial evacuation, the requirements of 24.3.14.4.3 through 24.3.14.4.6.4 shall apply to the communication and control circuit pathways between a room or rated enclosure containing fire alarm equipment and other room(s) or rated enclosure(s) containing fire alarm equipment required for occupant notification.

24.3.14.4.3* Where the building is constructed with a fire resistance rating that is equal to or greater than 2 hours, the installation shall comply with 24.3.14.4.6 or provide a pathway survivability of Level 2 or Level 3.

24.3.14.4.4* Where the building is constructed with a fire resistance rating that is at least 1 hour and less than 2 hours, the installation shall comply with 24.3.14.4.6 or provide a pathway survivability of Level 4.

24.3.14.4.5 Where the building is constructed with a fire resistance rating that is less than 1 hour, the installation shall comply with 24.3.14.4.6.

24.3.14.4.6 Class N or Class X circuits complying with Level 1 pathway survivability shall be installed in accordance with the requirements of 24.3.14.4.6.1 through 24.3.14.4.6.4.

24.3.14.4.6.1* The requirements of 12.3.8 for pathway separation shall not apply to conductors installed in accordance with 24.3.14.4.6.

24.3.14.4.6.2* The requirements of 23.6.1 for pathway faults shall not apply to conductors installed in accordance with 24.3.14.4.6.

24.3.14.4.6.3* Circuits shall be separated in accordance with at least one of the following:

(1) The primary and redundant, or outgoing and return, conductors are separated by a floor assembly.

(2) The primary and redundant, or outgoing and return, conductors are located in dissimilar protected areas separated by a minimum of 1-hour fire-rated construction.

(3) The primary and redundant, or outgoing and return, conductors are separated by at least one-third the maximum diagonal of the notification zone.

(4) Performance alternatives are approved by the authority having jurisdiction.

24.3.14.4.6.4* An open, ground fault, or short-circuit fault on the communication and control circuits between rooms or enclosures required by 24.4.8.6.6 shall not affect the operation of the in-building fire emergency voice/alarm control equipment within these rooms or enclosures.

24.3.14.5 Pathway survivability levels for in-building mass notification systems shall be determined by the risk analysis.

24.3.14.6 Pathway survivability levels for wide-area mass notification systems shall be determined by the risk analysis.

24.3.14.7 Two-way in-building wired emergency services communications systems (i.e., fire fighters' telephone systems) that are installed where the building has less than 2-hour fire-rated construction shall have a pathway survivability of Level 1, 2, 3, or 4.

24.3.14.8 Two-way in-building wired emergency services communications systems (i.e., fire fighters' telephone systems) that are installed where the building has 2-hour fire-rated construction or greater shall have a pathway survivability of Level 2 or 3.

24.3.14.9* Area of refuge two-way emergency communications systems for rescue assistance shall comply with 24.3.14.9.1 and 24.3.14.9.2.

24.3.14.9.1 Installation of all circuit pathways between locations, room(s), or rated enclosure(s) containing communications system equipment shall comply with the requirements of 24.3.14.4.3 through 24.3.14.4.6.4.

24.3.14.9.2 Circuits intended to transmit off-premises shall have a pathway survivability of Level 0, Level 1, Level 2, Level 3, or Level 4.

24.3.14.10 Elevator landing two-way emergency communications systems installation of all circuit pathways between all elevator lobbies and other room(s) or rated enclosure(s) containing related control equipment required for occupant communications shall comply with the requirements of 24.3.14.4.3 through 24.3.14.4.6.4.

24.3.14.11 Elevator landing two-way emergency communications systems circuits intended to transmit off-premises shall have a pathway survivability of Level 0, Level 1, Level 2, Level 3, or Level 4.

24.3.14.12 Occupant evacuation elevator lobby two-way wired emergency communications systems installation of communication and control circuit pathways shall have a pathway survivability of Level 3.

24.3.14.12.1* A single open, ground fault, or short-circuit fault on any circuit between control equipment and elevator lobbies shall not affect the operation of the communication to any other elevator lobby.

24.3.14.12.2 Circuits intended to transmit off-premises shall have a pathway survivability of Level 0, Level 1, Level 2, Level 3, or Level 4.

24.3.14.13* Stairway communications systems required for access control provisions of other codes (locked stair doors) that are not required to be provided by other codes or standards for required use during fire evacuations shall be permitted to have a pathway survivability Level 0, Level 1, Level 2, Level 3, or Level 4 for all system circuits.

24.3.14.14* Stairway communications systems required by other codes or standards for required use during fire evacuations shall comply with 24.3.14.9.

24.3.14.15 Central command station emergency communications systems shall have pathway survivability as determined by the risk analysis.

24.3.14.16 All other emergency communications system circuits shall have pathway survivability as determined by the risk analysis.

<u>24.4* In-Building Fire Emergency Voice/Alarm Communications Systems (EVACS).</u>

Section 24.4 shall be used in the design and application of in-building fire emergency voice/alarm communications for fire alarm systems.

24.4.8* Relocation and Partial Evacuation. The requirements of 24.4.8 shall apply only to systems used for relocation or partial evacuation during a fire condition.

24.4.8.1 New systems employing relocation or partial evacuation shall require documentation in accordance with Sections 7.3, 7.4, and 7.5 in addition to the minimum documentation requirements of Sections 7.2 and 24.13.

24.4.8.2 Systems shall be provided with manual voice transmission capabilities selectively to one or more notification zones or on an all-call basis.

24.4.8.3 Where the system is used to transmit relocation instructions or other fire emergency non-evacuation messages, a 1-second to 3-second alert tone followed by a message (or messages where multi-channel capability is used) shall be provided.

24.4.8.3.1* The sequence [the alert tone followed by the message(s)] shall be repeated at least three times to inform and direct occupants in the signaling zone where the alarm initiation originated, as well as other signaling zones in accordance with the building fire safety plan.

24.4.8.3.2* When the message is recorded, the repeated message sequence of 24.4.8.3.1 shall itself be repeated after a pause of 180 seconds maximum, or other time as established by the building safety fire plan and approved by the authority having jurisdiction, until automatically silenced or reset by emergency personnel.

24.4.8.3.3 Approved alternative fire alarm notification schemes shall be permitted as long as the occupants are effectively notified and are provided instructions in a timely and safe manner in accordance with the emergency response plan.

24.4.8.4* Where the system is used to transmit partial evacuation instructions, the alert tone specified in 24.4.2.1 followed by a message (or messages where multi-channel capability is used) shall be provided.

24.4.8.5 Where provided, loudspeakers in each enclosed stairway, each exit passageway, each occupant evacuation elevator lobby, and each group of elevator cars within a common hoistway or bank shall be connected to separate notification zones for manual paging only.

24.4.8.5.1 The evacuation signal specified in 18.4.2 shall not operate in elevator cars, exit stair enclosures, and exit passageways.

24.4.8.5.2 Manually activated loudspeakers shall be permitted in exit stair enclosures, exit passageways, and elevators in buildings that have emergency voice/alarm communications systems in accordance with Section 24.4.

24.4.8.5.3 Where required by other governing laws, codes, or standards, loudspeakers shall be provided in locations specified in 24.4.8.5 and shall conform to Section 24.4.

24.4.8.6 The requirements of 24.4.8.6 shall apply to both audible (tone and voice) and visual notification appliance circuits.

24.4.8.6.1* Fire alarm systems used for partial evacuation and relocation shall be designed and installed such that attack by fire within a notification zone does not impair control and operation of the notification appliances outside the notification zone.

24.4.8.6.2 Performance features provided to ensure operational reliability under adverse conditions shall be described and technical justification provided in the documentation submitted to the authority having jurisdiction with the analysis required in 23.4.3.1.

24.4.8.6.3* All circuits necessary for the operation of the notification appliances shall be protected until they enter the notification zone that they serve by the protection provided by the pathway survivability level required in 24.3.14.4.2.

24.4.8.6.4 Where the separation of in-building fire emergency voice/alarm control equipment locations results in the portions of the system controlled by one location being dependent upon the control equipment in other locations, the circuits between the dependent controls shall be protected against attack by fire by the protection provided by the pathway survivability level required in 24.3.14.4.2.

24.4.8.6.5 Protection of circuits between redundant control equipment locations that are not mutually dependent shall not be required.

24.4.8.6.6 Where the separation of the in-building fire emergency voice/alarm control equipment occurs as in 24.4.8.6.4, and where the circuits are run through junction boxes, terminal cabinets or control equipment, such as system control units, power supplies and amplifiers, and where cable integrity is not maintained, these components shall, in addition to the pathway survivability required by 24.3.14.4.2, be protected by using one of the following methods:

(1) A 2-hour fire-rated enclosure

(2) A 2-hour fire-rated room

(3) Other equivalent means to provide a 2-hour fire resistance rating approved by the authority having jurisdiction

24.4.8.6.7 Paragraphs 24.4.8 through 24.4.8.6.6 shall not automatically apply when relocation or partial evacuation is of a non-fire emergency unless identified and required by a risk analysis.

24.9* Two-Way Radio Communications Enhancement Systems.

All in-building two-way radio communications enhancement systems shall be designed, installed, and maintained in accordance with NFPA 1221. (Note: to be 1225 in future.)

NFPA 1225 - Standard for Emergency Services Communications[19]

Chapter 18 - In-Building Emergency Responder Communications Enhancement Systems (formerly NFPA 1221)

18.12.3 Component Requirements.

18.12.3.1 All cables shall be installed in accordance with Chapters 7 and 8 of NFPA 70.

18.12.3.2 Mechanical protection of work and raceways for coaxial cables shall comply with Article 820 of NFPA 70.

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18.12.3.3 Backbone cables and backbone cable components installed in buildings that are fully protected by an automatic sprinkler system in accordance with NFPA 13 shall not be required to have a fire resistance rating.

18.12.3.4* Backbone cables and backbone cable components installed in nonsprinklered buildings, in buildings that are partially protected by a sprinkler system, or in high-rise buildings shall be protected from attack by fire in accordance with one of the following:

(1) Use a cable with a listed fire-resistance rating in accordance with the following:

> (1) Where the primary structural frame of a building is required to have a fire-resistance rating of 2 hours or more or is classified as heavy timber construction, the minimum fire-resistance rating shall be 2 hours.
>
> (2) Where the primary structural frame of a building is required to have a fire-resistance rating of less than 2 hours, the minimum fire resistance rating shall be 1 hour.
>
> (3) Where the primary structural frame of a building does not require a fire-resistance rating, a fire resistance rating shall not be required.

(2) A protected enclosure or area shall have a fire-resistance rating in accordance with the following:

> (a) Where the primary structural frame of a building is required to have a fire-resistance rating of 2 hours or more or is classified as heavy timber construction, the minimum fire-resistance rating shall be 2 hours.
>
> (b) Where the primary structural frame of a building is required to have a fire-resistance rating of less than 2 hours, the minimum fire resistance rating shall be 1 hour.
>
> (c) Where the primary structural frame of a building does not require a fire-resistance rating, a fire resistance rating shall not be required.

18.12.3.5 Where backbone cables and distribution antenna cables are run in a fire-resistant enclosure or protected area, both of the following shall apply, except as permitted in 18.12.3.6:

(1) The connection between the backbone cable and the distribution antenna cables shall be made within an enclosure or protected area identified in 18.12.3.4.

(2) Passage of the distribution antenna cable in and out of the enclosure or protected area shall be fire-stopped to an equivalent rating of the enclosure or protected area.

18.12.3.6 If both the backbone cables and the backbone cable components are fire rated in accordance with 18.12.3.4, the connection of the distribution antenna cable shall not be required to be made within an enclosure or protected area.

Underwriters Laboratories, Inc. (UL)[20]

UL 2196, Fire Test for Circuit Integrity of Fire-Resistive Power, Instrumentation, Control and Data Cables

6. CONDITIONS OF ACCEPTANCE

6.1 Determination of Circuit Integrity

6.1.1 For power, instrumentation and control cables, the conductors shall maintain continuity and supply voltage and current to the load as described in Clauses 6.1.1.1 and 6.1.1.2.

6.1.1.1 The fuse required in Clause 5.1.6.6 shall not open for the duration of the test.

6.1.1.2 The visual or electrical indicator connected to the cable shall continue to indicate circuit integrity for the duration of the test.

6.1.1.3 The insulation resistance of the power, instrumentation, and control cable shall be reported.

6.1.2 For data cables, the cable shall maintain error free data transfer and retrieval throughout the test as described in Clause 6.1.2.1.

6.1.2.1 The bit error rates during the BER test shall not exceed the maximum for the total bits transferred as shown in Table 1.

6.1.3 Each fire-resistive cable system shall have a single hourly rating. The system hourly rating shall be the lesser of the hourly rating achieved by the system that is required to be tested.

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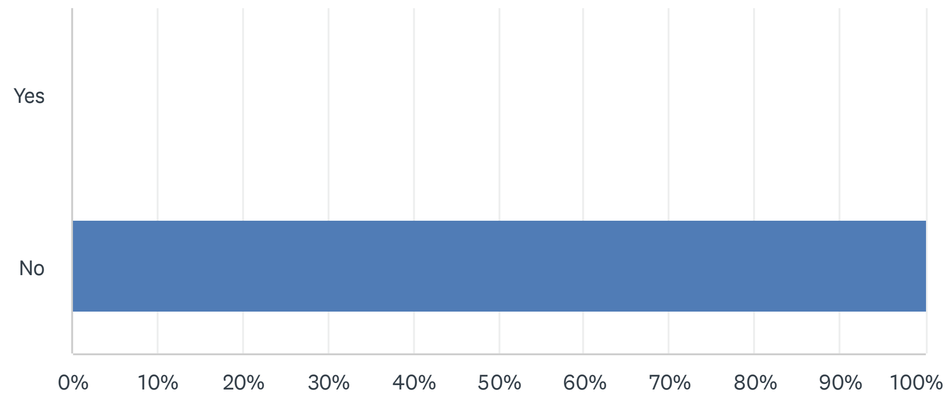
Annex B – Survey

SURVEY OVERVIEW AND CONTENT

On the next following pages you find the overview and content of the survey. One answer example has been added.

Q1 Are you aware of any operational cable (defined as any conductor, optical fiber, radio carrier, or other means for transmitting system information to remain operational during fire conditions) for life safety systems that failed due to fire/fire effects?

Answered: 3 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	0.00%	0
No	100.00%	3
TOTAL		3

Q2 What date did this cable failure due to fire or effects from fire occur?

Answered: 0 Skipped: 3

ANSWER CHOICES	RESPONSES	
Date / Time	0.00%	0

#	DATE / TIME	DATE
	There are no responses.	

Q3 Where did this cable failure due to fire or effects from fire occur? (City, State/Province, Country)

Answered: 0 Skipped: 3

#	RESPONSES	DATE
	There are no responses.	

Q4 What type of life safety system cable failed due to fire or effects from fire (if known)?

Answered: 0   Skipped: 3

#	RESPONSES	DATE
	There are no responses.	

Q5 What temperature (°F) did the cable fail due to fire or effects from fire (if known)?

Answered: 0 Skipped: 3

#	RESPONSES	DATE
	There are no responses.	

Q6 What type of occupancy did this occur (educational, healthcare, industrial etc.)

Answered: 0 Skipped: 3

#	RESPONSES	DATE
	There are no responses.	

Q7 What is the construction type in which the failure occurred?

Answered: 0 Skipped: 3

No matching responses.

ANSWER CHOICES	RESPONSES	
Concrete	0.00%	0
Steel	0.00%	0
Brick	0.00%	0
Wood	0.00%	0
Other (please specify)	0.00%	0
TOTAL		0

#	OTHER (PLEASE SPECIFY)	DATE
	There are no responses.	

Q8 Which of the following best describes your position/industry?

Answered: 0   Skipped: 3

No matching responses.

ANSWER CHOICES	RESPONSES	
First Responder	0.00%	0
Facility Manager	0.00%	0
Electrical	0.00%	0
Manufacturer	0.00%	0
Installer/Maintainer	0.00%	0
Engineer	0.00%	0
Consultant	0.00%	0
Other (please specify)	0.00%	0
TOTAL		0

#	OTHER (PLEASE SPECIFY)	DATE
	There are no responses.	

Q9 Is there anything else you would like to share about this cable failure due to fire or effects from fire?

Answered: 0 Skipped: 3

#	RESPONSES	DATE
	There are no responses.	