NUREG-1805, Vol. 2

# Fire Dynamics Tools (FDT$^s$) Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program

## Draft Report for Comment

## Appendices

**U.S. Nuclear Regulatory Commission**
**Office of Nuclear Reactor Regulation**
**Washington, DC 20555-0001**

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# Appendices

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# ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Reactor Regulation (NRR), Division of Systems Safety and Analysis (DSSA), Plant Systems Branch (SPLB), Fire Protection Engineering and Special Projects Section has developed quantitative methods, known as "Fire Dynamics Tools (FDT$^s$)," to assist regional fire protection inspectors in performing fire hazard analysis (FHA). These methods have been implemented in spreadsheets and taught at the NRC's quarterly regional inspector workshops. FDT$^s$ were developed using state-of-the-art fire dynamics equations and correlations that were pre-programmed and locked into Microsoft Excel® spreadsheets. These FDT$^s$ will enable the inspector to perform quick, easy, first-order calculations for the potential fire scenarios using today's state-of-the-art principles of fire dynamics. Each FDT$^s$ spreadsheet also contains a list of the physical and thermal properties of the materials commonly encountered in NPPs. This NUREG addresses the technical bases for FDT$^s$, which were derived from the principles developed primarily in the Society of Fire Protection Engineers (SFPE) *Handbook of Fire Protection Engineering,* National Fire Protection Association (NFPA) *Fire Protection Handbook*, and other fire science literature. The subject matter of this NUREG covers many aspects of fire dynamics and contains descriptions of the most important fire processes. A significant number of examples, reference tables, illustrations, and conceptual drawings are presented in this NUREG to expand the inspector's appreciation in visualizing and retaining the material and understanding calculation methods.

Key Words: Fire dynamics, Hazard analysis, Inspection, Significance determination process

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# APPENDIX A. NUCLEAR POWER PLANT ELECTRICAL CABLE FUNDAMENTALS

## A.1 Introduction

The function of a electrical cable is to provide a medium for transmitting electrical energy (power control or signals) between two points in a common electrical circuit, while simultaneously maintaining the electrical isolation of the transmission path from other elements of the same circuit and from other co-located circuits. Cable failure, therefore, implies loss of continuity in the energy transmission path or diversion of a sufficient fraction of the available electrical energy to an unintended circuit destination such that proper function of the circuit is no longer assured. A typical boiling water reactor (BWR) requires approximately 97 km (60 miles) of power cable, 80.5 km (50 miles) of control cable and 402 km (250 miles) of instrument cable. A pressurized water reactor (PWR) may require far more, as illustrated by the containment building of Waterford Steam Electric Generating Station, Unit 3 which required nearly 1,609 km (1,000 miles) of cable (NUREG/CR-6384). The majority of fire dynamics, fire risk evaluations will focus on electrical cables because of their thermal fragility. It is therefore necessary to have a fundamental understanding of electrical cables.

Fire can cause cable failures in several ways. Experience from actual fire events has shown that different modes of fire-induced failures in electrical cables can in turn, produce a variety of circuit faults, leading to a range of circuit faulting behaviors. The risk implications of a given circuit fault depend upon the associated component function.

This appendix describes the types of cables commonly encountered in nuclear power plant (NPP) applications and the modes of cable failure that might be observed. It also discusses the potential impact of various cable failure modes on power, control, and instrumentation circuits. In addition, this appendix identifies the factors that can influence the potential for each of the identified cable failure modes that may result from a fire. Because of the large quantity of cable in a typical NPP and the fact that much of the cable material (e.g., polymer insulation and outer jacket) is combustible, cables frequently comprise a significant fraction of the total combustible load in many areas of a NPP.

The fire at Browns Ferry Nuclear Power Plant (BFNP) Unit 1, provides the classic example of how loss of function and spurious signals can occur as a result of a cable fire (NRC Bulletin BL-75-04). As such, it represents one of the most serious events ever experienced at a U.S. commercial NPP. In that fire, which was initiated by a candle flame igniting polyurethane foam in an improperly sealed penetration, temperatures as high as 816 °C (1,500 °F) caused damage to more than 1,600 cables routed in 117 conduits and 26 cable trays. Of these, a large number were safety-related. The number of damaged safety-related cable can be categorized by Unit as: 482 from Unit 1, 22 from Unit 2, and 114 common to both units. As a result, the reactor lost control power to a significant amount of emergency core cooling system (ECCS) equipment. In fact, at one point in the event, all power to Unit 1 ECCS motors and valves was lost. Furthermore, fire-induced short circuits caused many instrument, alarm, and indicating circuits to provide false and conflicting indications of equipment operation, thereby impeding operators' ability to control reactor safety functions. For example, one panel indicated that all ECCS pumps were operating, while another panel indicated that there was no need for this operation. The fire was contained to a relatively small interior area of the plant [the cable spreading room (CRS) and Unit 1 reactor building] and the conditional core damage probability, for the event has been estimated to be about 0.4 (NUREG/CR-2497, "Precursors to Potential Severe Core Damage Accidents: 1969–1979, A Status Report," Volume 1 and 2).

The most intense part of the fire, which involved burning stacks of horizontal cable trays, covered an area roughly 3.3 m (10.9 ft) by 2.5 m (8.2 ft) in dimension. Due to reluctance to use water, fire suppression was considerably delayed; and the fire burnt some 7 hours after it started.

## A.2 Electrical Cable Construction

Cables come in a wide variety of configurations. The primary configuration features that define a given cable are the size of the individual conductors [expressed using the American Wire Gauge (AWG)], the number of conductors, shielding and/or armoring features, and the insulation/jacket materials used.

Of the materials available for use as cable insulation and jacketing, the broadest categories are thermoplastic and thermoset. Thermoplastic materials melt when heated and solidify when cooled. Thermoset materials do not melt, but do begin to smolder and burn if sufficiently heated. In general, thermoset materials are more robust, with failure temperatures of approximately 350 °C (662 °F) or higher. Thermoplastic materials typically have much lower 218°C (425 °F) failure temperatures, where failure is typically associated with melting of the material.

Cables typically consist of one or more metallic conductors, insulation, filler, shielding, sheaths, and jacket. Each metallic conductor (generally copper or aluminum) is electrically isolated by being encased in a layer of insulation. The insulation, which is often considered the single most important component of the cable is typically made from a dielectric material (e.g., plastic, rubber, polymeric, silicone-based, or rubber-based material of some type). The term "sheath" commonly refers to an aluminum or steel jacket, rather than rubber or plastic (e.g., armored sheathed cable). Some cables may also include one or more shields consisting of metallic tape, composition tape, or a metallic braid. The shield is wrapped around the insulated conductors under the jacket or sheath. Single or multiple insulated conductors with their associated shields and sheaths are grouped together within a single integral protective jacket. The jacket serves a strictly utilitarian purpose (physical protection) and has no electrical function.

Cable jackets are typically constructed of rubber or plastic materials. The purpose of the jacket is to provide the insulated conductor(s) with physical or environmental protection, and/or increased flame retardancy. Cable jackets designed for increased flame retardancy slow the flame spread across the jacket and reduce the fuel contribution from the cable once ignited. Nevertheless, having increased flame retardancy does not ensure functionally.

Insulation plays an essential roll in a cable's overall performance at normal and elevated temperatures. The function of insulation is to electrically separate each conductor from the others conductors and from the ground plane. In some cases, cable jackets and cable insulation are constructed of the same materials.

The number of insulated conductors within a cable are commonly identified as follows:

- Single-conductor cable (1/C)

- Multi-conductor cable e.g., 2 conductors (2/C), 7 conductors (7/C)
- Triplex-conductor (triple-conductor) cable (3/C)

Cables are also identified by their rated power voltage as shown in Table A-1 (Salley, 2000).

Table A-1. Designation of Electrical Rated Voltages

| Designation | Voltage |
|---|---|
| Low | Up to 600 V |
| Medium | 601 to 15,000 V |
| High* | 15,001 V and greater |
| *High voltage cables are typically not found inside the NPP. They may be used as a cable bus in trenches, or in the switchyards. | |

## A.3 Description of Cables

NPP use three functional type of cables. The function are, power, control, and instrumentation. Virtually every system in an NPP depends on the continued operation of one or more electrical cables. Power cables may be single-conductor, multi-conductor, or triplex. Control and instrumentation cables are generally of a multi-conductor design.

As the name implies, a single-conductor cable is a single insulated metal conductor that typically has an integral over-jacket. A triplex cable is a grouping of three signal-conductors that are manufactured together and are often twisted around a centrally located uninsulated core wire, which may be connected to the circuit ground. Basic electrical construction and configurations are illustrated in Figure A-1.

Multi-conductor cables are more varied and may come with virtually any number of conductors limited only by practical considerations such as overall physical diameter and handling ability. The most common configurations encountered in a NPPs are 2/C, 3/C, 7/C, and 12-conductor configurations. The 3/C, 7/C, and 12-conductor configurations are popular with manufacturers because they result in an overall cable product that maintains an essentially round outer profile. Another common configuration, particularly for instrument cables involves some number of twisted/shielded pairs within a protective jacket. In this case, the shield refers to a conductive wrap, such as a metal foil, wrapped around, conductor pairs. This is common in sensitive instrument circuits where stray electromagnetic or radio-frequency interference (EMI/RFI) may be a concern. These cables are also commonly used in communication systems.

The size of a cable is generally expressed as the number of conductors and the AWG of the individual conductors. Hence, a 3/C 12 AWG cable is a 3-conductor 12-gauge cable. Power cables typically range from relatively small 12 AWG cables (equivalent to cables used in residential applications for household power circuits) through very large cables in which the conductor diameter can approach or even exceed 2.54 cm (1 inch) (note that a higher gauge number indicates a smaller conductor.) For power cables, the size selection is generally based on the ampacity (current-carrying capacity) required in a specific application.

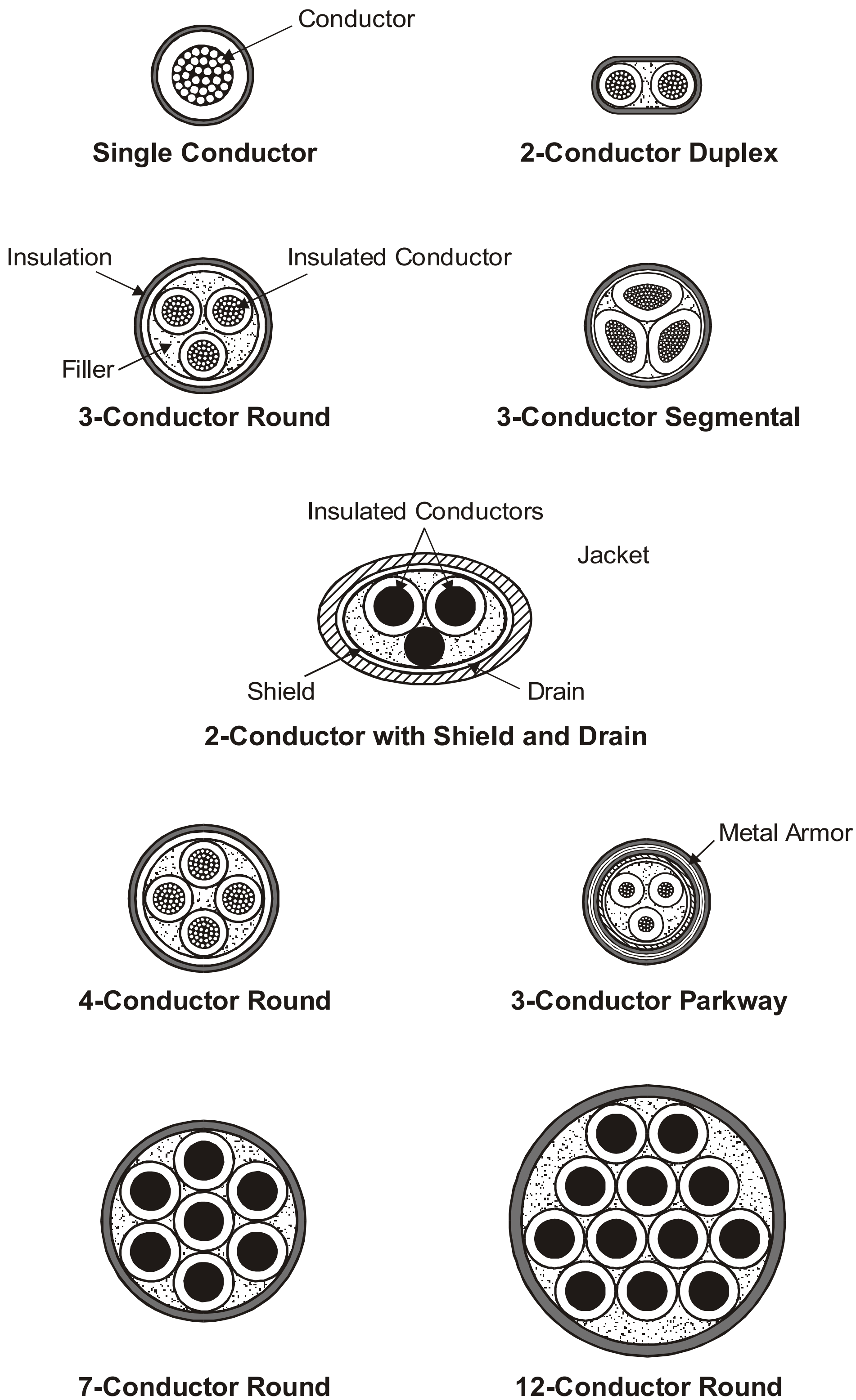



Figure A-1 Basic Electrical Cable Construction in Common Single- and Multi-Conductor Arrangements

Control cables are generally of a smaller gauge, commonly range from 16 AWG through 10 AWG with exceptions on the upper end of the size range. Instrumentation cables are generally of 16 AWG or smaller.

Voltage levels will also vary with the application. Instrument circuits generally use low voltages (50 volts or less). Control circuits are commonly in the 120–250-volt range, Power circuits encountered within an NPP generally range from 120 to 4,160 volts with offsite power circuits ranging to 15 kV or higher.

Cables are generally routed through the plant in horizontally raceways (generally trays or conduits) with vertical runs as required between different elevations in the plant. The cables are generally segregated by type (power, control, and instrumentation) but cables of various voltages and functions can be found together in some plants (generally older plants). High-voltage power cables are typically routed by themselves and may use maintained spacing address to ampacity concerns. Under maintained spacing, cables are not stacked and each cable is individually strapped to the electrical raceway. Gaps between cables ensure that they do not come into physical contact with each other. For most cables, random placement within the tray is common (that is, the cables are simply laid into the tray in a more or less random manner).

Fire exposure of an electrical cable can cause a loss of insulation resistance, loss of insulation physical integrity (i.e., melting of the insulation), and electrical breakdown or short-circuiting. Fire-induced damage to a cable can result in one of the following electrical conductor failure modes (LaChance et al., 2000):

- An open circuit result in a loss of electrical continuity of an individual conductor (i.e., the conductor is broken and the signal or power does not reach its destination).

- A short to Ground is experienced when an individual conductor comes into electrical contact with a grounded conducting medium (such as a cable tray, conduit, or a grounded conductor) resulting in a low-resistance path that diverts current from a circuit. The fault may be accompanied by a surge of excess current to ground (particularly in higher voltage circuits) that is often damaging to the conductor.

- A hot short is characterized by electrical faults that involve an energized conductor contacting another conductor of either the same cable (a conductor-to-conductor hot short) or an adjacent cable (a cable-to-cable hot short). A hot short has the potential to energize the affected conductor or to complete an undesirable circuit path.

It is important to note that a cable may have any number of conductors as discussed above and it is possible for more than one conductor failure mode to be active at a given time. For example, one set of 3-conductors may be shorted together (conductor-to-conductor hot short) while a fourth conductor shorts to ground.

Both shorts to ground and hot shorts may be manifested in the form of a low-impedance fault (often referred to as a bolted or dead-short) or as a high-impedance fault between the conductors. These two modes of shorting are distinguished on the basis of the following considerations:

- A high-impedance fault may allow power to pass from one conductor to another (or to ground) even between circuits with dissimilar voltages, while a low-impedance short between circuits of dissimilar voltage or between a circuit and ground often trips circuit protection features (fuses or breakers) in one or both circuits.

- A single low-impedance short in a power circuit typically trips the lowest level of upstream circuit protection, while multiple high-impedance faults may trip a higher-level circuit protection feature (if circuit protection coordination is not provided), leading to loss of a higher-level electrical bus.

- A high-impedance faults in an instrumentation circuit may lead to a biased indication that might not be detected by operators, while low-impedance shorts typically result in a more easily detectable situation (e.g., complete loss of indication or an indication at the extreme high or low scale).

## A.4 Cable Materials

For fire risk analysis, cable insulation and jacket materials can be separated into two board categories:

### A.4.1 Thermoplastic Materials

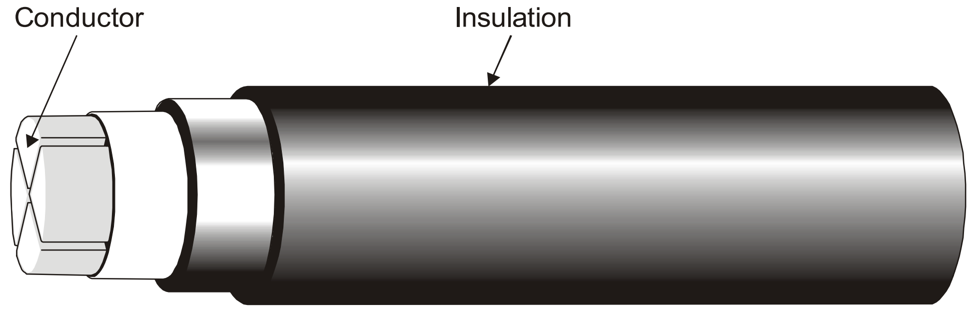
Thermoplastic materials are defined as high molecular weight polymers that are not cross-linked and are generally characterized by the distinct melting point of the insulation material. Thermoplastic materials can be repeatedly softened by heating and hardened by cooling within a temperature band that is a physical property of the material. This property is a function of the loose molecular bonding of the material. Some thermoplastic materials have a low melting point, which can be a disadvantage in that melting insulation can lead to conductor failures (e.g., conductor-to-conductor shorts and conductor to ground shorts) at relatively low temperatures. Some thermoplastic insulations are also problematic in that they produce dripping, flaming fires after ignition.

Thermoplastic insulation is generally easy to manufacture and economical to use. Common thermoplastic insulations include cellular; low and high polyethylene (PE); polyvinyl chloride (PVC); polyurethane; polypropylene (PPE); nylon; chlorinated polyethylene (CPE); tetrafluoroethylene (TFE), Teflon, and fluorinated polymers such as DuPont's TFE copolymers with ethylene (known as Tefzel®), DuPont's PFA (perflouroalkoxy branched polymers), Allied Chemical's Halar (ethylene copolymer with chlorotrifluoroethylene), and Dynamit Nobel's Dyflor (polyvinylidene fluoride). Figure A-2 shows typical thermoplastic (PVC) insulated cable construction.

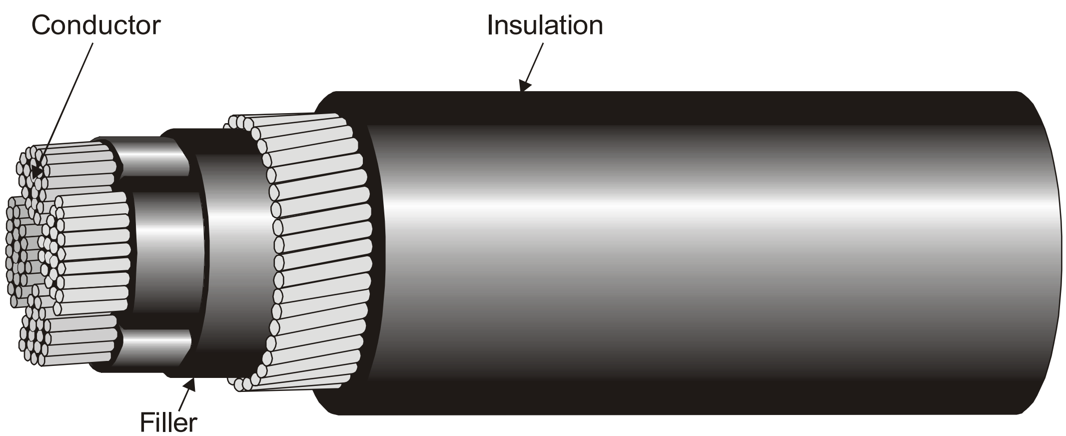
In general, cables that do not pass IEEE 383 rating (i.e., non-IEEE qualified) are thermoplastic.

### A.4.2 Thermosetting Materials

The molecular consist of chains that are tied together with covalent bonds in a network (cross-linked). Thermoset insulations are generally characterized as softening, but not melting, during higher-than-normal temperature exposures. While they soften, they tend to maintain the mechanical properties of the insulator. As a result, thermoset insulations generally exhibit better low-and-high temperature properties, thermal aging resistance, and overload resistance than




**Single-core, Sectoral Aluminum Conductor, PVC Insulated Cable**

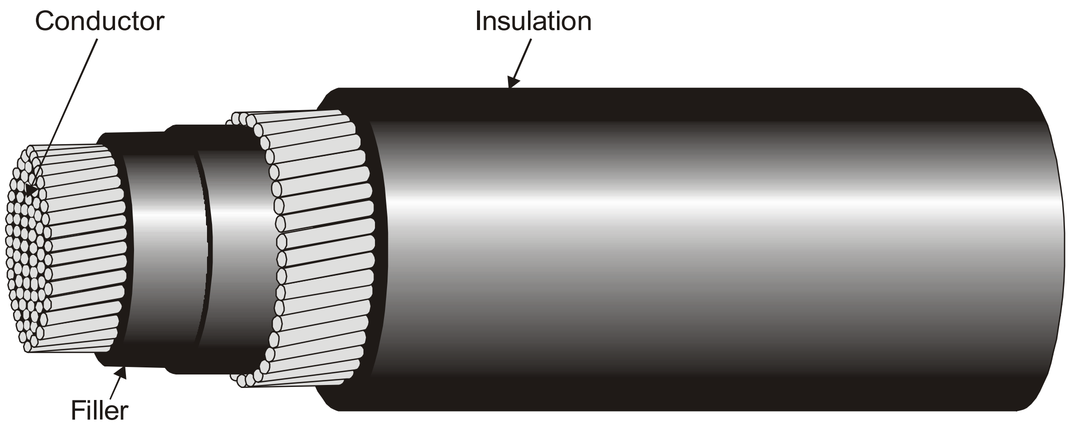



**Four-core, Cooper Conductor, PVC Insulated Cable**

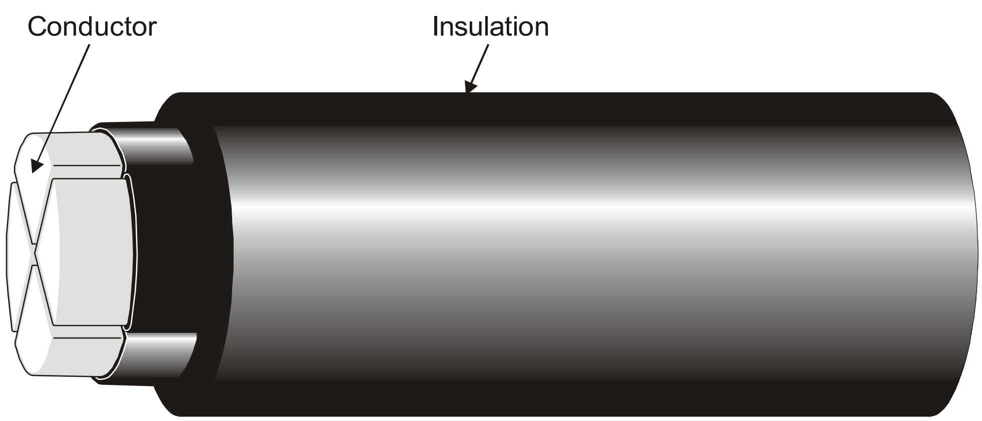
Figure A-2 Thermoplastic Insulated Cable Construction thermoplastic insulations. Thermoset materials are vulcanized by heat (or other methods) during their fabrication process. As such, the materials are substantially infusible and insoluble. The molecular structure is tightly interlocked (in contrast to thermoplastic insulations). Common thermosetting insulations include ethylene propylene rubber (EPR); cross-linked polyethylene (XLPE); DuPont's Hypalon (chlorosulphonated polyethylene); nitrile or rubber butadiene nitrite (NBR); styrene butadiene rubber (SBR); polybutadiene,;neoprene; and silicone rubber.

In general, cables that do pass IEEE 383 rating (i.e., IEEE 383 qualified) are thermoset cables.

In summary, thermoplastic materials are high molecular weight polymers that are not cross-linked, while the polymer chain of thermoset materials are cross-linked in covalent bonded networks. When thermoset resins are heated during manufacture, from ambient to upward of 232 °C (450 °F), they under go an irreversible chemical reaction, referred to as "curing" or "polymerization," to make the final cross-linked thermoplastic product. While thermoplastic materials can be reshaped by heating and cooling within the proper temperature ranges for the materials, thermoset materials cannot be reshaped once they have been cross-linked. Figure A-3 shows typical thermoset (XLPE) insulated cable construction.




**Single-core, XLPE Insulated Cable with Standard Conductor, Taped Bedding and Aluminum Wire Armor**




**Four-core Unarmored, XLPE Insulated Cable with Solid Aluminum Conductor**

Figure A-3 Thermoset Insulated Cable Construction

## A.5 References

LaChance, J., S.P. Nowlen, F. Wyant, and V. Dandini, "Circuit Analysis-Failure Mode and Likelihood Analysis," A Letter Report to USNRC, Sandia National Laboratory, Albuquerque, New Mexico, ADAMS Accession # ML010450362, May 8, 2000.

BL-75-04, "Cable Fire at Browns Ferry Nuclear Power Station," U.S. Nuclear Regulatory Commission, Washington, DC, March 24, 1975.

Salley, M.H., "An Examination of the Methods and Data Used to Determined Functionality of Electrical Cables When Exposed to Evaluated Temperatures as a Result of a Fire in a Nuclear Power Plant," Master of Science Thesis, Department of Fire Protection Engineering, University of Maryland, College Park, Maryland, 2000.

U.S. Nuclear Regulatory Commission (U.S.) (NRC), NUREG/CR-6384, "Literature Review of Environmental Qualification of Safety Related Electric Cables," Volume 1. NRC Washington, DC, April 1996.

U.S. Nuclear Regulatory Commission (U.S.) (NRC), NUREG/CR-2497, "Precursors to Potential Severe Core Damage Accidents: 1969–1979, A Status Report," Volume 1 and 2. NRC Washington, DC.

## A.6 Additional Reading

Grayson, S.J., P.V. Hess, U. Vercellotti, H. Breulet, and A. Green, "Fire Performance of Electric Cables - New Test Methods and Measurements Techniques," Interscience Communications Limited. United Kingdom, 2000.

Zalosh, R.G., *Industrial Fire Protection Engineering*, Chapter 9, "Electrical Cables and Equipment," John Wiley & Sons, New Jersey, 2003.

# APPENDIX B. FUNDAMENTALS OF FIRE PROTECTION

This appendix reviews some selected fundamentals and most relevant characteristics of fire chemistry and physics (temperature, combustion products, smoke, toxicity, and fire extinguishing agents, etc.). Those inspectors who have never been exposed to fire protection will benefit from studying these fundamentals.

## B.1 T-Squared ($t^2$) Fire Power Law Heat Release Rate

### B.1.1 Introduction

The primary mechanism driving the growth of a fire is the flame spreading across a fuel item or between multiple fuel items. This growing fire will continue until one or more of the following conditions exists:

- Flashover occurs and all combustible materials are involved simultaneously.
- The fire cannot spread further due to lack of combustible materials.
- The fire uses all available oxygen for combustion.
- The fire is extinguished by intervention.

### B.1.2 $t^2$ Heat Release Rate

Fire development varies depending on the combustion characteristics of the fuel(s) involved, the physical configuration of the fuel(s), the availability of combustion air, and the influences associated with the compartment. Once a stable flame is attained, most fires grow in an accelerating pattern, reach a steady state characterized by a maximum heat release rate (HRR), and then enter into a decay period as the availability of either fuel or combustion air becomes limited. Fire growth and development are limited by factors such as the quantity and arrangement of fuel, quantity of oxygen, and effect of manual and automatic suppression systems.

The primary parameter for describing fire growth is the HRR of the fire and how it changes with time. The fire growth rate depends on the ignition process; flame spread, which defines its perimeter; and the mass burning flux over the area involved. Once a combustible surface has ignited, the fire size increases as the flame spreads across the surface or as additional items in the room become involved. An important aspect is that the time required for the fire to grow is driven by the ignition source and combustible materials.

For most materials, a local ignition eventually involves the entire fuel item by flame-spreading processes. A typical sofa, for example, involves some combustion of horizontal, upward vertical, and downward vertical flame spread. For furniture and commodities, this complex fire growth process cannot be predicted by a simple formula. However, each item can have a characteristic growth time consistent with its composition and configuration. For example, a given item is ignited, it may achieve a heat release of 1 MW (1,000 kW) in 130 seconds, while another object might take 80 seconds. A complete mathematical description of this process is quite involved and relatively unpredictable given the range of ignition scenarios and the complexity of describing the burning item(s).

Nonetheless, testing has shown, that the overall HRR during the fire growth phase of many fires can often be characterized by simple-time dependent polynomial or exponential functions (Heskestad, 1997). The total heat release of fuel packages can be well approximated by the power law fire growth model for both single item burning and multiple items involved in a fire. Testing has also indicated that most growing fires can be expected to grow indefinitely until intervention by fire

fighters, and the fires have an early incubation period where fire does not conform to a power law approximation, as shown in Figure B.1-1. That figure illustrate that following an incubation period, the HRR of the fire grows continuously, proportional to the square of time.

The proposed model of the environment generated by fire in an enclosure is dependent on the assumption that the fire grows according to the following equation:

$$\dot{Q} = \alpha t^p \qquad \text{(B-1)}$$

Where:

$\dot{Q}$ = the heat release rate (HRR) of fire (kW)
$\alpha$ = a constant governing the speed of fire growth (kW/sec$^2$)
t = the time (sec)

The proposed model of the environment generated by fire in an enclosure is dependent on the assumption that the fire grows according to the following equation:

$$\dot{Q} = \alpha t^2 \qquad \text{(B-2)}$$

Where:

$\dot{Q}$ = the rate of heat release of fire (kW)
$\alpha$ = a constant governing the speed of fire growth (kW/sec$^2$)
t = the time (sec)

The growth rate approximately follows a relationship proportional to time squared for flaming and radially spreading fires, which are consequently called t-squared ($t^2$) fires. Such fires are classed by the speed of growth, identified as ultra-fast, fast, medium, and slow. Where these classes are used, they are defined on the basis of the time required for the fire to grow to a heat release rate (HRR) of 1,000 kW (1 MW). Table B.1-1 summarizes the fire intensity constant ($\alpha$) and the growth time ($t_g$) for each of these classes.

Table B.1-1. Summary of $t^2$ Fire Parameters

| Class of Fire Growth | Intensity Constant $\alpha$ (kW/sec$^2$) | Growth Time $t_g$ (sec) |
|---|---|---|
| Slow | 0.00293 | 600 |
| Medium | 0.01172 | 300 |
| Fast | 0.0469 | 150 |
| Ultra-Fast | 0.1876 | 75 |

Figure B.1-1 Fire Growth of $t^2$ Fitted to Data (Heskestad, 1997)
(Waiting for Copyright Permission)

Figure B.1-2 plots the $t^2$ fire growth rate curves that have been developed. The $t^2$ relationship has proven useful and has therefore been adopted into NFPA 72, "National Fire Alarm Code®," to categorize fires for siting of detectors as well as NFPA 92B "Guide for Smoke Management Systems in Mall, Atria, and Large Areas," for design of smoke control systems.

A $t^2$ fire can be viewed as one in which the HRR per unit area is constant over the entire ignited surface and the fire spreads as a circle with a steadily increasing radius. In such cases, the burning area increases in proportion to the square of the steadily increasing fire radius. Of course, fires that do not have such a conveniently regular fuel array and consistent burning rate might or might not actually produce a $t^2$ curve, but the $t^2$ approximation appears to be close enough for reasonable design decisions.

Figure B.1-3 provides the HRR results of various full-scale free burn tests performed at Factory Mutual Research Corporation (FMRC) (also reported by Nelson, 1987), superimposed on the $t^2$ HRR curves, using various standard test commodities for fuel arrays. Figure B.1-4 relates the classes of $t^2$ fire growth curves to a selection of actual fuel arrays. Figure B.1-5 plots the HRR curves for various upholstered furniture items. Figures B.1-3 to B.1-5 show that the actual fire growth curves for many common fuel arrays tend to be greater than the medium fire growth curve.

Table B.1-2 tabulates the maximum HRR for various warehouse materials. As shown, the majority of these materials exhibit fire growth rates in the fast or ultra-fast ranges. The preponderance of actual fire testing over 90's has shown that common fuel arrays exhibit fire growth rates that tend to exceed the medium $t^2$ fire growth rate.

Table B.1-2. Maximum Heat Release Rates of Warehouse Materials
(NFPA 72, 1999 Edition, Appendix B)

| Warehouse Material (See Notes 1 and 2) | Growth Time (sec) | Heat Release Rate ($\dot{Q}$) (Btu/sec-ft$^2$) (See Note 3) | Fire Growth Classification |
|---|---|---|---|
| Wood pallets, stacked, 1½ ft high (6%–12% moisture) | 150–310 | 110 | Fast-Medium |
| Wood pallets, stacked, 5 ft high (6%–12% moisture) | 90–190 | 330 | Fast |
| Wood pallets, stacked, 10 ft high (6%–12% moisture) | 80–110 | 600 | Fast |
| Wood pallets, stacked, 16 ft high (6%–12% moisture) | 75–105 | 900 | Fast |
| Mail bags, filled and stored 5 ft high | 190 | 35 | Medium |
| Cartons, compartmented and stacked 15 ft high | 60 | 200 | Fast |
| Paper, vertical rolls, stacked 20 ft high | 15–28 | - | (See Note 4) |

| Table B.1-2. Maximum Heat Release Rates of Warehouse Materials (NFPA 72, 1999 Edition, Appendix B) (continued) | | | |
|---|---|---|---|
| Warehouse Material (See Notes 1 and 2) | Growth Time (sec) | Heat Release Rate ($\dot{Q}$) (Btu/sec-ft$^2$) (See Note 3) | Fire Growth Classification |
| Cotton (also PE, PE/cot, acrylic/nylon/PE), garments in 12 ft high racks | 20–42 | - | (See Note 4) |
| Cartons on pallets, rack storage, 15 ft–30 ft high | 40–280 | - | Fast-Medium |
| Paper products, densely packed in cartons, rack storage, 20 ft high | 470 | - | Slow |
| PE letter trays, filled and stacked 5 ft high on cart | 190 | 750 | Medium |
| PE trash barrels in cartons, stacked 15 ft high | 55 | 250 | Fast |
| FRP shower stalls in cartons, stacked 15 ft high | 85 | 110 | Fast |
| PE bottles, packed in item 6 | 85 | 550 | Fast |
| PE bottles in cartons, stacked 15 ft high | 75 | 170 | Fast |
| PE pallets, stacked 3 ft high | 130 | - | Fast |
| PE pallets, stacked 6 ft–8 ft high | 30–55 | - | Fast |
| Methyl alcohol | - | 65 | - |
| Gasoline | - | 200 | - |
| Kerosene | - | 200 | - |
| Diesel oil | - | 180 | - |

Notes:
(1) For SI units, 1 ft = 0.305 m.

(2) FRP = fiberglass-reinforced polyester; PE = polyethylene; PS = polystyrene; PP = polypropylene; PU = polyurethane; PVC = polyvinyl chloride.

(3) The HRR per unit floor area are for fully involved combustibles, assuming 100-percent combustion efficiency. The growth times shown are those required to exceed 1,000 Btu/sec HRR for developing fires, assuming 100-percent combustion efficiency.

(4) Fire growth rate exceeds design data.

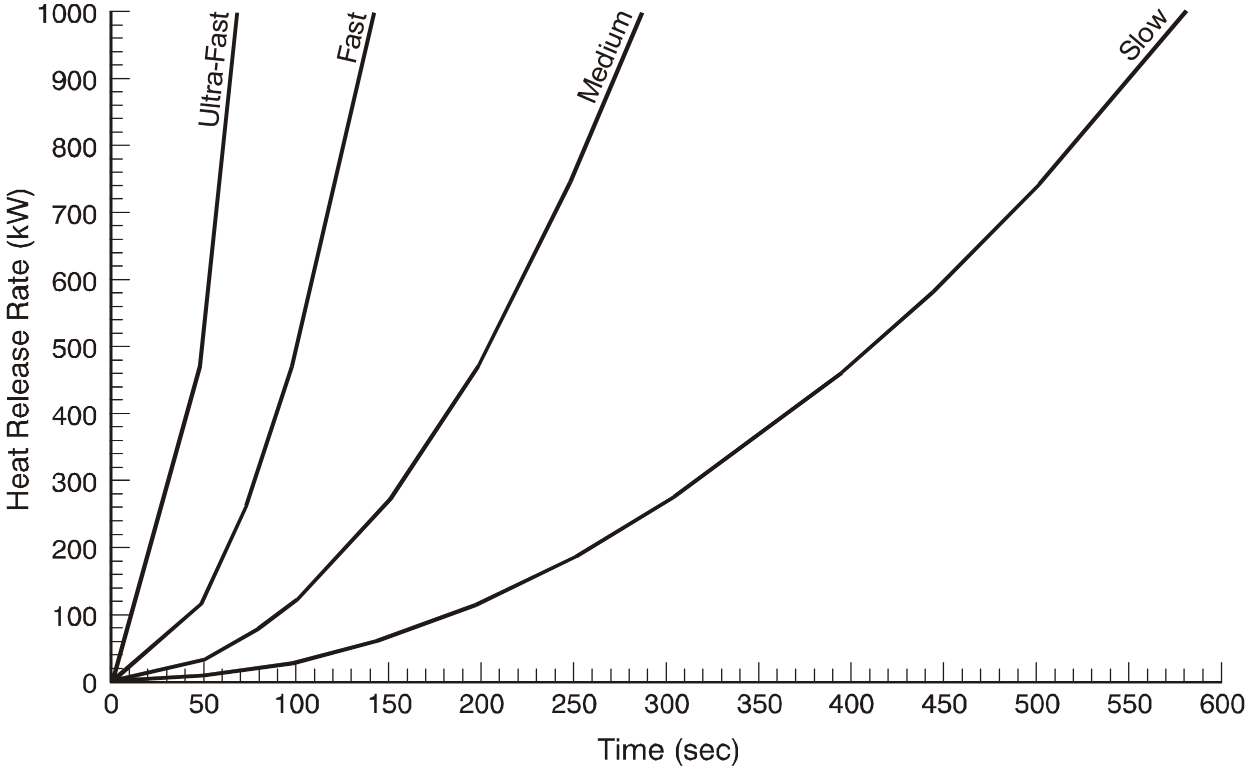



Figure B.1-2 Growth Rate Curves for $t^2$ Fire (NFPA, 72 and NFPA, 92B)

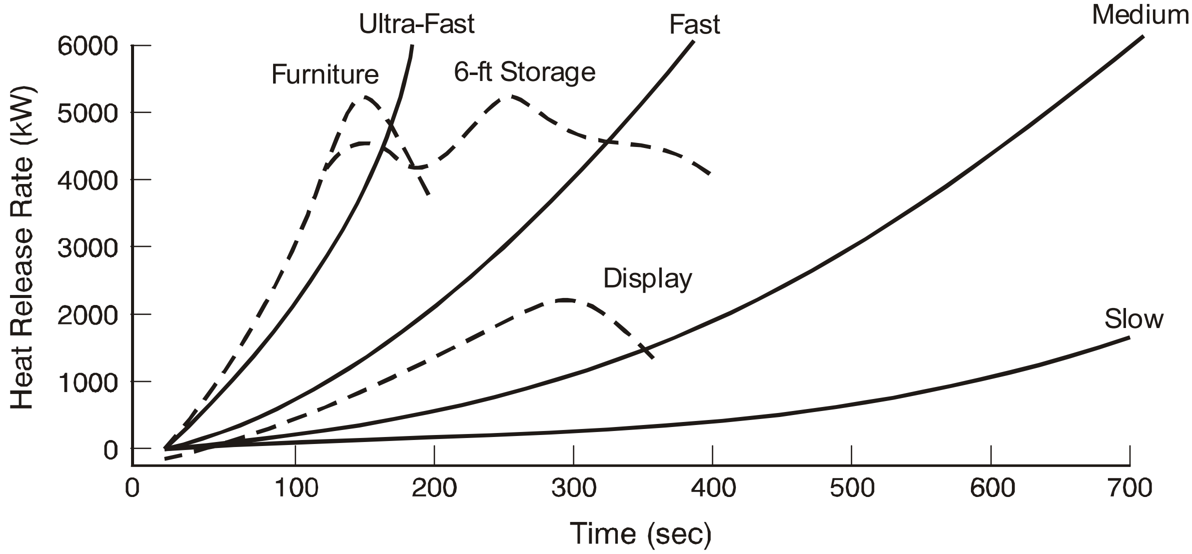



Figure B.1-3 Comparison of $t^2$ Heat Release Rate with Full-Scale Free-Burn Heat Release Rate (Nelson, 1987)

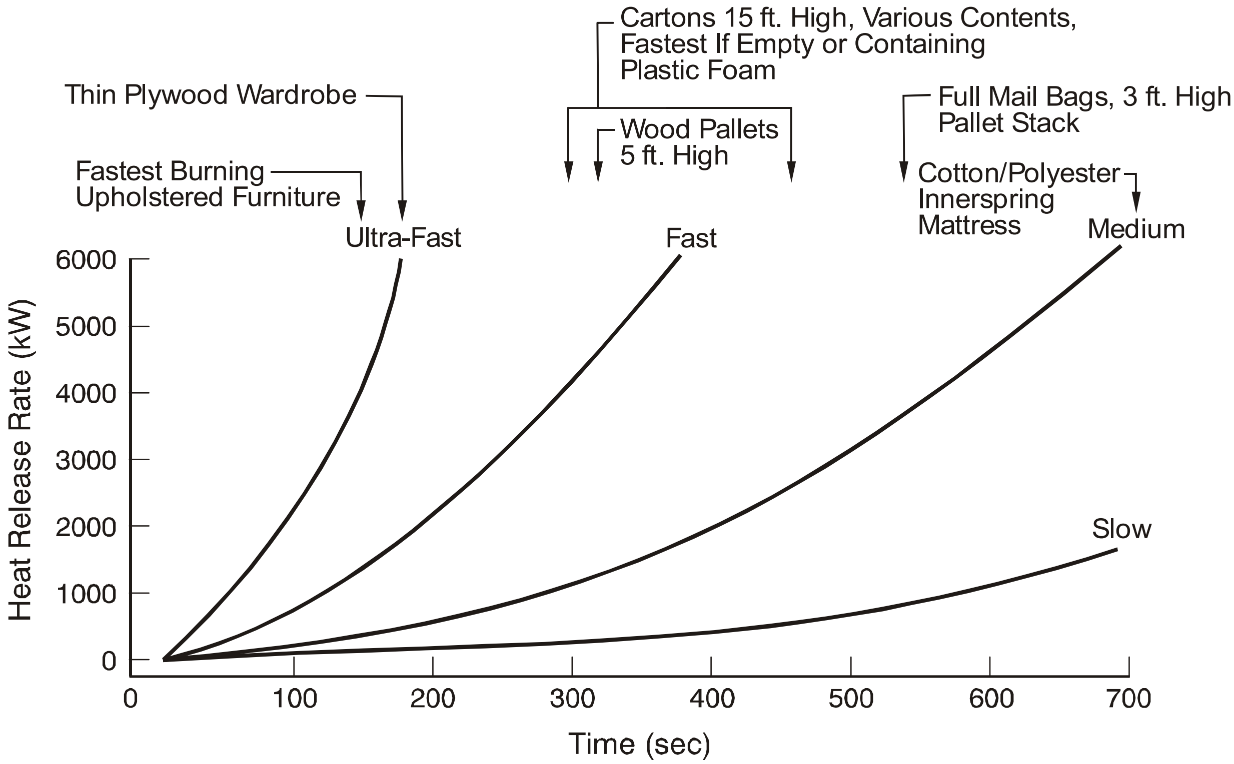



Figure B.1-4 Relation of $t^2$ Heat Release Rate to Some Fire Tests (Nelson, 1987)

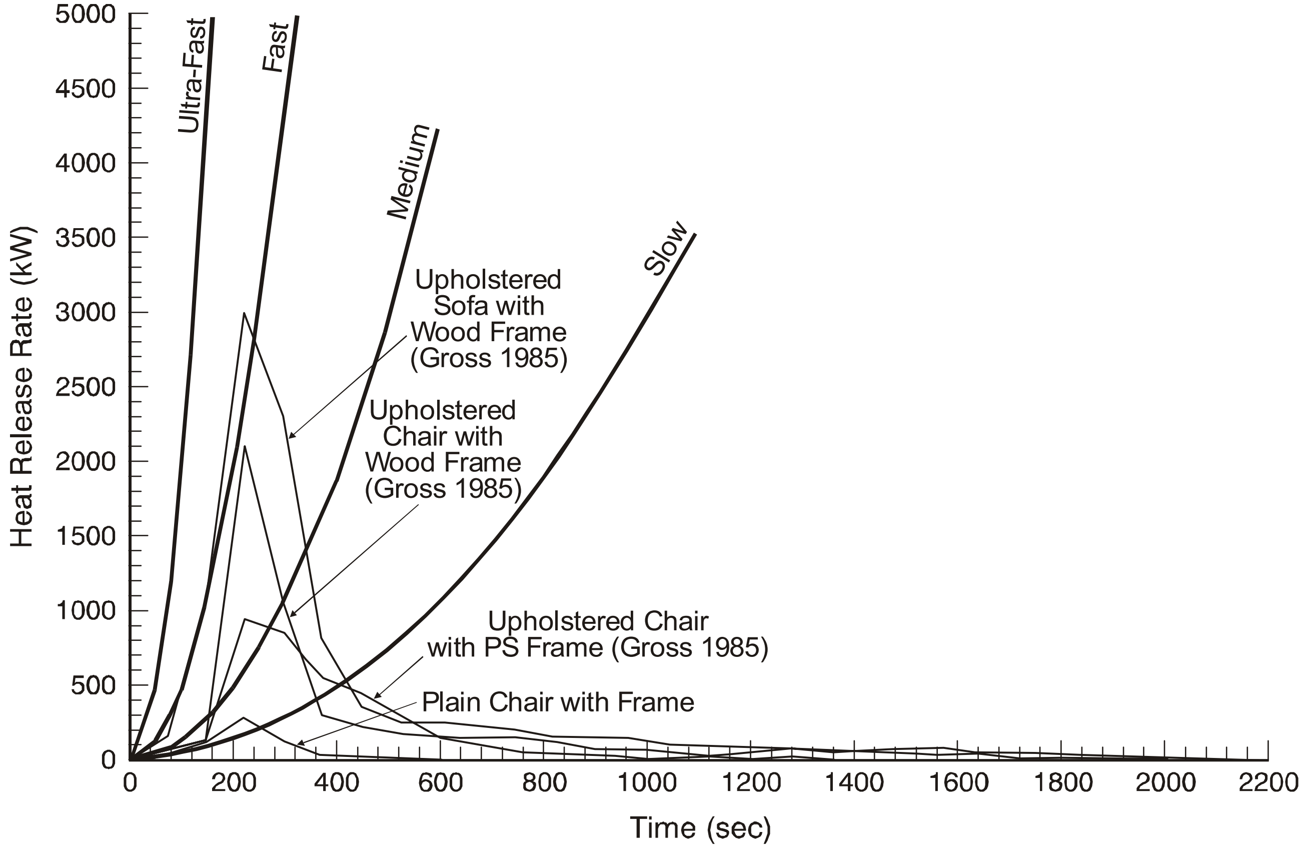



Figure B.1-5 Comparison of $t^2$ Heat Release Rates with Full-Scale Furniture Heat Release Rate

Madrzykowski (1996), compared HRR data for office work stations with standard $t^2$ HRR fire curves. Figure B.1-6 shows the HRR time history of the fire growth of a three-sided office work station compared to $t^2$ fire curves. Notice how the fire begins as a slow-medium growth rate fire, and then the slop increases to be representative of a fast-ultra-fast fire. As shown in Figure B.1-6, one can use the $t^2$ fire growth model to determined the HRR of similar fuel packages.

Figure B.1-7 shows the relationship between $t^2$ fire curves and six 1.2-m (4-ft) high stacks of mixed wooden pallets (8 to 9 pallets per stack) arranged in two rows of three stacks, with the three stacks in each row forming an unbroken line with 100-mm between the front and back rows. Figure B.1-7 shows that both tests exhibited there was an incubation period of about 120 seconds following which the fire growth rate was approximately parallel to the $t^2$ fast fire growth curve.

Figure B.1-8 shows the relationship between $t^2$ fire curves and six 12-m (4-ft) high stacks of cardboard boxes arranged in two rows of three stacks, with no gaps between the stacks. The boxes were ignited by setting light to a ball of crumpled newspaper pushed 100 mm under the front of the central stack in the front row of the array. Figure B-8 shows that both tests exhibited a long incubation period, as the ball of newspaper proved to be slow burning. However, the fire did break into the boxes immediately above the ignition source, and the flames eventually burst from the front of those boxes and then rapidly up the front of the central (ignition) stack. Thereafter the fire growth rate was similar to the ultra-fast $t^2$ fire curve.

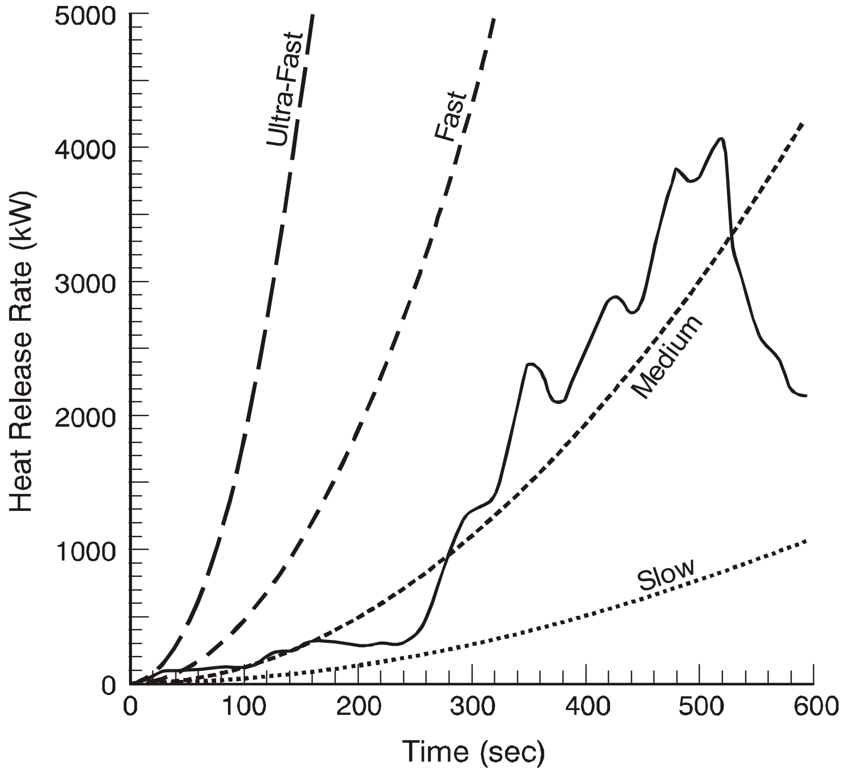



Figure B.1-6 Three-Sided Work Station Heat Release Rate Curve Compared with $t^2$ Curves (Madrzykowski, 1996)

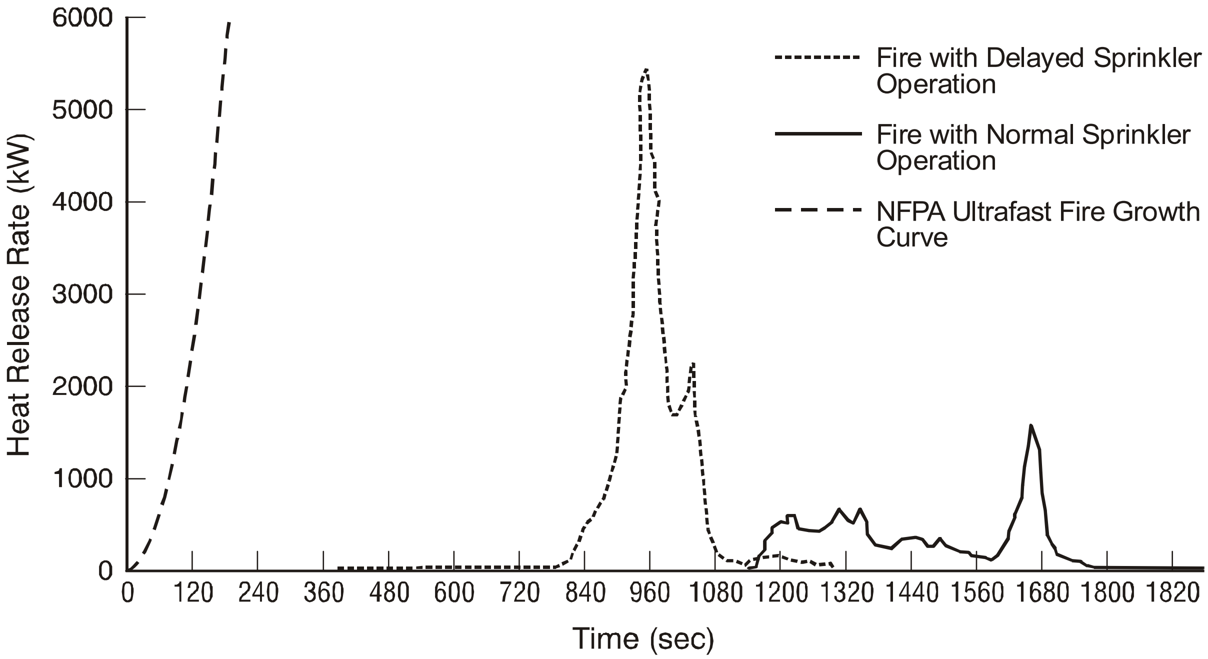



Figure B.1-7 Heat Release Rate Curve for Idle Pallets Compared with $t^2$ Curves (Garred and Smith, 1999)

Figure B.1-8 Heat Release Rate for Stacked Box Fires Compared with $t^2$ Curves (Garred and Smith, 1999) (Waiting for Copyright Permission)

### B.1.3 References

Garred, G., and D.A. Smith, "The Characterization of Fires for Design," Interflam 1996, Conference Proceedings of the 8th International Interflam Conference, Inter Science Communication Limited, England, pp. 555–566, June-July 1999.

Gross, D., "Data Sources for Parameter Used in Predictive Modeling of Fire Growth and Smoke Spread," NBSIR 85-3223, U.S. Department of Commerce, National Bureau of Standards (NBS), Gaithersburg, Maryland, 1985.

Heskestad, G. "Venting Practice," Section 7, Chapter 7, *NFPA Fire Protection Handbook*, 18th Edition, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts, pp. 7–105, 1997.

Madrzykowski, D., "Office Station Heat Release Study: Full Scale vs Bench Scale," Interflam 1996, Conference Proceedings of the 7th International Interflam Conference, Interscience Communication Limited, England, Compiled by C.A. Franks, pp. 47–55, 1996.

Nelson, H.E., "An Engineering Analysis of the Early Stages of Fire Development: The Fire at the Dupont Plaza Hotel and Casino on December 31, 1986," NBSIR 87-3560, U.S. Department of Commerce, National Bureau of Standards (NBS), Gaithersburg, Maryland, May 1987.

NFPA 72, "National Fire Alarm Code," 1999 Edition, National Fire Protection Association, Quincy, Massachusetts.

NFPA 92B, "Guide for Smoke Management Systems in Malls, Atria, and Large Areas," 2000 Edition. National Fire Protection Association, Quincy, Massachusetts.

## B.2 Elements of Hydraulic and Electrical Systems

Table B.2-1 provides the basic elements of a hydraulic systems along with the corresponding elements of an electrical system.

| Table B.2-1. Corresponding Elements of Hydraulic and Electrical Systems (NFPA 921, 2002 Edition) | |
|---|---|
| Elements of a Hydraulic System | Elements of an Electrical System |
| Pump | Generator |
| Pressure | Voltage (potential or electromotive force) |
| Pounds per square inch (psi) | Volts (V) |
| Pressure gauge | Voltmeter |
| Water | Electrons |
| Flow | Current |
| Gallons per minute (gpm) | Amperes (A) |
| Flowmeter | Ammeter |
| Valve | Switch |
| Friction | Resistance (Ohms) |
| Friction loss | Voltage drop |
| Pipe size (inside diameter) | Conductor size - AWG No. |

Hydraulic systems use a pump to create the hydraulic pressure necessary to force water through pipes. The amount of hydraulic pressure is expressed in pounds per square inch (psi) and can be measured with a pressure gauge. By contracts, electrical systems use a generator is used to create the necessary electrical pressure (voltage) to force electrons through a conductor. The amount of electrical pressure is expressed in volts and can be measured with a voltmeter.

In hydraulic systems, water flows in a useful way. The amount of water flow is expressed in gallons per minute (gpm) and may be measured with a flowmeter. By contrast, electrical systems, it is electrons that flow in a useful way in the form of electrical current. The amount of electrical current is expressed in amperes (A) and may be measured with an ammeter. Electric current can be either direct current (dc), such as supplied by a battery, or alternating current (ac), such as supplied by an electrical utility company.

In hydraulic systems, water pipes provide the pathway for the water to flow. By contrast, electrical systems, conductors such as wires provide the pathway for the current to flow.

In a closed circulating hydraulic system (as opposed to a fire hose delivery system, where water is discharged out of the end of the hose), water flows in a loop, returning to the pump, where it again circulates through the loop. When the valve is closed, the flow stops everywhere in the system. When the valve is opened, the flow resumes. By contrast, an electrical system *must* be a closed system, in that the current must flow in a loop known as a complete circuit. When the switch is turned on, the circuit is completed and the current flows. When the switch is turned off, the circuit is open (incomplete) and the current flow stops everywhere in the circuit. This voltage drop is called the potential or electromotive force.

Friction losses in the pipes of a hydraulic system result in pressure drops. By contrast, electrical friction (i.e., resistance) in conductors and other parts of an electrical system results in electrical pressure drops or voltage drops. Ohm's law must be used to express resistance as a voltage drop.

When electricity flows through a conducting material, such as a conductor, a pipe, or any piece of metal, heat is generated. The amount of heat depends on the resistance of the material through which the current is flowing and the amount of current. Some electrical equipment, such as heating units, are designed with appropriate resistance to convert electricity to heat.

The flow of water in a pipe at a given pressure drop is controlled by the pipe size. A larger pipe allows a greater volume (more gallons per minute) of water to flow than a smaller pipe at a given pressure drop. Similarly, larger conductors allow more current to flow than smaller conductors. Conductor sizes are given in American Wire Gauge (AWG) numbers. The larger the number, the smaller the conductor diameter. The larger the diameter (and hence the larger the cross-sectional area) of the conductor, the lower the AWG number and the less the resistance the conductor has.

### B.2.1 Reference

NFPA 921, "Guide for Fire and Explosion Investigations," 2001 Edition, National Fire Protection Association, Quincy, Massachusetts.

## B.3 Classes of Fires

Generally the purpose of a letter designation given to a particular fire category to classify it according to the type of fuel and possible spread of the fire. The letter classification also provides a general indication of the severity and type of the hazard. NFPA 10, "Standard for Portable Fire Extinguishers," classifies fires as either Class A, Class B, Class C, Class D, or Class K according to the fuel involved.

*Class A Fires*

Fires in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics.

*Class B Fires*

Fires in flammable or combustibles liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases,.

*Class C Fires*

Fires that involve energized electrical equipment where the electrical nonconductivity of the extinguishing media is of importance. (When electrical equipment is de-energized, fire extinguishers designed for Class A or Class B fires can be safely used).

*Class D Fires*

Fires in combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.

*Class K Fires*

Fires in cooking appliances that involve combustible cooking media (vegetable or animal oils and fats).

### B.3.1 Reference

NFPA 10, "Standard for Portable Fire Extinguishers," 2002 Edition, National Fire Protection Association, Quincy, Massachusetts.

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## B.4 Classification of Hazards

### B.4.1 Light (Low) Hazard

Light hazard occupancies are locations where the total amount of Class A combustible materials (including furnishings, decorations, and content), is a minor quantity. This can include some buildings or rooms occupied as offices, classrooms, churches, assembly halls, guest room areas of hotels/motels, and so forth. This classification anticipates that the majority of content items are either noncombustible or so arranged that a fire is not likely to spread rapidly. Small amounts of Class B flammables used for duplicating machines, art departments, and so forth, are included, provided that they are kept in closed containers and safely stored (Conroy, 1997 and NFPA 10).

### B.4.2 Ordinary (Moderate) Hazard

Ordinary hazard occupancies are locations where of Class A combustibles and Class B flammables are present in greater total amounts than expected under light (low) hazard occupancies. These occupancies could consist of dining areas, mercantile shops, and allied storage; light manufacturing, research operations, auto showrooms, parking garages, workshop or support service areas of light (low) hazard occupancies; and warehouses containing Class I or Class II commodities as defined by NFPA 231, "Standard for General Storage," (Conroy, 1997 and NFPA 10).

### B.4.3 Extra (High) Hazard

Extra hazard occupancies are locations where the total amount of Class A combustibles and Class B flammable (in storage, production, use, finished product, or combination thereof) is over and above those expected in occupancies classed as ordinary (moderate) hazard. These occupancies could consist of woodworking, vehicle repair, aircraft and boat servicing, cooking areas, individual product display showrooms, product convention center displays, and storage and manufacturing processes such as painting, dipping, and coating, including flammable liquid handling. Also included is warehousing or in-process storage of other than Class I or Class II commodities (Conroy, 1997 and NFPA 10).

### B.4.4 References

Conroy, M.T. "Fire Extinguisher Use and Maintenance," Section 6, Chapter 23, *NFPA Fire Protection Handbook*, 18th Edition, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts. 1997.

NFPA 10, "Standard for Portable Fire Extinguishers," 2002 Edition, National Fire Protection Association, Quincy, Massachusetts.

NFPA 231, "Standard for General Storage," National Fire Protection Association, Quincy, Massachusetts.

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## B.5 Classes of Fires and Extinguishing Agents

One or more of the following mechanisms—more often, several of them simultaneously—can be used to extinguish fire:

- Physically separating the combustible substance from the flame
- Removing or diluting the oxygen supply
- Reducing the temperature of the combustible or of the flame
- Introducing chemicals that modify the combustion chemistry

For example, when water is applied to a fire of a solid combustible burning in air, several extinguishing mechanisms are involved simultaneously. The solid is cooled by the contact with water, causing its rate of pyrolysis, or gasification, to decrease. The gaseous flame is cooled, causing a reduction in heat feedback to the combustible solid and a corresponding reduction in the endothermic pyrolysis rate. Steam is generated, which, under some confined conditions, may prevent oxygen from reaching the fire. Water in the form of fog may block radiative heat transfer.

As another example, consider the application of a blanket of aqueous foam to a burning pool of flammable liquid. Several mechanisms may be operative. The foam prevents the fire's radiant heat from reaching the surface and supplying the needed heat of vaporization. If the fire point of the flammable liquid is higher than the temperature of the foam, the liquid is cooled and its vapor pressure decrease. If the flammable liquid is water soluble, such as alcohol, then, by a third mechanism, it will become diluted by water from the foam, and the vapor pressure of the combustible will be reduced.

As yet an example, when dry chemical is applied to a fire, the following extinguishing mechanisms may be involved:

- Chemical interaction with the flame
- Coating of the combustible surface
- Cooling of the flame
- Blocking or radiative energy transfer

The agent mentioned above—water, foam, and dry chemicals—each work by a combination of several mechanisms, and the relative importance of the various contributions varies with circumstances. Table B.5-1 provide the classes of fires with examples and extinguishing agent.

| Table B.5-1. Fire Classes with Extinguishing Agents | | | |
|---|---|---|---|
| Fire Class | Description | Examples | Extinguishing Agents |
| A | Ordinary combustibles | Wood, cloth, paper, rubber, and many plastics | Water, dry chemicals, foam, and some Halon |
| B | Flammable liquids, gases, and liquid-derived solids | Gasoline, oils, LPG, paraffin or heavy lubricants, grease | $CO_2$, dry chemical agents, Halon, foam (Class B extinguishers isolate the fuel from the heat by cutting off oxygen to the combustion zone or by inhibiting and interrupting the formation of molecular chain reactions) |
| C | The same fuels as Class A and B fires, together with energized electrical equipment | Energized Class A material, such as household appliances | $CO_2$, dry chemical agents, Halon (Extinguishers for Class C fires are rated according to the nonconductive properties of the extinguishing agent) |
| D | Combustible metals or metallic alloy elements with combustible metal components | Magnesium, sodium, potassium, titanium, zirconium, and lithium | Dry chemical agents (Water and water-based extinguishers should never be used on Class D fires. To be effective on a Class D fire, an extinguisher must suppress the fire without reacting physically or chemically with the combustible metal materials) |
| K | Cooking appliances that involve combustible cooking media | Vegetable or animal oils and fats | Dry chemical agents |

## B.6 Classification of Flammable and Combustible Liquids

In common usage, *flammable* refers to a liquid that is readily ignited, burns rapidly and vigorously, and produces a lot of thermal energy—in other words, heat. *Combustible* usually refers to a liquid that is less easily ignited, burns less rapidly, and is, therefore, relatively safer. In simple terms, *flammable liquids* produce vapors at normal room temperature in concentrations that can be easily ignited by a small spark or flame. *Combustible liquids* do not produce vapors that can be ignited at normal room temperature. However, if a combustible liquid is heated up to or above its flash point, the vapors generated by the now-heated liquid can be ignited. In these cases, combustible liquids can be just as dangerous as flammable liquids. And, some of them, hydrocarbon fuels for examples, can burn just rapidly and evolve just much heat once they are ignited. Some common combustible liquids—mineral spirits and paint thinners, for example—are blended so they are just above the accepted dividing line between flammable and combustible. So, moderate heating of these liquids or storing them in a very warm environment can also present a fire hazard.

### B.6.1 Flammable Liquid

According to the most fire safety codes (NFPA 30, "Flammable Combustible Liquids Code"), a flammable liquid is generally defined as any liquid that has a closed-cup flash point below 37.8 °C (100 °F). Flash points are determined by procedures and apparatus set forth in ASTM D56, "Standard Method of Test for Flash Point by the Tag Closed Tester".

NFPA 11 defined flammable liquids as any liquid having flash point below 37.8 °C (100 °F) and having a vapor pressure not exceeding 276 kPa (40 psi) (absolute) at 37.8 °C (100 °F).

Flammable liquids can be divided into classes (which are further divided into sub-classes), based on their flash points as summarizes in Table B.6-1.

Class I - Liquids have a flash point below 38 °C (100 °F) and subdivided as follows:

Table B.6-1. Flammable Liquid Classifications
(NFPA 30, 2000 Edition)

| Classification | Flash Point (°F) | Boiling Point (°F) | Example(s) |
|---|---|---|---|
| Class IA Flammable | < 73 | < 100 | Ethyl ether<br>Acetic aldehyde,<br>Dimethyl sulfide,<br>Furan |
| Class IB Flammable | < 73 | ≥ 100 | Ethyl alcohol,<br>gasoline-92 octane,<br>Cyclohexane |
| Class IC Flammable | ≥73 and < 100 | N/A | Butyl ether |

### B.6.2 Combustible Liquid

A combustible liquid is defined as any liquid that has a closed-cup flash point above 37.8 °C (100 °F). Combustible liquids can be divided into classes (which are further divided into sub-classes), based on their flash points as summarizes in Table B.6-2.

Class II Combustible liquids with flash points at or above 38 °C (100 °F), but below 60 °C (140 °F).

Class III Combustible liquids with flash points at or above 60 °C (140 °F).

Table B.6-2. Combustible Liquid Classifications (NFPA 30, 2000 Edition)

| Classification | Flash Point (°F) | Boiling Point (°F) | Examples |
|---|---|---|---|
| Class II Combustible | ≥ 100 | N/A | Fuel oil # 1 (kerosene), diesel fuel oil # 1-D/2-D/4-D, glacial acetic acid, and jet fuel (A & A-1) |
| Class III A Combustible | ≥ 140 and < 200 | N/A | Fuel oil # 6, creosote oil, and butyl carbitol |
| Class III B Combustible | ≥ 200 | N/A | Fuel oil # 4, mineral oil, olive oil, and lubricating oil (motor oil) |

Assume that a liquid spill occurs on a summer day when the ground has been heated by the sun to 35 °C (95 °F). Clearly, a spill of Class I (flammable) liquid is extremely hazardous with regard to fire; however, a spill of a Class II liquid is dangerous from a fire viewpoint only if a heat source exists that is capable of moderately raising the temperature of the liquid and a spill of Class III liquid is safe from ignition unless a heat source exists that can substantially raise its temperature.

Table B.6-3 lists the flash points of some common flammable and combustible liquids. Notice the wide range, from -43 °C to +243 °C (-45 °F to +469 °F). These values are meaningful only for bulk liquids. If a liquid with a high flash point is in the form of a spray, a froth, or a foam, with air present, and comes into contact with even a very small ignition flame, the tiny amount of liquid in contact will be immediately heated to above its flash point and will begin to burn. The combustion energy released will vaporize the surrounding spray or foam, and the fire will propagate (spread).

| Table B.6-3. Flash Points of Flammable and Combustible Liquids (Benedetti, 1997) | |
|---|---|
| Liquid Fuel | Flash Point °C (°F) |
| Class I (Flammable) Liquids | |
| Gasoline | -43 (-45) |
| n-Hexane | -26 (-15) |
| JP-4 (jet aviation fuel) | -18 (0) |
| Acetone | -16 (3) |
| Toluene | 9 (48) |
| Methanol | 11 (52) |
| Ethanol | 12 (54) |
| Turpentine | 35 (95) |
| Class II (Combustible) Liquids | |
| No.2 fuel oil (domestic) | >38 (>100) |
| Diesel fuel | 40–50 (104–131) |
| Jet A (jet aviation fuel) | 47 (117) |
| Kerosene | 52 (126) |
| No. 5 fuel oil | >54 (>130) |
| Class III (Combustible) Liquids | |
| JP-5 (jet aviation fuel) | 66 (151) |
| SAE No. 10 lube oil | 171 (340) |
| Triresyl phosphate | 243 (469) |

### B.6.3 Storage of Flammable and Combustible Liquids

Flammable and combustible liquids are packed, shipped, and stored in bottle, drums, and other containers ranging in size up to 60 gal (225 L). Additionally, liquids are shipped and stored in intermediate bulk containers up to 793 gal (3,000 L) and in portable intermodal tanks up to 5,500 gal (20,818 L). Storage requirements for each these containers are covered in the NFPA 30 chapters entitled, "Containers and Portable Tank Storage," with the exception of those portable tanks larger than 793 gal (3,000 L) that are required to meet the applicable requirements covered in the NFPA 30 chapter entitled, "Tank Storage".

Examples of containers types used for the storage of liquids include glass, metal, polyethylene (plastic), and fiberboard. The maximum allowable size for the different types of containers is governed by the class of flammable or combustible liquid to be stored in it. Table B.6-4 lists the maximum allowable size (capacity) of a container or metal tank used to store flammable and combustible liquids.

| Table B.6-4. Maximum Allowable Size of Containers and Portable Tanks for Flammable and Combustible Liquids (NFPA 30, 2000 Edition) | | | | | |
|---|---|---|---|---|---|
| Liquids Container Type | Flammable Liquid | | | Combustible Liquid | |
| | Class IA | Class IB | Class IC | Class II | Class III |
| Glass | 1 pt | 1 qt | 1 gal | 1 gal | 5 gal |
| Metal (other than DOT drum) or approved plastic | 1gal | 5 gal | 5 gal | 5 gal | 5 gal |
| Safety cans | 2 gal | 5 gal | 5 gal | 5 gal | 5 gal |
| Metal drum (DOT specification) | 60 gal | 60 gal | 60 gal | 60 gal | 60 gal |
| Approved metal portable tank and IBC | 793 gal | 793 gal | 793 gal | 793 gal | 793 gal |
| Rigid plastic IBC (UN 31H1 or 31H2) or composite IBC (UN 31HZ1) | NP | NP | NP | 793 gal | 793 gal |
| Polyethylene (DOT specification 34, UN 1H1, or as authorized by DOT exemption) | 1 gal | 5 gal | 5 gal | 60 gal | 60 gal |
| Fiber drum (NMFC or UFC Type 2A; Types 3A, 3B-H, or 3B-L; or Type 4A) | NP | NP | NP | 60 gal | 60 gal |
| SI Units - 1pt = 0.473 L; 1 qt = 0.95 L; 1 gal = 3.8 L<br>NP = Not Permitted<br>IBC = Intermediate Bulk Container<br>DOT = U.S. Department of Transportation | | | | | |

### B.6.4 Flammable Combustible Storage Cabinets

Most commercially available and approved storage cabinets are built to hold 60 gallons (227 liters) or less of flammable and/or combustible liquids.

Not more than 120 gal (454 L) of Class I, Class II, and Class IIIA liquids shall be stored in a storage cabinet. Of this 120 gal total, not more than 60 gal (227 L) shall comprise Class I and Class II liquids.

### B.6.5 Definitions

*Flash Point*
The minimum temperature to which a liquid must be heated in a standardized apparatus, so that a transient flame moves over the liquid when a small pilot flame is applied.

Alternately, the flash point of a liquid may be defined as the temperature at which the vapor and air mixture lying just above its vaporizing surface is capable of just supporting a momentary flashing propagation of a flame prompted by a quick sweep of small gas pilot flame near its surface (hence the term flash point). The flash point is mainly applied to liquids. The flash point of liquid is one of its characteristics that normally determines the amount of fire safety features required for its handling, storage, and transport.

*Fire Point*
The minimum temperature to which a liquid must be heated in a standardized apparatus, so that sustained combustion results when a small pilot flame is applied, as long as the liquid is at normal atmospheric pressure.

*Boiling Point*
The temperature at which the transition from the liquid to the gaseous phase occurs in a pure substance at fixed pressure.

Alternately, the boiling point may defined as the temperature at which the vapor pressure of a liquid equals the surrounding atmospheric pressure. For purposes of defining the boiling point, atmospheric pressure shall be considered to be 14.7 psia (760 mm Hg). For mixtures that do not have a constant boiling point, the 20-percent evaporated point of a distillation performed in accordance with ASTM D86, "Standard Method of Test for Distillation of Petroleum Products," shall be considered to be the boiling point.

*Autoignition*
Initiation of fire or combustion by heat but without the application of a spark or flame.

*Autoignition Temperature*
The lowest temperature at which a mixture of fuel and oxidizer can propagate a flame without the aid of an initiating energy source (pilot, spark, or flame).

*High Risk Fuel*
Class IA, IB, IC, or II liquids as defined by NFPA 30, "Flammable and Combustible Liquids Code," or Class IIIA, or III B liquids heated to within 10 °C (50 °F) of their flash point, or pressurized to 174.4 kPa (25.3 psi) or more.

### B.6.6 Hazardous Materials

A substance (solid, liquid, or gas) capable of creating harm to people, property, and the environment. The general category of hazard assigned to a hazardous material under the U.S. Department of Transportation (DOT) regulation. Table B.6-5 lists the hazardous material classification.

| Table B.6-5. Hazardous Material Classification | |
|---|---|
| Hazard Class | Description |
| **Class 1 - Explosives**<br>Division 1.1<br>Division 1.2<br>Division 1.3<br>Division 1.4<br>Division 1.5<br>Division 1.6 | <br>Explosive with a mass explosion hazard<br>Explosives with a projection hazard<br>Explosives with predominantly a fire hazard<br>Explosives with no significant blast hazard<br>Very insensitive explosives<br>Extremely insensitive explosive articles |
| **Class 2**<br>Division 2.1<br>Division 2.2<br>Division 2.3<br>Division 2.4 | <br>Flammable gas<br>Nonflammable, non-poisonous compressed gas<br>Poison gas<br>Corrosive gas |
| **Class 3 - Flammable Liquid**<br>Division 3.1<br>Division 3.2<br>Division 3.3 | <br>Flammable liquids, flash point < 0 °F<br>Flammable liquids, flash point 0 °F and above but < 73 °F<br>Flammable liquids, flash point 73 °F and up to < 141 °F combustible liquid |
| **Class 4**<br>Division 4.1<br>Division 4.2<br>Division 4.3 | <br>Flammable solid<br>Spontaneously combustible material<br>Dangerous when wet material |
| **Class 5**<br>Division 5.1<br>Division 5.2 | <br>Oxidizer<br>Organic peroxide |
| **Class 6**<br>Division 6.1<br>Division 6.2 | <br>Poisonous material<br>Infectious material |
| **Class 7** | Radioactive material |
| **Class 8** | Corrosive material |
| **Class 9** | Miscellaneous hazardous material, ORM-D material |

### B.6.7 References

Benedetti, R.P., Editor, "Flammable and Combustible Liquids Code Handbook," 6th Edition,, National Fire Protection Association, Quincy, Massachusetts, 1997.

NFPA 11, "Standard for Low-Expansion Foam," 2002 Edition, National Fire Protection Association, Quincy, Massachusetts.

NFPA 30, "Flammable and Combustible Liquids Code," 2000 Edition, National Fire Protection Association, Quincy, Massachusetts.

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## B.7 Classification of Flammable Gases

### B.7.1 Classification

Flammable gases are classified according to the maximum experimental safe gap (MESG), which prevents flame passage. MESG is determined by test IEC 79-1A, "Electrical Apparatus for Explosive Gas Atmospheres," International Electrotechnical Commission (IEC), 1975 (Senecal, 1997).

| | |
|---|---|
| Class I | Group A - acetylene<br>Group B - hydrogen<br>Group C - ethylene<br>Group D - propane |
| Division 1 | Flammable gases or combustible dust may be present at ignitable concentrations, under normal operating conditions. |
| Division 2 | Where hazardous materials may be handled, processed, or used; ignitable atmospheres not normally present due to containment or ventilation of hazardous materials; areas adjacent to Division 1 locations. |

### B.7.2 Definitions

*Flammable Limits*
The minimum and maximum concentration of combustible material in a homogeneous mixture with a gaseous oxidizer that will propagate a flame.

*Upper and Lower Flammability Limits*
Concentration of fuel in air in which a premixed flame can propagate.

*Lower Flammability Limit*
The lowest concentration of fuel in air at normal temperature and pressure that can support flame propagation is known as the lower flammability limit (LFL) or lower explosive limit (LEL).

*Upper Flammability Limit*
The highest concentration of fuel in air at normal temperature and pressure that can support flame propagation is known as the upper flammability limit (UFL) or upper explosive limit (UEL).

### B.7.3 Reference

Senecal, J.A., "Explosion Prevention and Protection," Section 4, Chapter 14, *NFPA Fire Protection Handbook*, 18th Edition, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts, 1997.

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## B.8 Flammability Hhazards of Gases

### B.8.1 Flammability Potential of Gases

Flammability hazards in a tank or vessel dependent upon the potential for developing a flammable fuel/oxidant/inert gas mixture in the tank or vessel head space. Mixtures of fuel and air are only flammable for limited fuel/air ratio. The most flammable mixture is a stoichiometric mixture, in which the fuel and air (oxygen) are present in exactly the right proportions for oxidation, as dictated by the stoichiometry of the fuel/oxygen combustion reaction. Mixtures with some excess oxygen or excess fuel are also flammable, the lowest concentration of fuel in air that can support flame propagation at normal temperature and pressure is known as the lower explosive limit (LEL). Similarly, the highest concentration of fuel in air that can support flame propagation at normal temperature and pressure is known as the upper explosive limit (UEL). Mixtures of fuel in air with intermediate fuel concentrations will support flame propagation.

The flammability of gas mixtures is determined by one of two widely utilized laboratory methods. The first method uses a 5-foot-long tube that is filled with the test mixture, and a spark is used to ignite the mixture at one end to observed whether ignition occurs and whether the flame can propagate to the other end of the tube. The second method uses a spherical tank or vessel that is filled with the test mixture, and a spark is used to ignite the mixture at the center of the tank or vessel to measure the pressure increase to determine whether flame propagation occurred throughout the tank or vessel (Beyler, 1995). The spherical vessel test method is more representative of an actual tank or vessel than is the tube method.

The terms "explosive limits" and "flammable limits" are used interchangeably in the technical literature. Explosive limits simply refer to compositions, which define when flame propagation is possible. The flame propagation is known as a deflagration and results in a pressure increase as the flame passes through a vessel. This resulting overpressure is the origin of the term explosive limit, where an explosion is any event, that results in a sudden overpressure in the vessel.

The LEL mixture has excess oxygen and insufficient fuel for complete burning. This is known as "fuel lean". The potential heat output, which defines how hot the products of combustion can be is limited not by oxygen, but by fuel concentration. The ideal "no heat loss" post-combustion temperature is known as the "adiabatic flame temperature" (AFT). For most flammable gases, the AFT at atmospheric pressure is about 2,300 K (3,680 °F) for stoichiometric mixtures of fuel in air, and is reduces to about 1,600 K (2,420 °F) for LEL mixtures. The AFT can be calculated using any of a number of chemical equilibrium computer programs, like STANJAN (Reyonlds, 1986). The use of such a computer program allows the analysis to be performed for a tank-specific mixture, so that the results are representative of the actual tank environment.

### B.8.2 Flammability Potential of Hydrogen

Hydrogen is a highly flammable gas with novel flammability properties and unusually broad explosive limits. Based on upward propagation in the standard flammability tube, the LEL is 4-percent hydrogen in air and the UEL is 75-percent (Zabetaskis, 1965). For most gases, the LELs for upward and downward propagation do no differ greately. However, for hydrogen, the LEL for downward propagation is 8-percent (Furno et al., 1971). The significance of this difference is that in order for the flame to propagate throughout a tank or a vessel, it must propagate in all directions. As such, overpressures associated with hydrogen explosions are not observed at hydrogen concentrations below 8-percent. This behavior was observed by Furno et al., 1971, in 12-foot spherical vessel experiments using lean hydrogen/air mixtures. Overpressures were only measured above 8-percent hydrogen, and the pressures did not match the theoretical overpressures until about 10-percent hydrogen. Thus, while the LEL of hydrogen is widely quoted as 4-percent, explosion hazards will not occur below 8-percent.

The novel behavior of hydrogen is not reflected in documents like NFPA 69, "Standard on Explosion Prevention Systems." As such, standards of care like NFPA 69, provide an implicit additional safety factor for hydrogen that should be understood in assessing hazards.

### B.8.3 Flammable Limits, Detonable Limits, and Potential for Deflagration-to-Detonation Transitions

The formation of flammable fuel/oxidant mixtures within a tank can lead to premixed flame propagation in the form of deflagration or a detonation. The formation of a flammable mixture can result from steady-state generation and transport of flammable gases and oxidizers from an aqueous solution or waste containing radioactive isotopes, from episodic releases of such gases trapped within the waste, or from the formation of large gas bubbles within the waste which contain flammable mixtures of fuels and oxidizers.

Before assessing the potential flammable gas generation rates and resulting flammable gas mixture, it is useful to assess the relevant limits. In mixtures with fuel gas concentrations above the LEL indefinite propagation of a deflagration is possible. Above the detonable limit, indefinite propagation of a detonation is possible given a source that is capable of directly detonating the mixture. While LEL's are a property of the mixture alone, the detonable limits are also impacted by the environment. The ability for a deflagration-to-detonation transition (DDT) is contingent upon both the mixture and the environment. The primary flammable gas is hydrogen.

### B.8.4 Flammable Gas Generation

Flammable gases are generated with the aqueous solution or waste by several processes within a tank or a vessel. Specifically, these processes may include (1) radiolysis of the water and waste to produce hydrogen and ammonia, (2) corrosion of the steel liner to produce hydrogen, and (3) chemical decomposition of the waste. These processes generate hydrogen, methane, ammonia, and nitrous oxide, the first three of which are flammable gases, while the fourth is an oxidizer.

### B.8.5 Explosion Prevention Methods

The flammability of a tank or vessel can be managed by controlling either the flammable gas concentration or oxygen concentration. Where the oxygen concentration is to be controlled, it needs to be maintained below the limiting oxidant concentration (LOC) (NFPA 69) (LOC is define as the concentration of oxidant below which deflagration cannot occur is a specified mixture). Safety margins require maintaining the oxygen at 60-percent of the LOC if the LOC is above 5-percent, or 4-percent of the LOC if the LOC is below 5-percent. Where flammability is measured by controlling the flammable gas concentration, it needs to be maintained below 25-percent of the LEL.

Control of the oxygen concentration is achieved through the use of an inert purge gas. By contrast, control of flammable gas concentration is normally achieved through air dilution or by controlling of flammable gas evolution or regeneration or by catalytic oxidation of flammable gases.

While NFPA 69, provides standards for inerting the tanks, such inerting is not required by codes and standards for flammable liquid storage containers, such as the Uniform Fire Code Article 79; 1997, NFPA 30, 1996 Edition; 49 CFR; FM Data Sheet 7-88, "Storage Tanks for Flammable and Combustible Liquids," 1999; and FM Data Sheet 7-29, "Flammable Liquid Storage," 1999. These codes and standards recognize that ignition sources will not be present in passive containers, so that it is not necessary to control the composition of gases in the tank. By contrast, FM Data Sheet 7-32, "Flammable Liquids Operation," 1993, recommends that processing equipment with the potential for an explosion should have at least one of the following characteristics:

- equipped with explosion venting
- designed to withstand the explosion overpressure
- fitted with an inerting system
- fitted with an explosion suppression system

Tank inerting is recognized as a means of preventing explosions in processing vessels, which are inherently dynamic systems where ignition sources can be limited but not excluded.

### B.8.6 References

Beyler, C.L., "Flammability Limits of Premixed and Diffusion Flames," Section 2, Chapter 2-9, *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, P.J. DiNenno, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts, 1995.

FM Data Sheet 7-29, "Flammable Liquid Storage," Factory Mutual Engineering Corporation, Norwood, Massachusetts.

FM Data Sheet 7-32, "Flammable Liquid Operations," Factory Mutual Engineering Corporation, Norwood, Massachusetts.

FM Data Sheet 7-88, "Storage Tanks for Flammable and Combustible Liquids," Factory Mutual Engineering Corporation, Norwood, Massachusetts.

Furno, A., E. Cook, J. Kuchta, and D. Burgess, "Some Observations on Near-Limit Flames," Thirteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania, pp. 593–599, 1971.

NFPA 30, "Flammable and Combustible Liquids Code," 2000 Edition National Fire Protection Association, Quincy, Massachusetts.

NFPA 69, "Standard on Explosion Prevention Systems," 1997 Edition, National Fire Protection Association, Quincy, Massachusetts.

Reynolds, W.C., "The Element Potential Method for Chemical Equilibrium Analysis: Implementation in the Interactive Program STANJAN, Version 3, Department of Mechanical Engineering, Stanford University, 1986.

Uniform Fire Code (UFC), Article 79, "Flammable and Combustible Liquids," International Fire Code Institute, 1997.

*Code of Federal Regulations*, Title 49, Part 100–177, "Hazardous Materials Transportation," U.S. Government Printing Office, Washington DC.

Zabetakis, M.G., "Flammability Characteristics of Combustible Gases and Vapors," Bulletin 627, U.S. Bureau of Mines, Washington, DC, 1965.

## B.9 Combustion Properties of Pure Metals in Solid Form

Nearly all metals will burn in air under certain conditions. Some oxidize rapidly in the presence of air or moisture, generating sufficient heat to reach their ignition temperatures. Others oxidize so slowly that heat generated during oxidation dissipates before the metal becomes hot enough to ignite. Certain metals (notably magnesium, titanium, sodium, potassium, lithium, zirconium, hafnium, calcium, zinc, plutonium, uranium, and thorium) are referred to as "combustible metals" because of the ease of ignition when they reach a high specific area ratio (thin sections, fine particles, or molten states). However, the same metals are comparatively difficult to ignite in massive solid form.

Some metals (such as aluminum, iron, and steel) that are not normally thought of as combustible, may ignite and burn when in finely divided form. Clean fine steel wool, for example, may ignite. Particle size, shape, quantity, and alloy are important factors to be considered when evaluating metal combustibility. Combustibility of metallic alloys may differ and vary widely from the combustibility characteristics of the alloys' constituent elements. Metals tend to be most reactive when in finely divided form and may require shipment and storage under inert gas or liquid to reduce fire risks.

Hot or burning metals may react violently upon contact with other materials, such as oxidizing agents and extinguishing agents used on fires involving ordinary combustibles or flammable liquids. Temperatures produced by burning metals can be higher than temperatures generated by burning flammable liquids. Some metals can continue to burn in carbon dioxide, nitrogen, water, or steam atmospheres in which ordinary combustibles or flammable liquids would be incapable of burning.

Properties of burning metal cover a wide range. Burning titanium, for example, produces little smoke, while burning lithium exudes dense and profuse smoke. Some water-moistened metal powders (such as zirconium) burn with near-explosive violence, while the same powder wet with oil burns quiescently. Sodium melts and flows while burning; calcium does not. Some metals (such as uranium) acquire an increased tendency to burn after prolonged exposure to moist air, while prolonged exposure to dry air makes it more difficult to ignite.

The toxicity of certain metals is also an important factor in fire suppression. Some metals (especially heavy metals) can be toxic or fatal if they enter the bloodstream or their smoke fumes are inhaled. ***Metal fires should never be approached without proper protective equipment (clothing and respirators)***.

A few metals (such as thorium, uranium, and plutonium) emit ionizing radiation that can complicate fire fighting and introduce a radioactive contamination problem. Where possible, radioactive materials should not be processed or stored with other pyrophoric materials because of the likelihood of widespread radioactive contamination during a fire. Where such combinations are essential to operations, appropriate engineering controls and emergency procedures should be in place to prevent or quickly suppress fires in the event that the controls fail.

Because extinguishing fires in combustible metals involves techniques not commonly encountered in conventional fire fighting operations, it is necessary for those responsible for controlling combustible metal fires to be thoroughly trained before an actual fire emergency arises.

Table B.9-1. Melting, Boiling, and Ignition Temperatures of Pure Metals in Solid Form (Tapscott, 1997)(Waiting for Copyright Permission)

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### B.9.1 Reference

Tapscott, R.E. "Metals," Section 4, Chapter 16, *NFPA Fire Protection Handbook*, 18$^{th}$ Edition, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts. 1997.

## B.10 Extinguishing Agents for Metal Fires

Water is not usually recommended for fires involving metals since a number of metals can react exothermically with water to form hydrogen, which, of course, burns rapidly. Furthermore, violent steam explosions can result if water enters molten metal. As an exception, fires have been successfully extinguished when large quantities of water were applied to small quantities of burning magnesium in the absence of pools of molten magnesium.

Table B.9-1 lists extinguishing agents used for various metal fires. In general, metal fires are difficult to extinguish because of the very high temperatures involved and the correspondingly long cooling times required. Note that certain metals react exothermically with nitrogen or carbon dioxide, so the only acceptable inert gases for these metals are helium and argon. Halons should not be used on metal fires.

| Table B.10-1. Extinguishing Agents for Metal Fires<br>(Friedman, 1998 and Tapscott, 1997) (Waiting for Copyright Permission) | | |
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### B.10.1 References

Friedman, R., *Principles of Fire Protection Chemistry and Physics*, "Fire-Fighting Procedures," Chapter 14, 3rd Edition, National Fire Protection Association, Quincy, Massachusetts, 1998.

Tapscott, R.E., "Combustible Metal Extinguishing Agents and Application Techniques," Section 6, Chapter 26, *NFPA Fire Protection Handbook*, 18th Edition, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts, 1997.

## B.11 Occupancy Classification and Use Groups

National Fire Code (NFC) requirements are occasionally tied to specific type of occupancy. While NPPs are fundamentally industrial occupancy, it is important to have a basic understanding of other occupancy classifications in order to be able to recognize this connection.

The use group classification of a building is probably the most significant design factor that affects the safety of the occupants and fire suppression forces that are called upon in the event of fire. The building's height and size, type of construction, type and capacity of exit facilities, and fixed fire suppression systems are all dependent on this classification. The use group classification system as the foundation for the building and fire prevention codes.

### B.11.1 Occupancy Classification

The model building codes[1] and NFPA 101 (Life Safety Code®) separate buildings into about ten general uses:

- Assembly
- Business
- Educational
- Factory or Industrial
- High Hazard or Hazardous
- Institutional
- Mercantile
- Residential
- Storage
- Utility, Miscellaneous, or Special

The use are further separated into use groups based on specific characteristics. A church, a nightclub, and a family restaurant are all assemblies, but the specific characteristics of their occupants and functions differ drastically, requiring different built-in levels of protection. The occupants of a church are probably very familiar with the building that they occupy. They have been there before and they know the locations of alternative exits. The occupants of a nightclub may not be so familiar with the building. Dim lighting, loud music, and impairment by alcohol are all common features that may further compromise the ability of the occupants to identify a fire emergency and take appropriate measures to escape.

- Assembly (A) occupancies are subdivided by function, as well as the number of occupants they hold. Assemblies that hold fewer than 50 person are generally considered to be less-restrictive business uses. The Uniform Building Codes (UBC) and Standard Building Codes (SBC) further subdivide assemblies that hold many people. Such assemblies include

[1]Model Building Codes
Building Officials & Code Administrators International, Inc. (BOCA) - National Building Codes (NBC).
International Conference of Building Officials (ICBO) - Uniform Building Code (UBC).
Southern Building Code Congress International, Inc., (SBCCI) - Standard Building Code (SBC).

churches, restaurants with occupant loads that exceed 50 persons (100 under the SBC), auditoriums, armories, bowling alleys, courtrooms, dance halls, museums, theaters, and college classrooms that hold more than 50 persons (100 under the SBC).

- Business (B) areas include college classrooms with occupant loads up to 50 (100 under the SBC), doctor's and other professional offices, fire stations, banks, barber shops, and post offices. Dry cleaners who use noncombustible solvents (Types IV and V) also qualify as Business uses.

- Educational (E) areas include facilities that are *not* used for business or vocational training (shop areas) for students up to and including the twelfth grade. Colleges and universities are Business or Assembly areas (depending on the number of occupants). Day care facilities may be classified as Educational or Institutional depending on the model code.

- Factory or Industrial (F) areas include industrial and manufacturing facilities and are subdivided into moderate and low-hazard facilities. High-hazard factory and industrial areas are bumped up from the F Use Group to the H Use Group. Dry cleaners employing combustibles solvents (types II and III) are moderate-hazard factory and industrial uses.

- High Hazard or Hazardous (H) areas are those in which more than the exempt amount of a hazardous material or substance is used or stored. Exempt amounts of hazardous materials are not exempt from the provisions of the code. They are a threshold amounts by material, above which the occupancy must comply with the stringent requirements of the H Use Group.

- Institutional (I) areas may include halfway houses and group homes, hospitals and nursing homes, and penal institutions. The model codes differ in their breakdown. Care must be taken when considering homes for adults and day care centers as to whether the occupants are ambulatory or capable of self-preservation. The model codes all contain significantly more stringent requirements for institutional occupancies where a "defend-in-place" strategy is necessary because of the inability of the occupants to flee the structure without assistance.

- Mercantile (M) uses include retail shops and stores and areas that display and sell stocks of retail goods. Automotive service stations that do minor repairs are considered Mercantile uses.

- Residential (R) areas include hotels and motels, dormitories, boarding houses, apartments, townhouses, and one- and two-family dwellings.

- Storage (S) areas are used for to store goods and include warehouses, storehouses, and freight depots. Storage uses are separated into low and moderate-hazard storage uses. Auto repair facilities that perform major repairs, including engine overhauls and body work or painting are considered Moderate-Hazard Storage Occupancies by the National Building Codes (BOCA) and Standard Building Codes (SBCCI), and hazardous by the Uniform Building Codes (ICBO). Occupancies that store move than the exempt amounts of hazardous materials or substances are considered H Use Group Occupancies.

- Utility (U), Miscellaneous, or Special Structures, depending on the model code include those that are not classified under any other specific use. Such structures may include tall fences cooling towers, retaining walls, and tanks.
- Mixed use, buildings often contain multiple occupancies with different uses. For example, a three-story building might have a restaurant (assembly) and computer store (mercantile) on the first floor and professional offices throughout the rest of the building. The model code provides for such situations either by requiring that the whole building be constructed to all requirements of the most restrictive use group or by separating the areas with fire-rated assemblies, or by separating the building with fire walls, thereby creates separate buildings. By far the least expensive and most attractive method of separating mixed uses is by using fire separating assemblies, but this method is sometimes impossible because of building height and area requirements.

### B.11.2 Special Use and Occupancy Requirements

For most buildings and structures, assigning a use group and then specifying building requirements for all buildings within that use group works relatively well. Most mercantile occupancies share common hazards. Most business occupancies have similar occupants and processes. But what if a given business happens to be on the twenty-sixth floor of a high-rise building? Or what if the men’s clothing store is in the middle of a giant shopping mall? The relative hazards suddenly change, and we begin comparing apples to oranges.

Building codes provide an enhanced level of protection for certain occupancies to compensate for special hazards over and above those posed by the use of the building. The inherent hazards posed by being located twenty-six stories above the ground or in a large open area with high fire loading such as a shopping mall are addressed as special use requirements.

### B.11.3 Code Advances/Changes

It is important to recognize that NPPs have their design basis rotted in 1970's era code requirements. In some cases, fire science advances revise, or establish new code requirements. A good example is carpeting found in MCR. The original NPPs required ASTM E84, "Standard Test for Surface Characteristics of Building Materials,” Class A flame spread requirements. Fire science advances have developed more specialized test methods for carpeting, ASTM E648, "Standard Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source”. As a result of this, manufacturers do not test the material to 1970's vintage test method. When a NPP perform a plant modification, e.g., replace the carpet in the MCR, ASTM E84 rated carpet is not longer manufacturer. The licensee will either have to perform their own ASTM E84 testing on the proper carpet or prepare an engineering analysis on the commercially available carpeting that is tested to newer test methods recognized by NFPA 101, "Life Safety Code®”.

Another area of change is cable flame spread testing. Since no new NPPs are being built there is little incentive for cable vendors to qualify electrical cables to IEEE 383 requirements. In parallel, the building code groups are recognizing by grouped electrical cables and testing organizations prepared specialized test methods and rating systems based on application of the cable; UL 910

Test Method for Fire and Smoke Characteristics of Electrical and Optical-Fiber Cables used in Air Handling Spaces. UL 1581 Reference Standard for Electrical Wires, Cables, and Flexible Cords. UL 1666 Standard Test for Flame Propagation Height of Electrical and Optical-Fiber Cable installed Vertically in Shafts. UL 1685 Fire Test of Limited-Smoke Cables.

### B.11.4 References


ASTM Fire Test Standard, Fifth Edition, American Society of Testing and Materials, West Conshohocken, Pennsylvania, pp. 765-780, 1999.

ASTM E 648-98$^{\varepsilon 1}$,, "Standard Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source,"ASTM Fire Test Standard, Fifth Edition, American Society of Testing and Materials, West Conshohocken, Pennsylvania, pp. 894-907, 1998.

NFPA 101®, "Life Safety Code®," 2003 Edition, National Fire Protection Association, Quincy, Massachusetts.

UL 910, "Test Method for Fire and Smoke Characteristics of Electrical and Optical-Fiber Cables used in Air Handling Spaces".

UL 1581, "Reference Standard for Electrical Wires, Cables, and Flexible Cords".

UL 1666, "Standard Test for Flame Propagation Height of Electrical and Optical-Fiber Cable installed Vertically in Shafts".

UL 1685, "Fire Test of Limited-Smoke Cables".

## B.12 Building Limitations and Types of Construction

Two of the most effective methods used over the years to limit potential fire spread and prevent conflagration have been limiting the size of buildings and regulating the materials used in their construction. One of the primary purposes of a building code is to prescribe standards that will keep buildings from falling down. Besides gravity, there are many forces that act against a building. Snow loads, wind loads, and potential earthquake loads are provided for in the building code for design and construction of buildings. It can be considered that the potential force that requires the most extensive code provisions is fire. Large portion of the model building codes addresses fire protection issues, fire safety, emergency egress, and structural stability.

The key to understanding building code provisions for structural protection from fire is the concept of fire resistance. In broad terms, fire resistance (also called fire endurance) it is the ability of a building to resist collapse or total involvement in fire. Fire resistance is measured by the length of time typical structural members and assemblies resist specified temperatures. The building codes define fire resistance as that property of materials or their assemblies which prevents or retards the passage of excessive heat, hot gases, or flames under conditions of use.

### B.12.1 Types of Construction

There are three key points to remember when dealing with building construction types:

- All construction is either combustible (it will burn) or noncombustible (it won't).

- When applied to construction materials, "protected" refers to measures to reduce or eliminate the effects of fire encasement. Concrete, gypsum, and spray-on coatings are all used to protect construction elements. When the code means "protected with a sprinkler systems," it will say just that.

- Having the ability to determine the construction type by eyeballing a building is not a requirement.

### B.12.2 Five Construction Types

The model building codes and NFPA 220, "Standard on Types of Building Construction," recognize five construction types. The Standard Building Code subdivides noncombustible construction and uses six types. The terms vary a little between the different codes, but the concept is the same, based on the classifications from NFPA 220.

**Type I Fire Resistive** In Type I construction, the structural elements are noncombustible and protected. Type I is divided into two or three subtypes, depending on the model code. The difference between them is the level of protection for the structural elements (expressed in hours).

Only noncombustible materials are permitted, and structural steel must not be exposed. A high-rise building with an encased steel structure is an example of a Type I building.

**Type II Noncombustible** In Type II construction, the structural elements are either noncombustible or limited combustible. Type II is subdivided into subtypes, dependent upon the level of protection (in hours) for the structural elements. The buildings are noncombustible, but afford limited or no fire resistance to the structural elements. A strip shopping center, with block walls, steel bar joists, unprotected steel columns, and a steel roof deck is an example of a Type II building.

**Type III** **Limited Combustible (Ordinary)** In Type III construction, the exterior walls are noncombustible (masonry) and may be rated based on the horizontal distance to exposure. The interior structural elements may be combustible or a combination of combustible and noncombustible. Type III is divided into two subtypes (protected and unprotected). The brick, wood joisted buildings that line city streets are of Type III (ordinary) construction. Buildings with a masonry veneer over combustible framing are not Type III.

**Type IV** **Heavy Timber** In type IV construction, the exterior walls are noncombustible (masonry) and the interior structural elements are unprotected wood of large cross-sectional dimensions. Columns must be at least 8 inches if they support a floor load, joists, and beams must be a minimum of 6 inches in width and 10 inches in depth. Type IV is not subdivided. The inherent fire-resistant nature of large-diameter wood members is taken into account. Concealed spaces are not permitted.

**Type V** **Wood Frame** In Type V construction, the interior structure may be constructed of wood or any other approved material. Brick veneer may be applied, but the structural elements are wood frame. Type V is divided into two subtypes (protected and unprotected), again depending on the protection provided for the various structural elements.

### B.12.3 Fire Resistance Ratings

The various model codes and NFPA 220 each have a table containing the rating (in hours) of the various structural elements. Table B.12-1 summarizes the required ratings by building component type, depending upon the construction classification of the building. The construction classifications used by the model codes and NFPA 220 do not exactly match, type for type. Table B.12-1 and B.12-2 provides an approximate comparison. A notational system was developed to identify the fire resistance required for the three basic elements of the building. These elements are (1) the exterior wall (2) the primary structural frame, and (3) the floor construction. A three digit notation was developed, as follows:

(1) First digit - Hourly fire resistance requirement for exterior bearing wall fronting on a street or lot line.
(2) Second digit - Hourly fire resistance requirement for structural frame or columns and girders supporting loads from more than one floor.
(3) Third digit - Hourly fire resistance requirement for floor construction.

Thus for example, a "332" building would have 3-hr fire resistant exterior bearing walls, a 3-hr fire resistant structural frame, and 2-hr fire resistant floor construction, and would correspond to the NFPA 220 Type I (332) building, the BOCA National Building Code Type 1B building, the ICBO Uniform Building Code Type I FR (fire resistive) building, and SBCCI Standard Building Code Type II building.

Table B.12-1. Construction Classifications of the Model Codes and NFPA 220

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| NFPA 220 | I 443 | I 332 | II 222 | II 111 | II 000 | III 211 | III 200 | IV 2HH | V 111 | V 000 |
| UBC Table 6A | – | I FR | II FR | II 1HR | II 1HR | III 1HR | III N | IV HT | V 1HR | V N |
| BNBC Table 602 | 1A | 1B | 2A | 2B | 2C | 3A | 3B | 4 | 5A | 5B |
| SBC Table 600 | I | II | – | IV 1HR | IV U | V 1HR | V UNP | III | VI 1HR | VI UNP |
| IRC | – | – | 1A | 1B | IIA | IIIA | IIIB | I VHT | VA | VB |

Table B.12-2. Model Codes Standardization Council Recommended Types of Construction

| | | |
|---|---|---|
| | Noncombustible | |
| Type I (443)<br>Type I (332) | Type II (222)<br>Type II (111)<br>Type II (000) | |
| | Combustible | |
| Type III (211)<br>Type III (200) | Type IV (2HH) | Type V (111)<br>Type V (000) |

UBC - Uniform Building Code

BNBC - BOCA National Building Code
SBC - Standard Building Code
IRC - Institute of Research in Construction

### B.12.4 Reference

NFPA 220, "Standard on Types of Building Construction," National Fire Protection Association, Quincy, Massachusetts, 1999 Edition.

## B.13 Deep-Seated Fires in Class A Solid Materials

### B.13.1 General Information

Two types of fires can occur in Class A (ordinary) combustibles materials (e.g., wood, cloth, paper, rubber, and many plastics including cable insulation). In the first type, commonly known as flaming combustion, the source of combustion is volatile gases resulting from heating or decomposition of the fuel surface. In the second type, commonly called smoldering or glowing combustion oxidation occurs at the surface of, or within, the mass of fuel. These two types of fires frequently occur concurrently, although one type of burning may precede the other. For example, a wood fire may start as flaming combustion and become smoldering as burning progresses. Conversely, spontaneous ignition in a pile of oily rags may begin as a smoldering fire and break into flames at some later time (Friedman, 1997).

Smoldering combustion can not be immediately extinguished like flaming combustion. This type of combustion is characterized by a slow rate of heat loss from the reaction zone. Thus, the fuel remains hot enough to react with oxygen, even though the rate of reaction, which is controlled by diffusion processes, is extremely slow. Smoldering fires can continue to burn for many weeks, for example in bales of cotton and jute and within heaps of sawdust or mulch. A smoldering fire ceases to burn only either all of the available oxygen or fuel has been consumed or when the temperature of the fuel surface become too low to react. These fires are usually extinguished by reducing the fuel temperature, either directly by applying a heat absorbing medium, (such as water), or by blanketing the fuel with an inert gas. In the latter case, the inert gas slows the rate of reaction to the point at which heat generated by oxidation is less than the heat lost to the surroundings. This causes the temperature to fall below the level necessary for spontaneous ignition following removal of the inert gas atmosphere.

Smoldering fires are divided into two classes, in which the fire is either deep-seated or not. Basically, "deep-seated" implies the presence of sub-surface smoldering combustion that may continue for some time after surface flaming is suppressed. Deep-seated fires may become established beneath the surface of fibrous or particulate material. This condition may result from flaming combustion at the surface or from the ignition within the mass of fuel. Smoldering combustion then progresses slowly through the mass. Whether a fire will become deep-seated depends, in part, on the length of time it has been burning before the extinguishing agent is applied. This time is usually called the "pre-burn" time (Nolan, 2001).

As described above, a deep-seated fire is embedded in the material being consumed by combustion. To extinguish deep-seated fires, an individual must investigate the interior of the material once the surface fire has been extinguished to determine whether interior smoldering has also been extinguished by a gaseous agent. It should be noted, however, that the concentration of the extinguishing agent must be adequate—and must be applied for an adequate duration—to ensure that the smoldering has been effectively suppressed.

### B.13.2 Deep-Seated Cable Fires

A deep-seated fire occurs in cables when the burning involves pyrolysing beneath the surface, in addition to a surface phenomenon. This is postulated to occur when the cable fire reaches the stage of a fully developed fire. Extinguishing a cable surface fire does not guarantee that a deep-seated fire is also eliminated. A deep-seated fire is very difficult to suppress since fire suppressing agent cannot easily get to the seat of the fire, and it is also difficult to detect since combustion is primarily under the cooler surface.

Electrical cable fire tests have been conducted at the Sandia Fire Research Facility (Schmidt and Krause, 1982) in order to evaluate cable tray fire safety criteria. A burn mode concept was developed in order to describe and classify the thermodynamic phenomena which occur in the presence of smoke and to compare the fire growth and recession of different cable types under otherwise unchanged fire test conditions. The importance of deep-seated fires in cables trays from the standpoint of propagation, detection, and suppression is emphasized. The cable tray fire tests demonstrate that fire recession and deep-seated fires can result from a decreasing smoke layer and that reignition and secondary fire growth is possible by readmission of fresh air.

### B.13.3 Deep-Seated Charcoal Fires

The use of activated charcoal in NPPs presents a potential for deep-seated fires. Simply, that if it says that it is combustible, that it may be ignited, and that if it does become ignited, it is likely to become a deep-seated fire. It does not predict the frequency of those fires, nor form of ignition (Holmes, 1987). On July 17, 1977, a fire occurred at the Browns Ferry Nuclear Power Plant (BFNP) in Unit 3 off-gas system charcoal adsorber bed (Crisler, 1977). The elevation in adsorber bed temperature caused temperature rises of sufficient magnitude to cause carbon ignition.

### B.13.4 References

Crisler, H.E. Jr., "July 17, 1977, Off-Gas System Charcoal Adsorber Bed Fire at Browns Ferry Nuclear Plant," Proceedings of the CSNI Specialist Meeting on Interaction of Fire and Explosion with Ventilation Systems in Nuclear Facilities, Volume II , Report Number: LA-9911-C, Vol.2; CSNI-83, pp. 309-316, October 1983.

Friedman, R., "Theory of Fire Extinguishment," Section 1, Chapter 8, NFPA Fire Protection Handbook, 18th Edition, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts, 1997.

Holmes, W., "Adsorber Fires," Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0086-Vol. 2; CONF-860820-Vol.2, pp. 797-798, May 1987.

Nolan, D.P., *Encyclopedia of Fire Protection*, Delmar Publishers, Albany, New York. 2001.

Schmidt, W.H., and F.R. Krause, "Burn Mode Analysis of Horizontal Cable Tray Fires," NUREG/CR-2431, U.S. Nuclear Regulatory Commission, Washington, DC, February 1982.

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## B.14 Special Hazard Gaseous Fire Extinguishing Agents

### B.14.1 Introduction

A gaseous (or gas phase) fire suppression agent remains in the gaseous state at normal room temperature and pressure. It has low viscosity, can expand or contract with changes in pressure and temperature, and has the ability to diffuse readily and distribute itself uniformly throughout an enclosure. Gaseous fire extinguishing agents are categorized into two distinct classes, including halocarbon and inert gases (such as nitrogen and mixtures containing argon). Halocarbon agents (e.g., Halon 1301) act largely by absorbing although they also have some chemical effect on flame combustion reactions. Inert agents contains unreactive gases that act primarily by oxygen depleting. One important advantage of gaseous agents is that no cleaning is required if the agent is released in the absence of a fire; a couple of minutes of venting is all that is required. However, gaseous agents with the exception of Halon require a rather large storage area; this is particularly for nitrogen and argon, which are usually stored as compressed gases.

Halongenated extinguishing agents are hydrocarbons in which one or more hydrogen atoms in an organic compound (carbon) have been replaced by atoms from halogens (the chemicals in group 7 of the periodic table of the elements) chlorine (Cl), fluorine (F), bromine (Br), or iodine (I). This substitution confers flame extinguishing properties to many of the resulting compounds that make them useable for certain fire protection applications. The three halogen elements commonly found in Halon extinguishing agents used for fire protection are fluorine, chlorine, and Bromine. Compounds containing combinations of fluorine, chlorine, and bromine can possess varying degrees of extinguishing effectiveness, chemical and thermal stability, toxicity, and volatility. These agents appears to extinguish fire by inhibiting the chemical chain reaction that promotes the combustion process.

Carbon dioxide ($CO_2$) has a long history as an extinguishing agent, which is primarily used for flammable liquid fires and electrical equipment fires. $CO_2$ is noncombustible and does not react with most substances. It is a gas, but it can be easily liquified under pressure and is normally stored as a pressure-condensed gas. $CO_2$ provides its own pressure for release and blankets the fire area when released in sufficient amounts. $CO_2$ is extremely toxic; humans become unconscious at a 10-percent volume concentration followed by loss of life. Therefore, $CO_2$ cannot be released while people are present.

### B.14.2 Halogenated Agent Extinguishing Systems

Halogenated extinguishing agents are currently known simply as Halons, and are described by a nomenclature that indicate the chemical composition of the materials without the use of chemical names. In this nomenclature the first digit of the number definition represents the number of carbon atoms in the compound molecule; the second digit is the number of fluorine atoms; the third digit is the number of chlorine atoms; the fourth digit is the number of bromine atoms; and the fifth digit is if any, the number of iodine atoms. For example, the number definition for the chemical composition of Halon 1301, perhaps the most widely recognized halogenated extinguishing agent, is 1 (carbon), 3 (fluorine), 0 (chlorine), 1 (bromine), and 0 (iodine). This simplified system, proposed in 1950 by James Malcolm of the U.S. Army Corps of Engineers Laboratory, avoids the use of possibly confusing names. By contrast, the United Kingdom and parts of Europe still use the initial capital alphabet system [i.e., bromotrifluoromethane (Halon 1301) is BTM and bromochlorodifuoro-methane (Halon 1211) is BFC].

Due to the many chemical combinations available, the characteristics of halogenated fire extinguishing agents differ widely. It is generally agreed, however, that the agents most widely used for fire protection applications are Halon 1011, Halon 1211, Halon 1301, Halon 2402, and (to a lesser degree) Halon 122, which has been used as a test gas because of its economic advantages. However, because of its widespread use as a test agent, many individuals have wrongly assumed that Halon 122 is an effective fire extinguishing agent. Table B.14-1 illustrates the halogenated hydrocarbons most likely to be used today. Of all of these types, however, the most popular halogenated agent is Halon 1301, which offers superior fire extinguishing characteristics and low toxicity. Because Halon 1301 inhibits the chain reaction that promotes the combustion process, it chemically suppresses the fire very quickly, unlike other extinguishing agents that work by removing the fire's heat or oxygen. Stored as a liquid under pressure and released as a vapor at normal room temperature, Halon 1301 readily spreads into blocked and baffled spaces and leaves no corrosive or abrasive residue after use. A high liquid density permits compact storage containers, which on a comparative weight basis, makes Halon 1301 approximately 2.5 times more effective as an extinguishing agent than $CO_2$ (Grand, 1995).

Table B.14-1. Halogenated Hydrocarbons Commonly Used for Fire Protection

| Common Name | Chemical Name | Formula |
|---|---|---|
| Halon 1001 | Methyl Bromide | $CH_3Br$ |
| Halon 10001 | Methyl Iodide | $CH_3I$ |
| Halon1011 | Bromochloromethane | $CH_2BrCl$ |
| Halon 1202 | Dibromodifluoromethane | $CF_2Br_2$ |
| Halon 1211 | Bromochlorodifuoromethane | $CF_2BrCl$ |
| Halon 122 | Dichlorodifuoromethane* | $CF_2Cl_2$ |
| Halon 1301 | Bromotrifuoromethane | $CF_3Br$ |
| Halon 104 | Carbon Tetrachloride | $CCl_4$ |
| Halon 2402 | Dibromotetrafluoroethane | $C_2F_4Br_2$ |

* A popular test gas without substantial fire extinguishing properties.

Although halogenated agents may be applied using a variety of methods, the most common is the total flooding systems. According to the NFPA 12A, 1997 Edition, Section 2-3.1.1, a Halon 1301 total flooding system shall be automatically actuated for fires involving Class A ordinary combustible materials (e.g., wood, cloth, paper rubber, and many plastics including cables), with the exception that manual actuation shall be permitted if acceptable to the authority having jurisdiction (AHJ). NFPA 12A, 1997 Edition, Section 3-7.1.2, also indicate that the agent discharge shall be substantially completed in a nominal 10 seconds or as otherwise required by the AHJ. The rapid discharge is specified to prevent the fire from becoming deep-seated, minimize unwanted decomposition products, and achieve complete dispersal of the agent throughout the enclosure so that the Halon quickly knocks down the flames and extinguishes the fire. When exposed to deep-seated fires for long period of times, Halon 1301 decomposes into decomposition products, that are toxic to personnel and corrosive to electronic components (See Section B.18 for further discussion). Therefore, to extinguish fire effectively, while limiting the formation of hazardous decomposition products, it is important to disperse the agent during the incipient stage of the fire.

A significant problem in using of Halon 1301 is that, in the normal firefighting concentrations of 5-percent to 6-percent, it may fail to completely extinguish fires which originate in Class A solid materials (e.g., wood, cloth, paper, rubber, and many plastics). External and visible flame is instantly extinguished by Halon 1301, but internal and unseen flameless (but glowing) combustion may continue. As defined by the NFPA, if a 5-percent concentration of Halon 1301 will not extinguish a fire within 10 minutes of application, it is considered to be deep-seated, as described above. Such deep-seated fires usually require concentrations much higher than 10-percent and soaking times much higher than 10 minutes (NFPA 12A, 1971 Edition). The technical literature does not provide any satisfactory explanation for the ineffectiveness of Halon 1301 in deep-seated fires (Fielding and Woods, 1975).

Sandia National Laboratories (SNL) investigation of the effectiveness of the Halon 1301 fire suppression agent on electrical cables fires in 1981 and again in 1986 at the behest NRC. These full-scale fire suppression tests were performed to determine the concentration and minimum soaking time necessary to suppress electrical cable tray fires and prevent reignition of those fires. Halon 1301 was very effective in suppressing surface fires, but took much longer to suppress deep-seated cable tray fires. The results of Test 60 depicted on Figure B.14-1 indicated that even after Halon 1301 is discharged, the interior temperature of the cable bundle continues to rise, probably as a resulting of continued combustion of the cable insulation. Moreover, a second increase in temperature occurs air is readmitted during ventilation, thereby causing reignition of the cable insulation (Klamerus, 1981).

As illustrated in Figure B.14-1 the Halon 1301 concentration applied to the fire has a direct relationship to the time required to completely extinguish the fire. When the agent is first applied to the cable trays, the flames are immediately extinguished, but the deep-seated combustion (or glow), continues and the fire will reignite if the enclosure is then ventilated.

### B.14.2.1 Halon Concentration and Soaking Time

Soaking time is an important requirement for a Halon 1301 total flooding system. This is especially true for Class A fires that may reflash. A minimum soaking period of 10-minutes is typically required for fires in these applications, based on the full-scale total flooding fire suppression tests

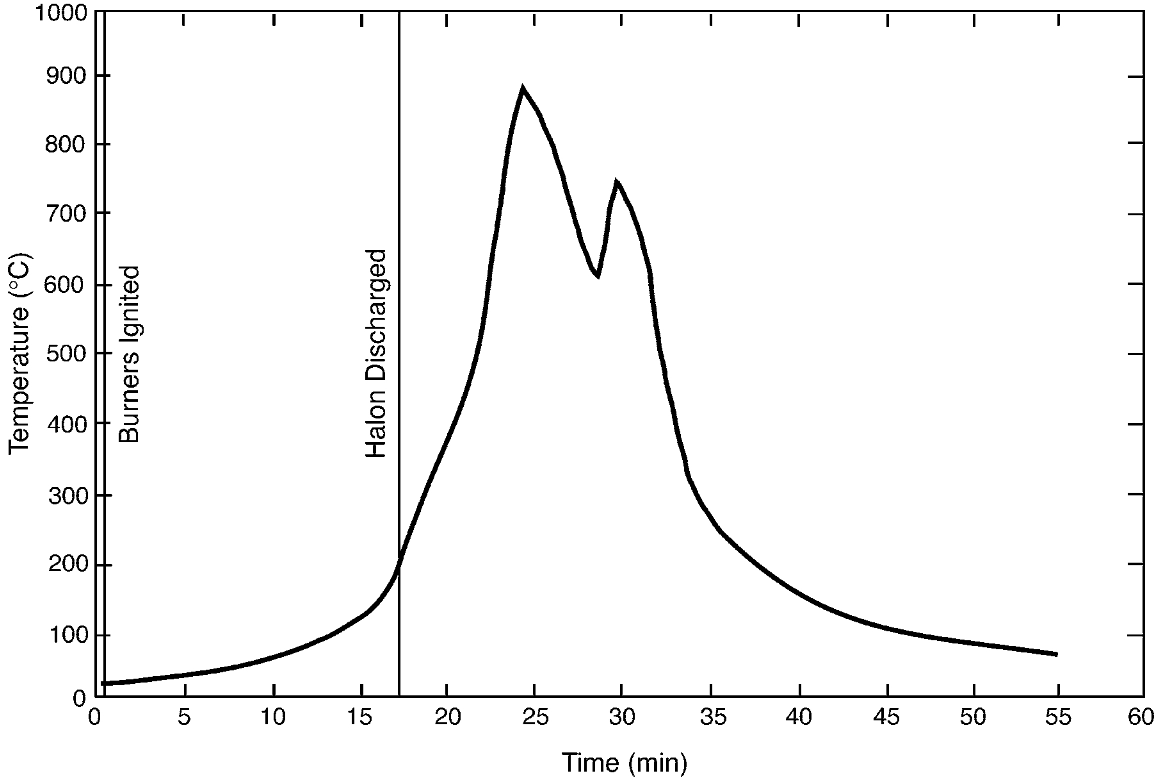


Figure B.14-1 Indication of Deep-Seated Fire and Reignition of Cables, Test # 60, IEEE-383 Qualified Cables, Horizontal Trays, 4-Minute Halon Soak Acceptor Tray Center Temperature (Klamerus, 1981) for electrical cable tray fires conducted by Klamerus (1981), and Chavez and Lambert (1986). A 6-percent Halon 1301 concentration with a 10-minute soak time successfully extinguished all cable fires in horizontally and vertically oriented trays filled with IEEE-383 unqualified cables, while IEEE-383 qualified cables required a 15-minute soaking time. The measure concentrations in these tests were based on a completely air tight enclosure during discharge (See Figure B.14-2 for Halon 1301 concentration requirements) concentration with 15 minute soak time successfully extinguished all cable fires in horizontal and vertical oriented tray filled with. The measured concentrations in this testing is based on completely tight enclosure during discharge and soaking time of Halon 1301 (see Figure B.14-2 for Halon 1301 concentration requirements).

### B.14.2.2 Agent Leakage

Because Halon 1301 is approximately five times heavier than air (with molecular weight 148.93 g/mol compared to 29 g/mol for air), there is a risk of Halon leakage from the protected space if the space is not completely airtight. Therefore, it is important to know the Halon percent and soak time at the highest combustible in the protected enclosure. NFPA 12A requires that the leakage rate should be low enough so that the design concentration is held in the hazard area long enough to ensure that the fire is completely extinguished. Reignition of the fire is a potential concern if the effective concentration are not maintained. In case of leakage during and after discharge, a greater amount of the agent is required to develop a given concentration. To maintain the agent concentration at a given level requires continuous agent discharge for the duration of the soaking period. The leakage rate from an enclosure could be predicted from the detailed knowledge of the size, location, and geometry of any leaks. However, these details are rarely known, as leakage may occur around doors and door seals; wall; ceiling; and floor cracks, duct, conduit, and cable tray penetrations; and fire and isolation dampers. Appendix B to NFPA 12A presents methods of estimating leakage area.

Discharging Halon 1301 into an enclosure to achieve total flooding results in an air/agent mixture with a higher specific gravity than the air surrounding the enclosure. Therefore, any openings in the lower portions of the enclosure will allow the heavier air/agent mixture to flow out and the lighter outside air to flow in. Fresh air entering the enclosure will collect toward the top, forming an interface between the air/agent mixture and fresh air. As the leakage proceeds, the interface will descend toward the bottom of the enclosure. The space above the interface will be completely unprotected, while the lower space will essentially contain the original extinguishing concentration. Grant (1995) presented methods of adjusting the Halon 1301 concentration to unprotected openings (leakage).

Rapid detection of a fire and prompt application of the extinguishing agent without outside assistance can help to prevent a Class A fire from becoming deep-seated. If a fire becomes deep-seated or (begins as a deep-seated fire), it will not likely be extinguished by Halon 1301 concentrations below 10-percent, and some deep-seated fires require concentrations above 18–30-percent to ensure that the glow is completely extinguished (Grant, 1995).

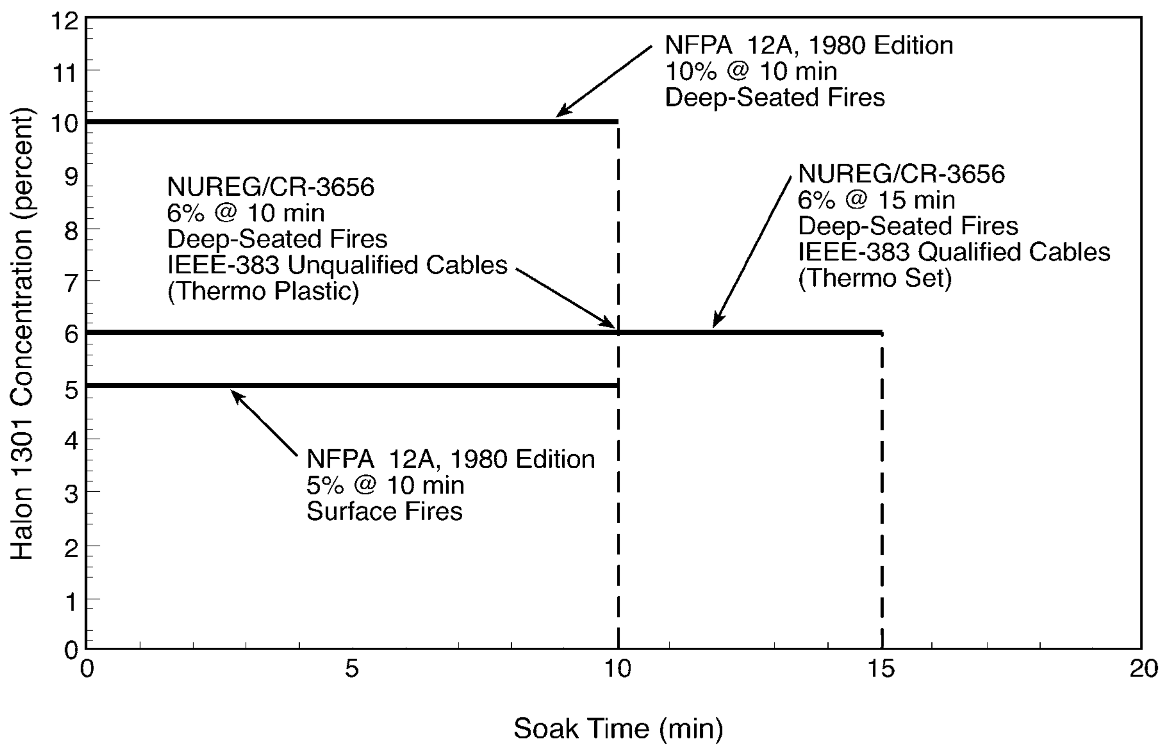


Figure B.14-2 Soaking Time vs. Halon 1301 Concentration for Deep-Seated and Surface Fires

It is important to remember that in most cases, halogenated agent extinguishing systems have only a single chance to extinguish a fire. Such systems should be tested and Halon concentrations measured at various heights within the protected space (at least at the point of the highest combustible) to demonstrate the design concentrations. Timely and automatic actuation of Halon systems would also provide reasonable assurance that a fire would be extinguished before spreading through the combustible material and becoming deep-seated.

## B.14.3 Carbon Dioxide Fire Extinguishing Systems

Carbon Dioxide ($CO_2$) is a colorless, odorless, inert, and electrically nonconductive agent that extinguishes a fire by displacing the normal atmosphere, thereby reducing the oxygen content below the 15-percent required for diffusion flame production. The $CO_2$ from either low-pressure or high-pressure extinguishing systems is stored and transported as a liquid through the piping system to the nozzles. With the release of pressure at the nozzles, the liquid $CO_2$ converts to a gas, with some minute solid particles, making it approximately 50-percent heavier than air.

Flame extinguishment by $CO_2$ is predominantly by a thermophysical mechanism in which reacting gases are prevented from achieving a temperature high enough to maintain the free radical population necessary for sustaining the flame chemistry. For inert gases presently used as fire suppression agent (argon, nitrogen, carbon, carbon, and mixture of these), the extinguishing concentration (as measured by the cup burner method , NFPA 2001) is observed to be linearly related to the heat capacity of the agent-air mixture. Although of minor importance in accomplishing fire suppression, $CO_2$ also dilutes the concentration of the reacting species in the flame, thereby reducing collision frequency of the reacting molecular species and slowing the rate of heat release.

$CO_2$ fire extinguishing systems are useful in protecting against fire hazards when an inert, electrically nonconductive, three-dimensional gas is essential or desirable and where clean up from the agent must be minimal. According to the NFPA, some of the types of hazards and equipment that carbon dioxide systems protect are "flammable liquid materials; electrical hazards, such as transformers, switches, circuit breakers, rotating equipment, and electronic equipment; engines utilizing gasoline and other flammable liquid fuels; ordinary combustibles such as paper, wood, and textiles; and hazardous solids" (NFPA 12).

Over the years, two methods of applying $CO_2$ have been developed. The first technique is the total flooding application, which involves filling an enclosure with $CO_2$ vapor to a prescribed concentration. In this technique, the $CO_2$ vapor flows through nozzles that are designed and located to develop a uniform concentration of the agent in all parts of the enclosure. The quantity of $CO_2$ required to achieve an extinguishing atmosphere is calculated on the basis of the volume of the enclosure and the concentration of the agent required for the combustibles material in the enclosure. This technique is applicable for both surface-type fires and potentially deep-seated fires.

For surface-type fires, as would be expected with liquid fuels, the minimum concentration is of 34-percent of $CO_2$ by volume. Considerable testing has been done with using $CO_2$ on liquid fuels and appropriate minimum design concentrations have been derived at for a large number of common liquid fire hazards.

For deep-seated hazards, the minimum concentration is 50-percent of $CO_2$ by volume. This 50-percent design concentration is used for hazards involving electrical gear, wiring insulation, motors, and the like. Hazards involving record storage, such as bulk paper require a 65-percent concentration of $CO_2$, while substances such as fur and bag-type house dust collectors require a 75-percent concentration.  It should be noted that most surface burning and open flaming will stop when the concentration of $CO_2$ in the air reaches about 20-percent or less by volume. Thus, it should be apparent that a considerable margin of safety is built into these minimum $CO_2$ concentrations required by the standard.  This is because those who developed the $CO_2$ standard never considered it sufficient to extinguish the flame.  By contrast, the guidelines given in some of the standards for other gaseous extinguishing agents merely mandate concentrations that are sufficient to extinguish open flame but will not produce a truly inert atmosphere.

The other method of applying $CO_2$ is local application.  This method is appropriate only for extinguishing surface fires in flammable liquids, gases, and very shallow solids where the hazard is not enclosed or where the enclosure of the hazard is not sufficient to permit total flooding. Hazards spray booths, printing presses, rolling mills, and the like can be successfully protected by a local application system designed to discharge $CO_2$ and direct the flow at the localized fire hazard. The entire fire hazard area is then blanketed in $CO_2$ without actually filling the enclosure to a predetermined concentration.

The integrity of the enclosure is a very important part of total flooding, particularly if the hazard has a potential for deep-seated fire.  If the enclosure is air tight, especially on the sides and bottom, the $CO_2$ extinguishing atmosphere can be retained for a long time to ensure complete extinguish of the fire.  If there are openings on the sides and bottom, however, the heavier mixture of $CO_2$ and air may rapidly leak out of the enclosure.  If the extinguishing atmosphere is lost too rapidly, glowing embers may remain and cause reignition when air reaches the fire zone.  Therefore, it is important to close all openings to minimize leakage or to compensate for the openings by discharging additional $CO_2$.

An extended discharge of $CO_2$ is used when an enclosure is not sufficiently air tight to retain an extinguishing concentration as long as needed.  The extended discharge is normally at a reduced rate, following a high initial rate to develop the extinguishing concentration in a reasonably short time.  The reduced rate of discharge should be a function of the leakage rate, which can be calculated on the basis of leakage area, or of the flow rate through ventilating ducts that cannot be shut.

Extended discharge is particularly applicable to enclosed rotating electrical equipment, such as generators, where it is difficult to prevent leakage until rotation stops.  Extended discharge can be applied to ordinary total flooding systems, as well to the local application systems where a small hot spot may require prolonged cooling.

### B.14.3.1 Carbon Dioxide Requirements for Deep-Seated Fires (NFPA 12)

NFPA 12 recognizes two types of $CO_2$ extinguishing systems.  The first type is the high-pressure $CO_2$ system, and the second is a low-pressure $CO_2$ system. The basic difference between the two types lies in the method of storing the $CO_2$.

The high-pressure system utilizes U.S. Department of Transformation (DOT) spun steel storage cylinders, which are usually kept at room temperature. At an ambient temperature of 21 °C (70 °F), the internal pressure in such a unit reaches 850 psi. These cylinders are available in capacities of 50, 75, or 100 pounds.

By contrast, the low-pressure storage unit maintains the $CO_2$ in a refrigerated pressure vessel with a typical storage temperature of -18 °C (0 °F) with a corresponding $CO_2$ vapor pressure of 300 psi. The refrigerated storage concept uses an American Society of Mechanical Engineers (ASME) coded pressure vessel with a working pressure of 2,413 kPa (350 psi). Such units are available in standard capacities from 1.25–60 tons. Larger units have also been made for special applications.

From this basic difference in storage configuration inspired different application and control methods for the two types of systems. Since the maximum capacity of a high-pressure cylinder is 100 pounds of $CO_2$, most systems consist of multiple cylinders manifolded together to provide the required quantity of agent. Each cylinder has its own individual discharge valve and, once opened, the cylinder contents will completely discharge.

NFPA 12 requires that the quantity of $CO_2$ for deep-seated fires must be based on fairly air tight enclosures. After the design concentration is reached, it shall be maintained for a substantial period of time, but not less than 20-minutes. Any possible leakage shall be receive special consideration since the basic flooding factor does not include any leakage allowance.

For deep-seated fires the design concentration shall be achieved within 7-minutes from the start of discharge, but the rate shall be not less than that required to develop a concentration of 30-percent within 2 minutes. For surface fires, the design concentration shall be achieved within 1-minute from the start of discharge.

### B.14.3.2 Personnel Protection from Carbon Dioxide

The $CO_2$ that is used to extinguish the diffusion combustion may pose a threat to human life, and NPP personnel must recognize and plan to cope with this threat

Human subjects exposed to low concentrations (less than 4-percent) of $CO_2$ for upto 30-minutes, dilation of cerebral blood vessels, increased pulmonary ventilation, and increased oxygen delivery to the tissues were observed (Gibbs et al.,1943, Patterson et al., 1955). These results were used by the United Kingdom regulatory community to differentiate between inert gas systems for fire suppression that contain $CO_2$ and those that do not (HAG, 1995). During similar low-concentration exposure scenarios in humans, however, other researchers have recorded slight increases in blood pressure, hearing loss, sweating, headache, and dyspnea (Gellhorn and Speisman, 1934, 1935; Schneider and Schulte, 1964). 6–7-percent $CO_2$ is considered the threshold level at which harmful effects become noticeable in human beings. At concentration above 9-percent, most people lose consciousness within a short time. Since the minimum concentrations of $CO_2$ in air used to extinguish fire exceed 9-percent, adequate safety precautions must be designed into every $CO_2$ fire extinguishing system.

### B.14.3.3 Harmful Effects of Carbon Dioxide Fire Suppression Systems

As described above $CO_2$ is lethal to humans at the minimum concentrations required to suppress fires. In fact, since 1975, accidents involving the discharge of $CO_2$ fire suppression systems have resulted in a total of 64 deaths and 89 injuries. Given its inherent hazard, $CO_2$ should not be used in areas that are subject to occupancy, except when the risk of fire is documented to be greater than the risk to personnel and no viable suppression alternatives exits.

In land-based workplace environments, Occupation Safety and Health Administration (OSHA) regulates the use of $CO_2$. These regulations are provided in 29 CFR Parts 1910.160 and 1910.162, which outline the requirements for general and gaseous fixed extinguishing systems, respectively. Despite the fact that the concentration of $CO_2$ needed to extinguish fires is above the lethal level, U.S. Occupation Safety and Health Administration (OSHA) does not prevent the use of $CO_2$ in normally occupied areas. (However, OSHA does explicitly limit the use of chlorobromomethane and carbon tetrachloride as extinguishing agents where employees may be exposed [29 CFR Part 1910.160 (b) (11)]. For $CO_2$ systems, OSHA requires a predischarge alarm for alerting employees of the impending release of $CO_2$ when the design concentration is greater than 4-percent (which is essentially true for all $CO_2$ systems). This predischarge alarm must allow sufficient time delay for personnel to safely exit the area prior to discharge. Although it is speculative, it is likely that these regulations would confer adequate protection only in the event of planned discharge, not accidental discharge. Accidental discharges have occurred, however, in which adherence to regulations has provided personnel protection, whereas some planned discharges have resulted in injury to personnel.

U.S. Environmental Protection Agency (EPA) has published a report to provide information on the use and effectiveness of $CO_2$ in fire protection systems and describes incidents involving inadvertent of personnel to the gas (EPA430-R-00-02, 2000). The results of this comprehensive review identify that from 1975 to the present, a total of 51 $CO_2$ incident records were located that reported a total of 72 deaths and 145 injuries resulting from accidents involving the discharge of $CO_2$ fire extinguishing systems. All the deaths that were attributed to $CO_2$ were the result of asphyxiation. Details about the injuries were generally not provided in the incident reports, although some OSHA inspections listed asphyxia as the nature of the injury. Prior to 1975, a total of 11 incident records were located that reported a total of 47 deaths and 7 injuries involving $CO_2$. Twenty of the 47 deaths occurred in England prior to 1963; however, the cause of these deaths is unknown. The remainder of this section presents representative examples of the hazards of $CO_2$ fire suppression systems:

- On July 28, 2000, a bank employee accidentally suffocated in a New York City bank vault after pulling a fire alarm that flooded the space with $CO_2$. The bank employee was putting stock receipts in the bank's basement vault when she accidentally became locked inside. Apparently thinking she could get help by pulling a fire alarm, she instead activated a $CO_2$

fire extinguishing system that sucked air from the vault. She was taken to a local hospital in extremely critical condition and was pronounced dead.

- On January 15, 1999, at 5:49 p.m., with the plant at full power, an inadvertent discharge of the $CO_2$ fire suppression system occurred in the Millstone Unit 3 cable spreading room (CSR), which is located in the control building directly below the control room. The actuation occurred when a non-licensed plant equipment operator trainee in the service building blew dust off a printed circuit board located in the CSR $CO_2$ control panel, which is located in the service building, rather than the control building. There were no plant personnel in the CSR at the time of the discharge. Shortly after the discharge, $CO_2$ was found to have migrated down into the switchgear rooms located directly below the CSR. Approximately 37-minutes after initiation, the licensee used a portable instrument to measure the concentration of $CO_2$ in one of the control building stairwells, which allows access to the control room, the CSR, and the switchgear rooms. The reading was off-scale high indicating that the $CO_2$ concentration was in excess of 50,000 parts per million (ppm). NRC Regulatory Guide 1.78 currently recommends a $CO_2$ toxicity limit of 10,000 ppm. On the basis of this indication, the licensee declared the area uninhabitable.

  Approximately 2 hours after the $CO_2$ discharge, operators aligned the control building purge system to remove $CO_2$ from the switchgear rooms. The switchgear rooms were selected for purging first because they contained important plant equipment, such as the auxiliary shutdown panel. The purge system is a non-safety-related system designed to remove $CO_2$ and smoke from various control building areas. Placing the purge system in service diverted air from the control room to the switchgear rooms, which reduced the pressure in the control room relative to the CSR. This pressure reduction in the control room may have allowed $CO_2$ from the CSR room to migrate up through penetrations into the control room. When the concentration of $CO_2$ reached 5,000 ppm in the control room, the operators donned self-contained breathing apparatus (SCBA), as required by the plant procedures. The concentration of $CO_2$ in the control room reached a peak level in excess of 17,000 ppm before it began to decrease. The operators wore SCBA for approximately 6 hours until the $CO_2$ was successfully purged from the control room.

- On July 29, 1998, a high-pressure, total flooding $CO_2$ extinguishing system discharged without warning during routine maintenance of electrical equipment, resulting in one fatality and several serious injuries in Building 648 of the Idaho National Engineering and Environmental Laboratory (INEEL) (EH2PUB/09-98/01A1). At the time of the accident, the newly installed $CO_2$ system releasing panel was electronically disabled and considered to be out of service. The work crew began opening circuit breakers in preparation for the preventive maintenance work. Shortly after the last breaker was opened, the $CO_2$ system discharge, creating near zero visibility. While the evacuation alarms may have briefly sounded for less than one second, they did not continuously sound in conjunction with $CO_2$ release. After the $CO_2$ discharge, the worker ran towards the exits, which were visible since they were held open by cables running into the building from portable generators. Eight of the workers were able to exit on their own; however, five remained inside of the building and were rendered unconscious by the $CO_2$. Three were later rescued by the workers who had earlier escaped, which left two people remaining in the building. One of the remaining workers was later revived, and the other perished.

- At Duane Arnold Unit 1 on March 22, 1992 (LER 331/92-004), the licensee performed a special test of the $CO_2$ fire suppression system in the CSR. This test was conducted to check corrective actions taken following a $CO_2$ discharge in 1990. At the time of this test, the reactor had been shut down and defueled. As a result of this test, $CO_2$ intruded into the control room, and this intrusion led to an unacceptable reduction in the oxygen level in the area within a few minutes. The operator recorded oxygen levels of 17-percent (at chest level) and 15-percent (at floor level), both of which were below the plant's acceptance criterion of 19.5-percent. Essential control room personnel donned SCBA and were able to remain in the control room. The reduced oxygen levels resulted from increased pressure in the CSR, which is directly beneath the control room. Sealed penetrations between the two rooms leaked under the high differential pressure.

  In this incident, the migration of $CO_2$ into various fire zones may have adversely affected the operators' ability to shut down the plant during a fire in the CSR. Consequently, one can conclude that a severe fire in the CSR may adversely affect the operators' ability to safely shut down the plant from the control room. In the event that the operators are required to evacuate the control room, plant procedures require operators to shut down the plant from the auxiliary shutdown panel and other panels, which are located in the switchgear rooms. During this event, the $CO_2$ concentration at the auxiliary shutdown panel would prohibit access without SCBA.

- At Surry Nuclear Power Station on December 9, 1986, an accidental discharge of both the $CO_2$ and Halon extinguishing systems was caused by water damage to the extinguishing system control panels. The water came from a pipe break in the feedwater system. Four died and four were injured in a fire associated with the accident. However, it is not clear if the release of the gases from fire extinguishing systems were responsible for these injuries and deaths (Warnick, 1986).

- At Hope Creek Generating Station, on September 4, 1984, a 10 tons $CO_2$ system was inadvertently discharged into a diesel generator fuel storage area. The warning bell and beacon light did not operate and workers who were cleaning the corridor walls outside of the fuel storage room with air/water guns under pressure were not alerted. The cause of the discharge was determined to be moisture (that entered the $CO_2$ control panel through openings at the top of an inadequately installed protective panel) that shorted the $CO_2$ control panel circuitry. The moisture was believed to have originated from the workers cleaning the corridor walls (PNO-I-85-64a).

### B.14.4 References


Chavez, J.M., and L.D. Lambert, "Evaluation of Suppression Methods for Electrical Cables Fires," NUREG/CR-3656, U.S. Nuclear Regulatory Commission, Washington, DC, October 1986.

EPA430-R-00-02, "Carbon Dioxide as a Fire Suppressant: Examining the Risk," U.S. Environmental Protection Agency, Office of Air and Radiation, Stratospheric protection Division, Washington DC, February 2000.

Fielding, G.H., and F.J. Woods, "Halon 1301: Mechanism of Failure to Extinguish Deep-Seated Fires," *Journal of Fire & Flammability*, Volume 6, pp. 37–43, January 1975.

Gellhorn, E., and I. Spiesman, "Influence of Variations of $O_2$- and Carbon Dioxide Tension in the Inspired Air Upon Hearing," Proceedings of Society of Exp. Biol. Med., Volume 32, pp. 46–44, 1934.

Gellhorn, E., and I. Spiesman, "Influence of Hyperpnea and Variations of O2- and CO2-Tension in the Inspired Air Upon Hearing," *American Journal of Physiol*ogy., Volume 112, pp. 519–528, 1935.

Gibbs, F.A., E.L Gibbs, E.G. Lennox, and L.F. Nims, "The Value of Carbon Dioxide in Counteracting the Effects of Low Oxygen," *Journal of Aviat. Med*., Volume 14, pp, 250–261, 1943.

Grand, C.C., "Halon Design Calculations," Section 4, Chapter 6, *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, P.J. DiNenno, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts, 1995.

HAG, "A Review of the Toxic and Asphyxiating Hazards of Clean Agent Replacements for Halon 1301," Prepared by the Halon Alternatives Group (HAG) in the UK, February 1995. As Cited in a Letter dated May 9, 1995 from J.S. Nicholas, Ansul Inc., to Karen Metchis, EPA.

Klamerus, L.J., "Electrical Cable Fire Suppression Tests with Halon 1301," SAND 81-1785, Sandia National Laboratories (SNL), Albuquerque, New Mexico, August 1981.

NFPA 12, "Carbon Dioxide Extinguishing Systems," National Fire Protection Association, Quincy, Massachusetts.

NFPA 12A, "Standard on Halon 1301 Fire Extinguishing Systems," 1992 Edition, National Fire Protection Association, Quincy, Massachusetts.

NFPA 12A, "Standard on Halon 1301 Fire Extinguishing Systems," 1971 Edition, National Fire Protection Association, Quincy, Massachusetts, pp. 59–69.

NFPA 2001, "Standard on Clean Agent Fire Extinguishing Systems," 2000 Edition, National Fire Protection Association, Quincy, Massachusetts.

NRC Information Notice: 99-05, "Inadvertent Discharge of Carbon Dioxide Fire Protection System and Gas Migration, March 8, 1999.

Patterson, J.L., H. Heyman, L.L Battery, and R.W. Ferguson, "Threshold of Response of the Cerebral Vessels of Man to Increases in Blood Carbon Dioxide," *Journal of Clin. Invest,* Volume 34, pp. 1857–1864, 1955.

Preliminary Notification of Event or Unusual Occurrence PNO-I-99-004: Carbon Dioxide Discharge into Cable Spreading Room, Millstone Unit 3. January 20, 1999.

Preliminary Notification of Event or Unusual Occurrence - PNO-I-85-64a, U.S. Nuclear Regulatory Commission Region I, September 5,1985.

Schult, J.H., "Sealed Environments in Relation to Health and Disease," Arch. Environment Health, Volume 8, pp. 438–452, 1964.

Sinclair, R.D., J.M. Clark, and B.E. Welch, "Comparison of Physiological Responses of Normal man to Exercise in Air and in Acute and Chronic Hypercapnia," Underwater Physiology, C.J. Lambertsen, Editor, Academic Press, New York, New York, pp. 409–417, 1971.

"Type A Accident Investigation Board Report of the July 28, 1998, Fatality and Multiple Injuries Resulting from the Release of Carbon Dioxide at Building 648, Test Reactor Area," Idaho National Engineering and Environmental Laboratory, U.S. Department of Energy, EH2PUB/09-98/01A1, September, 1998.

Warnick, L., "Inadvertent Actuation of Fire Suppression Systems, Surry Nuclear Power Station, Feedwater Pipe Failure," Virginia Power, Richmond, Virginia, 1986.

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## B.15 Dry Chemical Extinguishing Agents

Dry chemicals or powders, or solid phase agents provide an alternative to water or gaseous agents for extinguishing fire. Table B.15-1 lists the chemical names, formulae, and (commercial) names of the various dry chemical agents. In each case, the particles of powder (10–76 μm in size) are coated with an agent (such as zinc stearate or a silicone) to prevent caking and promote flowing, and are projected by an inert gas. The effectiveness of any of these agents depends on the particle size. The smaller the particles, the less agent is needed as long as particles are larger than a critical size. The reason for this fact is believed to be that the agent must vaporize rapidly in the flame to be effective. However, if an extremely fine agent were used, it would be difficult to disperse and apply to the fire.

Table B.15-1. Dry Chemical Agents

| Chemical Name | Formula | Popular Name(s) |
|---|---|---|
| Sodium bicarbonate | $NaHCO_3$ | Baking soda |
| Sodium chloride | $NaCl$ | Common salt |
| Potassium bicarbonate | $KHCO_3$ | Purple K |
| Potassium chloride | $KCl$ | Super K |
| Potassium sulfate | $K_2SO_4$ | Karate Massive |
| Monoammonium phosphate | $(NH_4)H_2PO_4$ | ABC or multipurpose |
| Urea and Potassium bicarbonate | $NH_2CONH_2 + KHCO_3$ | Monnex |

It is difficult to draw a precise comparison of effectiveness of one dry chemical with another because a comparison based on chemical differences would require each agent to have identical particle size. Furthermore, gaseous agents can be compared by studying the flammability limits of uniform mixtures at rest; however, if particles were present, they would settle out unless the mixture is agitated, thus modifying the combustion behavior. Nonetheless, some general comparisons of various powders have been made:

- Sodium bicarbonate (standard dry chemical) and sodium chloride have comparable effectiveness and are several times as effective (on a weight basis) as powders such as limestone or talc, which are supposedly chemically inert in a flame. Sodium bicarbonate (standard dry chemical) primarily consists of sodium bicarbonate (over 90-percent) with additives to improve fluidity, non-caking, and water-repellent characteristics.

- Potassium bicarbonate or potassium chloride is up to twice as effective (on a weight basis) as the corresponding sodium compounds.

- Under some conditions, monoammonium phosphate is more effective than potassium bicarbonate, however, it can be less effective under other conditions.

- Monnex is twice as effective as potassium bicarbonate because of the rapid thermal decomposition of the complex formed between urea and potassium bicarbonate, which cause a breakup of the particles in the flame to form very fine fragments, which then rapidly gasify.

Dry chemical formulations may be ranked with regard to their effectiveness in extinguishing fires according to their performance in tests. As previously described, this performance is a function of both the chemical composition and the particle size. It seems clear that the effective powders act on a flame through some chemical mechanism, presumably forming volatile species that react with hydrogen atoms or hydroxyl radicals. However, science has not yet firmly established the precise reactions. Although the primary action is probably removal of active species, the powders also discourage combustion by absorbing heat, blocking radiative energy transfer, and in the case of monoammonium phosphate, forming a surface coating.

Of the seven types of dry chemicals commonly in use, only monoammonium phosphate is considered effective against deep-seated fires because of a glassy phosphoric acid coating that forms over the combustible surface. All seven types of dry chemical extinguishing agents act to suppress the flame of a fire (Friedman, 1998), but require significant cleaning after use. As a result their use is limited almost exclusively to environments where this is not a serious concern. Dry chemicals are very common in manual extinguishers and to some extent for local applications. The most common application of these agents is for relatively small flammable liquid fires. Dry chemical total flooding suppression systems are designed to reach the design concentration within the entire protected volume in less than 30 seconds (NFPA 17, "Standard for Dry Chemical Extinguishing System"). Additional dry chemical is required to compensate for losses attributable to openings and ventilation in a compartment.

One reason for the popularity of dry chemical extinguishing agents other than monoammonium phosphate to do with corrosion. Any chemical powder can produce some degree of corrosion or other damage, but monoammonium phosphate is notably acidic and corrodes more readily than other dry chemicals, which are neutral or mildly alkaline. Furthermore, corrosion by the other dry chemicals is stopped by a moderately dry atmosphere, while phosphoric acid has such a strong affinity for water that an exceedingly dry atmosphere would be needed to stop corrosion. Monoammonium phosphate is also not recommended for kitchen fires involving hot fat because of its acidic nature; an alkaline dry chemical (such as potassium bicarbonate) is preferred.

Application of a dry chemical extinguishing agent on an electrical fire is safe (from the viewpoint of electric shock) for fire fighters. However, these agents (especially monoammonium phosphate) can damage delicate electrical equipment.

### B.15.1 Hazards Associated with Dry Chemicals

One hazard associated with the use of dry chemical extinguishing agents is attributable to the sudden release of the agent. Another hazard is unexpected reignition. The main toxic hazards following the use of dry chemical agents will generally be those attributable to the combustion processes, since dry chemicals themselves are non-toxic. According to Hague (1997), the ingredients used in dry chemical agents are nontoxic but can cause temporary breathing difficulty and can interfere with visibility.

### B.15.2 References


Friedman, R., *Principles of Fire Protection Chemistry and Physics*, 3rd Edition, Chapter 14, "Fire-Fighting Procedures," National Fire Protection Association, Quincy, Massachusetts, pp. 229–230, 1998.

Hague, D.R., "Dry Chemical Agents and Applications Systems," Section 6, *NFPA Fire Protection Handbook*, 18th Edition, National Fire Protection Association, Quincy, Massachusetts, 1997.

NFPA 17, "Standard for Dry Chemical Extinguishing Systems," 2002 Edition, National Fire Protection Association, Quincy, Massachusetts.

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## B.16 Fire Protection Using Foam

Extinguishing foams provide a primary alternative to water, particularly for large fires. Foams are widely used to control and extinguish fires involving of flammable and combustible Class B liquids (e.g., solvents, oil based paints, petroleum greases, paraffin or heavy lubricants, tars, lacquers, hydrocarbons, alcohols, LPG, LNG, and cooking fats). Foams are also suitable for Class A fires involving ordinary combustible materials (e.g., wood, cloth, paper, rubber, and many plastics).

If a flammable liquid is lighter than water and is insoluble in water, application of water to extinguish a fire would simply cause the liquid to float on the water and while continue to burn. Moreover, if the burning liquid is an oil or fat, the temperature of which is substantially above the boiling point of water, the water will penetrate the hot oil, turn into steam below the surface, and cause an eruption of oil that will accelerate the burning rate and possibly spread the fire. By contrast, if the flammable liquid is water soluble (such as alcohols), addition of sufficient water will dilute the liquid to the point where it is no longer flammable. However, if the involves a deep pool of alcohol (rather than a shallow spill), the time required to obtained sufficient dilution might be so great that an aqueous foam would be a better choice of extinguishing agent. If the nature of a liquid is unknown, an aqueous foam might still be chosen over direct application of water. Another important application of foam is on liquids or solids that are burning in spaces that are difficult to assess (such as a room in a basement or the hold of a ship). In such instances, the foam is used to flood the compartment completely.

Fire-fighting is mass of bubbles formed by various methods from aqueous solutions of specially formulated foaming agents. Some foams are thick and viscous, forming tough heat-resistant blankets over burning liquid surfaces and vertical areas. Other foams are thinner and spread more rapidly. Some are capable of producing a vapor-sealing film of surface-active water solution on a liquid surface, and others are meant to be used as large volumes of wet gas cells to inundate surfaces and fill cavities. The foam initially acts as a blanketing agent and then as a cooling agent as the water drains from the foam, as a cooling agent.

The effectiveness of foam is attributable to following factors:

- prevents air from reaching fire
- generates steam, which dilutes the air as well as absorbed heat
- penetrates crevices because of low surface tension
- provides protection of exposed material that not yet burning

Nonetheless, foam is an unstable air-water emulsion, which can easily be broken down by physical or mechanical forces, and certain chemical vapors or fluids can quickly destroy foam. Consequently, when certain other extinguishing agents are used in conjunction with foam, severe breakdown of the foam can occur. In addition, turbulent air or violently uprising combustion gases can divert light foam from the burning area.

Foam breaks down and vaporizes its water content under attack by heat and flames. Therefore, it must be applied to a burning surface in sufficient volume and at a sufficient rate to compensate for this loss and guarantee a residual foam layer over the extinguished portion of the burning liquid. The process of foam spread over a burning liquid fuel is similar to the spread of a less dense liquid (such as oil) on a more dense liquid (such as water).

### B.16.1 Properties of Foam

Foams used for fire fighting should possess certain general properties, including (1) expansion, (2) cohesion, (3) stability, (4) fluidity, (5) fuel resistance, and (6) resistance. Clearly, foam extinguishing agents must have an appreciable expansion ratio, the bubbles must adhere together to form a blanket, and the foam must retain its water and remain stable, flowing while freely over the liquid surface and around any obstacles. In addition, foam agents must not pick up so much fuel that the foam would be liable to burn, and the agent must resist the heat of flames on the liquid. Foams for use on alcohol fires must also be alcohol resistant.

Three quantitative criteria for foam are (1) the expansion (2) the fluidity and (3) the drainage time. Expansion is quantitatively measured by the expansion ratio. While fluidity is measured in terms of shear stress. A shear stress in the range 150–200 dyn/cm$^2$, measured on a torsional viscometer, is typical of a good foam extinguishing agent. The drainage of liquid out of the foam is usually expressed as the 25-percent drainage rate, which is the time in minutes for 25-percent of the total liquid content to drain away under standard conditions. For a good foam, this drainage time is typically 2–5 minutes.

Foam extinguishing agents can also be affected by the quality of the water used. A study by Dimaio and Lange (1984) detected deleterious effects from contaminants (such as corrosion inhibitors, anti-fouling agents, etc.). In general, however, such effects were found to be much weaker if high application rates were used.

### B.16.2 Hazards Associated with Foam

Foam is a water based, consequently, hazards associated with water also apply to foam. These hazards include increased vaporization of low-boiling flammable combustible liquids, reaction with incompatible materials and electric shock from live electrical equipment. Another hazard is rupture of the foam blanket and burn back, which may put fire fighters at risk. Hazards can also arise from the use of a foam on a liquid at a temperature of 100 °C (212 °F) or above, because the formation of steam can cause a four-fold expansion of the foam with slopover of the burning liquid. In the case of the medium- and high-expansion foams used to fill spaces, there is the additional hazard of asphyxiation.

Another hazard of foam is ignition of hydrocarbons in a storage tank roof by static electricity from foam injection, as described by Howells (1993). This author describes several incidents in which ignition of volatile refined products in a floating roof storage tank appears to have been caused by foam injection. He suggests two possible modes of charge generation, including (1) the setting of water droplets through the hydrocarbon liquid and (2) the streaming current of the foam mixture leaving the nozzle.

### B.16.3 Delivery Systems for Foam

Foam is delivered to a fire by means similar to those used for water, which primarily include fixed systems such as foam-water spray systems and fixed foam-water monitors, and mobile foam-water systems such as fire hoses. For low expansion foam, one type of Fixed foam systems used for low-expansion foam include the foam-water deluge system is the foam-water monitor. Fixed-foam systems are used for fire prevention, extinguishment, and control in bunds or on spills. Relevant codes are NFPA 11, "Standard for Low-Expansion Foam," NFPA 11A, "Standard for Medium-and High-Expansion Foam Systems," and NFPA 16, "Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems". There is limited use of foam in portable devices.

The delivery of foam involves three stages, including (1) proportioning the foam concentrate, (2) generating foam, and (3) distributing foam. There are a number of methods for proportioning the foam concentrate. The devices for generating the foam are incorporated in the devices used for its distribution, as previously described. The basic generation method is aspiration of air into the foam.

### B.16.4 Application of Foam

Fire extinction by blanketing may be achieved using foam. Foam can be used for all modern fire protection in warehouses, high storage areas, and process plants of all types for commodities such as rubber tires, rolled paper, and plastics; in bulk storage areas and conveyor tunnels, coal mines, coal handling equipment tunnels, and diked areas; in electric power plants aircraft hangars, and aboard ships. An example of application in a BWR is the use of a foam water sprinkler system (NFPA 16) to protect the large oil hazard of the recirculation pumps motor generator (MG) set.

Low expansion foam is mainly used to prevent, extinguish, or control fires in storage tank tops and bunds and on spills. Medium- and high-expansion foams are used to prevent, extinguish, or control fire in spaces such as fires below grades (e.g., basement).

Foam should be used only if compatible with the hazardous liquid. In particular, foam is essentially expanded water and, apart from its density, has the general characteristics of water. Consequently, it is just as unsuitable as water for fighting fires involving electrical equipment or substances that have undesirable reactions with water. Other prerequisites for the use of foam are that the liquid surface must be horizontal and the temperature of the liquid must be below the boiling point. In addition, the liquid temperature is below the boiling point of the given hazardous liquid, but above 100 °C (212 °F), water in the foam will turn to steam, which can result in very large expansion of the foam.

There are optimum rates of foam application. For low-expansion foam with an expansion ratio of 8:1, an application rate of 0.1 US gal/ft$^2$-min will give 0.8 US gal/ft$^2$-min of foam. Application systems for medium- and high-expansion foams comprise both (1) total flooding systems and (2) local application systems. Fighting a major fire requires a very large quantity of foam. An example quoted by Nash (1966) is a requirement of 300 x 5 UK gal drums for a 30-minute foam attack on a single 150-ft diameter oil storage tank. The supply and disposal of such a large number of drums in an area congested with appliances and hoses constitutes a major problem. Consequently, Nash describes the alternative of providing a piped supply of foam concentrate.

A particularly important application of foam is the protection of storage tanks. For fixed roof tanks, some principle arrangements are foam chambers, internal tank distributors, and subsurface foam injection. Foam chambers are installed at intervals on the outside near the top of the tank wall, providing an over-the-top foam generation. An alternative is internal distributors fitted inside the tank. Application of foam at the top of the tank poses several problems. If the fire is initiated by an explosion, the explosion itself may also disable the foam system. The upward flow of air caused by the fire may also interfere with the distribution of the foam and the foam may not reach the center of a large tank. Subsurface foam injection is designed to counter these difficulties. Such systems inject under pressure up through the liquid in the tank. Injection may be through the product pipe or a dedicated line. Mobile foam trucks may be used to provide the foam supply.

Floating roof tanks may be open topped or closed. Both have a good fire record, so foam systems are generally not required. The one exception to this rule is the need to allow for rim fires, which can occur on either type of tank. An open-topped floating roof tank may be protected by a fixed foam system, which pours foam into the annulus formed by the tank wall and a foam dam. A closed floating roof tank may be protected using a top injection system similar to those used in fixed roof tanks. Subsurface foam injection is not generally used for floating tanks, since a tilted or sunken roof can cause poor foam distribution.

Foam trucks are the principal means of mobile foam of delivery. The trucks are typically purpose-built twin-agent trucks with the capability to deliver dry chemicals in addition to aqueous film forming foam (AFFF). Foam trucks carry a supply of foam concentrate and delivery hoses and can be equipped with telescoping booms or articulated towers. They also have low clearances to allow passage under pipe bridges. Monitor capacities are on the order of 500–1000 US gal-min.

A variety of mobile devices can be used to apply foam to the top of a storage tank that is on fire. These include mobile foam monitors and foam towers. However, using a foam monitor for this purpose poses numerous problems, such as crosswinds and fire updrafts, which can waste a significant proportion of the foam.

Use of foam extinguishing agents is not limited to fire control and extinguishment. Another important application is the suppression of vaporization from toxic liquid spills. This use of foam is treated in ASTM F1129-88, "Standard Guide for Using Aqueous Foams to Control the Vapor Hazard from Immiscible Volatile Liquids". A 500 to 1 foam ratio can be used to control fires and reduce vaporization from liquefied natural gas (LNG) spills.

### B.16.5 Types of Foam

A large family of foams of different types and applications are currently available. Water-based foams are available in the following forms:

- chemical foam

- protein-based mechanical foam
  - — standard low-expansion foam
  - — high-expansion foam
  - — medium-expansion foam
- special foam
  - — fluorochemical for light-water foam
  - — fluoroprotein foam

- synthetic detergent foam
  - — aqueous film forming foam (AFFF)
  - — film forming fluoroprotein (FFFP) foam
  - — alcohol resistant foam
  - — low temperature foam

One broad distinction is the viscosity of the foam. The blanket formed by the more viscous type is resistant to rupture by flame, but the less viscous type flows more readily over a liquid surface.

- *Chemical Foam*

Chemical foam is produced by reacting an aqueous solution of sodium bicarbonate and aluminum sulphate in the presence of a foam stabilizer. The reaction generates $CO_2$, which both forms foam and ejects the mixture from the apparatus. This type of foam may be generally regarded as obsolete, given that its use has long been almost entirely confined to mobile and portable equipment.

- *Protein-Based Mechanical Foam*
  - — Mechanical foam is generated by mechanical aeration of aqueous solutions of certain chemicals, which usually have a protein base. For example, one type is based on blood hydrolyzed by caustic soda. Standard foam is made by introducing the foam compound into the water in the hose to give a 3–6-percent aqueous solution and then mixing the solution with air in an ejector nozzle to give an approximately 10:1 expansion. This type of foam is the most widely used for both fixed and mobile apparatus. Such standard low-expansion foam is often very economical.

— High-expansion foam is generally similar to standard foam, with the exception that it has a much higher expansion of approximately 1,000:1. Because this type of foam contains little water, it acts almost entirely by blanketing rather than cooling. In addition, it is very light and become easily blown away, it is more suitable for fires in contained spaces than for those in open situations (such as bunds).

— Medium-expansion foam is also generally similar to standard foam, with the exception that has an expansion of approximately 100–150:1. This type of foam is also light, but is not so easily blown away as high-expansion foam. Both medium- and high-expansion foams have a good three-dimensional extinction capability and can be used against fires on piles of materials (such as rubber).

A disadvantage of protein foams is that if the foam blanket is broken, the liquid may re-ignite and burn back the blanket. Low-expansion foam, however, has an advantage in this regard, given that it has reasonably good heat and burnback resistance.

- *Special Foam*

— Fluorochemical for Light Water Foam
Fluorochemical foam is one agents that has been developed to overcome the problem of reignition and burnback. One type is fluorochemical foam. This light-water foam contains a straight-chain fluorocarbon surface active agent. This has the effect that as the water drains from the foam, it spreads in a thin film over the liquid and seals it. Even if the film is disturbed by agitation, it reforms rapidly. Light-water foam behaves differently, however, on different liquids, and it is expensive and not universally effective.

— *Fuoroprotein Foam*
Another agent that works in a manner similar to fluorochemical light-water foam is fluoroprotein foam, which contains a branched chain fluorocarbon. Where good burnback resistance is needed, this alternative is less expansive and appears (in many cases) to be more effective than light-water foam. In particular, fluoroprotein foam is less prone to pick up oil particles when passed through oil. This fuel-shedding property is useful in subsurface foam injection on storage tanks. This type of foam also tends to have good compatibility with dry chemicals.

- *Synthetic Detergent Foam*
Synthetic detergent foam is generated by mechanical aeration of an aqueous solution containing 2–3 -percent detergent. This foam is less stable than protein-based foam, but it appears to be useful in massive application in a knockout attack. Depsite its limitations, detergent foam has enjoyed some popularity, because it is even less expensive than protein foam.

— *Aqueous Film Forming Foam (AFFF)*
AFFF has low viscosity and spreads easily over a liquid surface so it can be an effective agent against deep-seated fires. Another useful property of AFFF is that it does not need elaborate foaming devices and can be used in many water sprinkler and water spray systems.

— Film-Forming Fluoroprotein (FFFP) Foam
FFFP foam is another type of foam that has low viscosity and good spreading properties and can be used in many water spray systems. FFFP foam tends to drain rapidly and, therefore, is less reliable in maintaining a foam blanket.

— *Alcohol-Resistant Foam*
Regular air foams do not perform well on liquids that are of the polar solvent type (notably alcohol). Alcohol-resistant foams have been developed to solve that problem. The first generation of alcohol-resistant foams were not entirely satisfactory, but effective foams have since been developed. One type of alcohol-resistant foam is polymeric-alcohol resistant AFFF.

— *Low Temperature Foam*
Foam have been developed for use at low ambient temperatures; one quoted temperature for such foams is -29 °C (-20 °F). These foams come in both protein and AFFF types.

### B.16.6 References


Dimaio, L.R., and R.F. Lange, "Effect of Water Quality on Fire Fighting Foams," *Plant/Operations Progress*, Volume, 3, 1984.

Friedman, R., *Principles of Fire Protection Chemistry and Physics*, 3rd Edition, National Fire Protection Association, Quincy, Massachusetts, 1998.

Howells, P., "Electrostatic Hazards of Foam Blanketing Operations," *Health, Safety and Loss Prevention*, p. 312, 1983.

Nash, G., "New Concept in the Supply of Foam Compound to Oil Fires," *Fire International*, Volume 1, No. 12, p. 40, 1966.

NFPA 11, "Standard for Low-Expansion Foam," 2002 Edition, National Fire Protection Association, Quincy, Massachusetts.

NFPA 11A, "Standard for Medium-and High-Expansion Foam Systems," 1999 Edition, National Fire Protection Association, Quincy, Massachusetts.

NFPA 16, "Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems," 1999 Edition, National Fire Protection Association, Quincy, Massachusetts.

### B.16.7 Additional Reading

Woodworth, S.P., and J.A. Frank, *Fighting Fire with Foam*, Van Nostrand Reinhold, New York, 1994.

## B.17 Harmful Properties of Toxic Gases Found in Fires

### B.17.1 Introduction

Historically, more people are injured or killed by fire combustion products than by direct exposure to heat and flame. Evaluations have shown that personnel at distance from the source of a fire are particularly at risk from fire effluent in post-flashover fire scenarios (Beitel et al., 1998). Toxic gases are lethal largely because they cause people to become disoriented and panic thereby making it difficult to find escape routes. Following a period of hyperventilation, resulting from inhaling irritant gases the final cause of death is often carbon monoxide (CO) poisoning or scorching of the lungs by hot fire gases, rather than actual burning by the flames.

The most significant effluent toxicants in ordinary fires are CO, hydrogen cyanide (HCN), carbon dioxide ($CO_2$), hydrogen chloride (HCl), and nitrogen dioxide ($NO_2$). Speaking very generally, CO alone accounts for half of the fire toxicity problem, although it is far less toxic than many of the other gases found in fires. Nonetheless, CO is considered to be the primary toxicant because of its copious generation by all fires. The importance of any toxic gas species to a particular fire must reflect both its toxicity and its actual concentration in that particular fire. The time of exposure is also important for determining the effects from toxic gases. In general, a higher concentration allows the same biological effect to be reached in a shorter time. For toxicity data, the exposure period normally used is 30 minutes.

The following definitions of toxicity related terms are commonly used in fire and combustion toxicology, as defined by ASTM Standard E176-98.

***Toxic hazard*** is the potential for physiological harm from the toxic products of combustion. Toxic hazard reflects both the quantity and quality of toxic products (quality is typically expressed as toxic potency. Toxic hazard is not the only hazard associated with fire, and is not an intrinsic characteristic of a material or product. Rather, toxic hazard depends upon the fire scenario, the condition of use of the material or product, and possibly other factors.

***Toxic potency*** is a quantitative expression that relates concentration and exposure time to a particular degree of adverse physiological effects (for example, death) on exposure of humans or animals. The toxic potency of the smoke from any material, product, or assembly is related to the composition of that smoke, which, in turn, depends upon the conditions under which the smoke is generated.

Toxic potency of the smoke from a specimen or product is determined on a per-unit-specimen-mass basis. At present, for fire research, the dominant biological end point adopted is death and the measured quantity is the $LC_{50}$, which is the concentration ($g/m^3$) of smoke which is lethal to 50-percent of the exposed specified test animals in a specified time period [the meaning of this variable is the amount of mass that needs to be dispersed into a volume of 1 $m^3$ in order to cause a 50-percent probability of lethality. For substances where the composition is known (e.g., purge gases), the $LC_{50}$ is usually expressed in units of ppmv. The definition here is that 1 ppmv of gas means that there is one part of gas per million parts of air. The "v" denotes parts by volume rather than weight. The $LC_{50}$ notation must include the exposure time, generally 30 minutes (along with a 14-day post-exposure observation period) (Babrauskas et al., 1991). The toxic potency is not an intrinsic characteristic of a material.

### B.17.2 Smoke and Toxic Gases

Many studies have been undertaken on toxic combustion products of organic materials, with the objective of realistically assessing the associated hazard. Toxicities of CO, $CO_2$, HCN, HCl, and low $O_2$ have been examined in depth by Babrauskas (1991), who determined that narcosis is caused by fire gases, such as CO and HCN, as well as low $O_2$ concentrations and high $CO_2$ concentrations. Narcotic gases cause incapacitation mainly by acting on the central nervous system and, to some extent, the cardiovascular system. Most narcotic fire gases produce their effects by causing brain tissue hypoxia. Since the body possesses powerful adaptive mechanisms designed to maximize oxygen delivery to the brain, it is usually possible to maintain normal body functions up to a certain concentration of a narcotic, and be unaware of the impending intoxication. However, once the threshold is reached where normal functioning can no longer be maintained, deterioration is rapid and severe, beginning with signs similar to the effects of alcohol intoxication, including lethargy or euphoria with poor physical coordination, followed rapidly by unconsciousness and death if exposure continues (Tamura, 1994).

The manual of the American Conference of Governmental Industrial Hygienists, Inc., gives the threshold limit values (TLVs) and a description of various toxic gases. The TLV is defined as the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek to which nearly all workers may be repeatedly exposed, day after day without adverse effect. The TLVs and biological effects of concentrations above the TLV for toxic gases are as follows (Tamura, 1994):

#### B.17.2.1 Carbon Monoxide (CO)

CO is a common product of combustion generated in a fire environment. This highly toxic, non-irritating gas has long been recognized as a primary cause of fatalities related to combustion sources including fire. In fact, the majority of all fire fatalities are attributed to CO inhalation. CO is produced as a result of incomplete combustion of materials containing carbon and is present in large quantities in most fires. Invisible, odorless, tasteless, and slightly lighter than air, CO is the most significant toxicant as it can cause occupants to become incapacitated if the concentration is high enough and the exposure is long enough. CO acts by combining with hemoglobin in the blood to form carboxyhemoglobin (COHb). This is important because hemoglobin carries oxygen throughout the body, and it cannot do this if it is tied up as COHb and, therefore, unavailable for oxygen transport. In the absence of other contributing factors, a COHb concentration of 50-percent or greater is generally considered lethal in the blood of fire victims.

The highest concentration of CO to which people can be exposed day after day without adverse effect is 50 ppm. This concentration keeps the COHb level below 10-percent. Concentrations of 400 to 500 ppm can be inhaled for 1 hour without appreciable effect. Concentrations of 1,000 to 1,200 ppm cause unpleasant symptoms after 1 hour of exposure. Concentrations of 1,500 to 2,000 ppm for 1 hour of exposure are dangerous, and concentrations above 4,000 ppm are fatal in exposure of less than 1 hour (Sumi and Tsuchiya, 1971).

#### B.17.2.2 Hydrogen Cyanide (HCN)

HCN is one of the most rapidly acting toxicants, being approximately 20 times more toxic than CO. HCN is produced when materials involved in a fire contain nitrogen [for example, polyacrylonitrile (Orlon®), polyamide (nylon), wool, polyurethane, urea-formaldehyde, and acrylonitrile-butadiene-styrene (ABS)]. Inhalation of HCN may cause severe toxic effects and death within a few minutes up to several hours, depending upon the concentration inhaled. The action of HCN is attributable to the cyanide ion, which is formed by hydrolysis in the blood. Unlike CO, which remains primarily in the blood, the cyanide ion is distributed throughout the body fluids, bringing it into contact with the cells of vital tissues and organs.

The TLV for HCN is 10 ppm, and it can be inhaled for several hours without appreciable effect at concentrations of 20–40 ppm. The maximum amount that can be inhaled for 1 hour without serious reaction is 50–60 ppm. Concentrations of 120–150 ppm are dangerous in 30–60 minutes, and concentrations of 3,000 ppm or more are rapidly fatal (Sumi and Tsuchiya, 1971).

#### B.17.2.3 Carbon Dioxide ($CO_2$)

$CO_2$ usually evolves in large quantities from fires. While not particularly toxic at observer levels, moderate concentrations of $CO_2$ (on the order of 2-percent) increase both the rate and depth of breathing by about 50-percent, thereby increasing the respiratory minute volume (RMV). This condition contributes to the overall hazard of a fire gas environment by causing accelerated inhalation of toxicants and irritants. If 4-percent $CO_2$ is breathed, the RMV is approximately doubled, but the individual may scarcely noticed the effect. Given any further increase in $CO_2$ from 4 percent up to 10-percent, the RMV may be 8 to 10 times the resting level (Hartzell, 1989).

The TLV of $CO_2$ is 5,000 ppm. Stimulation of respiration is pronounced at a concentration of 5-percent (50,000 ppm), and a 30-minute exposure produces signs of intoxication. Above 70,000 ppm, unconsciousness results in a few minutes (Sumi and Tsuchiya, 1971).

#### B.17.2.3 Hydrogen Chloride (HCl)

HCl is formed from the combustion of materials containing chlorine, the most notable of which is polyvinyl chloride (PVC) as used in common thermoplastic electrical cables. HCL is both a potent sensory irritant and potent pulmonary irritant. It is a strong acid, being corrosive to sensitive tissue such as the eyes. If inhaled, HCl will irritate and damage the upper respiratory tract and lead to asphyxiation or death.

The TLV for HCl is 5 ppm. Concentrations as low as 75 ppm are extremely irritating to the eyes and upper respiratory tract, and behavioral impairment has been suggested. The maximum concentration allowable for short exposures of 30–60 minutes is 50 ppm. Concentrations of 1,000–2,000 ppm are dangerous even for short exposures (Sumi and Tsuchiya, 1971).

### B.17.2.4 Nitrogen Dioxides

Nitrogen dioxides ($NO_2$ and $N_2O_4$) the common oxides of nitrogen (N) produced in a fire (the other nitric oxide, or NO). Nitrogen dioxide, which is very toxic, can be produced from the combustion of N-containing material. Nitric oxide has a short life in atmospheric air because it is converted into dioxide in the presence of oxygen. These compounds are strong irritants, particularly to mucous membranes. When inhaled, they damage tissues in the respiratory tract by reacting with moisture to produce nitrous and nitric acids. The TLV for nitrogen dioxide is 5 ppm. Immediate throat irritation can begin at 62 ppm. Short-exposure concentrations of 117–154 ppm are dangerous, and rapidly fatal at 140–775 ppm (Sumi and Tsuchiya, 1971).

### B.17.3 Toxic Data

Toxicity or toxic data usually reflect the results of animal testing. The table of relative acute toxicity criteria given below was published by the National Institute for Occupational Safety and Health (NIOSH) in the Registry of the Toxic Effects of Chemical Substances (RTECS) in 1967. It is widely used to interpret animal toxicity data; the lower the dose number, the greater the toxicity. The measures of toxicity used in the Table B.17-1, $LD_{50}$ and $LC_{50}$ are explained in the discussion following the table (Spero, Devito, and Theodore, 2000).

Table B.17-1. Tonicity Data

| Rating | Keywords | $LD_{50}$ Single Oral Dose* (mg/kg) | $LC_{50}$ Inhalation Vapor Exposure* (ppm) | $LD_{50}$ Skin** (mg/kg) |
|---|---|---|---|---|
| 4 | Extremely hazardous | #1 | #10 | #5 |
| 3 | Highly hazardous | 50 | 100 | 43 |
| 2 | Moderately hazardous | 500 | 1000 | 340 |
| 1 | Slightly hazardous | 5,000 | 10,000 | 2,800 |
| 0 | No significant hazard | >5,000 | >10,000 | >2,800 |

* Rats
**Rabbits

Data on animal toxicity usually identify the route of entry into the body (oral ingestion, inhalation, adsorption through the skin, etc.) first, followed by the test animal (mouse, rat, human, etc.), followed by the measure of toxicity. The most common measures of toxicity are as follows:

- Lethal Dose 50-percent ($LD_{50}$) is the dose required to kill 50-percent of the test animals when administered by a route of entry other than inhalation. The dose of the chemical (usually solids or liquids) is given as mg/kg, which represents milligrams of chemical per kilogram of body weight of the test animal. The $LD_{50}$ is expressed in this manner because more chemical is needed to kill a larger animal. For example, the oral rat $LD_{50}$ for the HAP calcium cyanamide is 159 mg/kg.

- Lethal Concentration 50-percent ($LC_{50}$) is similar to $LD_{50}$ except that the route of entry is inhalation. The concentrations of the inhaled chemicals (usually gases) are expressed as parts per million (ppm) or milligrams per cubic meter ($mg/m^3$).

- Lethal Dose Low ($LDL_o$) is the lowest dose required to kill any of the animals in the study when administered by a route of entry other than inhalation.

- Lethal Concentration Low ($LCL_o$) is the same as $LDL_o$ except that the route of entry is inhalation.

- Toxic Dose Low ($TDL_o$) is the lowest dose used in the study that caused any toxic effect (not just death) when adminstered by a route of entry other than inhalation.

- Toxic Concentration Low ($TCL_o$) is the same as $TDL_o$ except that the route of entry is inhalation.

- $EC_{50}$ is the concentration required to cause a 50-percent reduction in growth.

- Acute Risks are the risks associated with brief exposures to high concentrations.

- Chronic Risks are the risks associated with long-term exposures to low concentrations.

### B.17.4 References


ASTM E176-98, "Standard Terminology of Fire Standards," ASTM Fire Test Standard, 5th Edition, American Society of Testing and Materials, West Conshohocken, Pennsylvania, pp. 834–842, 1999.

Babrauskas, V., "Effective Measurement Techniques for Heat, Smoke, and Toxic Fire Gases," *Fire Safety Journal*, Volume 17, No. 1, pp. 13–26, 1991.

Babrauskas, V., B.C. Levin, R.G. Gann, M. Paabo, R.H. Harris, R.D. Peacock, and S. Yusa, "Toxic Potency Measurement for Fire Hazard Analysis," NIST Special Publication 827, U.S. Department of Commerce, National Institute of Standards and Technology (NIST), Building and Fire Research Laboratory (BFRL), Gaithersburg, Maryland, 1991.

Beitel, J.J., C.L. Beyler, L.A. McKenna, and F.W. Williams, "Overview of Smoke Toxicity Testing and Regulations," NRL/MR/6180-98-8128, Naval Research Laboratory, Naval Technology Center for Safety and Survivability Branch, Chemistry Division, Washington, DC, April 15, 1998.

Hartzell, G.E., "Understanding of Hazards to Humans," Chapter 3, *Advances in Combustion Toxicology*, Volume One, Gordon, E. Hartzell, Editor, Technomic Publishing, Inc., 1989.

Spero, J.M., B. Devito, and L. Theodore, *Regulatory Chemicals Handbook*, Marcel Dekker, Inc., New York, 2000.

Sumi, K., and Y. Tsuchiya, "Toxic Gases and Vapors Produced at Fires," *Canadian Building Digest*, National Research Council of Canada, CBD 144, December 1971.

Tamura, G.T., *Smoke Movement & Control*, National Fire Protection Association, Quincy, Massachusetts, December 1994.

## B.18 Effects of Decomposition Products of Halogenated Fire Extinguishing Agents

### B.18.1 Introduction

When an ineffective Halon fire extinguishing system that is incapable of extinguishing its design-basis fire is installed in a compartment, the system discharge will actually degrade environmental conditions by introducing additional toxic gases.

The 18th Edition of the National Fire Protection Association (NFPA) Fire Protection Handbook (Taylor, 1997) identifies the effects of the decomposition products of Halon 1301 and 1211 fire extinguishing agents, as follows:

> *"Consideration of life safety during the use of halogenated agents must also include the effects of decomposition (or breakdown) products, which are relatively more toxic to humans. Decomposition of halogenated agents takes place on exposure to flame or surface temperatures above approximately 482 °C (900 °F). In the presence of available hydrogen (from water vapor or the combustion process itself), the main decomposition products of Halon 1301 are hydrogen fluoride (HF), hydrogen bromide (HBr), and free bromine ($Br_2$). Although small amounts of carbonyl halides ($COF_2$, $COBr_2$) were reported in the early tests, more recent studies have failed to confirm the presence of these compounds."*

Table B.18.1-1 summarizes the major decomposition products of Halon 1301 and 1211. The approximate lethal concentration (ALC) for a 15-minute exposure to some of these compounds are given in Column 2 of Table B.18-1. Column 3 gives the concentrations of these materials that have been quoted as "dangerous" for short exposure.

Even in minute concentrations of only a few parts per millions (ppm), the decomposition products of the halogenated agents have a characteristically sharp, acrid odor. This characteristic provides a built-in warning system for the agent, but also creates a noxious, irritating atmosphere for those who must enter the hazard area following a fire. It also serves as a warning that other potentially toxic products of combustion (such as CO) will be present.

### B.18.2 Toxicity of Decomposition Products of Halogenated Fire Suppression Agents

Hill (1977), summarizes the effects of hydrogen fluoride (HF) on humans at various concentrations. At concentrations as low as 32 ppm, irritation of eyes and nose occurs. At 60 ppm, irritation of the respiratory tract occurs after 60 seconds. At concentrations of 120 ppm, irritation of the conjunctival and respiratory tracts is tolerable for only 60 seconds. Concentrations between 50 and 100 ppm are considered dangerous to life after several minutes of exposure. Generally, the HF containing atmospheres are so irritating that personnel will be forced to evacuate before serious health risk is incurred. Decomposition product data clearly indicate that life-threatening concentrations of HF likely. HF concentrations of 300 ppm are typically measured in full-scale tests.

| Table B.18-1. Approximate Lethal Concentrations (ALC) for Predominant Halon 1301 and Halon 1211 Decomposition Products | | |
|---|---|---|
| Compound | ALC for 15-minute Exposure (ppm by Volume in Air) | Dangerous Concentrations (ppm by Volume in Air) |
| Hydrogen fluoride, HF | 2,500 | 50–250 |
| Hydrogen bromide, HBr | 4,752 | - |
| Hydrogen chloride, HCl | - | - |
| Bromine, $Br_2$ | 550 | - |
| Chlorine, $Cl_2$ | - | 50 |
| Carbonyl fluoride, $COF_2$ | 1,500 | - |
| Carbonyl chloride, $COCl_2$ | 100–150 | - |
| Carbonyl bromide, $COBr_2$ | - | - |

DeMonburn and McCormick (1973) have reported on the design and testing of Halon 1301 in extinguishing a wool bag filter fire in an industrial baghouse situation. The baghouse studied has an area of approximately 13.3 $m^2$ (144 $ft^2$). These studies indicate that using rate of thermal detectors and the complete shutdown of the air flow through the baghouse, a 4-percent concentration of Halon 1301 would extinguish a fully developed fire. However, it should be noted that following extinguishment and 20 minutes soaking time, toxic levels of hydrogen fluoride, hydrogen cyanide, and hydrogen sulfide were detected in the unoccupied baghouse as shown in Table B.18-2.

| Table B.18-2. Concentration of Hazardous Gases Attributable to Decomposition of Halon 1301 in Industrial Baghouse Fire Situation | | | |
|---|---|---|---|
| Time (minutes) | Decomposition Product Concentration (ppm) | | |
| | Hydrogen Fluoride (HF) | Hydrogen Cyanide (HCN) | Hydrogen Sulfide ($H_2S$) |
| 0–4 | 55 | 1,643 | 2,452 |
| 20–24 | 10 | 194 | 112 |

The National Research Council Advisory Center reviewed the toxicity of Halon 1301 for consideration by NASA. In a letter to Dr. G.J. Stopps of the Haskell Laboratory, dated September 22, 1967, R.C. Wands, Director of the Toxicology Center, stated: "*Personnel can be exposed without significant hazard for a maximum of 5 minutes to normal air at 1 atmosphere and mixed with up to 6-percent mean concentration by volume of bromotrifluoromethane ($CF_3Br$ (Halon 1301)] as a fire extinguishing agent. This assumes appropriate engineering design to sense the fire and deliver the agent so as to extinguish the fire promptly in order to minimize that pyrolysis products*," (Atomic Energy Commission, 1970).

Ford (1975) has evaluated the issue of the decomposition of Halon 1301, and believes caution and limitations should be applied to the utilization of extinguishing systems containing that agent:

- Although safe at a design concentration of 5–7-percent, the Halon 1301 agent will not extinguish deep-seated Class A fires with these concentrations. Thus, water systems should be provided and higher concentrations of Halon 1301 should be used for extinguishment in these situations. If higher concentrations of Halon 1301 are provided, the design of the system should incorporate all of the requirements of the NFPA Standard 12A, and the operation of the system in relation to the personnel hazard should be identical to that of a $CO_2$ extinguishing system.

- Halon 1301 may decompose to untenable concentrations of hydrogen fluoride and hydrogen bromide when the vapor is in contact with heated surface above 482 °C (900 °F), or when the agent is applied to a large fire in a small enclosure. Table B.18-3 summarizes the relationship between the flame shield exposure and room size. Note in Situation One that the ratio of flame dimension to room size is 0.60, while in Situation Two, the ratio of flame dimension to room size is 6.0. The concentrations of the hydrogen fluoride and hydrogen bromide acid gases in situation two are beyond tolerable limits for human exposure. However, it must be remembered in this situation and the previous industrial baghouse situation presented by DeMonburn and McMormick, that the toxic products of combustion from the fire would in all probability also create an intolerable atmosphere for human exposure. The primary life hazard involves the entry of personnel into the area immediately following extinguishment. These characteristics of the Halon agent under intense thermal or flame exposure make the installation of these systems of oven or furnace chamber unsuitable where the temperature is above 260 °C (500 °F).

### B.18.3 Physical Properties of Halon 1301

Under normal conditions, Halon 1301 is a colorless, odorless gas with a density approximately 5 times that of air. It can be liquefied upon compression for convenient shipping and storage. Unlike $CO_2$, Halon 1301 cannot be solidified at temperatures above -167.8 °C (-270 °F). The molecular weight of Halon 1301 is 148.93 (see Table B.18-4).

### B.18.4 Physical Properties of Halon 1211

Under normal conditions, Halon 1211 is a colorless gas with a faintly sweet smell and a density about 5 times that of air. It can be readily liquefied by compression for storage in closed vessels. The molecular weight of Halon 1211 is 165.38 (see Table B.18-4 for properties of Halon).

| Table B.18-3. Halon 1301 Decomposition Produced by n-Heptane Fires | | | | | |
|---|---|---|---|---|---|
| Situation One<br>1,695 foot Enclosure Volume; 4-Percent Halon 1301 by Volume | | | | | |
| Fire pan size ($ft^2$) | Fuel area to volume $ft^2$/1000 $ft^2$ | Discharge time (sec) | Extinguishment time (sec) | Decomposition products (ppm volume in air) | |
| | | | | Hydrogen Fluoride (HF) | Hydrogen Bromide (HBr) |
| 0.1 | 0.06 | 23.0 | 11.5 | 1.8 | 3.5 |
| 0.1 | 0.06 | 13.5 | 7.1 | 1.8 | 2.1 |
| 0.1 | 0.06 | 5.7 | 4.8 | 1.4 | 2.8 |
| Situation Two<br>1,695 foot Enclosure Volume; 4-Percent Halon 1301 by Volume | | | | | |
| Fire pan size ($ft^2$) | Fuel area to volume $ft^2$/1000 $ft^2$ | Discharge time (sec) | Extinguishment time (sec) | Decomposition products (ppm volume in air) | |
| | | | | Hydrogen Fluoride (HF) | Hydrogen Bromide (HBr) |
| 10.0 | 6.0 | 25.0 | 20.0 | 1,907 | 397 |
| 10.0 | 6.0 | 15.0 | 16.3 | 1,206 | 382 |
| 10.0 | 6.0 | 6.0 | 10.0 | 666 | 112 |
| 10.0 | 6.0 | 6.0 | 5.2 | 320 | 38 |

| Table B.18-4. Selected Properties of Halon 1301, 1211, and 2402 | | | |
|---|---|---|---|
| Extinguishing Agent | Halon 1301 ($CF_3Br$) | Halon 1211 ($CF_2ClBr$) | Halon 2402 ($C_2F_4Br_2$) |
| Boiling point °C (°F) | -58 (-72.5 °F) | -4 (25 °F) | 47 (117 °F) |
| Liquid density at 20 °C (g/cc) | 1.57 | 1.83 | 2.17 |
| Latent heat of vaporization (J/g) | 117 | 134 | 105 |
| Vapor pressure at 20 °C (atm) | 14.5 | 2.5 | 0.46 |

### B.18.5 References


Atomic Energy Commission, "Prepackaged Halon 1301 Fire Suppression System Tests," Number 294, Atomic Energy Commission, Health and Safety Information, Washington, DC, 1970.

DeMonburn, J.R., and J.W. McCormick, "Extinguishment of Wool Bag Filter Fires Using Halon 1301," Y-JA-94, Union Carbide Corporation, 1973.

Ford, C.B., "Why Not Halon1301?" *Fire Journal*, Volume 69, pp. 80–81, 1975.

Hill, R., "Evaluation of Halon 1301 System for Aircraft Internal Protection from a Postcrash External Fuel Fire," National Aviation Facilities Experimental Center, Atlantic City, New Jersey, March 1977.

Taylor, G.M., Halogenated Agent and Systems, Chapter 18, Section 6, *NFPA Fire Protection Handbook*, 18th Edition, Edition, A.E. Cote, Editors-in-Chief, National Fire Protection Association, Quincy, Massachusetts, 1997.

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## B.19 An Introduction to Computer Fire Models

### B.19.1 Introduction

ASTM E176 defines a fire model as a physical or mathematical representation of burning or other processes associated with fire. Physical models attempt to reproduce fire phenomena in a simplified physical situation. For example, scale models are a very widespread form of modeling, as full-scale experiments are expensive, difficult, and sometimes wholly infeasible. Insight can often be gained by studying fire phenomena at a reduced physical scale. Mathematical fire models include one or more empirical equation(s) that can be solved analytically or a set of complex differential and algebraic equations that must be solved numerically on a computer. A computer program to accomplish the numerical solution of complex set of differential and algebraic equations is called a computer fire model. Fire modeling can normally be considered as the prediction of fire characteristics by the use of a mathematical method which is expressed as a computer program.

The computer fire models have invaluable tools to assist in a wide range of uses in fire protection engineering research and development, fire-safe design of a structure, fire hazard analyses, fire spread, smoke control systems design, structural response of building members, human behavior and egress in the event of fire, actuation of thermal devices (sprinklers, detectors, ceiling vents etc.), hydraulic design of fire suppression systems, and fire investigation and reconstruction. Many building and fire regulations (including NFPA 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants") allow for use of computer fire modeling as part of the performance-based fire safety designs to help bridge the gap between building functionality and fire code. The performance-based fire safety engineering is defined as "an engineering approach to fire protection design based on (1) agreed fire safety goals, loss objectives, and design objectives; (2) deterministic and probabilistic evaluation of fire initiation, growth, and development; (3) the physical and chemical properties of fire and fire effluents; and (4) quantitative assessment of the effectiveness of design alternatives against loss objectives and performance objectives" (Meacham and Custer, 1995 and Custer and Meacham, 1997).

### B.19.2 Categories of Computer Fire Model

Fire model can be grouped into two categories: probabilistic or stochastic fire model and deterministic fire models. Probabilistic fire models involve the evaluation of the probability of risk due to fire based on the probabilities of all parameters influencing the fire such as human behavior, formation of openings and distribution of fuel load in the compartment of fire origin. The results of the models are in terms of the statistical likelihood of the occurrences of fires and fire outcomes, based on the random nature of fire and the likelihood of occurrence. Little or no information is given with respect to production and distribution of combustion products. In contrast to the probabilistic fire models, deterministic fire models are based on physical, chemical and thermodynamic relationship and empirical correlation to calculate the impact of fire. Deterministic fire models can be very simple requiring a short computing time or highly complex requiring hours of computation. Typically deterministic fire models can be classified as zone models, field models, and other models. The most commonly used computer fire models simulate the consequences of a fire in an enclosure are zone and field models. Other models are special purpose models such as building evacuation (egress) models, models of thermal actuation devices (sprinklers and detection systems), models of structural fire resistance/endurance, fire sprinkler hydraulic design models, smoke movement/migration models, and fire-sprinkler interaction models.

A large number of fire computer models have been developed in recent years indicating the interest of researchers in the computer fire modeling field. A complete listing of these fire models is available in the fire model survey website, www.firemodelsurvey.com. This website contains information about the latest survey of computer fire models as completed by the developers of these models.

### B.19.2.1 Zone Models

A zone model is essentially a one-dimensional model that solves the basic conservation equation for distinct volumes as a function of time. This type of model is used to predict fire growth and smoke spread in single or multi-enclosure structures. The model calculates the temperature and concentration of gas species (oxygen, carbon dioxide, etc.) as a function of time throughout the spaces modeled.

Zone model usually divide each room into two spaces or zones; an upper hot zone that contains the gases produced by the fire and a lower cool zone that is the source of the air for combustion. Zone sizes change during the course of the fire. The upper zone can expand and occupy virtually the entire room volume. By definition, zone models will always be approximate. The primary advantage of a zone model is its relative simplicity, which permits the inclusion of more phenomena. Also, cases may be run more rapidly and inexpensively on a personal computer.

A zone model requires input of the basic geometry of the space(s) being modeled, including physical dimensions, thermal properties of bounding materials, vent opening sizes and locations, mechanical ventilation, and position and growth rates of the specified fire. Output includes the upper and lower smoke layer temperature, interface location between zones (smoke layer height), oxygen and carbon monoxide concentrations, visibility, smoke flow in and out of openings, and heat flux from the hot gas layer to a target in the compartment as a function of time. Some examples of zone models are CFAST, FASTlite, ASET, COMPBRN-III, BRI-2, MAGIC, BRANZFIRE, FIGRO-II, FIREWIND, and FLAMME-S.

### B.19.2.2 Field Models

Field models avoid the simplifications inherent in zone models and, consequently, their results are very refined compared to those of a zone fire model. Some field model calculations can be made on fast PCs; however, more complex problems are best run on powerful workstations and advanced computers. Such models numerically solve the conservation of mass, energy, and momentum, as well as diffusion and species equations associated with fire. The temperature, velocity, and gas concentration are calculated in two- or three-dimensional fields by using a finite difference, finite element, or boundary element method. A compartment or space (domain) is descretized into computational cells. The greater the number of cells, the more refined the solution. The model determines the temperature, pressure, velocity, and species concentration within each cell at each time step.

The advantage of field models over zone models is that they can provide detailed information on fluid motions. The application of field modeling to fire problems has been dramatically increased over time. The ready availability of commercial computational fluid dynamics (CFD) software packages with increasing sophistication enables more widespread application. Applications of field models to fire problems include aircraft terminal atria spaces, air-supported structures, electrical generating stations, aircraft cabins, tunnels, hospitals wards, shopping malls, and warehouses. Some examples of field models are FDS, FLUENT, STAR-CD, JASMINE, PHOENICS, KOBRA-3D, FIRE, VESTA, and SOFIE.

#### B.19.2.3 Building Evacuation Model

Egress models are not truly fire models. They were developed in response to the need to evaluate the impact of fires on the occupants of a building. Most egress models describe the building as a network of paths along which the occupants travel. The occupants travel rates are usually derived from studies on people movement and vary with the age and ability of the occupants, crowding, and the types of travel paths. Model inputs include the geometry of the building and rooms, the openings between rooms, the number of occupants located each floor throughout the building, and the smoke data if the effect of smoke blockage is to be considered. The outputs include the location of each occupant with time, floor clearing time, stairwell clearing time, exit clearing time, and how many occupants used an exit. Some examples of evacuation models are EVACNET, EVACS, EGRASS, EXIT89, buildingEXODUS, BFIRII, Allsafe, EgressPro, and EESCAPE.

#### B.19.2.4 Models of Thermal Actuation Devices

Sprinkler and detection activation models are used to calculate the response time of sprinklers and detectors installed below unconfined smooth ceilings. These models also are used to estimate the size of a fire when a detection system activates, at which point egress can begin. Sprinkler and detection activation models use a heat transfer equation to calculate the temperature increase of detector sensing elements. These models assume that the thermal devices are located in a relatively large area and are heated by the ceiling jet flows (convective heat transfer), and predict the device actuation time for a user-specified heat release rate history. The sensitivity of the sprinkler/detector sensing element to an elevated temperature is often characterized by a constant parameter known as the response time index (RTI) which is derived experimentally. The required model inputs are the height of the ceiling above the fuel, distance of the thermal device from the axis of the fire, actuation temperature of the thermal device, RTI for the device, and heat release rate of the fire. The model outputs are the ceiling gas temperature at the device location and the device temperature (both as a function of time), time required for the device to actuate, and heat release rate at actuation. Some examples of thermal actuation modeled are DETACT-QS, DETACT-T2, LAVENT, JET, G-JET, and SPRINK.

#### B.19.2.5 Models of Structural Fire Resistance/Endurance

Structural fire resistance models estimate the structural fire endurance of a building system or member exposed to a fire environment by numerically solving the conservation of energy equations using a finite difference or finite element technique. The solution techniques are very similar to those used with field models. The structural fire resistance models evaluate the time-temperature history within a solid exposed to a fire environment. The solid region is divided into elements in much the same way that the field models divide a compartment into regions.

Steel and concrete configurations are most commonly analyzed with and without fire protection insulation. The models allow nonlinear material properties and boundary conditions. An effective analysis makes use of a mesh that fine where there are large temperature gradients. The thermal properties that are necessary to perform such an analysis are the thermal conductivity and specific heat. The density is also required, as are phase change (intumescent) data. The time-temperature history of the fire environment is considered by specifically defining the temperature at each time step during the solution. The heat transfer process attributable to the fire exposure is modeled using convection and/or radiation in the fire boundary and conduction through the solid. Some examples of PC-based structural fire resistance models are FIRES-T3, HEATING 7, FASBUS, and TASEF.

#### B.19.2.6 Fire Sprinkler Hydraulic Design Models

Fire sprinkler hydraulic design models are used to perform all necessary calculations to design a sprinkler system with a grid or loop, as required by NFPA 13, "Standard for Installation of Sprinkler Systems," to ensure that water supplies will meet the water density requirements for the control and extinguishment of fire. These models estimate sprinkler head requirements, water supply pressure, the lowest supply pressure that can adequately drive the sprinkler system, pipe sizes, and equivalent lengths for fittings. These models use conservation of mass and momentum equations based on the principles of hydraulic (fluid) motion. The fire sprinkler models work by dividing a sprinkler system network into a series of nodes and links. The nodes represent pipe junctions of sprinklers, while links represent pipes. The user can specify which sprinklers are open and the model balance the flow and pressure. The inputs to the model are pipe junctions, diameters, and length; the locations and types of fittings; and the sprinkler locations. Some examples of fire sprinkler hydraulic design models are FIRE, HCALC, HP4M-Grid Fire Sprinkler Design, HP6M-Tree and Loop Fire Sprinkler Design, THE, HASS, HyperCalc, and Sprinkler-CALC.

#### B.19.2.7 Smoke Movement Models

Smoke movement/migration models calculate the airflow and pressure differences throughout a building in which a smoke control system is operating in a fire situation. In these modes, a building is represented as a network of spaces or nodes, each at a specific pressure and temperature. The stairwells and other shafts are modeled by a vertical series of spaces, one for each floor. The air flow is a function of pressure differences across the leakage paths. That is, air flows through leakage paths from regions of high pressure to regions of low pressure. These leakage paths are doors and windows that may be opened or closed. Leakage can also occur through partitions, floors, and exterior walls and roofs. The model inputs include the interior and exterior building temperatures, a description of the building flow network, and the flow produced by the ventilation or smoke control system. The outputs include the steady-state pressure and flows throughout the building. These models are capable of modeling the stack effect created in taller buildings during extreme temperature conditions. Some examples of smoke movement/migration models are ASCOS, CONTAMW, AIRNET, and ASMET.

### B.19.2.8 Fire-Sprinkler Interaction Models

Fire-sprinkler interaction models simulate the environment and the response of sprinkler actuation links in compartment fires with draft curtains and fusible link operated ceiling vents. They include the effects of the ceiling jet and upper layer of hot gases beneath the ceiling. The program inputs include the compartment geometry, thermo-physical properties of the ceiling, fire elevation, fire heat release rate, fire diameter, ceiling vent area, fusible link RTI and actuation temperature, fusible link positions along the ceiling, link assignment to each ceiling vent, and ambient temperature. The model outputs include the temperature, mass, and height of the upper layer; temperature of each link; ceiling jet temperature and velocity at each link; radial temperature distribution along the interior surface of the ceiling; radial distribution of heat flux to the interior and exterior surfaces of the ceiling; fuse time of each link; and vent area that has been open. Examples of fire-sprinkler interaction models include LAVENT and JET.

### B.19.2.9 Specialized Fire Models

Special purpose fire simulation programs includes, (1) BREAK1 (Berkeley Algorithm for Window Glass in a Compartment Fire) is a program which calculates the temperature history of a glass window exposed to user described fire condition (2) ELVAC (Elevator Evacuation) is an interactive computer program that estimates the time required to evacuate people from a building with the use of elevators and stairs. It is cautioned that elevators generally are not intended as a means of fire evacuation, and they should not be used during fires. However, it is possible to design elevator systems that for fire emergencies, and ELVAC can be used to evaluate the potential performance of such system (3) FIRDEMND simulates the suppression of post-flashover charring and non-charring solid-fuel fire in compartments using water sprays from portable hose-nozzle equipment used by the fire department. The output of the Fire Demand Model (FDM) shows the extinguishment effects of water spray at various flow rates and droplet sizes (4) SES (Subway Environment Simulation) computer program and subway environmental design handbook were developed in the early 1970's under sponsorship of the Urban Mass Transportation Administration (former name of the Federal Transit Administration (FTA)) to assist in the planning, design, and construction of subway ventilation systems. The SES fulfilled an unmet need in the transit engineering community, and has been widely used in the design of new rail systems or line extensions in: Washington, District of Columbia; Atlanta, Buffalo, Baltimore, Dallas, Los Angeles, San Francisco, Montreal, Toronto, the Seattle Bus Tunnel, and in rail transit systems around the world. The SES provides tunnel designers with the tools to: properly size and locate ventilation shafts, evaluate tunnel geometry and fan size, optimize temperature, and model the effects of heat and smoke resulting from fires and other sources. The most recent enhancement is the validation of the subroutine which describes the behavior of smoke in emergency conditions.

### B.19.3 Limitations and Uncertainties Associated with Computer Fire Modeling

Fire model permit development of a better understanding of the dynamics of building fires, to quantify the performance of a building, and can aid in the fire safety decision making process. This evaluation gives an overall fire assessment of the building systems in terms of preventing fire growth, providing for safe evacuation, fire resistance design, as well as predicting occupant behavior.

Nonetheless, there are certain limitations and uncertainties associated with fire modeling predictions. The decision to use a particular fire model should be based on the understanding of the limitations and assumptions of the model. The limits of applicability of any fire model must be clearly stated and known to the user so that the user does not go beyond the boundaries of realistic application of the theory utilized. The input uncertainty is primarily attributable to error and assumptions in the input data. Sensitivity analyses are used to identify the critical input parameters, which must be specified with much greater care than the parameters to which the model is relatively insensitive. The model uncertainty is primarily attributable to the assumptions made by the model, and can be quantified as a result of the validation process. Full-scale fire test data are subject to experimental uncertainty. Therefore, discrepancies between model predictions and experimental data might be at least partly, attributable to measurement errors. There are many problems in comparing the results from fire model simulations to data from full-scale experiments. Some of the problem are attributable to the difference between the form of the recorded experimental data and the form needed for computer model predictions. For example, contrary to the assumption of pre-flashover compartment zone models, there often is not a clear and sharp change distinguishing the lower and upper gas layers.

Extreme care must be exercised in interpreting the fire modeling results. For scenarios where the level of predicted hazard is well below the damage threshold, the results can be used with a high level of confidence, provided that there is a high level of confidence that all risk-significant scenarios have been considered. For scenarios where the level of predicted hazard is near the damage threshold, the results should be used with caution in view of the inherent uncertainties.

A primary method of handling modeling uncertainties is the use of engineering judgment. Among other things, this judgment is reflected in the selection of appropriate fire scenarios, hazard criteria, and fire modeling techniques. A slightly more formal application of engineering judgment is the use of safety factors, which can be applied in the form of fire size, increased or decreased fire growth rate, or conservative hazard criteria (Custer and Meacham, 1997). Experimental data obtained from fire tests, statistical data from actual fire experience, and other expert judgment can also be used to improve judgment and potentially decrease the level of uncertainty.

When using a fire model, it is wise to perform a sensitivity analysis of the output to changes in the input to determine if changes in the data or the model assumptions and applicability will lead to a different decision. The sensitivity analysis will determine the most dominant and significant variables. It will also determine whether the user should pay careful attention to particular input values that might affect the result significantly.

### B.19.4 Fire Models

A verity of computer fire models employing different features are currently available. Table B.19-1 provide a short description for some common fire models.

| Table B.19-1. Computer Fire Models | | |
|---|---|---|
| Model Name | Classification | Model Use |
| CFAST<br>**C**onsolidated Model of **F**ire **G**rowth and **S**moke **T**ransport | Zone model | CFAST is a zone model that predicts the effect of a specified fire on temperatures, various gas concentrations and smoke layer heights in a multi-compartment structure. |
| FPETool<br>**F**ire **P**rotection **E**ngineering **Tool** | Zone model | FPETool is a set of engineering equations useful in estimating potential fire hazard and the response of the space and fire protection systems to the developing hazard. Version 3.2 incorporates an estimate of smoke conditions developing within a room receiving steady-state smoke leakage from an adjacent space. Estimates of human viability resulting from exposure to developing conditions within the room are calculated based upon the smoke temperature and toxicity. |
| FASTLite | Zone model | FASTLite is a user friendly software package which builds on the core routines of FPEtool and the computer model CFAST to provide calculations of fire phenomena for use by the building designer, code official, fire protection engineer, and fire-safety related practitioner. |
| ASET<br>**A**vailable **S**afe **E**gress **T**ime | Zone model | A simple, user-friendly, one-room smoke-filling model computer code which simulates the smoke layer thickness, temperature, and concentrations of products of combustion due to fire of time-dependent, user-specified, energy and product release rate. |

| Table B.19-1. Computer Fire Models (continued) | | |
|---|---|---|
| Model Name | Classification | Model Use |
| BRANZFIRE | Zone model | A zone model to predict the environment in a compartmented structure. |
| COMPBRAN III | Zone model | Zone model for compartment fires, compatible with probabilistic analysis. |
| MAGIC | Zone model | Two zone mode, able to handle up to 24 compartment. MAGIC is designed for nuclear power plants. MEGIC is being extended to include non-rectangular room, convex and sloping ceiling, room cluttered with objects, spread of fire through ventilation ducts, and extinction. |
| FireWind | Zone model | FireWind is a collection of 18 programs which include one- and two-room zone models, heat radiation calculation, egress calculations, a heat conductivity model and more. |
| FIGARO II<br>**F**ire and **G**as Spread in **R**oom | Zone model | It is a two-layer model which can be used for single-room and multi-room fire simulation. |
| FDS<br>**F**ire **D**ynamics **S**imulator | CFD model | General purpose low Mac number CFD code specific to fire-related flows. |
| Star-CD | CFD model | General purpose CFD code, which contains industry standard models for modeling fire and smoke movement. |
| JASMINE | CFD model | A CFD or field model for predicting consequences of fire to evaluate design issues as the assessment of smoke ventilation design and/or interaction with HVAC and other fire protection measures. |
| PHOENICS | CFD model | PHONICS is a general purpose CFD code for use by academia and industry as a design and analysis tool for any process involving fluid flow, combustion, and heat and mass transfer. |

| Table B.19-1. Computer Fire Models (continued) | | |
|---|---|---|
| Model Name | Classification | Model Use |
| SOFIE<br>**S**imulation of **F**ire in **E**nclosures | CFD model | SOFIE is a field modeling code based upon the solution of the Reynolds average Navier-Stokes equations using a finite volume approach. |
| KOBRA-3D | CFD model | Three-dimensional CFD model for complex geometries to be used for smoke spread and heat transfer analyses. |
| FIRE | CFD model | CFD model with water sprays and coupled to solid/liquid phase fuel to predict burning rate and extinguishment. |
| DETACT-QS<br>**DET**ector **ACT**uation-**Q**uasi **S**teady | Detector actuation | A program for calculating the actuation time of thermal devices below unconfined ceilings for fires with arbitrary heat release rates. |
| DETACT-T2<br>**DET**ector **ACT**uation-**T**ime Squared | Detector actuation | A program for calculating the actuation time of thermal devices below unconfined ceilings for fires with heat release rates which grow with time squared. |
| LAVENT<br>**L**ink **A**ctuation **VENT**s | Zone model | A zone model which predicts the actuation of fusible links as a function of depth below the ceiling and distance from the plume center in response to a ceiling jet produced by a user specified fire. |
| JET | Zone model | LET is a single compartment zone model for use in spaces where the lower layer remains close to ambient temperature and the fire is not ventilation limited. The model provides temperature predictions for the plume, ceiling jet, upper layer and ceiling as well as the upper layer depth. |
| G-JET | Smoke detection model | Design tool for all categories of smoke detectors to predict their response to performance requirements in applications. |

| Table B.19-1. Computer Fire Models (continued) | | |
|---|---|---|
| Model Name | Classification | Model Use |
| EVACNET4 | Evacuation/ egress model | EVACNET4 is a user-friendly interactive computer program that models building evacuations. The program accepts a network description and information on its initial contents at the beginning of the evacuation. |
| ELVAC | Elevator evacuation | Calculates emergency evacuation time using elevators. |
| EGRESS | Evacuation simulation model | Versatile model for predicting the evacuation of crowds which may be used in a large variety of situations. |
| EXIT89 | Evacuation model | An evacuation model designed to handle the evacuation of a large population of individuals from a high-rise building. |
| buildingEXODUS | Human behavior/ evacuation model | A PC based evacuation model that simulates individual people, behavior and enclosure details. The model includes |
| FIRES-T3<br>**FI**re **RE**sponse of **S**tructures - **T**hermal **Three** - Dimensional Version | Finite element heat transfer | FEM for 1-, 2- or 3-D conduction heat transfer with time-varying boundary conditions and temperature-dependent material properties. |
| TASEF<br>**T**emperature **A**nalysis of **S**tructures **E**xposed to **F**ire | Structural | TASEF is a computer program for temperature of structures exposed to fire. This program is based on the finite element method. It is developed for temperature analysis of two dimensional and axisymmetrical structures. |
| ASCOS<br>**A**nalysis of **S**moke **CO**ntrol **S**ystems | Network air flow analysis | ASCOS is a program for steady air flow analysis of smoke control system |
| CONTAMW | Airflow model | A network model is used to predict pressure differences and airflow between compartments in a building |

| Table B.19-1. Computer Fire Models (continued) | | |
|---|---|---|
| Model Name | Classification | Model Use |
| ASMET<br>**A**tria **S**moke **M**anagement **E**ngineering **T**ools | Package of engineering tools | ASMET consists of a set of equations and a zone fire model for analysis of smoke management systems for large spaces such as atria, shopping malls, arcades, sports arenas, exhibition halls and airplane hangers |
| BREAK1<br>Berkeley Algorithm for Breaking Window Glass in a Compartment Fire | | BREAK1 is a program which calculates the temperature history of a glass window exposed to user described fire conditions. The calculations are stopped when the glass breaks. |

### B.19.5 References

ASTM E176, "Standard Terminology of Fire Standards," ASTM Fire Test Standard, 5th Edition, American Society of Testing and Materials, West Conshohocken, Pennsylvania. 1999.

Custer, R.L. and B.J. Meacham, *Introduction to Performance-Based Fire Safety* , "Uncertainty and Safety Factors," Chapter 9, Society of Fire Protection Engineers (SFPE) and National Fire Protection Association (NFPA), Quincy, Massachusetts. 1997.

"Information about Computer Models for Fire Growth and Smoke Transport," available at Fire Model Survey Web Site, www.firemodelsurvey.com This Web Site contains information about the latest survey of computer fire models, as completed by the developers of those models.

Meacham, B.J., and R.L.P. Custer, "Performance-Based Fire Safety Engineering: An Introduction of Basic Concepts," *SFPE Journal of Fire Protection Engineering*, Volume 7, No. 2. pp. 35–54: 1995.

### B.19.6 Additional Readings

ASTM E1355-97, "Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models," ASTM Fire Test Standard, 5th Edition, American Society of Testing and Materials, West Conshohocken, Pennsylvania, pp. 1115–1120, 1999.

ASTM E1472, "Standard Guide for Documenting Computer Software for Fire Models," ASTM Fire Test Standard, 5th Edition, American Society of Testing and Materials, West Conshohocken, Pennsylvania, 1999.

Friedman, R., "An International Survey of Computer Models for Fire and Smoke," *SFPE Journal of Fire Protection Engineering*, Volume 4, No. 3. pp. 81–92, November 1992.

Hunt, S.P., "Computer Fire Models," NFPA Update, Issue 839, p. 7, October/November, 2000.

Janssens, M.L., "Evaluating Computer Fire Models," *Fire Protection Engineering Magazine*, Society of Fire Protection Engineers, Bethesda, Maryland. pp. 19–22, Winter 2002.

Olenick, S.M., and D.J. Carpenter, "An Updated International Survey of Computer Models for Fire and Smoke," *SFPE Journal of Fire Protection Engineering*, Volume13, No. 2. pp. 87–110, May 2003.

Tubbs, J., "An Overview of the CFAST Computer Model," NFPA Update, Issue 840, p. 5, December/January, 2001.

# APPENDIX C. SOURCES OF FIRE

This appendix discusses the various topics related to fire phenomena.

## C.1 Heat Sources

Heat sources may vary widely in size, intensity, and duration. For instance, a tiny spark, a hot pin head, an exposure fire, and sun are all heat sources as are the following representative examples:

- A paper match contains about 1 kilo-joule (kJ) of heat energy released at a heat of about 45 watts (W).
- A standard laboratory candle contains about 1,500 kJ of heat energy released at a heat power of about 50 W.
- A small wooden match contains about 1.5 kJ of heat energy released at a heat of about 50 W.
- A large wooden safety match contains about 3 kJ of heat energy released at a heat of about 90 W.
- A common butane-type cigarette lighter contains about 230 kJ of heat energy. A 10 cm flame releases energy at a power of about 150 W; a 5 cm flame about 90 kW.
- A handheld plumber's propane torch contains up to 20 MJ of heat energy. A 10 cm flame releases energy at a power of about 1,800 W, or 1.8 kW.
- The heat energy required to ignite a flammable gas or vapor may be as low as 0.3 mJ (milli-joules).
- The heat energy required to ignite a flammable dust cloud may be as low as 20 mJ.

Table C.1-1 summarizes the common engineering terms and symbols related to heat sources, as they apply to fire hazard analysis.

| Table C.1-1. Common Engineering Terms Related to Heat Sources | | | | |
|---|---|---|---|---|
| Term | Term Symbol* | Basic Unit | Recommended Units | |
| | | | Symbol | Name |
| **Heat quantity** is the total amount of heat energy released by the heat source. | Q | joules | kJ | Klio-joules |
| **Heat flux** is the rate of heat energy released from the igniter per second. | $\dot{Q}$ | watt | W | watt |
| **Heat flux density** is the amount of heat energy per unit area emitted from the heat source per second. | $\dot{q}''$ | watt per square meter | $kW/m^2$ | kilowatt per square meter |
| **Heat intensity** is the temperature of a heat source. | T | Kelvin | K | Kelvin |
| **Duration** is the length of time between any two events (e.g., initial ignition to full room involvement). When a duration is specified, the beginning and ending events should be identified. Duration can also be used to represent the length of time the heat source is present. | t | second | s | second |
| *In fire protection engineering, Q and q are usually reserved for heat energy. Lower case t is conventionally used for time; capital T is usually used for temperature, but *never* time. | | | | |

### C.1.1 Reference

SI Units Fire Protection Engineering, 1980 Report of the Measurement of Fire Phenomena Committee, Society of Fire Protection Engineers (SFPE), Boston, Massachusetts, March 1980.

## C.2 Incident Heat

Table C.2-1 summarizes the common engineering terms and symbols related to incident heat (heat arriving at the surface of the target fuel).

Table C.2-1. Incident Heat

| Term | Term Symbol | Basic Unit | Recommended Units | |
|---|---|---|---|---|
| | | | Symbol | Name |
| **Incident heat flux** is the heat energy arriving at the target fuel surface from the igniter per second. | $\dot{Q}_i$ | watt | W | watt |
| **Incident heat flux** density is the amount of heat energy per unit area arriving at the target fuel surface from the igniter per second. | $\dot{q}_i''$ | watt per square meter | $kW/m^2$ | $kW/m^2$ |
| **Heat intensity** is the incident temperature near the target fuel surface. | T | Kelvin | K | Kelvin |
| **Incident duration** is the length of time the heat is received at the target fuel surface. | t | second | s | second |

### C.2.1 Reference

SI Units Fire Protection Engineering, 1980 Report of the Measurement of Fire Phenomena Committee, Society of Fire Protection Engineers (SFPE), Boston, Massachusetts, March 1980.

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## C.3 Target Fuel

Table C.3-1 summarizes the common engineering terms related to target fuel, focusing on heat-producing materials (i.e., combustibles) that may be driven to ignition by the incident heat source.

Table C.3-1. Target Fuel

| Term* | Term Symbol | Basic Unit | Recommended Units | |
|---|---|---|---|---|
| | | | Symbol | Name |
| **Heat power resistance** is the maximum heat energy that the exposed surface of an initial target fuel can receive per second without causing initial ignition. | $\dot{Q}$ | watt | W | watt |
| **Heat power density resistance** is the amount of heat energy per unit area received from an igniter (heat source) each second without causing ignition. | $\dot{q}''$ | watt per square meter | $W/m^2$ | kilowatt per square meter |
| **Heat Intensity resistance** is the maximum surface temperature that the target fuel will tolerate without experiencing self-sustained burning with a pilot flame present. | T | Kelvin | K | Kelvin |
| **Duration resistance** is the length of time a target fuel can receive heat energy from an igniter at a given level without igniting. | t | second | s | second |

*Target fuels generally respond on a time and energy basis. The higher the energy, the lower the time to ignition. This phenomenon is extremely complex (e.g., it depends on geometry, heat balance, and pilot ignition).

### C.3.1 Reference

SI Units Fire Protection Engineering, 1980 Report of the Measurement of Fire Phenomena Committee, Society of Fire Protection Engineers (SFPE), Boston, Massachusetts, March 1980.

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## C.4 Flame/Heat Growth

Table C.4-1 summarizes common engineering terms related to flame/heat growth, focusing on burning within a space, room, or enclosure.

| Table C.4-1. Flame/Heat Growth | | | | |
|---|---|---|---|---|
| Term | Term Symbol | Basic Unit | Recommended Units | |
| | | | Symbol | Name |
| **Heat flux** is the heat energy released from the igniter per second. | $\dot{Q}$ | watt | MW | megawatt |
| **Heat flux** density is the amount of heat energy per unit area delivered from the burning material into the surrounding space per second. | $\dot{q}''$ | watt per square meter | $kW/m^2$ | kilowatt per square meter |
| **Heat intensity** is the temperature within the burning space. The location of this reading within the space should be identified. | T | Kelvin | K | Kelvin |
| **Duration** is the length of time between two identical events during the fire growth within the space (e.g., time from ignition to first steady flame out the door). | t | Second | s | kilo-second |
| **Duration to full room involvement** is the length of time the fire takes to reach full room involvement (from ignition). | t | Second | s | kilo-second |
| **Ventilation rate** is the volume of air (oxygen) entering the burning space per second. | $\dot{V}$ | m | $m^3/s$ | cubic meters per second |

### C.4.1 Reference

SI Units Fire Protection Engineering, 1980 Report of the Measurement of Fire Phenomena Committee, Society of Fire Protection Engineers (SFPE), Boston, Massachusetts, March 1980.

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## C.5 Fire Resistance

The fire resistance of a building may be defined as (1) its ability to withstand exposure to fire without losing its load bearing function and (2) its ability to act as a barrier to the spread of fire. These two abilities confine the fire to the compartment where it started and provide time for people to evacuate a building before it collapses as a result of a fire.

Before the room is fully involved, the temperatures are relatively low and they have a negligible influence on the fire resistance of building elements. The risk that structural members or fire barriers will fail actually begins when the fire reaches the fully developed stage. During In this stage, temperatures of 1,300 K or 1,027 °C (1,881 °F) or higher can be reached, and the heat transferred to building elements may substantially reduce their strength and ability to perform as a fire barrier. This risk also continues to exist during the decay period of the fire.

The behavior of fire-exposed building elements depends, in part on the fire severity and in part on the properties of the fire-exposed elements. The following tables summarizes the most important quantities that determine fire severity and the fire performance of building elements in response to fire exposure.

| Table C.5-1. Common Engineering Terms Related to Fire Severity | | | | |
|---|---|---|---|---|
| Term | Term Symbol | Basic Unit | Recommended Units | |
| | | | Symbol | Name |
| **Total load** is the total amount of heat energy available for possible release. | Q | joules | kJ | klio-joules |
| **Heat load density** is the amount of heat energy available possible release per unit area (floor or bounding room surface area). | $Q''$ | joule per square meter | $MJ/m^2$ | mega-joule per square meter |
| **Heat flux density** is the amount of heat energy per unit area emitted from the heat source per second. | $\dot{Q}$ | watt | MW | magawatt |
| **Heat intensity** is the temperature of the fire. The specific point of measurement should be identified (e.g., flame temperature, average ceiling temperature, average hot gas layer temperature). | T | Kelvin | K | Kelvin |
| **Duration of severity** is the length of time heat is produced by the fire that could expose building elements to the fire. | T | second | ks | kilosecond |
| Opening factor is the measure of the rate of temperature increase associated with the fire, defined as the area of the openings multiplied by the square root of the height of the openings, divided by the total bounding surface area of the room. | F | square root meter | $\sqrt{m}$ | square root meter |
| **Emissivity** is the ratio of the intensity of radiation emitted by the fire to that emitted by a blackbody of the same temperature. | $\varepsilon$ | dimensionles | - | - |

| Table C.5-2. Common Engineering Terms Related to Fire Performance | | | | |
|---|---|---|---|---|
| Term | Term Symbol | Basic Unit | Recommended Units | |
| | | | Symbol | Name |
| **Heat load resistance** is the heat load required to cause the failure of a structural member or fire barrier. | $Q_r$ | joules | MJ | mega-joules |
| **Heat flux density** is the amount of heat energy received from the fire per unit area of the element per unit time. | $\dot{q}''$ | watt per square meter | $kW/m^2$ | kilowatt per square meter |
| **Heat intensity** is the temperature of the element at various locations during exposure to fire. | T | Kelvin | K | Kelvin |
| **Thermal conductivity** is the length of time the fire produces heat that could expose building elements to the fire. | k | watt per meter Kelvin | W/m-k | watt per meter Kelvin |
| **Specific heat capacity** is the heat necessary to increase the temperature of unit mass one degree | $c_p$ | joule per kilogram Kelvin | kJ/Kg-K | kilojoule per kilogram Kelvin |
| **Density** is the mass per unit volume of a material. | ρ | kilogram per cubic meter | $kg/m^3$ | kilogram per cubic meter |
| **Thermal diffusivity** is one of the quantities that determine the rate of temperature increase in a material at points away from the surface. It is equal to the thermal conductivity divided by the product of the specific heat and density | α | square meter per second | $mm^2/s$ | square millimeter second |
| **Emissivity absorbed** is the ratio of the intensity of radiation absorbed by the element to that absorbed by a blackbody of the same temperature. | ε | dimensionless | - | - |
| **Coefficient of thermal expansion (linear)** is the expansion of length per unit degree increase in temperature. | α | reciprocal degree Kelvin | 1/K | reciprocal degree Kelvin |

| Table C.5-2. Common Engineering Terms Related to Fire Performance (continued) | | | | |
|---|---|---|---|---|
| Term | Term Symbol | Basic Unit | Recommended Units | |
| | | | Symbol | Name |
| **Modulus of elasticity** is a measure of elastic deformation, defined as the stress needed to produce a unit strain. | E | Pascal | MPa | mega-pascal |
| **Yield strength** is the stress at which material exhibits a specified permanent deformation. | $F_y$ | Pascal | MPa | mega-pascal |
| **Ultimate strength** is the highest stress a material can sustain before its ruptures. | $F_u$ | Pascal | MPa | mega-pascal |

### C.5.1 Reference

SI Units Fire Protection Engineering, 1980 Report of the Measurement of Fire Phenomena Committee, Society of Fire Protection Engineers (SFPE), Boston, Massachusetts. March 1980.

## C.6 Fire Resistance/Endurance Ratings

This section identifies some of the most common fire-resistance ratings used in construction and industry. "A," "B," and "C" ratings were originally defined by the Safety of Life at Sea (SOLAS) regulations. Hydrocarbon fire exposures for pool and jet fires have recently evolved.

**Fire Barriers** (NFPA 255, "Standard Method of Test of Surface Burning Characteristics of Building Materials".)

The average temperature increase of any set of thermocouples for each class of element protected is more than 121 °C (250 °F) above the initial temperature; or the temperature increase of any one thermocouple of the set for each class of element protected is more than 163 °C (325 °F) above the initial temperature. Where required by the conditions of acceptance, a duplicate specimen shall be subjected to a fire exposure test for a period equal to one-half of that indicated as the resistance period in the fire endurance test, but not for more than 1 hour. Immediately there after, the specimen shall be subjected to the impact, erosion, and cooling effects of a hose stream directed first at the middle and then at all parts of the exposed face, with changes in direction made slowly. *However,* The hose stream test shall not be required in the case of construction having a resistance period, as specified in the fire endurance test, of less than 1 hour.

***A Barriers (SOLAS or Title 46, Section 72.05–75.10, of the Code of Federal Regulations)***

**A 0** Cellulosic Fire, 60-minute barrier against flame/heat passage, no temperature insulation.

**A 15** Cellulosic Fire, 60-minute barrier against flame/heat passage, 15-minute temperature insulation.

**A 30** Cellulosic Fire, 60-minute barrier against flame/heat passage, 30-minute temperature insulation.

**A 60** Cellulosic Fire, 60-minute barrier against flame/heat passage, 60-minute temperature insulation.

Class A divisions are those divisions formed by decks and bulkheads that comply with the following:

- They are constructed of steel or material of equivalent properties.
- They are suitably stiffened.
- They are constructed to prevent the passage of smoke and flame for a 1 hour standard fire test.
- They are insulated with approved noncombustible materials so that the average temperature of the unexposed side will not rise more than 180 °C (356 °F) above the original temperature within the time listed (A60: 60 minutes; A30: 30 minutes; A15: 15 minutes; A0: 0 minutes).

***B Barriers (SOLAS or Title 46, Sections 72.05–72.10, of the <u>Code of Federal Regulations</u>)***

**B 0** Cellulosic Fire, 30-minute barrier against flame/heat passage, no temperature insulation.

**B 15** Cellulosic Fire, 30-minute barrier against flame/heat passage, 15-minute temperature insulation.

Class B divisions are those divisions formed by decks and bulkheads that comply with the following:

- They are constructed to prevent the passage of flame for a 30-minutes standard fire test.

- They have an insulation layer such that the average temperature on the unexposed side will not rise more than 139 °C (282 °F) above the original temperature, nor will the temperature at any one point, including any joint, rise more than 225 °C (437 °F) above the original temperature (B15: 15 minutes; B0: 0 minutes).

- They are constructed of noncombustible materials.

***C Barriers (SOLAS or Title 46, Sections 72.05–72.10 of the <u>Code of Federal Regulations</u>)***

**C** Noncombustible Construction.

Class C barriers are constructed of noncombustible materials and are not rated to provide any smoke, flame, or temperature passage restrictions.

***H Barriers (UL 1709)***

An exposure rating to a hydrocarbon (petroleum) fire is typically given one of the following H ratings:

**H 0** Hydrocarbon Fire, 120-minute barrier against flame/heat passage, no temperature insulation.

**H 60** Hydrocarbon Fire, 120-minute barrier against flame/heat passage, 60-minute temperature insulation.

**H 120** Hydrocarbon Fire, 120-minute barrier against flame/heat passage, 120-minute temperature insulation.

**H 240** Hydrocarbon Fire, 120-minute barrier against flame/heat passage, 240-minute temperature insulation.

**J Ratings**

Jet fire exposure or impingement ("J" ratings) are specified by some vendors or property owners for resistance to hydrocarbon jet fire exposures. Currently, no standardized test or test specification has been adopted by an industry or governmental body. Some recognized fire testing and experimental laboratories (SINTEF, Shell Research, etc.) have conducted extensive research on jet fire exposures and have proposed a test standard based on these studies (Ref. Offshore Technology Report OTO 93028, "Interim Jet Fire Test Procedure for Determining the Effectiveness of Passive Fire Protection Materials").

***Fire Doors*** (NFPA 252, "Standard Methods of Tests of Door Assemblies")

A fire door assembly, which can consist of single doors, doors in pairs, special-purpose doors (e.g., dutch doors, double-egress doors), or multisection doors assembly for which a fire protection rating is determined and that is intended for installation in door openings in fire-resistive walls and provide a specific degree of fire protection to the opening.

The fire test can be conducted until the desired fire protection rating period is reached or until failure to meet any of the performance criteria specified in Chapter 5 of NFPA 252 as follows:

- 0.3 hour (20 minutes), Cellulosic fire
- 0.5 hour (30 minutes), Cellulosic fire
- 0.75 hour (45 minutes), Cellulosic fire
- 1.0 hour (60 minutes), Cellulosic fire
- 1.5 hour (90 minutes), Cellulosic fire
- 3.0 hour (180 minutes), Cellulosic fire
- Over 3.0 hours (in hourly increments), Cellulosic fire

Except for 20-minute rated door assemblies, for which it is optional, immediately following the fire endurance test, the door test assembly shall be subjected to the impact, erosion, and cooling effects of a hose stream. Temperature increase are listed at 121 °C, 232 °C, and 343 °C (250 °F, 450 °F, and 650 °F); absence of a temperature rating indicates an increase of more than 343 °C (650°F) on the unexposed surface of the door after 30 minutes of testing.

***Fire Windows*** (NFPA 257, "Standard on Fire Test for Window and Glass Block Assemblies").

Fire ratings of windows were normally limited to the failure of wired glass at approximately 870 °C (1,600 °F); however, advances in glazing technology have increased the available fire-resistance ratings of window assemblies, as follows:

- 0.3 hour (20 minutes), Cellulosic fire
- 0.5 hour (30 minutes), Cellulosic fire
- 0.75 hours(45 minutes), Cellulosic fire

Higher ratings are also available based on the application of other fire-resistance standard fire tests (NFPA 255, "Standard Method of Test of Surface Burning Characteristics of Building Materials").

- 1.0 hour (60 minutes), Cellulosic fire
- 1.5 hour (90 minutes), Cellulosic fire
- 3.0 hours (180 minutes), Cellulosic fire
- Over 3.0 hours (in hourly increments), Cellulosic fire

Within 2 minutes following the fire endurance test, the fire-exposed side of the fire window assembly is subjected to the impact, erosion, and cooling effects of a standard hose stream.

***Fire Dampers (UL Std. 555)***

The fire test can be conducted on the fire dampers until the desired fire protection rating period is reached or until failure to meet any of the performance criteria specified in UL Standard 555 as follows:

- 0.3 hour (20 minutes), Cellulosic fire
- 0.75 hour (45 minutes), Cellulosic fire
- 1.0 hour (60 minutes), Cellulosic fire
- 1.5 hours (90 minutes), Cellulosic fire

***Smoke Dampers (UL Std. 555S)***

Smoke dampers are specified on the basis of the leakage class, maximum pressure, maximum velocity, installation mode (horizontal or vertical), and degradation test temperature of the fire.

***Roof Coverings*** (NFPA 256, "Standard Tests of Fire Tests of Roof Coverings")

The fire test can be conducted on the fire dampers until the desired fire protection rating period is reached or until failure to meet any of the performance criteria specified in NFPA Standard 256 as follows:

- Class A: flame spread less than 6 feet (1.82 meters)
- Class B: flame spread less than 8 feet (2.44 meters)
- Class C: flame spread less than 13 feet (3.96 meters)

For all classes of roof coverings, there is to be no significant lateral flame spread, no flying brands or particles are to continue to flame or glow after reaching the floor, no flaming is to be produced on the underside of the deck of the test sample, and the roof deck should not be exposed.

***Fusible Links***

Fusible links are available in temperature ratings of 51.6 °C–260 °C (125 °F–500 °F) and in various load ratings.

The following table summarizes the fire-resistance test standards for building materials, aerosol, liquid paints, and plastics.

| Table C.6-1. Fire-Resistance Test Standards for Building Materials | | | |
|---|---|---|---|
| Organization and Test Specification | Name of Test | Sample | Property Measured |
| ASTM E69 | Crib test | Treated wood | Combustible properties |
| ASTM E84 | Surface burning of building materials | Building materials | Flame spread index, Smoke developed |
| ASTM E108 Building Codes,<br>UBC 32-7<br>UL-790 | Fire rating of roof coverings | Coatings, shingle shake, insulation, etc. | Spread of flame, intermittent flame, burning brand, flying brand |
| ASTM E136 | Behavior of materials in vertical tube furnace | Building materials | Combustibility or non-combustibility of building materials |
| ASTM E160 | Crib test | Treated wood | Combustible properties |
| ASTM E162 | Surface flammability of materials using a radiant heat source | Sheet laminates, tiles, fabrics, liquids, films | Flame spread index, visual characteristics |
| ASTM E648<br>NFPA 253 | Critical radiant flux of floor covering systems | Floor covering systems | Critical radiant flux at flameout |
| ASTM E662 | Specific optical density of smoke generated by solid materials | Solid materials (e.g., wood, plastic) | Specific optical density |
| CPSC<br>HH-I-515D,<br>HH-I-521F,<br>HH-I-1030B<br>16CFR 1209.6 | Critical radiant flux of attic insulation | Exposed attic floor insulation | Critical radiant flux at flameout |

| Table C.6-1. Fire-Resistance Test Standards for Building Materials (continued) | | | |
|---|---|---|---|
| Organization and Test Specification | Name of Test | Sample | Property Measured |
| NIST NBSIR-82-2532 | Combustion product toxicity | All materials | Inhalation toxicity |
| NY State, Dept. of State 15,1120 | Modified Pittsburgh Test | All materials | Inhalation toxicity |

| Table C.6-2. Fire-Resistance Test Standards for Aerosol and Liquid Paints | | | |
|---|---|---|---|
| Organization and Test Specification | Name of Test | Sample | Property Measured |
| ASTM D56, D92, D93, D1310 | Flash point | Liquids | Flash point |
| ASTM D3243 D3278 | Flash point-set a flash | Liquids, aviation turbine fuels | Flash point |
| ASTM D1360 | Fire retardancy of paint | Paint | Fire retardancy |
| FHSA ASTM-API 16 CFR 500.43 | Flash point (tag open cup) | Aerosols | Flash point |
| FHSA CSMA 16 CFR 500.45 | Flame projection | Aerosols | Flame projection |
| CSMA Aerosol Guide | Drum test | Aerosols | Inhalation toxicity |
| NIST NBSIR-82-2532 | Combustion product toxicity | All materials | Inhalation toxicity |
| NY State, Dept. of State 15, 1120 | Modified Pittsburgh test | All materials | Inhalation toxicity |

| Table C.6-3. Fire-Resistance Test Standards for Plastics | | | |
|---|---|---|---|
| Organization and Test Specification | Name of Test | Sample | Property Measured |
| ASTM D568 | Flammability of plastics 0.050" and under | Plastic sheets and film | non-burning, self-extinguishing, burning rate, visual characteristics |
| ASTM D635 | Rate of burning (self- supporting plastics) | Rigid plastics | Burning rate, visual characteristics |
| ASTM D757 | Incandescence resistance (rigid plastics) | Rigid plastics | Burning rate, visual characteristics |
| ASTM D1929, Procedure B | Ignition properties of plastics | Plastic sheets and films, thermo-plastic pellets | Flash ignition temperature, self-ignition temperature, visual characteristics |
| ASTM D2843 | Smoke density from the burning of plastics | Plastic material | Percent of light absorption |
| Bureau of Ships NObs 84814 MIL-M-14g | Flammability and toxicity | Generally melamine plastic; any material | Flash ignition, self-ignition, composition and toxicity gases evolved |
| CPSC CS 192-53 16- CFR 1611.4 ASTM D-1433 | Flammability of plastic film | Plastic films, coated fabrics | Ignition time, rate of burning |
| Federal Test Method Std. FTMS 406 Method 2023 | Flame resistance of plastics | Plastics difficult to ignite | Ignition time, burning time, flame travel |
| NIST NBSIR-82-2532 | Combustion product toxicity | All materials | Inhalation toxicity |
| NY State, U.S. Department of State 15,1120 | Modified Pittsburgh test | All materials | Inhalation toxicity |

### C.6.1 Reference

Nolan, D.P., *Encyclopedia of Fire Protection*, Delmar Publishers, Albany, New York, 2001.

## C.7 FIRE TEST STANDARDS

This section lists the empirical standard tests for fire-resistance, flame spread, and flammability.

The following list identifies the empirical standard fire-resistance tests.

| Test Standard | Title |
|---|---|
| API 6 FA | Fire Tests for Valves |
| API 607 | Fire Tests of Quarter-Turn Valves |
| ASTM E119 | Fire Test of Building Constructions and Materials |
| ASTM E814 | Fire Tests of Through-Penetration Fire Stops (Penetration Seals) |
| ASTM E1529 | Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies |
| ASTM E1623 | Determination of Fire and Thermal Parameters of Materials, Products, and Systems Using an Intermediate-Scale Calorimeter (ICAL) |
| ASTM E163A | Fire Tests of Window Assemblies |
| ASTM E2074 | Fire Tests of Door Assemblies |
| BS 476, Part 20, 21 | Fire Test of Building Construction and Materials, Window Assemblies, and Door Assemblies (BSI) |
| ISO 834 | Fire Tests of Building Constructions and Materials |
| ISO 3008 | Fire Tests of Door Assemblies |
| ISO 3009 | Fire Tests of Window Assemblies |
| NFPA 251 | Fire Tests of Building Constructions and Materials |
| NFPA 252 | Fire Tests of Door Assemblies |
| NFPA 257 | Fire Tests of Window Assemblies |
| UBC 26-2 | Evaluation of Thermal Barriers |
| UBC 7-1 | Fire Tests of Building Constructions and Materials |
| UBC 7-2 | Fire Test of Door Assemblies |
| UBC 7-4 | Fire Test of Window Assemblies |
| UBC 7-5 | Fire Tests of Through-Penetration Fire Stops (Penetration Seals) |
| UL 9 | Fire Test of Window Assemblies |
| UL 10A/10B | Fire Test of Door Assemblies |
| UL 72 | Fire Resistance of Record Protection Equipment |
| UL 155 | Fire Test of Door Assemblies |
| UL 263 | Fire Test of Building Construction and Materials |
| UL 555 | Fire Dampers and Ceiling Dampers |
| UL 1479 | Fire Test of Through Penetration Fire Seals |
| UL 1709 | Rapid Rise Fire Tests of Protection Materials for Structural Steel |
| UL 2085 | Insulated Above Ground Tanks for Flammable and Combustible Liquids |

The following list identifies the empirical standard flame spread tests.

| Test Standard | Title |
|---|---|
| ASTM E84 | Surface Burning Characteristics of Materials |
| ASTM E162 | Surface Flammability of Materials Using a Radiant Heat Energy Source |
| ASTM E648 | Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source |
| ASTM E970 | Critical Radiant Flux of Exposed Attic Floor Insulation Using a Radiant Heat Energy Source |
| IEEE 383 | Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations |
| IEEE 634 | Standard Cable Penetration Fire Stop Qualification Test |
| IEEE 1202 | Standard for Flame Testing of Cablefor Use in Cable Tray in Industrial and Commercial Occupancies |
| NFPA 255 | Surface Burning Characteristics of Materials |
| NFPA 262 | Fire and Smoke Characteristics of Electrical and Optical Fiber Cables in Air Handling Spaces |
| NFPA 265 | Full-Scale Test for Room Fire Growth Contribution of Textile Wall Coverings |
| UBC 8-1 | Surface Burning Characteristics of Materials |
| UBC 8-2 | Full-Scale Test for Room Fire Growth Contribution of Textile Wall Coverings |
| UBC 26-3 | Room Fire Test Standard for Interior of Foam Plastic Systems |
| UL 910 | Fire and Smoke Characteristics of Electrical and Optical Fiber Cables in Air Handling Spaces |
| UL 1256 | Under-deck Roof Construction Test |
| UL 1581 | Reference Standard for Electrical Wires, Cables, and Flexible Cords, 1080, VW-1 Vertical Wire Flame Test. |
| UL 1581 | Reference Standard for Electrical Wires, Cables, and Flexible Cords, 1160, UL Vertical-Tray Flame Test. |
| UL 1715 | Room Fire Test Standard of Interior of Foam Plastic Systems |
| UL 1820 | Fire Test of Pneumatic Tubing for Flame and Smoke Characteristics |
| UL 1887 | Fire Test of Plastic Sprinkler Pipe for Flame and Smoke Characteristics |

The following list identifies the empirical standard small-scale flammability tests.

| Test Standard | Title |
|---|---|
| 16 CFR 1610.4 (CPSC) | Flammability of Wearing Apparel |
| 16 CFR 1630.4 (CPSC) | Flammability of Finished Textile Floor Covering Materials |
| 16 CFR 1653.4 (CPSC) | Flammability of Finished Textile Floor Covering Materials |
| ASTM C 1166 | Flame Propagation of Dense and Cellular Elastomeric Gaskets and Accessories |
| ASTM D635 | Rate of Burning and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position |
| ASTM D1692 | Flammability of Plastic Sheeting and Cellular Plastics |
| ASTM D1929 | Ignition Properties of Plastics |
| ASTM D2584 | Ignition Loss of Cured Reinforced Plastics |
| ASTM D2859 | Flammability of Finished Textile Floor Covering Materials |
| ASTM D2863 | Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics |
| ASTM D3801 | Method for Measuring the Comparative Extinguishing Characteristics of Solid Plastics in a Vertical Position |
| ASTM D3806 | Small-Scale Evaluation of Fire-Retardant Paints |
| ASTM D3894 | Evaluation of Fire Response of Rigid Cellular Plastics Using a Small Corner Configuration |
| ASTM D4804 | Flammability Characteristics of Nonrigid Solid Plastics |
| ASTM D4986 | Horizontal Burning Characteristics of Cellular Polymeric Materials |
| ASTM D5048 | Comparative Burning Characteristics and Resistance to Burn-Through of Solid Plastics Using a 125-mm Flame |
| ASTM E136 | Behavior of Materials in a Vertical Tube Furnace at 750°C |
| ASTM E662 | Specific Optical Density of Smoke Generated by Solid Materials |
| ASTM E1354 | Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter |
| ASTM F501 | Aerospace Materials Response to Flame, With Vertical Test Specimen |
| Boston Fire Dept. Code Sec.11.2 & 11.3 | Fire Tests of Flame Resistant Textiles and Films |
| Boston Fire Dept. IX-1 | Classification Fire Tests of Fabrics |
| Calif. Title 19 | Fire Tests of Flame-Resistant Textiles & Films; Intermediate Scale |
| CS 191 | Flammability of Wearing Apparel |
| FAA OSU | Rate of Heat Release Evaluation |
| FAR 25.853 | Test Procedure of Showing Compliance with §§ 25.853, 25.855 and 25.1359 (Aircraft Compartment Interior Fire Test) |
| FMVSS 302 | Flammability of Interior Materials—Passenger Cars, Multipurpose Passenger Vehicles, Trucks, and Buses |
| FTMS 191 | Flame Resistance of Cloth |
| ISO 5660 | Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter |

| Test Standard | Title |
|---|---|
| NFPA 253 | Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source |
| NFPA 258 | Specific Optical Density of Smoke Generated by Solid Materials |
| NFPA 263 | Rate of Heat Release Evaluation |
| NFPA 264 | Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter |
| NFPA 701 | Fire Tests for Flame Resistant Textiles and Films |
| NFPA 702 | Flammability of Wearing Apparel |
| NFPA 703 | Fire-Retardant Treated Wood |
| UBC 2-1 | Behavior of Materials in a Vertical Tube Furnace at 750 °C |
| UBC 26-6 | Ignition Properties of Plastics |
| UBC 26-7 | Rate of Burning and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position |
| UBC 31-1 | Flame-Retardant Membranes |
| UL 94 | Flammability of Plastic Materials |
| UL 214 | Tests for Flame Propagation of Fabrics and Films |
| UL 1975 | Fire Tests for Foamed Plastics Used for Decorative Purposes |

Abbreviations

| | |
|---|---|
| API | American Petroleum Institute |
| ASTM | American Society for Testing and Materials |
| BS | British Standard |
| CPSC | Consumer Product Safety Commission |
| FAA | Federal Aviation Administration |
| IEEE | Institute of Electrical and Electronic Engineers |
| ISO | International Standards Organization |
| NFPA | National |
| OSU | Ohio State University |
| UBC | Uniform Building Code |
| UL | Underwritters  Laboratories |

# APPENDIX D. NRC DOCUMENTS RELATED TO FIRE PROTECTION

This appendix provides the various NRC reference documents related to fire protection.

## D.1 *Code of Federal Regulations* Related to Nuclear Regulatory Commission Fire Protection

The *Code of Federal Regulations* is a codification of the general and permanent rules published in the *Federal Register* by the Executive departments and agencies of the Federal Government. The code is divided into 50 titles, which represent broad areas subject to Federal regulation. Each title is divided into chapters, which usually bear the name of the issuing agency. Each chapter is further subdivided into parts covering specific regulatory areas. Title 10, "Energy," is composed of four volumes. These volumes are subdivided as Parts 1–50, 51–199, 200–499, and 500–end. The first and second volumes containing parts 1–199 comprise Chapter I, "Nuclear Regulatory Commission." The U.S. Nuclear Regulatory Commission sets requirements for the safe operation of commercial nuclear power reactors, licenses the construction and operation of the reactors, and inspects them to ensure that they are operating safely within the agency's regulations. NRC resident inspectors are stationed at each nuclear power plant and additional safety reviews are done by experts from NRC regional offices and headquarters.

(1) *Code of Federal Regulations*, Title 10, "Energy," Section 50.12, "Specific Exemption", U.S. Government Printing Office, Washington DC.

(2) *Code of Federal Regulations*, Title 10, "Energy," Section 50.48, "Fire Protection," U.S. Government Printing Office, Washington DC.

(3) *Code of Federal Regulations*, Title 10, "Energy," Part 50, Appendix A, "General Design Criterion 3 - Fire Protection," U.S. Government Printing Office, Washington DC.

(4) *Code of Federal Regulations*, Title 10, "Energy," Part 50, Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979," U.S. Government Printing Office, Washington DC.

(5) *Code of Federal Regulations*, Title 10, "Energy," Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," U.S. Government Printing Office, Washington DC.

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## D.2 Branch Technical Positions Related to Fire Protection

A branch technical position (BTP) sets forth a solution found to be acceptable by the NRC staff in dealing with a safety problem or safety-related problem. BTPs are included in the standard review plan (SRP) to serve as guides for the NRC staff reviewers as a means of achieving uniformity of interpretation and application of NRC requirements. Like regulatory guides, a BTP sets forth an acceptable method of complying with applicable regulations and not the only acceptable method.

The BTPs related to fire protection has been developed to provide comprehensive review guidance for nuclear power plant (NPP) fire protection programs (FPPs). These guidance identifies the scope and depth of fire protection that the Commission considers acceptable for NPPs. BTPs may be used for review of existing fire protection programs and program elements, proposed changes to existing programs that are subject to NRC review, new applications, fire vulnerability analyses [e.g., fire probabilistic risk assessments (PRA)], and programs for plant shutdown and decommissioning. Risk-informed and performance-based alternatives to the guidance presented in this regulatory guide may be acceptable and are evaluated on a case-by-case basis.

(1) BTP APCSB 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants," May 1, 1976, February 24, 1977.

(2) Appendix A to BTP APCSB 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants, Docketed Prior to July 1, 1976," (August 23, 1976), February 24, 1977.

(3) BTP ASB 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants," Revision 1, March 1979.

(4) BTP CMEB 9.5-1 (Formerly ASB 9.5-1), "Guidelines for Fire Protection for Nuclear Power Plants," Revision 2, July 1981.

(5) BTP SPLB 9.5-1, (Formerly CMEB 9.5-1), "Guidelines for Fire Protection for Nuclear Power Plants," Draft, Revision D, December 2002.

Abbreviations

| | |
|---|---|
| APCSB | Auxiliary and Power Conversion Systems Branch |
| ASB | Auxiliary Systems Branch |
| CMEB | Chemical and Mechanical Engineering Branch |
| SPLB | Plant Systems Branch |

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## D.3 NRC Regulatory Guides Related to Fire Protection

The Regulatory Guide (RG) provides guidance to licensees and applicants on implementing specific parts of the NRC's regulations, techniques used by the staff in evaluating specific problems or postulated accidents, and data needed by the staff in its review of applications for permits or licenses. Some guides delineate techniques used by the NRC to evaluate specific situations. Other provide guidance to applicants concerning information needed by the NRC in its review of construction permit (CP) and operating license (OL) applications. Many guides refer to or endorse national codes or standards (e.g., American Society of Mechanical Engineers (ASME), American National Standard Institute (ANSI), National Fire Protection Association (NFPA) etc.) that are developed by recognized national organizations. The guides are issued in the following ten broad divisions:

(1) Power Reactors
(2) Research and Test Reactors
(3) Fuels and Materials Facilities
(4) Environmental and Siting
(5) Materials and Plant Protection
(6) Products
(7) Transportation
(8) Occupational Health
(9) Antitrust and Financial Review
(10) General

Draft RGs are issued for public comment in the early stages of the development of a regulatory position. They have not received complete staff review and do not present an official NRC staff position until finalized and issued. Table D.3-1 provide the list of RGs related to fire protection.

Table D.3-1. NRC Regulatory Guides Related to Fire Protection

| Regulatory Guide | Title | Issue Date |
|---|---|---|
| 3.16 | General Fire Protection Guide for Plutonium Processing and Fuel Fabrication Plants | January 1974 |
| 1.39 | Housekeeping Requirements for Water-Cooled Nuclear Power Plants, Revision 2 | September 1977 |
| 1.120 | Fire Protection Guidelines for Nuclear Power Plants, Revision 1 | November 1977 (Withdrawn August 2001) |
| 1.52 | Design, Testing, and Maintenance Criteria for Post -accident Engineered Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants, Revision 2 | March 1978 |

| Table D.3-1. NRC Regulatory Guides Related to Fire Protection (continued) | | |
|---|---|---|
| Regulatory Guide | Title | Issue Date |
| 1.75 | Physical Independence of Electric Systems, Revision 2 | September 1978 |
| 1.91 | Evaluations of Explosions Postulated To Occur on Transportation Routes Near Nuclear Power Plants, Revision 1 | February 1978 |
| RTS 809-5 | Qualification Test for Cable Penetration Fire Stops for Use in Nuclear Power Plants | July 1979 |
| 1.175 | An Approach for Plant-Specific, Risk-Informed Decisionmaking: Inservice Testing, August 1998, RS809-5 Qualification Test for Cable Penetration Fire Stops for Use in Nuclear Power Plants | September 1979 |
| RS 902-4 | Fire Stops for Use in Nuclear Power Plants (Second Proposed Revision 3 to Regulatory Guide 1.33) Quality Assurance Program Requirements (Operation) | November 1980 |
| 1.10 | Emergency Planning and Preparedness for Nuclear Power Reactors, Revision 3 | August 1992 |
| 1.174 | An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis | July 1998 |
| 1.184 | Decommissioning of Nuclear Power Reactors (Draft was issued as DG-1067) | August 2000 |
| 1.189 | Fire Protection for Operating Nuclear Power Plants (Draft was issued as DG-1097) | April 2001 |
| 1.191 | Fire Protection Program for Nuclear Power Plants during Decommissioning and Permanent Shutdown (Draft was issued as DG-1069) | May 2001 |
| DG-1110 | (Proposed Revision 1 to Regulatory Guide 1.174), "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis | June 2001 |
| 1.188 | Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses (Drafts were DG-1104 issued 8/00, DG-1047 issued 8/96, Draft DG-1009 issued 12/90) | July 2 2001 |
| 1.170.4 | Fire Protection Considerations for Nuclear Power Plants | |

## D.4 NRC Generic Communications Related to Fire Protection

A generic communication is a transmittal to one or more classes of licensees. There are 6 types of generic communications, i.e., administrative letters, bulletins, circulars, generic letters, information notices, and regulatory issue summaries. Circulars were discontinued in February 1985.

### D.4.1 NRC Administrative Letters Related to Fire Protection

Administrative letter (AL) is a type of generic communication issued to:

- Inform addressees of any of the following:
  - (1) Administrative procedure changes relating to implementation of the regulations or NRC staff positions.
  - (2) The issuance of a topical report evaluation or a NUREG-type document that is not technical in nature, does not contain a new or revised staff position, and is not appropriate for inclusion in either a generic letter or an information notice.
  - (3) Changes in NRC internal procedures or organizations.

- Request voluntary submittal of information of an administrative nature which will assist NRC in the performance of its function.
- Announce events of interest such as workshops or Regulatory Information Conferences.
- Other purposes of a strictly administrative nature.

Table D.4-1 provide the list of administrative letters related to fire protection.

Table D.4-1. NRC Administrative Letters Related to Fire Protection

| Administrative Letter Number | Title | Issue Date |
|---|---|---|
| 94-03 | Announcing An NRC Inspection Procedure On Licensee Self-Assessment Programs For NRC Area-Of-Emphasis Inspections | 03-17-1994 |
| 94-07 | Distribution of Site-Specific and Site Emergency Planning Information | 05-06-1994 |
| 95-06 | Relocation of Technical Specification Administrative Controls Related to Quality Assurance | 12-12-1995 |
| 96-04 | Efficient Adoption of Improved Standard Technical Specifications | 10-09-1996 |
| 98-02 | Revisions to Event Reporting Guidelines for Power Reactors | 03-17-1998 |
| 98-09 | Priority for NRR Review of Risk-Informed Licensing Actions | 10-30-1998 |
| 98-10 | Dispositioning of Technical Specifications That Are Insufficient to Assure Plant Safety | 12-29-1998 |

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### D.4.2 NRC Bulletins Related to Fire Protection

A bulletin (BL) is used to address significant issues having generic applicability that also have great urgency. A BL requests information from, requests specified action by, and requires a written response in accordance with Section 182.a of the Atomic Energy Act of 1954, as amended, and 10 CFR 50.54(f), from the addresses regarding matters of safety, safeguards, or environmental significance. Addressees may be asked to take compensatory action that is commensurate with urgency of the issue being addressed, and provide requested information and perform and submit analyses by a specific time. A BL may not request long term actions. A BL may request new or revised license commitments that are based on analyses performed and license-proposed corrective action. A BL may not require license commitments. To extent that circumstances permit, NRC staff will interact with the nuclear industry on the issue being addressed. Table D.4-2 provide a list of NRC BLs related to fire protection.

Table D.4-2. NRC Bulletins Related to Fire Protection

| BL No. | Title | Issue Date |
|---|---|---|
| 75-04 | Cable Fire at Browns Ferry Nuclear Power Station | 03-24-1975 |
| 75-04A | Cable Fire at Browns Ferry Nuclear Power Station | 04-03-1975 |
| 75-04B | Cable Fire at Browns Ferry Nuclear Power Station | 11-03-1975 |
| 77-08 | Assurance of Safety and Safeguards During an Emergency-Locking Systems | 12-28-1977 |
| 78-01 | Flammable Contact-Arm Retainers in G.E. CR120A Relays. | 01-16-1978 |
| 78-03 | Potential Explosive Gas Mixture Accumulation Associated with BWR Offgas System Operations | 02-08-1978 |
| 81-03 | Flow Blockage of Cooling Water to Safety System Components by Corbicula Sp. (Asiatic Clam) and Mytilus Sp. (Mussel) | 04-10-1981 |
| 92-01 | Failure of Thermo-Lag 330 Fire Barrier System to Maintain Cabling in Wide Cable Trays and Small Conduits Free From Fire Damage | 06-24-1992 |
| 92-01 Supp-1 | Failure of Thermo-Lag 330 Fire Barrier System to Perform Its Specified Fire Endurance Function | 08-28-1992 |

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### D.4.3 NRC Circulars Related to Fire Protection

A circular (CR) is a type of generic communication used to transmit information to licensees or permit holders when the information is of safety, safeguards, or environmental interest but replies from licensees are not necessary for IE to assess the significance of the matter. A CR does not involve a specific response to the NRC but, rather, informs the licensees or permit holder. Table D.4-3 provide a list of NRC CRs related to fire protection.

| Table D.4-3. List of NRC Circulars Related to Fire Protection | | |
|---|---|---|
| Circular Number | Title | Issue Date |
| 77-03 | Fire Inside a Motor Control Center | 02-28-1977 |
| 78-04 | Installation Error that Could Prevent Closing of Fire Doors | 05-15-1978 |
| 78-18 | UL Fire Test | 11-02-1978 |
| 79-13 | Replacement of Diesel Fire Pump Starting Contactors | 07-16-1979 |

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### D.4.4 NRC Generic Letters Related to Fire Protection

A generic letter (GL) is used to address an emergent or routine technical issue having generic applicability that is a matter on which NRC staff has interacted with the nuclear industry and has concluded that a genetic communication is an appropriate means to effect resolution, or a risk significant, compliance, or adequate protection matter that NRC staff has concluded should be brought to the attention of the nuclear industry without extensive, prior interaction. A GL may request information from and/or request specific action by the addressees regarding matters of safety, safeguards, or environmental significance. The addressee may ask to accomplish the actions and report their completion by letter, with or without prior NRC approval of the action taken. Information requests typically will be on a voluntary basis, i.e., will not require a written response in accordance with Section 182.a of the Atomic Energy Act of 1954, as amended, and 10 CFR 50.54(f). A GL may request that the analyses be performed and, as appropriate, submitted for staff review, that description of proposed corrective action and other information be submitted for staff review, and that corrective actions be taken by a specified time. A GL may request new or revised license commitments based on analyses performed and proposed corrective actions, but may not require license commitments. Table D.4-4 provide the list of NRC GLs related to fire protection.

Table D.4-4. NRC Generic Letters Related to Fire Protection

| Generic Letter | Title | Issue Date |
|---|---|---|
| 77-02 | Fire Protection Functional Responsibilities, Administrative Control and Quality Assurance | 08-29-1977 |
| 80-45 | Fire Protection Rule | 05-19-1980 |
| 80-48 | Revision To 5/19/80 Letter On Fire Protection | 05-22-1980 |
| 80-56 | Commission Memorandum And Order On Equipment Qualification | 06-25-1980 |
| 80-96 | Fire Protection | 11-14-1980 |
| 80-100 | Appendix R to 10 CFR 50 Regarding Fire Protection-Federal Register Notice | 11-24-1980 |
| 80-103 | Fire Protection - Revised Federal Register Notice | 11-25-1980 |
| 81-12 | Fire Protection Rule (45 FR 76602, November 19, 1980), February 20, 1981, and Clarification Letter | 03-31-1982 |
| 82-21 | Technical Specifications for Fire Protection Audits | 10-06-1982 |
| 83-33 | NRC Positions on Certain Requirements of Appendix R to 10 CFR 50 | 10-19-1983 |

| Table D.4-4. NRC Generic Letters Related to Fire Protection (continued) | | |
|---|---|---|
| Generic Letter | Title | Issue Date |
| 85-01 | Fire Protection Policy Steering Committee Report,January 9, 1985 (GL 85-01 was issued only as a DRAFT for comment at public meetings which were held in 1984. However, GL 85-01 was never issued as a final and therefore is not available.) | 01-09-1985 |
| 86-10 | Implementation of Fire Protection Requirements | 04-24-1986 |
| 86-10 Supp-1 | Fire Endurance Test Acceptance Criteria for Fire Barrier Systems Used to Separate Redundant Safe Shutdown Trains Within the Same Fire Area | 03-25-1994 |
| 88-12 | Removal of Fire Protection Requirements from Technical Specifications | 08-02-1988 |
| 88-20 | Individual Plant Examination for Severe Accident Vulnerabilities | 11-23-1988 |
| 88-20 Supp-1 | Initiation of the Individual Plant Examination for Severe Accident Vulnerabilities - 10 CFR50.54 | |
| 88-20 Supp-2 | Accident Management Strategies for Consideration in the Individual Plant Examination Process | 04-04-1990 |
| 88-20 Supp-4 | Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities | 06-29-1991 |
| 88-20 Supp-5 | Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities - 10 CFR50.54(f) | 09-08-1995 |
| 89-13 | Service Water System Problems Affecting Safety-Related Equipment | 07-18-1989 |
| 89-13 Supp-1 | Service Water System Problems Affecting Safety-Related Equipment | 04-04-1990 |
| 91-18 | Information to Licensees Regarding Two NRC Inspection Manual Sections on Resolution of Degraded and Nonconforming Conditions and Operability | 11-07-1991 |
| 91-18 Rev. 1 | Information to Licensees Regarding Two NRC Inspection Manual Sections on Resolution of Degraded and Nonconforming Conditions and Operability | 10-08-1997 |
| 92-08 | Thermo-Lag 330-1 Fire Barriers | 12-17-1992 |
| 93-03 | Verification of Plant Records | 10-20-1995 |

| Table D.4-4. NRC Generic Letters Related to Fire Protection (continued) | | |
|---|---|---|
| Generic Letter | Title | Issue Date |
| 93-06 | Research Results on Generic Safety Issue 106, Piping and the Use of Highly Combustibles Gases in Vital Areas | 10-25-1993 |
| 95-01 | NRC Staff Technical Position on Fire Protection for Fuel Cycle Facilities | 01-26-1995 |

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### D.4.5 NRC Information Notices Related to Fire Protection

An information notice (IN) is a type of generic communication used to inform the nuclear industry of recently-identified, significant safety, safeguards, or environmental issues. Licensees are expected to review the information for applicability to their facilities or operations and consider actions, as appropriate, to avoid similar problems. INs do not convey changes in NRC policy or guidance and do not recommend specific courses of action. The suggestions contained in INs do not constitute NRC requirements and, therefore, no specific action or written response is required. The are rapid transmittals of information that may not yet have been completely analyzed by the NRC but that licensees should be aware of. Table D.4-5 provide the list of all INs related to fire protection.

Table D.4-5. List of Information Notices Related to Fire Protection

| IN Number | Title | Issue Date |
|---|---|---|
| 79-32 | Separation of Electrical Cables for HPCI and ADS | 12-18-1979 |
| 80-11 | Generic Problems with ASCO Valves in Nuclear Applications Including Fire Protection Systems | 03-14-1980 |
| 80-25 | Transportation of Pyrophoric Uranium | 05-30-1980 |
| 81-27 | Flammable Gas Mixtures in the Waste Gas Decay Tanks in PWR Plants | 09-03-1981 |
| 82-28 | Hydrogen Explosion while Grinding in the Vicinity of Drained and Open Reactor Coolant System | 07-23-1982 |
| 82-53 | Main Transformer Failures at the North Anna Nuclear Power Station | 12-22-1982 |
| 83-41 | Actuation of Fire Suppression System Causing Inoperability of Safety-Related Equipment | 06-22-1983 |
| 83-69 | Improperly Installed Fire Dampers at Nuclear Power Plants | 10-21-1983 |
| 83-83 | Use of Portable Radio Transmitters Inside Nuclear Power Plants | 12-19-1983 |
| 84-09 | Lessons Learned From NRC Inspections of Fire Protection Safe Shutdown Systems (10 CFR 50, Appendix R) | 02-13-1984 |
| 84-09r1 | Lessons Learned From NRC Inspections of Fire Protection Safe Shutdown Systems (10 CFR 50, Appendix R) | 03-07-1984 |
| 84-16 | Failure of Automatic Sprinkler System Valves to Operate | 03-02-1984 |
| 84-42 | Equipment Availability For Conditions During Outages not Covered by Technical Specifications | 06-05-1984 |

| Table D.4-5. Information Notices Related to Fire Protection (continued) | | |
|---|---|---|
| IN Number | Title | Issue Date |
| 84-92 | Cracking of Flywheels On Cummins Fire Pump Diesel Engines | 12-17-1984 |
| 85-09 | Isolation Transfer Switches and Post-Fire Shutdown Capability | 01-31-1985 |
| 85-30 | Microbiologically Induced Corrosion of Containment Service Water System | 04-19-1985 |
| 85-85 | Systems Interaction Event Resulting in Reactor System Safety Relief Valve Opening Following a Fire-Protection Deluge System Malfunction | 10-31-1985 |
| 86-13 | Standby Liquid Control System Squib Valves Failure to Fire | 02-21-1986 |
| 86-13 Supp-1 | Standby Liquid Control System Squib Valves Failure to Fire | 08-05-1985 |
| 86-17 | Update of Failure of Automatic Sprinkler System Valves to Operate | 03-24-1986 |
| 86-35 | Fire in Compressible Material at Dresden Unit 3 | 05-15-1986 |
| 86-106 | Feedwater Line Break | 12-16-1986 |
| 86-106 Supp-1 | Feedwater Line Break | 02-13-1987 |
| 86-106 Supp-2 | Feedwater Line Break | 03-18-1987 |
| 86-106 Supp-3 | Feedwater Line Break | 11-10-1988 |
| 87-14 | Actuation of Fire Suppression System Causing Inoperability of Safety-Related Ventilation Equipment | 03-27-1987 |
| 87-20 | Hydrogen Leak in Auxiliary Building | 04-20-1987 |
| 87-50 | Potential LOCA at High- and Low-Pressure Interfaces from Fire Damage | 10-09-1987 |
| 88-04 | Inadequate Qualification and Documentation of Fire Barrier Penetration Seals | 02-05-1988 |
| 88-04 Supp-1 | Inadequate Qualification and Documentation of Fire Barrier Penetration Seals | 08-09-1988 |
| 88-05 | Fire in Annunciator Control Cabinets | 02-12-1988 |
| 88-45 | Problems in Protective Relay and Circuit Breaker Coordination | 07-07-1988 |

| Table D.4-5. Information Notices Related to Fire Protection (continued) | | |
|---|---|---|
| IN Number | Title | Issue Date |
| 88-56 | Potential Problems with Silicone Foam Fire Barrier Penetration Seal | 08-04-1988 |
| 88-60 | Inadequate Design and Installation of Watertight Penetration Seals | 08-11-1988 |
| 88-61 | Control Room Habitability - Recent Reviews of Operating Experience | 08-11-1988 |
| 88-64 | Reporting Fires in Nuclear Process Systems at Nuclear Power Plants | 08-18-1988 |
| 89-44 | Hydrogen Storage on the Roof of the Control Room | 04-27-1989 |
| 89-52 | Potential Fire Damper Operational Problems | 06-08-1989 |
| 90-70 | Pump Explosions Involving Ammonium Nitrate | 11-06-1990 |
| 91-17 | Fire Safety of Temporary Installations or Services | 03-11-1991 |
| 91-20 | Electrical Wire Insulation Degradation Caused Failure in a Safety-Related Motor Control Center | 03-19-1991 |
| 91-37 | Compressed Gas Cylinder Missile Hazards | 06-19-1991 |
| 91-47 | Failure of Thermo-Lag Fire Barrier Material to Pass Fire Endurance Test | 08-06-1991 |
| 91-53 | Failure of Remote Shutdown System Instrumentation Because of Incorrectly Installed Components | 09-04-1991 |
| 91-77 | Shift Staffing at Nuclear Power Plants | 11-26-1991 |
| 91-79 | Deficiencies in the Procedures for Installing Thermo-Lag Fire Barrier Materials | 12-06-1991 |
| 91-79 Supp-1 | Deficiencies Found in Thermo-Lag Fire Barrier Installation | 08-04-1994 |
| 92-14 | Uranium Oxide Fires at Fuel Cycle Facilities | 02-21-1992 |
| 92-18 | Potential for Loss of Remote Shutdown Capability During a Control Room Fire | 02-28-1992 |
| 92-28 | Inadequate Fire Suppression System Testing | 04-08-1992 |

| Table D.4-5. Information Notices Related to Fire Protection (continued) | | |
|---|---|---|
| IN Number | Title | Issue Date |
| 92-46 | Thermo-Lag Fire Barrier Material Special Review Team Final Report Findings, Current Fire Endurance Tests, and Ampacity Calculation Errors | 06-23-1992 |
| 92-55 | Current Fire Endurance Test Results For Thermo-Lag Fire Barrier Material | 07-27-1992 |
| 92-82 | Results of Thermo-Lag 330-1 Combustibility Testing | 12-15-1992 |
| 93-40 | Fire Endurance Test Results for Thermal Ceramics FP-60 Fire Barrier Material | 05-26-1993 |
| 93-41 | One Hour Fire Endurance Test Results for Thermal Ceramics Kaowool, 3M Company FS-195, and 3M Company Interam E-50 Fire Barrier Systems | 05-28-1993 |
| 93-71 | Fire At Chernobyl Unit 2 | 09-13-1993 |
| 94-12 | Insights Gained From Resolving Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment | 02-09-1994 |
| 94-22 | Fire Endurance and Ampacity Derating Test Results for 3-hour Fire-Rated Thermo-Lag 330-1 Fire Barriers | 03-16-1994 |
| 94-26 | Personnel Hazards and Other Problems From Smoldering Fire-Retardant Material in the Drywell of a Boiling-Water Reactor | 03-28-1994 |
| 94-28 | Potential Problems With Fire-Barrier Penetration Seals | 04-05-1994 |
| 94-31 | Potential Failure of Wilco, Lexan-Type HN-4-L Fire Hose Nozzles | 04-14-1994 |
| 94-34 | Thermo-Lag 330-660 Flexi-Blanket Ampacity Derating Concerns | 05-13-1994 |
| 94-53 | Hydrogen Gas Burn Inside Pressurizer During Welding | 07-18-1994 |
| 94-58 | Reactor Coolant Pump Lube Oil Fire | 08-16-1994 |
| 94-59 | Accelerated Dealloying of Cast Aluminum-Bronze Valves Caused by Microbiologically Induced Corrosion | 08-17-1994 |
| 94-86 | Legal Actions Against Thermal Science, Inc., Manufacturer of Thermo-Lag | 12-22-1994 |
| 94-86 Supp-1 | Legal Actions Against Thermal Science, Inc., Manufacturer of Thermo-Lag | 11-15-1995 |

| Table D.4-5. Information Notices Related to Fire Protection (continued) | | |
|---|---|---|
| IN Number | Title | Issue Date |
| 95-27 | NRC Review of Nuclear Energy Institute, Thermo-Lag Combustibility Evaluation Methodology Plant Screening Guide | 05-31-1995 |
| 95-32 | Thermo-lag 330-1 Flame Spread Test Results | 08-10-1995 |
| 95-33 | Switchgear Fire and Partial Loss of Offsite Power at Waterford Generating Station, Unit 3 | 08-23-1995 |
| 95-36 | Potential Problems with Post-Fire Emergency Lighting | 08-29-1995 |
| 95-36 Supp-1 | Potential Problem in Post-Fire Emergency Lighting | 06-10-1997 |
| 95-48 | Results of Shift Staffing Study | 10-10-1995 |
| 95-49 | Seismic Adequacy of Thermo-Lag Panels | 10-27-1995 |
| 95-49 Supp-1 | Seismic Adequacy of Thermo-Lag Panels | 12-10-1997 |
| 95-52 | Fire Endurance Test Results for Electrical Raceway Fire Barrier Systems Constructed From 3M Company Interam Fire Barrier Material | 11-14-1995 |
| 95-52 Supp-1 | Fire Endurance Test Results for Electrical Raceway Fire Barrier Systems Constructed from 3M Company Interam Fire Barrier Materials | 03-17-1998 |
| 96-23 | Fires in Emergency Diesel Generator Exciters During Operation Following Undetected Fuse Blowing | 04-22-1996 |
| 96-33 | Erroneous Data from Defective Thermocouple Results in a Fire. | 05-24-1996 |
| 96-34 | Hydrogen Gas Ignition During Closure Welding of a VSC-24 Multi-Assembly Sealed Baske | 05-31-1996 |
| 97-01 | Improper Electrical Grounding Results in Simultaneous Fires in the Control Room and the Safe-Shutdown Equipment Room | 01-08-1997 |
| 97-23 | Evaluation and Reporting of Fires and Unplanned Chemical Reactor Events at Fuel Cycle Facilities | 05-07-1997 |
| 97-37 | Main Transformer Fault with Ensuring Oil Spill into Turbine Building | 06-20-1997 |
| 97-48 | Inadequate or Inappropriate Interim Fire Protection Compensatory Measures | 07-09-1997 |
| 97-59 | Fire Endurance Test Results of Versawrap Fire Barriers | 08-01-1997 |

| Table D.4-5. List of Information Notices Related to Fire Protection (continued) | | |
|---|---|---|
| IN Number | Title | Issue Date |
| 97-70 | Potential Problems with Fire Barrier Penetration Seals | 09-19-1997 |
| 97-72 | Potential for Failure of the Omega Series Sprinkler Heads | 09-22-1997 |
| 97-73 | Fire Hazard in the Use of a Leak Sealant | 09-23-1997 |
| 97-82 | Inadvertent Control Room Halon Actuation Due to a Camera Flash | 11-28-1997 |
| 98-31 | Fire Protection System Design Deficiencies and Common-Mode Flooding of Emergency Core Cooling System Rooms at Washington Nuclear Project Unit 2 | 08-18-1998 |
| 99-03 | Exothermic Reactions Involving Dried Uranium Oxide Powder (Yellowcake) | 01-29-1999 |
| 99-05 | Inadvertent Discharge of Carbon Dioxide Fire Protection System and Gas Migration | 03-08-1999 |
| 99-07 | Failed Fire Protection Deluge Valves and Potential Testing Deficiencies in Pre-Action Sprinkler Systems | 03-22-1999 |
| 99-17 | Problems Associated with Post-Fire Safe-Shutdown Circuit Analyses | 06-03-1999 |
| 99-28 | Recall of Star Brand Fire Protection Sprinkler Heads | 09-30-1999 |
| 99-28 Supp-1 | Recall of Star Brand Fire Protection Sprinkler Heads | 03-22-2002 |
| 99-34 | Potential Fire Hazard in the Use of Polyalphaolefin in Testing of Air Filters | 12-28-1999 |
| 00-12 | Potential Degradation of Firefighter Primary Protective Garments | 09-21-2000 |
| 00-14 | Non-Vital Bus Fault Leads to Fire and Loss of Offsite Power | 09-27-2000 |
| 01-04 | Neglected Fire Extinguisher Maintenance Causes Fatality | 04-11-2001 |
| 01-10 | Failure of Central Sprinkler Company Model GB Series Fire Sprinkler Head | 06-28-2001 |
| 01-12 | Hydrogen Fire at Nuclear Power Station | 07-13-2001 |
| 01-12 (Errata) | Hydrogen Fire at Nuclear Power Station | 08-08-2001 |

| Table D.4-5. Information Notices Related to Fire Protection (continued) | | |
|---|---|---|
| IN Number | Title | Issue Date |
| 02-01 | Metalclad Switchgear Failures and Consequent Losses of Offsite Power | 01-08-2002 |
| 02-04 | Wire Degradation at Breaker Cubicle Door Hinges | 01-10-2002 |
| 02-07 | Use of Sodium Hypochlorite for Cleaning Diesel Fuel Oil Supply Tanks | 01-28-2002 |
| 02-15 | Hydrogen Combustion Events in Foreign BWR Piping | 04-12-2002 |
| 02-15 Supp. 1 | Potential Hydrogen Combustion Events in BWR Piping | 05-06-2003 |
| 02-24 | Potential Problems With Heat Collectors on Fire Protection Sprinklers | 07-19-2002 |
| 02-27 | Recent Fires at Commercial Nuclear Power Plants in the United States | 09-20-2002 |

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### D.4.6 NRC Regulatory Issue Summaries Related to Fire Protection

A regulatory issue summary (RIS) is an informational document that is used to communicate with the nuclear industry on a board spectrum have generic applicability. It dose not involve a request for action or information unless it is stickily voluntary. Listed below are examples of way in which a RIS may be used:

- Document NRC endorsement of industry-developed resolutions to issues.
- Document NRC endorsement of industry guidance on technical or regulatory matters.
- Provide the status of staff interaction with the nuclear industry on a matter.
- Request the voluntary participation of licensees in staff-sponsored pilot programs.
- Inform licensees of opportunities for regulatory relief.
- Announce staff technical or policy positions on matters that have not been broadly communicated to the nuclear industry or are not fully understood.
- Provide guidance to licensees on regulatory matters, such as the scope and detail of information that should be provided in licensing applications to facilitate staff review.
- Announce the issuance and availability of regulatory documents (topical reports, NUREG-series documents and memoranda documenting the closeout generic safety issues (GSI)).
- Request the voluntary submittal of information which will assist the NRC in the administration of the regulatory process.
- Announce events of interest such as workshops and conferences.
- Announce changes in regulatory practices that could impact licensees.
- Announce changes in agency practices that could impact licensees.

Table D.4-6 provide the list of regulatory summaries related to fire protection.

Table D.4-6. Regulatory Issue Summaries Related to Fire Protection

| Regulatory Issue Summary Number | Title | Issue Date |
|---|---|---|
| 99-02 | Relaxation of Technical Specification Requirements for Porc Review of Fire Protection Program Changes | 10-13-1999 |
| 01-09 | Control of Hazard Barriers | 04-02-2001 |

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## D.5 Commission (SECY) Papers Related to Fire Protection

The primary decision making tool of the Commission is the written issue paper submitted by the Offices of the Executive Director for Operations (EDO), Chief Financial Officer (CFO), Chief Information Officer (CIO), or other offices reporting directly to the Commission. Policy, rulemaking, and adjudicatory matters, as well as general information, are provided to the Commission for consideration in a document style and format established specifically for the purpose. Such documents are referred to as "SECY Papers". A SECY paper gains its nomenclature through the designation (e.g., SECY-95-189) assigned to it by the Secretariat. Headings on the first page designate whether the subject matter relates to the formulation of policy (Policy Issue papers), or to the promulgation of agency rules (Rulemaking Issue papers), or to the granting, suspending, revoking, or amending of licenses (Adjudicatory Issue paper). As described below, each paper also indicates the type of action expected of the Commission:

- Commission Meeting Paper indicates a major issue on which collegial deliberation and vote at a Commission meeting, usually in a public session, is anticipated.

- Notation Vote Paper indicates an issue requiring consideration by the Commission or consultation with the Commission prior to action by the staff, but not requiring discussion among Commissioners or a formal vote in a meeting.

- Affirmation Paper indicates Commission business that does not require discussion among the Commissioners in a meeting mode, but by law must be voted by the Commissioners in the presence of each other.

- Negative Consent Paper indicates a relatively minor action proposed to be taken by the staff in the future. The Commission is authorized a period of time (usually 10 days) in which to make its contrary views known; otherwise, SECY will advise the staff that the action proposed in the paper may be taken.

- Information Paper provide information on policy, rulemaking, or adjudicatory issues.

As a general policy, SECY papers will be released to the public immediately after Commission action is completed unless they contain specific, limited types of information which warrant protection (adjudicatory, enforcement or investigatory, lawyer-client or legal work product, classified or proprietary, and personal privacy information). Table D.5-1 provide the list of SECY papers related to fire protection.

| Table D.5-1. Commission (SECY) Papers Related to Fire Protection | | |
|---|---|---|
| SECY | Title | Issue Date |
| 81-513 | Plan for Early Resolution of Safety Issues | 08-25-1991 |
| 82-267 | Fire Protection Role for Future Plants | 1982 |
| 83-133 | Integrated Safety Assessment Program (ISAP) | 03-23-1983 |
| 83-269 | Memorandum from W. J. Dircks to the Commissioners, "Fire Protection Role for Future Plants (SECY 82-267)" | 07-1983 |
| 89-081 | Final Report on Chernobyl Implications. | 03-07-1989 |
| 89-170 | Fire Risk Scoping Study: Summary of Results and Proposed Staff Actions | 06-07-1989 |
| 89-244 | Training Symposium on Firearms and Explosives Recognition and Detection | 08-21-1989 |
| 90-16 | Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirements | 01-12-1990 |
| 91-283 | Evaluation of Shutdown and Low Power Risk Issues | 09-09-1991 |
| 92-263 | Staff Plans for Elimination of Requirements Marginal to Safety | 08-26-1992 |
| 93-049 | Implementation of 10 CFR Part 45, Requirements for Renewal of Operating Licenses for Nuclear Power Plants | 03-01-1993 |
| 93-087 | Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (LWR) Designs | 04-02-1993 |
| 93-143 | NRC Staff Actions to Address the Recommendations in the Report on the Reassessment of the NRC Fire Protection Program | 05-21-1993 |
| 94-084 | Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Design. | 03-28-1994 |
| 94-090 | Institutionalization of Continuing Program for Regulatory Improvement | 03-31-1994 |
| 94-127 | Options for Resolving the Thermo-Lag Fire Barrier Issue | 05-12-1994 |
| 94-219 | Proposed Agency-Wide Implementation Plan for Probabilistic Risk Assessment (PRA) | 08-19-1994 |
| 95-034 | Status of Recommendations Resulting from the Reassessment of the NRC Fire Protection Program | 02-13-1994 |

| Table D.5-1. Commission (SECY) Papers Related to Fire Protection (continued) | | |
|---|---|---|
| SECY | Title | Issue Date |
| 99-079 | Status Update of the Agency-Wide Implementation Plan for Probabilistic Risk Assessment | 03-30-1995 |
| 96-134 | Option for Pursuing Regulatory Improvement in Fire Protection Regulations for Nuclear Power Plants | 06-21-1996 |
| 96-162 | Nuclear Power Plant-Specific Time-Temperature Curves for Testing and Qualifying Fire Barriers | 07-19, 1996 |
| 96-267 | Fire Protection Functional Inspection Program | 12-24-1996 |
| 97-127 | Development of a Risk-Informed, Performance-Based Regulation for Fire Protection at Nuclear Power Plants | 06-19-1997 |
| 97-278 | Staff Requirements, Plans to Issue Confirmatory Orders Concerning Schedules for Corrective Actions Regarding Licensee Use of Thermo-Lag 330-1 Fire Barriers | 12-24-1997 |
| 97-287 | Final Regulatory Guidance on Risk-Informing Regulations: Policy Issue | 12-12-1997 |
| 98-058 | Development of a Risk-Informed, Performance-Based Regulation for Fire Protection at Nuclear Power Plants | 03-26-1998 |
| 98-144 | White Paper on Risk-Informed and Performance-Based Regulation | 01-22-1998 |
| 98-161 | The Westinghouse AP600 Standard Design as it Related to the Fire Protection and the Spent Fuel Pool Cooling Systems. | 07-01-1998 |
| 98-187 | Interim Status Report - Fire Protection Functional Inspection Program | 08-03-1998 |
| 98-230 | Insights from NRC Research on Fire Protection and Related Issues | 10-02-1998 |
| 98-247 | Risk-Informed, Performance-Based Regulation for Fire Protection at Nuclear Power Plants | 10-27-1998 |
| 99-007 | Recommendations for Reactor Oversight Process Improvements | 01-08-1999 |
| 99-007A | Recommendations for Reactor Oversight Process Improvements | 03-22-1999 |
| 00-040 | Second Interim Status Report - Fire Protection Functional Inspection Program | 02-05-1999 |
| 99-140 | Recommendations for Reactor Fire Protection Inspections | 05-20-1999 |
| 99-152 | Status of Reactor Fire Protection Projects | 06-07-1999 |

| Table D.5-1. Commission (SECY) Papers Related to Fire Protection (continued) | | |
|---|---|---|
| SECY | Title | Issue Date |
| 99-168 | Improving Decommissioning Regulations for Nuclear Power Plants | 06-30-1999 |
| 99-182 | Assessment of the Impact of Appendix R Fire Protection Exemptions on Fire Risk | 07-09-1999 |
| 99-183 | Proposed Rule: Elimination of the Requirement for Noncombustible Fire Barrier Seal Materials and Other Minor Changes (10 CFR Part 50) | 07-14-1999 |
| 99-204 | Kaowool and FP6-60 Fire Barriers | 08-04-1999 |
| 00-0009 | Rulemaking Plan, Reactor Fire Protection Risk-Informed, Performance-Based Rulemaking | 01-13-2000 |
| 00-0055 | Status Report on The Comprehensive Fire Protection Regulatory Guide For Operating Reactors | 03-02-2000 |
| 00-0080 | Final Rule: Elimination of the Requirement for Noncombustible Fire Barrier Penetration Seal Materials and Other Minor Changes | 04-10-2000 |
| 02-131 | Update of the Risk-Informed Regulation Implementation Plan | 02-12-2002 |
| 02-132 | Proposed Rule: Revision of 10 CFR 50.48 to Permit Light-Water Reactors to Voluntarily Adopt National Fire Protection Association (NFPA) Standard 805, "Performance-Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plants," 2001 Edition (NFPA 805) as an Alternative Set of Risk-Informed, Performance-Based Fire Protection Requirements | 07-15-2002 |
| 03-0002 | Evaluation of the Effects of the Baltimore Tunnel Fire on Rail Transportation of Spent Nuclear Fuel | 03-25-2003 |
| 03-0100 | Rulemaking Plan on Post-Fire Operator Manual Actions | 06-17-2003 |

## D.6 NRC Preliminary Notifications Related to Fire Incidents

Preliminary Notifications issued by the Regions to inform the Commission and NRC staff of incidents of interest occurring at NRC regulated facilities and some state regulated facilities. The following fire incidents were last more than 10 minutes, and the reports are preliminary in nature. Table D.5.1 provide the a list of preliminary notifications related to fire incidents.

**Preliminary Notifications Issued in 1997**

Table D.6-1. Preliminary Notifications of Fire Incidents

| PN Number | Title | Issue Date |
|---|---|---|
| 29713 | Turkey Point 3&4 - Electrical Fire | 03-041997 |
| 19749 | Haddam Neck - Control Room Evacuation Due To Halon Activation | 08-08-1997 |
| 39780 | Quad Cities 1, 2 - Fire Response Safe Shutdown Procedure Deficiencies | 09-29-1997 |
| 49764 | General Atomics - Fire in Hot Cell Undergoing Decommissioning | 11-03-1997 |
| 39799 | Quad Cities 1 - Unit 1 Shut Down Because Appendix R (Fire) Safe Shutdown Analysis Not Completed | 12-23-1997 |

**Preliminary Notifications Issued in 1998**

| Table D.6-1. Preliminary Notifications of Fire Incidents (continued) | | |
|---|---|---|
| PN Number | Title | Issue Date |
| 29816 | General Electric Company - Fire In Dumpster | 03-17-1998 |
| 29818 | GTS Duratek - Bag House Fire | 03-25-1998 |
| 29820 | Kenton Meadows Company, Inc. - Gauge Involved In Building Fire | 03-30-1998 |
| 49817 | Siemens Nuclear Power Corporation - Fire in Waste Handling Area | 04-15-1998 |
| 49817a | Siemens Nuclear Power Corporation - Fire in Waste Handling Area (Update) | 04-16-1998 |
| 29831 | Turkey Point - Notice of Unusual Event Due to Fire on Site Lasting More than 10 Minutes | 06-10-1998 |
| 49826 | Washington Nuclear 2 - Internal Flooding Caused by Fire Header Line Valve Rupture | 06-18-1998 |
| 49826a | Washington Nuclear 2 - Update to Internal Flooding Caused by Fire Water System Valve Rupture and Arrival of Augmented Inspection Team | 06-19-1998 |
| 49826b | Washington Nuclear 2 - AIT Activities for Internal Flooding Caused by Fire Water System Valve Rupture and Termination of NOUE | 06-23-1998 |
| 29833 | Schlumberger Technology - Well Fire Involving 40 Millicurie Cesium 137 Source | 07-02-1998 |
| 29833a | Schlumberger Technology - Well Fire Involving 40 Millicurie Cesium 137 Source (Update) | 07-07-98 |
| 39844 | Department of the Army - Tritium Contamination Event (Broken Fire Control Devices) | 09-14-1998 |
| 19849 | Safety Light Corporation - Fire in Building on Safety Light Corporation Site | 10-19-1998 |
| 19849a | Safety Light Corporation - Fire in Building on Safety Light Corporation Site (Update) | 10/21/1998 |
| 39848 | Fermi 2 - Decl. of Alert Cond. Due to Fire in Emerg. Diesel Gen. Control Panel | 10-21-1998 |
| 39858 | Portsmouth Gaseous Diffusion Plant - Fire in Process Building | 12-09-1998 |

## Preliminary Notifications Issued in 1999

| Table D.6-1. Preliminary Notifications of Fire Incidents (continued) | | |
|---|---|---|
| PN Number | Title | Issue Date |
| 39858a | Portsmouth Gaseous Diffusion Plant - Fire in Process Building-Update | 12/15/1998 |
| 39901 | Prairie Island 1 - Station Auxiliary Transformer Explosion and Fire | 01-06/1999 |
| 39858b | Portsmouth Gaseous Diffusion Plant - Fire in Process Building - Second Update | 01-13-1999 |
| 19903 | Fitz Patrick - Notification of Unusual Event Due to a Fire at an Onsite Hydrogen Storage Facility | 01-15-1999 |
| 19904 | Millstone 3 - Carbon Dioxide Discharge Into Cable Spreading Room | 01-20-1999 |
| 19926 | Pilgrim 1 - Main Transformer Fire - Media Interes | 05-19-1999 |
| 39931 | Palisades 1 - Minor Hydrogen Burns During Cask Welding Activities | 06-10-1999 |
| 39932 | Palisades 1 - Dry Cask Storage Project Office Damaged by Fire | 06-18-1999 |
| 39945 | Allied Signal, Inc. - Brush Fire on Site Property One-Fourth Mile From Plant | 10-01-1999 |
| 19946 | Nine Mile Point 1 - Unusual Event Declaration Due to Carbon Dioxide Discharge in Administration Building | 10-8-1999 |
| 29950a | Fairfax County Government - Fixed Gauge Damaged in a Fire | 12-27-1999 |

**Preliminary Notifications Issued in 2000**

| Table D.6-1. Preliminary Notifications of Fire Incidents (continued) | | |
|---|---|---|
| PN Number | Title | Issue Date |
| 400011 | Unusual Event Because of a Fire Lasting Greater than 15 Minutes | 05-152-00 |
| 400011a | Update - Unusual Event Because of a Fire Lasting Greater Than 15 Minutes | 05-16-2000 |
| 400011b | Unusual Event Because of a Fire Lasting Greater Than 15 Minutes | 05-26-2000 |
| 400016 | Range Fire Nearby NRC Licensed Facilities (Siemens Power Corporation and WNP-2) | 06-30-2000 |
| 200031 | Alert Declared by Farley Due to Fire and Trip of the 2C Service Water Pump | 08-17-2000 |
| 200039 | Fire in B Main Power Transformer | 09-22-2000 |

**Preliminary Notifications Issued in 2001**

| Table D.6-1. Preliminary Notifications of Fire Incidents (continued) | | |
|---|---|---|
| PN Number | Title | Issue Date |
| 401001 | Accidental Fire Damages Three Portable Gauges | 01-05-2001 |
| 201002 | Incinerator Fire | 01-6-2001 |
| 401004 | Circuit Breaker Failure and Fire, Resulting in Reactor Shutdown | 2-06-2001 |
| 301010 | Alert Declared Due to Small Fire on an Emergency Diesel Generator Bearing Cover | 03-22-2001 |
| 401025 | Fire Affecting The Startup Transformer at Cooper Nuclear Station | 06-25-2001 |
| 401024 | Switchyard Fire Caused by the Failure of the Phase a Bus Potential Transformer. | 06-25-2001 |
| 301027 | Electrical Panel Fire During Plant Startup | 08-06-2001 |
| 301029 | Fixed Gauges Damaged in Fire | 08-29-2001 |
| 301036 | Potential Small Fire Event | 11-06-2001 |

**Preliminary Notifications Issued in 2002**

| Table D.6-1. Preliminary Notifications of Fire Incidents (continued) | | |
|---|---|---|
| PN Number | Title | Issue Date |
| 302025 | Fire in D.C. Cook Unit 1 Switchyard | 06-12-2002 |
| 302025A | Fire in D.C. Cook Unit 1 Switchyard (UPDATE) | 06-13-2002 |
| 302028 | Fire at Decommissioned Westinghouse-Hematite Uranium Fuel Fabrication Facility | 06-20-2002 |
| 302028A | Fire at Decommissioned Westinghouse-Hematite Uranium Fuel Fabrication Facility (Update) | 06-21-2002 |
| 202031 | Fire Trip of 1C Service Water Pump | 08-21-2002 |
| 202032 | Notification of Unusual Event (NOUN) Due to Fire in the Turbine Building - McGuire (Event Number 39145) | 08-23-2002 |
| 202036 | Unusual Event Declared, Fire in Control Building at Watts Bar Unit 1, Hydro Plant | 09-26-2002 |
| 202036A | Unusual Event Declared, Fire in Control Building at Watts Bar Unit 1, Hydro Plant | 09-30-2002 |

**Preliminary Notifications Issued in 2003**

| Table D.6-1. Preliminary Notifications of Fire Incidents (continued) | | |
|---|---|---|
| PN Number | Title | Issue Date |
| 303014 | Unusual Event Declared Due to Fire in the Main Turbine | 04-29-2003 |

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## D.7 NRC Miscellaneous Documents Related to Fire Protection

"Operating Experience Assessment, Energetic Faults in 4.16 kV to 13.8 kV Switchgear and Bus Ducts That Caused Fire in Nuclear Power Plants 1986-2001," Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC, February 2002. (ADAMS Accession # ML021290358).

RES/OERAB/S02-01, Vol.1, "Fire Events - Update of U.S. Operating Experience, 1986-1999, Commercial Power Reactors," Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC, January 2002. (ADAMS Accession # 020360172) and (ADAMS Accession # ML020450056)

AEOD/S97-03, "Special Study: Fire Events - Feedback of U.S. Operating Experience," U.S. Nuclear Regulatory Commission, Office for Analysis and Evaluation of Operational Experience, June 1997.

"Fire Protection Barriers to Effective Implementation of NRC's Safety Oversight Process," U.S. Nuclear Regulatory Commission Washington, DC, Report to the Honorable Edward J. Markey, House of Representatives, GAO/REED-0039, U.S. General Accounting Office, Washington, DC, April 2000. (ADAMS Accession # ML003718163)

"Circuit Analysis-Failure Mode and Likelihood Analysis," A Letter Report to USNRC, Sandia National Laboratory, Albuquerque, New Mexico, ADAMS Accession # ML010450362, May 8, 2000. (This letter report is available through the NRC Public Document Room under a NRC cover memorandum from T. L. King, NRC/RES/DRAA to G. M. Holahan, NRC/NRR/DSSA and M.E. Mayfield, NRC/RES/DET, dated June 13, 2000.)

"A Evaluation of the Fire Barrier System Thermo-Lag 330-1," SANDIA 94-0146, Sandia National Laboratories (SNL), Albuqerque, New Mexico, September 1994.

NRC Inspection Manual, Part 9900 (IM STS-10) - Technical Guidelines, Standard Technical Specification, Section 1.0 - Operability, p. 31, 1986.

NRC Inspection Manual, Chapter 0609, Appendix F, "Determining Potential Risk Significance of Fire Protection and Post-Fire Safe Shutdown Inspection Findings", February 27, 2001.

Inspection Procedure 64100, (IP 64100) - Postfire Safe Shutdown Emergency Lighting and Oil Collection Capability at Operating and Near-term Operating Reactor Facilities.

Inspection Procedure 64150, (IP 64150) - Triennial Postfire Safe Shutdown Capability.

Inspection Procedure 64704, (IP 64704) - Fire Protection Program, June 24, 1998.

Inspection Procedure 71111.05, (IP 71111.05) - Fire Protection, April 3, 2000.

Temporary Instruction 2515/62 (TI 2515/62) - Post Fire Safe Shutdown Emergency Lighting and Oil Collection Capability at All Operating Plants, Revision 2, February 14, 1985.

Temporary Instruction 2515/XX (TI 2515/XX) - Fire Protection Functional Inspection.

NRR Office Instruction, "NRR Interface With the Office of the General Counsel", September 11, 2002. (ADAMS Accession # ML020910237)

Memorandum for Z. Rosztoczy from S. Bajwa, "Generic Issue 148: Smoke Control and Manual Fire Fighting Effectiveness; Generic Issue 149: Adequacy of Fire Barriers," April 3, 1991.

Letter to D. Basdekas (NRC) from L. Lambright (SNL), "Generic Issue 1480: Smoke Control and Manual Fire Fighting Effectiveness," March 4, 1992.

Memorandum for W. Minners from E. Beckjord, "Generic Issue 148: Smoke Control and Manual Fire Fighting Effectiveness; Generic Issue 149: Adequacy of Fire Barriers," August 26, 1992.

Memorandum from T. King to A. Thadani, "Staff Review Guidance for Generic Issue (GSI) 148: Smoke Control and Manual Fire Fighting Effectiveness; Generic Issue 149: Adequacy of Fire Barriers," July 22, 1992.

Memorandum dated July 22 1999, from Thomas L. King, Office of Nuclear Regulatory Research, NRC, to Ashok C. Thadani, Office of Nuclear Regulatory Research, NRC, Subject: Staff Review Guidance for Generic Safety Issue (GSI) 148, "Smoke Control and Manual Fire-Fighting Effectiveness."

Letter dated November 12, 1999, from Dana A. Powers, Chairman ACRS, NRC, to Dr. William D. Travers, Executive Director of Operations, NRC, Subject: Proposed Resolution of Generic Safety Issue (GSI)-148, "Smoke Control and Manual Fire-Fighting Effectiveness."

Letter dated December 15, 1999, from William D. Travers, Executive Director of Operations, NRC, to Dana A. Powers, Chairman ACRS, NRC, Subject: Resolution of Generic Safety Issue (GSI)-148, "Smoke Control and Manual Fire-Fighting Effectiveness."

NRC Letter to All Licensees Holding Operating Licenses and Construction Permits for Nuclear Power Reactor Facilities, "Individual Plant Examination for Severe Accident Vulnerabilities - 10 CFR § 50.54(f), (Generic Letter 88-20)," November 23, 1988, (Supplement 1) August 29, 1989, (Supplement 2) April 4, 1990, (Supplement 3) July 65, 1990, (Supplement 4) June 28, 1991.

ZAR-791030-01, "Report of the President's Commission on the Accident at Three Mile Island," J G. Kemeny, et al., November 30, 1979.

Memorandum for E. Beckjord from J. Murphy, "Staff Review Guidance for Generic Safety Issue (GSI) 147, Fire-Induced Alternate Shutdown/Control Room Panel Interactions," March 9, 1994.

Memorandum for W. Russell from T. Murley, "Final Report-Special Review Team for the Review of Thermo-lag Fire Barrier Performance," April 21, 1992.

Memorandum to Dr. Dana A. Powers, Chairman Fire Protection Subcommittee from, A. Singh, "Proposed Resolution of Generic Safety Issue 148, Smoke Control and Manual Fire-Fighting Effectiveness," September 17, 1999.

Koski, J.A., J.G. Bobbe, M. Arviso, S.D. Wix, D.E. Beene, R. Byrd, and J. Graupmann, "Experimantal Determination of the Shipboard Fire Environment for Simulated Radioactive Material Packages," SAND 97-0606, Sandia National Laboratories, Albuquerque, New Mexico, 1997.

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## D.8 NRR Staff Presentations and Publications Related to Fire Protection

Connell, E.A., "Individual Plant Examination of External Events Program: Perspectives on The Fire Risk Assessment of Operating Reactors," Second International Conference on Fire Research and Engineering on August 12, 1997, at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland.

Connell, E.A., "Fire PRA Needs—Regulators Perspective," Proceedings from International Workshop on Fire Risk Assessment, Organized by the Nuclear Energy Agency (NEA), Committee on the Safety of Nuclear Installation (CSNI) Helsinki, Finland, 29 June–2 July 1999, NEA/CSNI/R(99)26.

Iqbal, N., and M.H. Salley, "Development of a Quantitative Fire Scenario Estimating Tool for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program," Structural Mechanics in Reactor Technology (SMiRT) Post-Conference Fire Protection Seminar No. 1, August 20-23, 2001, at the Millstone Nuclear Power Station Conference Facility in Waterford, Connecticut.

Iqbal, N., and M.H. Salley, "First Applications of a Quantitative Fire Hazard Analysis Tool for Inspection in the U.S. Commercial Nuclear Power Plants," 5$^{th}$ Meeting, International Collaborative Project to Evaluate Fire Models for Nuclear Power Plants Applications, Building and Fire Research Laboratory (BFRL), National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, May 2–3, 2002.

Madden, P.M., "Defense-In-Depth: A Regulatory Approach for Assuring Post-Fire Safe-Shutdown Capability," Proceedings, Specialist Meeting on Fire Protection and Fire Protection Systems in Nuclear Power Plants, Committee on the Safety of Nuclear Installation (CNSI), Organization for Economic Co-Operation and Development (OECD), Cologne, Germany, 6–9 December 1993.

Madden, P.M., "Assessment of Postulated Fires Resulting From Turbine Failures and Their Mitigation at U.S. Nuclear Power Facilities," Fire Safety 1994 Conference, Barcelona, Spain.

Madden, P.M., "Fire Safety Rulemaking Issues Confronting Regulatory Change in the United States," Structural Mechanics in Reactor Technology (SmiRT) 14, Fifth Post Conference Seminar No. 6, Fire Safety in Nuclear Power Plants and Installations," August 25–28, 1997, Lyon, France.

Notley, D.P., "Fire Protection in Nuclear Power Plants - Understanding Competing Requirements for Safety," Proceedings of an International Symposium on Fire Protection and Fire Fighting in Nuclear Installation, Organized by the International Atomic Energy Agency (IAEA) Vienna, Austria, 27 February to 3 March 1989, pp. 53–63.

Salley, M.H, "Tests to Develop Corrective Measures For Electrical Raceway Fire Barrier Systems: Part 1 "Ten Rules of Fire Endurance Testing," The Society of Fire Protection Engineers (SFPE) Technical Symposium on Application of Fire Testing in Fire Protection Engineering Practice, March 12–13, 1998, Hyatt Fair Lakes Hotel, Fairfax, Virginia

Salley, M.H, "Perspectives on the Implementation of Fire Protection Risk-Informed, Performance-Based Regulations in the United States Nuclear Power Industry," NFPA World Fire Safety Congress and Exposition, Baltimore, Maryland, May 19, 1999.

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## D.9 NRC Technical reports in the NUREG series Related to Nuclear Power Plant Fire Protection Engineering Research and Development (R&D)

The NRC publishes a variety of technical and regulatory reports, normally issued as NUREGs (NUREG is the NRC technical report designation (Nuclear Regulatory Commission)).

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The following is a list of NUREG reports related to fire protection:

NUREG-75/014, WASH-1400, "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," October 1975.

NUREG-75/087, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," LWR Edition, Interim Report, September 1975.

NUREG-75/087 (A11), "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," LWR Edition, Interim Report, September 1975.

NUREG-75/087-CH2, "Standard Review Plan," Chapter 2, November 24, 1975.

NUREG-0050, "Recommendations Related to Browns Ferry Fire," Report by Special Review Group, February 1976.

NUREG/TR-0018, "Review of Literature on Vapor Explosion: First Technical Report on Research Project BMFT - RS 76", February 1976.

NUREG-0061, "Operation of Browns Ferry, Units 1 and 2 Following the March 22, 1975 Fire," Safety Evaluation Report, March 1976.

NUREG-0061-Suppl-1, Operation of Browns Ferry, Units 1 and 2 Following the March 22, 1975 Fire," Safety Evaluation Report, Supplement 1, 18 June, 1976.

NUREG-766516, "Report on Task I - Fire Protection System Study," February 1977.

NUREG/CR-0075, "Accidental Vapor Phase Explosion on Transportation Routes Near Nuclear Power Plant," April 1977.

NUREG-0206, "Progress Report on Fire Protection Research," June 1977.

BNL-NUREG-23316, "Turbine Oil Fires as Related to Nuclear Power Stations," September 1977.

BNL-NUREG-23364, "Fire Damage Data Analysis as Related to Current Testing Practices for Nuclear Power Application," October 1977.

BNL-NUREG-23392, "Design Base Fires in Nuclear Power Plants," October 1977.

NUREG-0298 (Vol.1) (No.1), "Fire Protection Action Plan: Status Summary Report," 13 February, 1978.

NUREG/CR-0366, "Fire Protection Research Quarterly Progress Report (October - December 1977)," March 8, 1978.

BNL-NUREG-23910, "Fire Scenarios in Nuclear Power Plant,"1978.

NUREG/CR-0152, "Development and Verification of Fire Tests for Cable Systems and System Components," June 1978.

NUREG-0298 (Vol.1) (No.3), "Fire Protection Action Plan, Status Summary Report, Data for Decisions, Management by Objectives," 28 August, 1978.

NUREG/CR-0403, "High Temperature Testing of Smoke Detector Sources," September 1978.
NUREG/CR-0346, "Development and Verification of Fire Tests for Cable Systems and System Components," September 1978.

NUREG/CR-0381, "A Preliminary Report on Fire Protection Research Program Fire Barriers and Fire Retardant Coatings Tests", September 1978.

NUREG/CR-0376, "Models of Horizontal Electrical Cables and Cable Trays Exposed to a Fire Plume," September 1978.

BNL-NUREG-25101, "Performance of Fire Protection Systems Under Post Earthquake Conditions," October 1978.

NUREG/CR-0596, "Preliminary Report on Fire Protection Research Program Fire Barriers and Suppression (September 15, 1978, Test)," December 1978.

NUREG-0298 (Vol.1)(No.4), "Fire Protection Action Plan, Status Summary Report, Data for Decisions, Management by Objectives," December 1978.

NUREG/CR-0488, "Nuclear Power Plant Fire Protection-Fire Detection," (Subsystems Study Task 2), March 1979.

NUREG/CR-0636, "Nuclear Power Plant Fire Protection-Ventilation," (Subsystems Study Task 1), August 1979.

NUREG/CR-0468, "Nuclear Power Plant Fire Protection-Fire Barriers," (Subsystems Study Task 3), September 1979.

NUREG/CR-0654, "Nuclear Power Plant Fire Protection Fire-Hazard Analysis (Subsystems Study Task 4)," September 1979.

NUREG-0585, "TMI Lessons Learned Task Force Final Report," October 1979.

NUREG/CR-1156, "Environmental Assessment of Ionization Chamber Smoke Detectors Containing Am-241," November 1979.

NUREG/CR-0833, "Fire Protection Research Program Corner Effects Tests," December 1979.

NUREG-0654, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants," Interim Report, January 1980.

NUREG/CR-1405, "NACOM Code for Analysis of Postulated Sodium Spray Fires in LMFBRs," March 1980.

NUREG/CR-1798, "Acceptance and Verification for Early Warning Fire Detection Systems," Interim Guide, May 1980.

NUREG/CR-1184, "Evaluation of Simulator Adequacy for the Radiation Qualification of Safety-Related Equipment," May 1980.

NUREG/CR-2269, "Probabilistic Models for the Behavior of Compartment Fires," August 1980.

NUREG/CR-1552, "Development and Verification of Fire Tests for Cable Systems and System Components," September 1980.

NUREG/CR-1614, "Approaches to Acceptable Risk: A Critical Guide," September 1980.

NUREG/CR-1819, "Development and Testing of a Model for Fire Potential in Nuclear Power Plants," November 1980.

NUREG/CR-1741, "Models for the Estimation of Incapacitation Times Following Exposures to Toxic Gases or Vapors," December 1980.

NUREG-0492, "Fault Tree Handbook," January 1981.

NUREG/CR-1682, "Electrical Insulators in a Reactor Accident Environment," January 1981.

NUREG/CR-1930, "Index of Risk Exposure and Risk Acceptance Criteria," February 1981.

NUREG/CR-1916, "A Risk Comparison," February 1981.

NUREG/CR-1748, "Hazards to Nuclear Power Plants from Nearby Accidents Involving Hazardous Materials-A Preliminary Assessment," April 1981.

NUREG/CP-0018, Proceedings of the Workshop on Frameworks for Developing a Safety Goal, Palo Alto, California, April 1-3, 1981.

NUREG/CR-2079, "Analysis of Credible Accidents for Argonaut Reactors, Report for October 1980-April 1981," April 1981.

NUREG/CR-2040, "Study of the Implications of Applying Quantitative Risk Criteria in the Licensing of Nuclear Power Plants in the United States," May 1981.

NUREG/CR-2269, "Probabilistic Models for the Behavior of Compartment Fires," August 1981.

NUREG/CR-2017-Volume IV of IV, "Halon Inerting as a Hydrogen Control Measure for Sequoyah," Proceedings of the Workshop on the Impact of Hydrogen on Water Reactor Safety, Edited by M. Berman, September 1981.

NUREG/CR-2258, "Fire Risk Analysis for Nuclear Power Plants," September 1981.

NUREG/CR-2017-Volume 3, "Flammability Limits and Pressure Development in Hydrogen-Air Mixtures," Proceedings of the Workshop on the Impact of Hydrogen on Water Reactor Safety, September 1981.

NUREG/CR-2017-Volume 4, "Halon 1301 Protection System for Nuclear Containment," Proceedings of the Workshop on the Impact of Hydrogen on Water Reactor Safety, September 1981.

NUREG/CR-2321, "Investigation of Fire Stop Test Parameters," Final Report, September 1981.

NUREG/CR-2377, "Tests and Criteria for Fire Protection of Cable Penetrations," October 1981.

NUREG/CR-2490, "Hazards to Nuclear Power Plants From Large Liquefied Natural Gas (LNG) Spills on Water," November 1981.

NUREG/CR-2431, "Burn Mode Analysis of Horizontal Cable Tray Fires," February 1982.

NUREG/CR-2486, "Final Results of the Hydrogen Igniter Experimental Program," February 1982.

NUREG/CR-3214, "Aging with Respect to Flammability and Other Properties in Fire-Retarded Ethylene Propylene Rubber and Chlorosulfonated Polyethylene," March 1982.

NUREG/CR-2409, "Requirements for Establishing Detector Siting Criteria in Fires Involving Electrical Materials,"July 1982.

NUREG/CR-2868, "Aging Effects on Fire-Retardant Additives in Organic Materials for Nuclear Plant Applications," August 1982.

NUREG/CR-2730, "Hydrogen Burn Survival: Preliminary Thermal Model and Test Results," August 1982.

NUREG/CR-2927, "Nuclear Power Plant Electrical Cable Damageability Experiments," October 1982.

NUREG/CR-2650, "Allowable Shipment Frequencies for the Transport of Toxic Gases Near Nuclear Power Plants," October 1982.

NUREG/CR-2859, "Evaluation of Aircraft Crash Hazards for Nuclear Power Plants," 1982.

NUREG/CR-2300, "PRA Procedures Guide - A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants," Volume 1 and 2 January 1983.

NUREG/CR-2607, "Fire Protection Research Program for the U.S. Nuclear Regulatory Commission 1975-1981," April 1983.

NUREG/CR-3239, "COMPBRN-A Computer Code for Modeling Compartment Fires," May 1983.

NUREG/CR-2475, "Hydrogen Combustion Characteristics Related to Reactor Accidents," July 1983.

NUREG/CR-2658, "Characteristics of Combustion Products: A Review of the Literature," July 1983.

NUREH/CR-3385, "Measures of Risk Importance and Their Application," July 1983.

NUREG/CR-3122, "Potentially Damaging Failure Modes of High-and Medium-Voltage Electrical Equipment," July 1983.

NUREG/CR-3330, "Vulnerability of Nuclear Power Plant Structures to Large External Fires," August 1983.

NUREG/CR-2726, "Light Water Reactor Hydrogen Manual," August 1983.

NUREG/CR-2462, "Capacity of Nuclear Power Plant Structure to Resist Blast Loading," September 1983.

NUREG/CR-3192, "Investigation of Twenty-Foot Separation Distance as a Fire Protection Method as Specified in 10 CFR 50, Appendix R," October 1983.

NUREG/CR-3242, "Los Alamos National Laboratory/New Mexico State University Filter Plugging Test Facility: Description and Preliminary Test Results" October 1983.

NUREG/CR-3527, "Material Transport Analysis for Accident-Induced Flow In Nuclear Facilities," October 1983.

NUREG/CR-3541, "Measures of the Risk Impacts of Testing and Maintenance Activities," November 1983.

NUREG/CR-3527, "Material Transport Analysis for Accident-Induced Flow in Nuclear Facilities," December 1983.

NUREG/CR-3548, "Hazardous Materials Accidents Near Nuclear Power Plants: An Evaluation of Analyses and Approaches," 1983.

NUREG/CR-2462, "Capacity of Nuclear Power Plant Structures to Resist Blast Loading," 1983.

NUREG/BR-0075, "NRC Field Policy Manual," January 1984.

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, April 1984.

NUREG/CR-3735, "Accident-Induced Flow and Material Transport in Nuclear Facilities: A Literature Review," April 1984.

NUREG/CR-3139, "Scenarios and Analytical Methods for UF Releases at NRC-licensed Fuel Cycle Facilities," June 1984.

NUREG-0675, Supplement 23, "Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant, Units 1 and 2," June 1984.

NUREG-0681, Supplement 4, "Safety Evaluation Report Related to the Operation of South Texas Project, Unit 1 and 2," July 1984.

NUREG/CR-3493, "Review of the Limerick Generating Station Severe Accident Risk Assessment - Review of Core-Melt Frequency," July 1984.

NUREG/CR-3521, "Hydrogen-Burn Survival Experiments at Fully Instrumented Test Site (FITS)," August 1984.

NUREG/CR-3719, "Detonation Calculations Using a Modified Version of CSQII: Examples for Hydrogen-Air Mixtures," August 1984.

NUREG/CR-3922, "Survey and Evaluation of System Interaction Events and Sources," Appendices A and B, Volume 1, January 1985.

NUREG/CR-3922, "Survey and Evaluation of System Interaction Events and Sources," Appendices C and D, Volume 2, January 1985.

NUREG/CR-4479, "Use of a Field Model to Assess Fire Behavior in Complex Nuclear Power Plant Enclosures: Present Capabilities and Future Prospects," January 1985.

NUREG/ CR-4112-Volume 1, "Investigation of Cable and Cable System Fire Test Parameters, Volume 1, Task A: IEEE 383 Flame Test," January 1985.

NUREG/CR-4112-Volume 2, "Investigation of Cable and Cable System Fire Test Parameters, Volume 2, Task B: Firestop Test Method," January 1985.

NUREG/CR-3638, "Hydrogen-Steam Jet-Flame Facility and Experiments," February 1985.

NUREG/CR-4230, "Probability-Based Evaluation of Selected Fire Protection Features in Nuclear Power Plants," May 1985.

NUREG/CR-4264, "Investigation of High-efficiency Particulate Air Filter Plugging by Combustion Aerosols," May 1985.

NUREG/CR-4231, "Evaluation of Available Data for Probabilistic Risk Assessments (PRA) of Fire Events at Nuclear Power Plants," May 1985.

NUREG/CR-4229, "Evaluation of Current Methodology Employed in Probabilistic Risk Assessment (PRA) of Fire Events at Nuclear Power Plants," May 1985.

NUREG-1148, "Nuclear Power Plant Fire Protection Research Program," July 1985.

NUREG/CR-4321, "Full-scale Measurements of Smoke Transport and Deposition in Ventilation System Ductwork, July 1985.

NUREG/CR-2815, "Probabilistic Safety Assessment Procedures Guide," August 1985.

BNL-NUREG-36946, "Use of a Field Model to Analyze Probable Fire Environments Encountered Within the Complex Geometries of Nuclear Power Plants," August 1985.

BNL-NUREG-36873, "Probabilistic Analysis of Fires in Nuclear Plants," 1985.

NUREG/CR-4310, "Investigation of Potential Fire-Related Damage to Safety-Related Equipment in Nuclear Power Plants," November 1985.

NUREG/CR-4138, "Data Analysis for Nevada Test Site (NTS) Premixed Combustion Tests," May, 1985.

NUREG/CR-4136, "SMOKE: A Data Reduction Package for Analysis of Combustion Experiments," September 1985.

NUREG/CR-4561, "FIRAC User's Manual: A Computer Code to Simulate Fire Accidents in Nuclear Facilities," April 1986.

NUREG/CR-4330-Vol.1, "Review of Light Water Reactor Regulatory Requirements: Identifications of Regulatory Requirements That May Have Marginal Importance to Risk," Volume 1, April 1986.

NUREG/CR-4330-Vol.2, "Review of Light Water Reactor Regulatory Requirements: Identifications of Regulatory Requirements That May Have Marginal Importance to Risk," Volume 2, June 1986.

NUREG/CR-4596, "Screening Tests Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires," June 1986.

NUREG/CR-4570, "Description and Testing of an Apparatus for Electrically Initiating Fires Through Simulation of a Faulty Connection," June 1986.

NUREG/CR-4566, "COMPBRN III - A Computer Code for Modeling Compartment Fires," July 1986.

NUREG/CR-4586, "User Guide for a Personnel-Computer-Based Nuclear Power Plant Fire Data Base," August 1986.

NUREG/CR-4638/1of 2, "Transient Fire Environment Cable Damageability Test Results: Phase I," September 1986.

NUREG/CR-3656, "Evaluation of Suppression Methods for Electrical Cables Fires," October, 1986.

NUREG/CR-4680, "Heat and Mass Release for Some Transient Fuel Sources Fires: A Test Report," October 1986.

NUREG/CR-3468, "Hydrogen-Air-Steam Flammability Limits and Combustion Characteristics in the FITS Vessel," December 1986.

BNL-NUREG-38839, "Fire Environment Determination in the LaSalle NPP Control Room," 1986.

NUREG/CR-4905, "Detonability of $H_2$-Air-Diluent Mixtures," 1986.

NUREG-1250, "Report on the Accident at the Chernobyl Nuclear Power Station," January 1987.

NUREG/CR-4679, "Quantitative Data on the Fire Behavior of Combustible Materials Found in Nuclear Power Plants: A Literature Review," February 1987.

NUREG/CR-4829, "Shipping Container Response to Severe Highway and Railway Accident Condition," February 1987.

NUREG/CR-4681, "Enclosure Environment Characterization Testing for Base Line Validation of Computer Fire Simulation Codes," March 1987.

NUREG/CR-4736, "Combustion Aerosols Formed During Burning of Radioactively Contaminated Materials, Experimental Results," March 1987.

NUREG/CR-4830, "MELCOR 1.0 and HECTR 1.5 Calculations for Browns Ferry Reactor Building Burns, MELCOR Validation and Verification: 1986 Papers," March 1987.

NUREG/CR-4527/1 of 2, "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets: Part 1: Cabinet Effects Tests," April 1987.

NUREG/CR-4330-Vol.3, "Review of Light Water Reactor Regulatory Requirements: Identifications of Regulatory Requirements That May Have Marginal Importance to Risk: Post-Accident Sampling System, Turbine Missiles, Combustible Gas Control, Filters," Volume 3, May 1987.

NUREG/CR-4517, "An Aging Assessment of Relays and Circuits Breakers and System Interactions," June 1987.

NUREG/CR-4855, "Development and Application of a Computer Model for Large-Scale Flame Acceleration Experiments," July 1987.

NUREG/CR-4534, "Analysis of Diffusion Flame Tests," August 1987.

NUREG/CR-5037, "Fire Environment Determination in the LaSalle Nuclear Power Plant Control Room," October 1987.

NUREG/CR-5042, "Evaluation of External Hazards to Nuclear Power Plants in the United States," December 1987.

NUREG-1250, Rev. 1, "Report on the Accident at the Chernobyl Nuclear Power Station," Prepared by, the U.S. Department of Energy, Electric Power Research Institute, U.S. Environmental Protection Agency, Federal Emergency Management Agency, Institute of Nuclear Power Operation, and the U.S. Nuclear Regulatory Commission, December 1987.

NUREG/CR-4763, "Safety-Related Equipment Survival in Hydrogen Burns in Large Dry PWR Containment Buildings," March 1988.

NUREG/CR-2331, "Safety Research Programs Sponsored by Office of Nuclear Regulatory Research," Volume 7, No. 2 and 3, June 1988.

NUREG/CR-5233, "Computer Code for Fire Protection and Risk Analysis of Nuclear Plants," September 1988.

NUREG/CP-0097, "The Effects of Aging on the Fire Vulnerability of Nuclear Power Plant Component," Proceedings of the 16$^{th}$ Water Reactor Safety Meeting, October 1988.

NUREG/CR-4527, Volume 2, "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets: Part II: Room Effects Tests," November, 1988.

NUREG/CR-5088, "Fire Risk Scoping Study: Investigation of Nuclear Power Plant Fire Risk, Including Previously Unaddressed Issues," December 1988.

NUREG/CR-5088, "Fire Risk Scoping Study: Investigation of Nuclear Power Plant Fire Risk, Including Previously Unaddressed Issues," January 1989.

NUREG/CR-5042, Supplement 2, "Evaluation of External Hazards to Nuclear Power Plants in the United States: Other External Events," , February 1989.

NUREG/CR-3037, "A Computer Code to Estimate Accidental Fire and Radioactive Airborne Releases in Nuclear Fuel Cycle Facilities," User's Manual for FIRIN, February 1989.

NUREG/CR-5281, "Value/Impact Analyses of Accident Preventive and Mitigative Options for Spent Fuel Pools," March 1989.

NUREG/CR-1251, Vol. 1, "Implications of the Accident at Chernobyl for Safety Regulation of Commercial Nuclear Power Plants in the United States," Volume 1, Main report: Final report. April 1989.

NUREG/CR-1251, Vol. 2, "Implications of the Accident at Chernobyl for Safety Regulation of Commercial Nuclear Power Plants in the United Sates," Volume 2, Appendix - Public Comments and their Disposition: Final Report, April 1989.

NUREG-1335, "Individual Plant Examination: Submittal Guidance," Final Report, Office of Nuclear Regulatory Research, and Office of Nuclear Reactor Regulation, August 1989.

NUREG/CR-5079, "Experimental Results Pertaining to the Performance of Thermal Igniters," October 1989.

NUREG/CR-5457, "Review of the Three Mile Island-1 Probabilistic Risk Assessment," November 1989.

NUREG/CR-5384, "A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories,1975-1987," December 1989.

NUREG/CR-5275, "FLAME Facility: The Effect of Obstacles and Transverse Venting on Flame Acceleration and Transition to Detonation for Hydrogen/Air Mixture at Large Scale," 1989.

NUREG/CR-5464, "An Identification and Initial Assessment of Potential Fire Safety Issues Associated with Plant Aging," April 1990.

NUREG-1409, "Backfitting Guidelines," July, 1990.

NUREG-1150, Volume 1, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," December 1990.

NUREG/CR-4550, "Analysis of Core Damage Frequency: Peach Bottom Unit 2 External Events," December 1990.

NUREG/CR-4840, "Procedures for the External Event Core Damage Frequency Analyses for NUREG-1150," December 1990.

NUREG/CR-5619, "The Impact of Thermal Aging on the Flammability of Electric Cables," March 1991.

NUREG/CR-5546, "An Investigation of the Effects of Thermal Aging on the Fire Damageability of Electric Cables," May 1991.

NUREG/CR-5655, "Submergence and High Temperature Steam Testing of Class 1E Electrical Cables," May 1991.

NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities Study," June 1991.

NUREG/CR-5525, "Hydrogen-Air-Diluent Detonation Study for Reactor Safety Analyses," 1991.

NUREG/CR-5669, "Evaluation of Exposure Limits to Toxic Gases for Nuclear Reactor Control Room Operations," July 1991.

NUREG-1422, "Summary of Chernobyl Followup Research Activities," U.S. Nuclear Regulatory Commission, Division of Safety Issue Resolution, June 1992.

NUREG/CR-4839, "Methods for External Event Screening Quantification: Risk Methods Integration and Evaluation Program (RMIEP) Methods Development, July 1992.

NUREG/CR-4832, "Analysis of the LaSalle Unit 2 Nuclear Power Plant: Risk Methods Integration and Evaluation Program (RMIEP)," July 1992.

NUREG/CR-5790, "Risk Evaluation for a Babcock & Wilcox Pressurized Water Reactor, Effects of Fire Protection System Actuation on Safety-Related Equipment: Evaluation of Generic Issue 57," September 1992.

NUREG/CR-4832-Volume 4, "Analysis of the LaSalle Unit 2 Nuclear Power Plant: Risk Methods Integration and Evaluation Program (RMIEP). Initiating Events and Accident Sequence Delineation," October 1992.

NUREG/CR-5580, "Evaluation of Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment," (Vol.1, 2, 3, 4, and 5), December 1992 .

NUREG/CR-5789, "Risk Evaluation for a Westinghouse PWR, Effects of Fire Protection System Actuation on Safety-Related Equipment: Evaluation of Generic Issue 57," December 1992.

NUREG/CR-5791, "Risk Evaluation for a General Electric BWR, Effects of Fire Protection System Actuation on Safety-Related Equipment: Evaluation of Generic Issue 57," December 1992.

NUREG/CR-4832, "Analysis of the LaSalle Unit 2 Nuclear Power Plant: Risk Methods Integration and Evaluation Program (RMIEP), Volume 9 , Internal Fire Analysis," March 1993.

NUREG/CP-0129, Proceedings of the Workshop on Program for Elimination of Requirements Marginal to Safety, Bethesda, Maryland, April 27-28, 1993.

NUREG-1364, "Resolution Regulatory Analysis For the Resolution of Generic Safety Issue 106: Piping and the Use of Highly Combustible Gases in Vital Areas," June 1993.

NUREG/CP-0130-Vol.2, "Development of a Personal Computer Code for Fire Protection Analysis of DOE Facility Air-cleaning Systems," Proceedings of the 22nd DOE/NRC Nuclear Air Cleaning Conference, July 1993.

NUREG-1472, "Regulatory Analysis for the Resolution of Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment," October 1993.

BNL-NURG-49137, "Fire Protection of Safe Shutdown Capability at Commercial Nuclear Power Plants," 1993.

NUREG/CR-6103, "Prioritization of Reactor Control Components Susceptible to Fire Damage as a Consequence of Aging," January 1994.

NUREG/CR-5904, "Functional Issues and Environmental Qualification of Digital Protection Systems of Advanced Light-Water Nuclear Reactors," April 1994.

NUREG/CR-6095, "Aging, Loss-of-Coolant Accident (LOCA, and High Potential Testing of Damaged Cables)," April 1994.

NUREG/CR-6143-Volume 3, "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit 1: Analysis of Core Damage Frequency from Internal Fire Events for Plant Operational State 5 During a Refueling Outage, July 1994," 1994.

NUREG/CR-6144-Volume 3-Pt.2, "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry, Unit 1: Analysis of Core Damage Frequency from Internal Fires During Mid-Loop Operations," Volume 3, Part 2: Appendices, July 1994.

NUREG/CR-6213, "High Temperature Hydrogen+Air+Steam Detonation Experiments in the BNL Small Scale Development Apparatus," August 1994.

NUREG/CR-6220, "An Assessment of Fire Vulnerability for Aged Electrical Relays," March 1995.

NUREG/CR-6017, "Fire Modeling of the Heiss Dampf Reaktor Containment," September 1995.

NUREG/CR-6358-Vol. 2, "Assessment of United States Industry Structural Codes and Standards for Application to Advanced Nuclear Power Reactors," Appendices, Volume 2, October 1995.

NUREG/CP-0148, "Preliminary Studies on the Impact of Smoke on Digital Equipment," Transactions of the 23rd Water Reactor Safety Information Meeting, Bethesda, Maryland, October 1995.

NUREG/CR-6173, "A Summary of the Fire Testing Program at the German HDR Test Facility," November 1995.

NUREG/CR-6384, "Literature Review of Environmental Qualification of Safety Related Electric Cables," Volume 1, April 1996.

NUREG-1552, "Fire Barrier Penetration Seals in Nuclear Power Plants," July 1996.

NUREG-1547, "Methodology for Developing and Implementing Alternative Time-Temperature Curves for Testing the Fire Resistance of Barriers for Nuclear Power Plant Applications," August 1996.

NUREG/CR-5973, "Codes and Standards and Other Guidance Cited in Regulatory Documents," August 1996.

NUREG/CR-6406, "Environmental Testing of an Experimental Digital Safety Channel," September 1996.

NUREG/CR-6476, "Circuit Bridging of Components by Smoke," October 1996.

NUREG/CR-6530, "Deliberate Ignition of Hydrogen-Air-Steam Mixtures in Condensing Steam Environments," May 1997.

NUREG-1601, "Chemical Process Safety at Fuel Cycle Facilities," August 1997.

NUREG/CP-0153, "Potential for HEPA Filter Damage From Water Spray Systems in Filter Plenums," Proceedings of the 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference, August 1997, pp. 752–777.

NUREG-1611, "Aging Management of Nuclear Power Plant Containment for License Renewal, Office of Nuclear Reactor Regulation, September 1997.

NUREG/CP-0161, "A Recent Results of an Experimental Study on the Impact on Digital I&C Equipments," Transactions of the 25th Water Reactor Safety Information Meeting, Bethesda, Maryland, October 20-22, 1997.

NUREG/CR-6543, "Effects of Smoke on Functional Circuits," October 1997.

NUREG/CR-6479, "Technical Basis for Environmental Qualification of Microprocessor-Based Safety-related Equipment in Nuclear Power Plants," January 1998.

NUREG/CR-6410, "Nuclear Fuel Cycle Facility Accident Analysis Handbook," March 1998.

NUREG/CR-6544, "Methodology for Analyzing Precursors to Earthquake-Initiated and Fire-Initiated Accident Sequences," April 1998.

NUREG/CR-6509, "The Effect of Initial Temperature on Flame Acceleration and Deflagration-to-Detonation Transition Phenomenon," May 1998.

NUREG-1521, "Technical Review of Risk-Informed, Performance-Based Methods for Nuclear Power Plant Fire Protection Analyses," **Draft Report for Public Comments**, Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, July 1998.

NUREG/CR-6524, "The Effect of Lateral Venting on DDT in Hydrogen-Air-Steam Mixtures at Various Temperature," 1998.

NUREG-1552, Supplement 1, "Fire Barrier Penetration Seals in Nuclear Power Plants," January 1999.

NUREG-0933, "A Prioritization of Generic Safety Issues," April 1999.

BNL-NUREG-66831, "Fire Safety in Nuclear Power Plants: A Risk-Informed and Performance-Based Approach," November 1999.

NUREG/CP-0170, "International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications: Summary of Planning Meeting," Held at University of Maryland College Park, Maryland, October 25-26, 1999, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC, March 2000.

NUREG-1649, Revision 3, "Reactor Oversight Process," July 2000.

NUREG/CR-6681, "Ampacity Derating and Cable Functionality for Raceway Fire Barriers," August 2000.

NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, January 2001.

NUREG/CR-6597, "Results and Insights on the Impact of Smoke on Digital Instrumentation and Control," January 2001.

NUREG/CP-0173, "International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications: Summary of 2$^{nd}$ Meeting," Held at Institute for Protection and Nuclear Safety, Fontenay-aux-Roses, France, June 19–20, 2000, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC, March 2001.

NUREG-1800, "Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants," July 2001.

NUREG-1801, Volume 1, "Generic Aging Lessons Learned (GALL) Report—Summary," July 2001.

NUREG-1801, Volume 2, "Generic Aging Lessons Learned (GALL) Report—Tabulation of Results," July 2001.

NUREG/CR-6738, "Risk Methods Insights Gained From Fire Incidents," September 2001.

NUREG/CR-6752, "A Comparative Analysis of Special Requirements for Systems, Structures, and Components (SSCs) of Nuclear Power Plants With Commercial Requirements of Non-Nuclear Power Plants," January 2002.

NUREG/CR-6042, Rev. 2, "Perspective on Reactor Safety," March 2002.

NUREG-1753, "Risk-Based Performance Indicators: Results of Phase 1 Development," April 2002.

NEREG-1742, Volume 1, Final Report, "Perspectives Gained from Individual Plant Examination of External Events (IPEEE) Program," Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC, April 2002.

NEREG-1742, Volume 2, Final Reports Tables, "Perspectives Gained from Individual Plant Examination of External Events (IPEEE) Program," Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC, April 2002.

NUREG-1758, "Evaluation of Fire Models for Nuclear Power Plant Applications: Cable Tray Fires, International Panel," Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC, June 2002.

NUREG/CR-6776, "Cable Insulation Resistance Measurements Made During Cable Fire Tests," June 2002.

NUREG/CR-6788, "Evaluation of Aging and Qualification Practices for Cable Splices Used in Nuclear Power Plants," September 2002.

NUREG/CP-0179, "Proceedings of the International Conference on Wire System Aging, November 2002.

NUREG/CR-6797, "Guidance for Post-Fire Safe Shutdown Analysis Including Risk Insights," **Draft Report** for Public Comments, Office of Nuclear Reactor Regulation, December 16, 2002.

NUREG/CR-6799, Revision 1, "Analysis of Rail Car Components Exposed to a Tunnel Fire Environment," March 2003.

## D.10 Safety Evaluation Reports Related to License Renewal for Operating Nuclear Power Plants

NUREG-1705, "Safety Evaluation Report Related to the License Renewal of Calvert Cliffs Nuclear Power Plant, Units 1 and 2," December 1999.

NUREG-1723, "Safety Evaluation Report Related to the License Renewal of Oconee Nuclear Station, Units 1, 2, and 3," March 2000.

NUREG-1743, "Safety Evaluation Report Related to the License Renewal of Arkansas Nuclear One, Unit 1," May 2001.

NUREG-1803, "Safety Evaluation Report Related to the License Renewal of Edwin I. Hatch Nuclear Plant, Units 1 and 2," December 2001.

NUREG-1759, "Safety Evaluation Report Related to the License Renewal of Turkey Point Nuclear Plant, Units 3 and 4," April 2002.

NUREG-1766, "Safety Evaluation Report Related to the License Renewal of North Ann Power Station, Units 1 and 2, and Surry Power Station, Units 1 and 2," December 2002.

NUREG-1772, "Safety Evaluation Report Related to the License Renewal of McGuire Nuclear Station, Units 1 and 2, and Catawba Nuclear Station, Units 1 and 2, March 2003.

NUREG-1769, "Safety Evaluation Report Related to the License Renewal of Peach Bottom Atomic Power Station, Units 2 and 3," March 2003.

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## D.11 National Fire Protection Association (NFPA) Codes and Standards for Nuclear Facilities

(1) NFPA 801, "Standard for Fire Protection for Facilities Handling Radioactive Materials," 1998 Edition, National Fire Protection Association, Quincy, Massachusetts.

(2) NFPA 804, "Standard for Fire Protection for Advanced Light Water Reactor Electric Generating Plants," 2001 Edition, National Fire Protection Association, Quincy, Massachusetts.

(3) NFPA 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," 2001 Edition, National Fire Protection Association, Quincy, Massachusetts.

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# APPENDIX E. CURRENT NATIONAL FIRE PROTECTION ASSOCIATION (NFPA) CODES AND STANDARDS

NFPA develops, publishes, and disseminates timely consensus codes and standards intended to minimize the possibility and effects of fire and other risks. Virtually every building, process, service, design, and installation in society today is affected by NFPA documents. More than 300 NFPA codes and standards are used around the world. This series is referred to as the National Fire Codes (NFC).

NFPA codes and standards have great influence because they are widely used as a basis of legislation and regulation at all levels of government, from local to international. Several NFPA codes have received worldwide recognition, such as the *Life Safety Code*®, the *National Electrical Code*®, and the *National Fuel Gas Code*. Many codes are referenced by Federal Government agencies, such as the regulations of the U.S. Nuclear Regulatory Commission (NRC), General Services Administration (GSA), and U.S. Occupational Safety and Health Administration (OSHA). The documents are also used by insurance authorities for risk evaluation and premium rating and as references in designs and specifications. Table E-1 provides titles of all current NFPA codes, standards, and recommended practices. It is important to recognize that the NFPA codes and standards are constantly revised and updated on 3 to 5 year cycles. The code or standard in effect at the time of design or implementation is the code of record (COR) for that application.

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