NFPA®

806

Performance-Based Standard for Fire Protection for Advanced Nuclear Reactor Electric Generating Plants Change Process

2020

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NFPA® 806

Performance-Based Standard for

Fire Protection for Advanced Nuclear Reactor Electric Generating Plants Change Process

2020 Edition

This edition of NFPA 806, *Performance-Based Standard for Fire Protection for Advanced Nuclear Reactor Electric Generating Plants Change Process*, was prepared by the Technical Committee on Fire Protection for Nuclear Facilities. It was issued by the Standards Council on November 4, 2019, with an effective date of November 24, 2019, and supersedes all previous editions.

This edition of NFPA 806 was approved as an American National Standard on November 24, 2019.

Origin and Development of NFPA 806

The need for fire protection in nuclear power facilities has been demonstrated in a number of incidents, including the Browns Ferry Fire in 1975 and other more recent incidents in the United States and abroad. Probabilistic risk assessments of existing plants have shown that fire is one of the largest single contributors to the possibility of reactor damage. This document represents a comprehensive consensus of baseline fire protection requirements for all aspects of change process for advanced nuclear reactor electric generating plants, including their construction and all phases of operation, such as shutdown, degraded conditions, and decommissioning.

The first edition of NFPA 806 focused on risk-informed fire protection in advanced nuclear plants where any change process is being performed and was based on current industry best practices and source materials.

The 2015 edition was edited for consistency with NFPA 805, and references to NFPA 251, a withdrawn standard, were removed. Changes were made to include the definitions and requirements from NFPA *101* and NFPA 1144 on combustible, noncombustible, and limited-combustible materials.

The changes made to the 2020 edition are mainly to update extracted material to the current editions of the source documents. Additional language from NFPA *101* has also been incorporated to more clearly identify materials that should be considered limited-combustible.

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Committee Scope: This Committee shall have primary responsibility for documents on the safeguarding of life and property from fires in which radiation or other effects of nuclear energy might be a factor.

Contents

NFPA 806

Performance-Based Standard for

Fire Protection for Advanced Nuclear Reactor Electric Generating Plants Change Process

2020 Edition

NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

A reference in brackets [ ] following a section or paragraph indicates material that has been extracted from another NFPA document. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

Information on referenced and extracted publications can be found in Chapter 2 and Annex E.

Chapter 1 Administration

1.1* Scope. This standard provides minimum requirements for a risk-informed, performance-based change process for the fire protection program for advanced nuclear reactor electric generating plants during construction and all phases of plant operation, including shutdown, degraded conditions, and decommissioning. Fundamental fire protection elements for advanced nuclear reactor electric generating plants can be found in NFPA 804.

1.2 Purpose.

1.2.1 This standard covers those requirements essential to ensure that the consequences of fire will have minimal impact on the safety of the public and on-site personnel and on the physical integrity of plant components.

1.2.2 Protecting the safety of the public, the environment, and plant personnel from a plant fire and its potential effect on safe reactor operations is paramount to this standard.

1.3 Application. The requirements in this standard shall apply to all advanced nuclear reactor electric generating plants as deemed applicable by the authority having jurisdiction.

1.4 Units and Formulas. The inch-pound value for a measurement and the SI value given in parentheses shall each be acceptable for use as primary units for satisfying the requirements of this standard.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 259, *Standard Test Method for Potential Heat of Building Materials,* 2018 edition.

NFPA 804, *Standard for Fire Protection for Advanced Light Water Reactor Electric Generating Plants,* 2020 edition.

2.3 Other Publications.

2.3.1 ANS Publications. American Nuclear Society, 555 North Kensington Avenue, La Grange Park, IL 60526.

ANSI/ANS 58.23, *Fire PRA Methodology*, 2007.

Δ **2.3.2 ASTM Publications.** ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, 2016.

ASTM E136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C*, 2016.

ASTM E1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*, 2012.

ASTM E2652, *Standard Test Method for Behavior of Materials in a Tube Furnace with a Cone-Shaped Airflow Stabilizer, at 750°C*, 2016.

ASTM E2965, *Standard Test Method for Determination of Low Levels of Heat Release Rate for Materials and Products Using an Oxygen Consumption Calorimeter*, 2016.

2.3.3 NEI Publications. Nuclear Energy Institute, 1201 F St., NW, Suite 1100, Washington, DC 20004-1218.

NEI 00-01, *Guidance for Post-Fire Safe Shutdown Analysis.*

Δ **2.3.4 UL Publications.** Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials*, 2008, revised 2013.

2.3.5 US Government Publications. US Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401-0001.

Title 10, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation."

2.3.6 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

2.4 References for Extracts in Mandatory Sections.

NFPA *101*®, *Life Safety Code*®, 2018 edition.
NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials,* 2020 edition.
NFPA 804, *Standard for Fire Protection for Advanced Light Water Reactor Electric Generating Plants,* 2020 edition.
NFPA 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants,* 2020 edition.
NFPA 1141, *Standard for Fire Protection Infrastructure for Land Development in Wildland, Rural, and Suburban Areas,* 2017 edition.
NFPA 1144, *Standard for Reducing Structure Ignition Hazards from Wildland Fire,* 2018 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary,* 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction. An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

3.2.3 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

3.2.4* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.5 Shall. Indicates a mandatory requirement.

3.2.6 Should. Indicates a recommendation or that which is advised but not required.

3.2.7 Standard. An NFPA Standard, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and that is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions are not to be considered a part of the requirements of a standard and shall be located in an appendix, annex, footnote, informational note, or other means as permitted in the NFPA Manuals of Style. When used in a generic sense, such as in the phrase "standards development process" or "standards development activities," the term "standards" includes all NFPA Standards, including Codes, Standards, Recommended Practices, and Guides.

3.3 General Definitions.

3.3.1 Action.

3.3.1.1 *Compensatory Action.* Actions taken if an impairment to a required system, feature, or component prevents that system, feature, or component from performing its intended function. These actions are a temporary alternative means of providing reasonable assurance that the necessary function will be compensated for during the impairment, or an act to mitigate the consequence of a fire. Compensatory measures include but are not limited to actions such as firewatches, administrative controls, temporary systems, and features of components. [**805,** 2020]

3.3.1.2 *Recovery Action.* Activities to achieve the nuclear safety performance criteria that take place outside of the main control room or outside of the primary control station(s) for the equipment being operated, including the replacement or modification of components. [**805,** 2020]

3.3.2* Advanced Nuclear Reactor. Reactor plant design incorporating evolutionary improvements in design which have been developed during the lifetime of the currently operating reactor designs, such as improved fuel technology, passive safety systems, and standardized design.

3.3.3 As Low As Reasonably Achievable (ALARA). Making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part [10 CFR 20] as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest. [10 CFR 20]

3.3.4 Availability. The probability that the system, structure, or component of interest is functional at a given point in time. [**805,** 2020]

3.3.5 Combustible. A combustible material is any material that, in the form in which it is used and under the conditions anticipated, will ignite and burn or will add appreciable heat to an ambient fire. [**1144,** 2018]

3.3.5.1 *In Situ Combustible.* Combustible materials that are permanently located in a room or an area (e.g., cable insulation, lubricating oil in pumps). [**805,** 2020]

3.3.5.2 *Limited-Combustible (Material).* See Section 4.5.

3.3.6 Containment. Structures, systems, or components provided to prevent or mitigate the release of radioactive materials. [**805,** 2020]

3.3.7 Core Damage Frequency (CDF). The expected number of core damage events per unit of time.

3.3.8 Damage.

3.3.8.1 ***Free of Fire Damage.*** The structure, system, or component under consideration is capable of performing its intended function during and after the postulated fire, as needed. [**805,** 2020]

3.3.8.2 ***Fuel Damage.*** Exceeding the fuel design limits. [**805,** 2020]

3.3.9* Fire Area. An area that is physically separated from other areas by space, barriers, walls, or other means in order to contain fire within that area. [**805,** 2020]

3.3.10* Fire Barrier. A continuous membrane or a membrane with discontinuities created by protected openings with a specified fire protection rating, where such membrane is designed and constructed with a specified fire resistance rating to limit the spread of fire. (SAF-FIR) [***101,*** 2018]

3.3.11* Fire Compartment. A subdivision of a building or plant that is a well-defined enclosed room, not necessarily bounded by rated fire barriers. A fire compartment generally falls within a fire area and is bounded by noncombustible barriers where heat and products of combustion from a fire within the enclosure will be substantially confined.

3.3.12 Fire Hazard Analysis (FHA). An analysis to evaluate potential fire hazards and appropriate fire protection systems and features used to mitigate the effects of fire in any plant location. [**805,** 2020]

3.3.13 Fire Model. Mathematical prediction of fire growth, environmental conditions, and potential effects on structures, systems, or components based on the conservation equations or empirical data. [**805,** 2020]

3.3.14 Fire Prevention. Measures directed toward avoiding the inception of fire. [**801,** 2020]

3.3.15 Fire Protection Feature. Administrative controls, fire barriers, means of egress, industrial fire brigade personnel, and other features provided for fire protection purposes. [**805,** 2020]

3.3.16 Fire Protection Program. The integrated effort involving components, procedures, and personnel utilized in carrying out all activities of fire protection. It includes system and facility design and analyses, fire prevention, fire detection, annunciation, confinement, suppression, administrative controls, fire brigade organization, inspection and maintenance, training, quality assurance, and testing.

3.3.17 Fire Protection System. Any fire alarm device or system or fire-extinguishing device or system, or combination thereof, that is designed and installed for detecting, controlling, or extinguishing a fire or otherwise alerting occupants, or the fire department, or both, that a fire has occurred. [**1141,** 2017]

3.3.18 Fire Resistance Rating. The time, in minutes or hours, that materials or assemblies have withstood a standard fire exposure as established in accordance with an approved test procedure appropriate for the structure, building material, or component under consideration.

3.3.19 Fire Scenario. In nuclear facilities, a description of a fire and any factors affecting or affected by it from ignition to extinguishment, including, as appropriate, ignition sources, nature and configuration of the fuel, ventilation characteristics, locations of occupants, condition of the supporting structure, and conditions and status of operating equipment. [**805,** 2020]

3.3.19.1 ***Limiting Fire Scenarios.*** Fire scenario(s) in which one or more of the inputs to the fire modeling calculation (e.g., heat release rate, initiation location, or ventilation rate) are varied to the point that the performance criterion is not met. The intent of this scenario(s) is to determine that there is a reasonable margin between the expected fire scenario conditions and the point of failure. [**805,** 2020]

3.3.19.2 ***Maximum Expected Fire Scenarios.*** Scenarios that represent the most challenging fire that could be reasonably anticipated for the occupancy type and conditions in the space. These scenarios can be established based on electric power industry experience with consideration for plant-specific conditions and fire experience. [**805,** 2020]

3.3.20* Fire Zone. A subdivision of a fire area not necessarily bounded by fire-rated assemblies. Fire zone can also refer to the subdivision of a fire detection or suppression system, which provide alarm indications at the central alarm panel.

3.3.21 Flame Spread Index. A comparative measure, expressed as a dimensionless number, derived from visual measurements of the spread of flame vs. time for a material tested in accordance with ANSI/UL 723 or with ASTM E84. [**805,** 2020]

3.3.22 Industrial Fire Brigade. An organized group of employees within an industrial occupancy who are knowledgeable, trained, and skilled in at least basic fire-fighting operations, and whose full-time occupation might or might not be the provision of fire suppression and related activities for their employer.

3.3.23 Large Release. A plant radioactive release that (1) has the potential for early health effects or (2) can lead to a statistically significant (measurable) increase in latent health effects. What specifically constitutes a large release is defined by the plant license holder.

3.3.24 Noncombustible (Material). See Section 4.5.

3.3.25 Owner/Operator. The organization(s) with fiscal responsibility for the operation, maintenance, and profitability of the nuclear plant. [**805,** 2020]

3.3.26 Performance-Based Approach. An approach that relies upon measurable (or calculable) outcomes (i.e., performance results) to be met but provides more flexibility as to the means of meeting those outcomes. A performance-based approach is one that establishes performance and results as the primary basis for decision-making and incorporates the following attributes: (1) Measurable or calculable parameters exist to monitor the system, including facility performance; (2) objective criteria to assess performance are established based on risk insights, deterministic analyses, and/or performance history; (3) plant operators have the flexibility to determine how to meet established performance criteria in ways that will encourage and reward improved outcomes; and (4) a framework exists in which the failure to meet a performance criterion, while undesirable, will not in and of itself constitute or result in an immediate safety concern. [**805,** 2020]

3.3.27 Performance Criteria. Specific measurable or calculable parameters for systems and features that are quantified and described in engineering terms. [**805,** 2020]

3.3.28 Plant Change Evaluation. An evaluation performed in the event of a change to a previously approved fire protection program element or other plant changes that could impact the fire protection program.

3.3.29 Prior Distribution. Probability distribution quantifying the analyst's state of knowledge regarding the parameter to be estimated prior to collection of new data. [**805,** 2020]

3.3.30 Probabilistic Safety Assessment (PSA). A comprehensive evaluation of the risk of a facility or process; also referred to as a probabilistic risk assessment (PRA). [**805,** 2020]

3.3.31* Reliability. The probability that the system, structure, or component of interest will perform its specified function under given conditions upon demand or for a prescribed time.

3.3.32 Risk. The probability and consequences of an event, as expressed by the "risk triplet" that is the answer to the following three questions: (1) What can go wrong? (2) How likely is it? and (3) What are the consequences if it occurs?

3.3.33 Risk Informed. Consideration of risk insights together with other factors to establish performance requirements that better focus attention on design and operational issues commensurate with their importance to public health and safety.

3.3.34 Safe and Stable Conditions. For fuel in the reactor vessel, head on and tensioned, safe and stable conditions are defined as the ability to maintain $K_{eff} < 0.99$, with a reactor coolant temperature at or below the requirements for hot shutdown for a boiling water reactor and hot standby for a pressurized water reactor. For all other configurations, safe and stable conditions are defined as maintaining $K_{eff} < 0.99$ and fuel coolant temperature below boiling. [**805,** 2020]

3.3.35 Site. The contiguous property that makes up a nuclear power plant facility. This would include areas both inside the protected area and the owner-controlled property. [**805,** 2020]

3.3.36 Source Term Limitation. Limiting the source of radiation available for release. [**805,** 2020]

3.3.37* Spurious Operation. An unwanted change in state of equipment due to fire-induced faults (e.g., hot shorts, open circuits, or shorts to ground) on its power or control circuitry. [**804,** 2020]

3.3.38 Uncertainty.

3.3.38.1 ***Completeness Uncertainty.*** Uncertainty in the predictions of a model due to model scope limitations. This uncertainty reflects an unanalyzed contribution or reduction of risk due to limitations of the available analytical methods. [**805,** 2020]

3.3.38.2 ***Model Uncertainty.*** Uncertainty in the predictions of a model related to the equations in the model being correct, whether or not they are appropriate to the problem being solved, and whether or not they are sufficiently complete. [**805,** 2020]

3.3.38.3 ***Parameter Uncertainty.*** Uncertainty in the predictions of a model due to uncertainties in the numerical values of the model parameters. [**805,** 2020]

3.3.39 Uncertainty Analysis. An analysis intended to (1) identify key sources of uncertainties in the predictions of a model, (2) assess the potential impacts of these uncertainties on the predictions, and (3) assess the likelihood of these potential impacts. Per this definition, sensitivity analysis performs some but not all of the functions of uncertainty analysis. *(See also 3.3.38.1, Completeness Uncertainty; 3.3.38.2, Model Uncertainty; and 3.3.38.3, Parameter Uncertainty.)* [**805,** 2020]

Chapter 4 General Requirements

4.1 Fire Protection Defense-in-Depth.

4.1.1 Protecting the safety of the public, the environment, and plant personnel from a plant fire and its potential effect on safe reactor operations shall be paramount to this standard.

4.1.2 The fire protection standard shall be based on the concept of defense-in-depth.

4.1.3 Defense-in-depth shall be achieved when each of the following elements is provided:

(1) Preventing fires from starting
(2) Rapidly detecting, controlling, and extinguishing promptly those fires that do occur, thereby limiting fire damage
(3) Providing an adequate level of fire protection for structures, systems, and components important to safety, so that a fire that is not promptly extinguished will not prevent the goals for nuclear safety and radioactive release from being achieved

4.2 Goals.

4.2.1 Nuclear Safety Goal. The nuclear safety goal shall be to provide reasonable assurance that a fire during any operational mode and plant configuration will not prevent the plant from achieving and maintaining the reactor core in a safe and stable condition.

4.2.2 Radioactive Release Goal. The radioactive release goal shall be to provide reasonable assurance that a fire will not result in a radiological release that adversely affects the public, plant personnel, or the environment.

4.3 Performance Objectives.

4.3.1 Nuclear Safety Objectives. In the event of a fire during any operational mode and plant configuration, the plant nuclear safety objectives shall be as follows:

(1) Reactivity control — capable of achieving and maintaining subcritical conditions
(2) Fuel cooling — capable of achieving and maintaining decay heat removal
(3) Fission product boundary — capable of maintaining fundamental fuel geometry
(4) Heat transfer medium inventory control — capable of maintaining the necessary quantity of heat transfer medium

4.3.2 Radioactive Release Objective. The source term from sources not including fuel in the core shall be capable of being limited.

4.4 Performance Criteria.

4.4.1 Nuclear Safety Performance Criteria.

4.4.1.1 Fire protection features shall be capable of providing reasonable assurance that in the event of a fire the plant is not placed in an unrecoverable condition.

Δ **4.4.1.2** To demonstrate that assurance, the following performance criteria shall be met:

(1) Reactivity control.

(a) Reactivity control shall be capable of inserting negative reactivity to achieve and maintain sub-critical conditions.

(b) Negative reactivity inserting shall occur rapidly enough such that fuel design limits are not exceeded.

(2) Fission product boundary. The fundamental geometric relationship between the fuel and the moderator shall be maintained such that reactivity control and decay heat removal can be accomplished.

(3) Heat transfer medium inventory control. The heat transfer medium utilized by the reactor shall be maintained in sufficient quantity to ensure that decay heat removal can be accomplished.

(4) Decay heat removal. Decay heat removal shall be capable of removing sufficient heat from the reactor core and spent fuel such that they are maintained in a safe and stable condition.

(5) Vital auxiliaries. Vital auxiliaries shall be capable of providing the necessary auxiliary support equipment and systems to ensure that the systems required under 4.4.1.2(1) through 4.4.1.2(4) and 4.4.1.2(6) are capable of performing their required nuclear safety function.

(6)* Process monitoring. Process monitoring shall be capable of providing the necessary indication to ensure that the criteria addressed in 4.4.1.2(1) through 4.4.1.2(5) have been achieved and are being maintained.

4.4.2 Radioactive Release Performance Criteria. Radiation release to any unrestricted area (but not involving fuel damage to fuel in the core during operation) shall be as low as reasonably achievable and shall not exceed applicable regulatory limits.

4.5 Materials.

4.5.1* Noncombustible Material. [***101***:4.6.13]

Δ **4.5.1.1** A material that complies with any of the following shall be considered a noncombustible material:

(1)* A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat

(2) A material that is reported as passing ASTM E136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C*

(3) A material that is reported as complying with the pass/fail criteria of ASTM E136 when tested in accordance with the test method and procedure in ASTM E2652, *Standard Test Method for Behavior of Materials in a Tube Furnace with a Cone-shaped Airflow Stabilizer, at 750°C*

[***101***:4.6.13.1]

4.5.1.2 Where the term *limited-combustible* is used in this document, it shall also include the term *noncombustible.* [***101***:4.6.13.2]

Δ **4.5.2* Limited-Combustible Material.** A material shall be considered a limited-combustible material where one of the following is met:

(1) The conditions of 4.5.2.1 and 4.5.2.2, and the conditions of either 4.5.2.3 or 4.5.2.4, shall be met.

(2) The conditions of 4.5.2.5 shall be met.

[***101***:4.6.14]

4.5.2.1 The material shall not comply with the requirements for noncombustible material in accordance with 4.5.1. [***101***:4.6.14.1]

4.5.2.2 The material, in the form in which it is used, shall exhibit a potential heat value not exceeding 3500 Btu/lb (8141 kJ/kg) where tested in accordance with NFPA 259. [***101***:4.6.14.2]

4.5.2.3 The material shall have the structural base of a noncombustible material with a surfacing not exceeding a thickness of ⅛ in. (3.2 mm) where the surfacing exhibits a flame spread index not greater than 50 when tested in accordance with ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, or ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials.* [***101***:4.6.14.3]

4.5.2.4 The material shall be composed of materials that, in the form and thickness used, neither exhibit a flame spread index greater than 25 nor evidence of continued progressive combustion when tested in accordance with ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, or ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials*, and shall be of such composition that all surfaces that would be exposed by cutting through the material on any plane would neither exhibit a flame spread index greater than 25 nor exhibit evidence of continued progressive combustion when tested in accordance with ASTM E84 or ANSI/UL 723. [***101***:4.6.14.4]

N **4.5.2.5** Materials shall be considered limited-combustible materials where tested in accordance with ASTM E2965, *Standard Test Method for Determination of Low Levels of Heat Release Rate for Materials and Products Using an Oxygen Consumption Calorimeter*, at an incident heat flux of 75 kW/m^2 for a 20-minute exposure and both of the following conditions are met:

(1) The peak heat release rate shall not exceed 150 kW/m^2 for longer than 10 seconds.

(2) The total heat released shall not exceed 8 MJ/m^2. [***101***:4.6.14.5]

4.5.2.6 Where the term *limited-combustible* is used in this document, it shall also include the term *noncombustible.* [***101***:4.6.14.6]

Chapter 5 Methodology

5.1 Intent.

5.1.1 This chapter shall describe the general approach for self-approval of plant changes, including programmatic changes, that potentially impact the approved or accepted plant fire protection program for advanced reactor designs.

5.1.2 The chapter shall provide the requirements for the engineering analyses used to evaluate the potential impact of plant changes, in particular the analyses used for a risk-informed, performance-based approach to ensuring that the fire protection program will continue to fulfill the goals, objectives, and criteria provided in Chapter 4.

5.2* General Approach. The general approach of this standard shall involve the following steps *(see Figure 5.2)*:

(1) Identify and fully describe the proposed plant change.
(2) Identify the plant features and the approved fire protection program features that will potentially be impacted by the proposed change.
(3) Identify the performance criteria that apply to each of the plant features and fire protection program features potentially impacted by the change as specified in Chapter 4.
(4) Determine whether the existing approved program will be met or modified or a risk-informed performance-based (RI/PB) change evaluation process will be applied to evaluate the change.

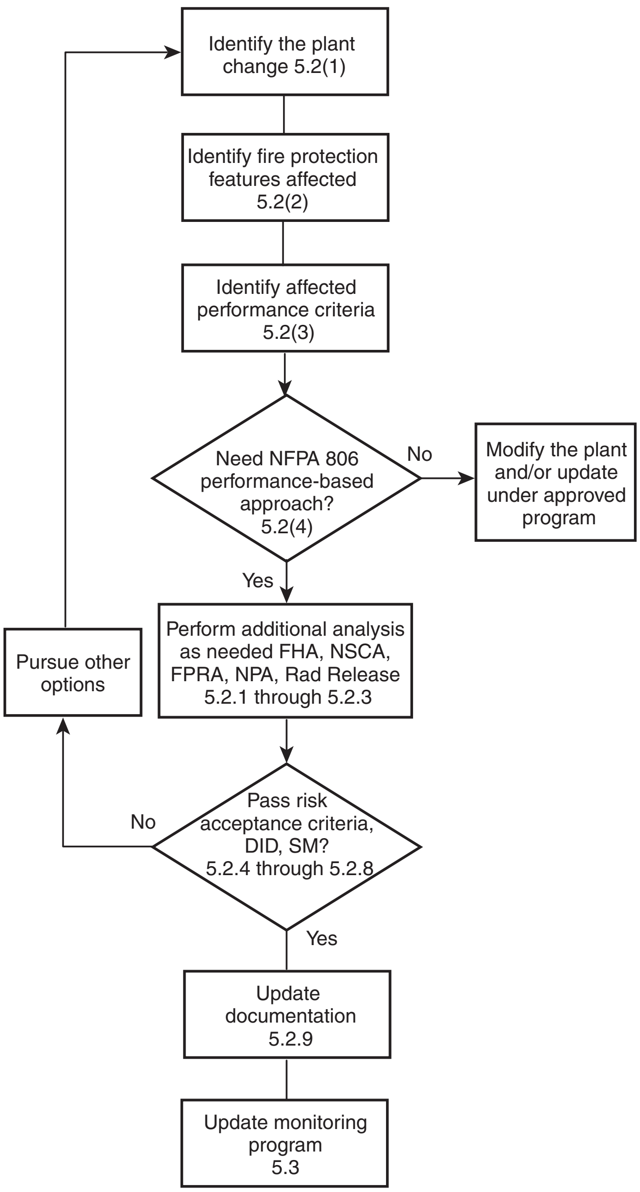

FIGURE 5.2 Methodology.

5.2.1* When a risk-informed, performance-based approach is being applied, engineering analyses, including the change evaluation, shall be performed to demonstrate that performance-based requirements would be satisfied during and after the proposed change is implemented.

5.2.1.1 Evaluating Performance Criteria. To determine whether the proposed plant change will impact the ability to satisfy the performance criteria, an analysis shall be performed on a fire area basis, considering the potential fire exposures and damage thresholds.

5.2.1.2 Nuclear Safety Capability Assessment.

5.2.1.2.1 A nuclear safety capability assessment shall be performed to confirm that the proposed plant change will not have an unacceptable impact on the capability of the plant to meet the nuclear safety performance criteria.

5.2.1.2.2 A nuclear safety capability assessment shall be performed in accordance with NEI 00-01, *Guidance for Post-Fire Safe Shutdown Analysis.*

5.2.1.3* Fire Hazard Analysis. A fire hazard analysis shall be performed to assess the impact on all the affected fire protection features.

5.2.2 Radiation Release.

5.2.2.1 To fulfill the criteria for radiation release described in Chapter 4, the source of radiation shall be limited, or the ability to contain any release shall be established so that the consequences of any release of radioactivity are acceptable.

5.2.2.2 Designs that balance source term limitation and containment shall also be acceptable.

5.2.3* Fire Modeling.

5.2.3.1 Fire modeling calculations shall be a required component of a risk-informed, performance-based analysis, because they provide important input to the analysis, including support for the risk assessment.

5.2.3.2 Fire modeling shall be used to examine the potential fire risk associated with a proposed plant changes.

5.2.3.3* Acceptable Models. Only fire models that are acceptable to the authority having jurisdiction shall be used in fire modeling calculations.

5.2.3.4 Limitations of Use. A fire model shall be applied only within the limitations of that fire model.

5.2.3.5 Validation of Models. The fire models shall be verified and validated according to ASTM E1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models.*

5.2.3.6 Fire Modeling Calculations. Fire modeling used to support the plant change evaluation for the fire protection program shall be in accordance with 5.2.3.6.1 through 5.2.3.6.6.2.

5.2.3.6.1 Identify Targets. The equipment and required circuits within the physical confines of the fire area or compartment under consideration needed to achieve the nuclear safety performance criteria shall be determined and the physical plant locations identified in accordance with the provisions of this chapter.

5.2.3.6.2* Establish Damage Thresholds. Within the fire area or compartment under consideration, the damage thresholds shall be established in accordance with Section 5.3 for the equipment and cables needed to achieve the nuclear safety performance criteria.

5.2.3.6.3* Determine Limiting Condition(s). The limiting conditions shall be the combination of equipment or required cables with the highest susceptibility to any fire environment.

5.2.3.6.4 Establish Fire Scenarios.

5.2.3.6.4.1 Fire scenarios shall establish the fire conditions for the fire area or compartment under consideration.

5.2.3.6.4.2 The fire scenario(s) for the fire area under consideration shall be established in accordance with the following:

(1) When fire modeling is used, a set of fire scenarios shall be defined for each plant area or compartment being modeled.
(2) For plant areas or compartments that have fire modeling calculations included in the approved fire protection program, the plant change evaluation shall be permitted to look only at fire scenarios that would potentially change as a result of the proposed plant change.
(3) The fire scenarios shall establish the conditions under which a proposed plant change could potentially impact the capability to continue to meet the performance criteria.
(4) The set of fire scenarios for each plant area or compartment modeled shall include the following:
    (a) Maximum expected fire scenarios
    (b) Limiting fire scenario(s)

5.2.3.6.5 Defining the Fire Scenario. A fire scenario shall consider all operational conditions of the plant, including 100 percent power, cold shutdown, refueling modes of operation, and the following characteristics as necessary to meet the required performance criteria:

(1)* *Combustible materials.* The type, quantity, location, concentration, and combustion characteristics of in situ and expected transient combustible materials shall be considered in defining the area fire scenarios.
(2) *Ignition sources.* The potential in situ and transient ignition sources shall be considered for the plant area. For fire modeling purposes, the combustibles shall be assumed to have become ignited by an ignition source.
(3)* *Plant area configuration.* The area, zone, or room configuration shall consider the plant construction surrounding the area, area geometry, geometry between combustibles, ignition sources, targets, and surrounding barriers.
(4)* *Fire protection systems and features.* Those fire protection systems and features in the area that could mitigate the effects of the fire shall be evaluated.
(5)* *Ventilation effects.* Natural ventilation or forced ventilation effects shall be evaluated.

5.2.3.6.6 Evaluation of Fire Modeling Results.

5.2.3.6.6.1 Results of the fire modeling shall be evaluated against the performance criteria.

5.2.3.6.6.2 The results of the fire modeling shall be evaluated in conjunction with the risk assessment.

5.2.4* Plant Change Evaluation. A risk-informed plant change evaluation shall be performed, and the results used to ensure that the public risk associated with fire-induced nuclear fuel damage accidents is low, consistent with the concept of defense-in-depth, and that safety margins are maintained.

5.2.4.1* The effectiveness of the fire protection features shall be evaluated in relation to their ability to detect, control, suppress, and extinguish a fire and provide passive protection to achieve the performance criteria and not exceed the damage threshold defined in 5.2.8 for the plant area being analyzed.

5.2.4.2* Fire Risk Evaluations. Use of fire risk evaluation shall consist of an integrated assessment of the acceptability of risk, defense-in-depth, and safety margins.

5.2.4.2.1 Fire risk evaluation shall satisfy the applicable requirements and capability category of ANSI/ANS 58.23, *Fire PRA Methodology*, for the specific application.

5.2.4.2.2 The probabilistic safety assessment (PSA) methods, tools, and data used to provide risk information to the change analysis shall conform to the following:

(1)* The PSA shall use core damage frequency (CDF) and large release frequency (LRF) as measures for risk.
(2)* The PSA shall address the risk contribution associated with all potentially risk-significant fire scenarios.
(3) The PSA methods and data shall be appropriate for the nature and scope of the design or change being evaluated and acceptable to the AHJ.

5.2.5* Risk Acceptance Criteria.

5.2.5.1 The change in public health risk from any plant change shall be acceptable to the AHJ.

5.2.5.2 The change in CDF and LRF as a result of the plant change shall be used to determine the acceptability of the plant change.

5.2.5.3 If more than one change is proposed, additional requirements shall apply.

5.2.5.4 The cumulative effect of the previous changes shall be evaluated.

5.2.5.5 If more than one plant change is combined into a group for the purposes of evaluating acceptable risk, the evaluation of each individual change shall be performed along with the evaluation of combined changes.

5.2.5.6 If previous changes have increased risk but have met the acceptance criteria, the cumulative effect of those changes shall be evaluated.

5.2.5.7 The PSA shall be based on the as-built and as-operated and maintained plant and reflect the operating experience at the plant.

5.2.5.8 When recovery actions are used to ensure nuclear safety performance criteria, the additional risk presented by their use shall be evaluated, including feasibility and reliability.

5.2.6* Defense-in-Depth. The plant change evaluation shall ensure that the philosophy of defense-in-depth is maintained, relative to fire protection *(see Section 4.1)* and nuclear safety.

5.2.7* Safety Margins. The plant change evaluation shall ensure that safety margins are maintained.

5.2.8 Evaluating the Damage Threshold.

5.2.8.1 When fire modeling is used or when analysis is performed in support of the performance-based approach, damage thresholds for safe and stable conditions (SSC), including circuits, required to meet the performance criteria and limiting conditions for plant personnel shall be defined.

5.2.8.2 The damage threshold(s) shall consider the following:

(1) *Thermal impacts:* The critical temperature and critical heat flux used for the evaluation of the potential for thermal damage of structures, systems, and components
(2) *Smoke impacts:* The susceptibility of structures, systems, and components to smoke damage
(3) *Fire suppressants impacts:* The susceptibility of structures, systems, components, and operations response to suppressant damage (due to discharge or rupture)

5.2.8.3* Where the proposed change does not meet the accepted criteria, other options shall be determined and evaluated in accordance with Section 5.2.

5.2.9* For the completed evaluation, documentation shall be provided to ensure the quality of the analyses and that the change is implemented in accordance with the evaluation.

5.3* Monitoring.

5.3.1 Plant changes shall have a monitoring program to ensure that assumptions and inputs used in the plant change evaluations shall be monitored to ensure that the availability and reliability of the fire protection systems and features are maintained and to assess the performance of the fire protection program in meeting the performance criteria.

5.3.2 Availability, Reliability, and Performance Levels. Levels of availability, reliability, and performance shall be established.

5.3.3 Monitoring Availability, Reliability, and Performance.

5.3.3.1 Methods to monitor availability, reliability, and performance shall be established.

5.3.3.2 The methods shall consider the plant operating experience and industry operating experience.

5.3.4 Corrective Action.

5.3.4.1* If the established levels of availability, reliability, or performance are not met, corrective actions to return to the established levels shall be implemented.

5.3.4.2 Monitoring shall be continued to ensure that the corrective actions are effective.

5.4 Program Documentation, Configuration Control, and Quality.

5.4.1 Content.

5.4.1.1 General.

5.4.1.1.1 The analyses performed to demonstrate compliance with this standard shall be documented for each nuclear power plant (NPP).

5.4.1.1.2 The intent of the documentation shall be that the assumptions be clearly defined and the results be easily understood, that results be clearly and consistently described, and that sufficient detail be provided to allow future review of the entire analyses.

5.4.1.1.3 Documentation shall be maintained for the life of the plant and be organized so that it can be checked for adequacy and accuracy either by an independent reviewer or by the AHJ.

5.4.1.2* Fire Protection Program Design Basis Document.

5.4.1.2.1 A fire protection program design basis document shall be established that defines the fire protection design basis for the plant.

5.4.1.2.2 As a minimum, the fire protection design basis document shall include fire hazards identification and nuclear safety capability assessment (NSCA), on a fire area basis, for all fire areas that could affect the nuclear safety or radioactive release performance criteria defined in Chapter 4.

5.4.1.3* Supporting Documentation. If not included in the principal document, detailed information used to develop and support the design basis document shall be referenced as separate documents.

5.4.2 Configuration Control.

5.4.2.1 Design Basis Document.

5.4.2.1.1 The design basis document shall be maintained up-to-date as a controlled document.

5.4.2.1.2 Changes affecting the design, operation, or maintenance of the plant shall be reviewed to determine if these changes impact the fire protection program documentation.

5.4.2.2 Supporting Documentation.

5.4.2.2.1 Detailed supporting information shall be retrievable records for the duration of plant operation.

5.4.2.2.2 Records shall be revised as needed to maintain the design basis document up-to-date.

5.4.3* Quality.

5.4.3.1 Review.

5.4.3.1.1 Each analysis, calculation, or evaluation performed shall be independently reviewed.

5.4.3.1.2 The fire PSA shall be subjected to a baseline peer review.

5.4.3.2* Verification and Validation. Each calculation model or numerical method used shall be verified and validated through comparison with test results or comparison with other acceptable models.

5.4.3.3 Limitations of Use.

5.4.3.3.1 Acceptable engineering methods and numerical models shall be used only for applications to the extent these methods have been subject to verification and validation.

5.4.3.3.2 These engineering methods shall be applied only within the scope, limitations, and assumptions prescribed for that method.

5.4.3.4* Qualification of Users. Cognizant personnel who use and apply engineering analyses and numerical models shall be competent in that field and experienced in the application of these methods as they relate to nuclear power plants, nuclear power plant fire protection, and power plant operations.

5.4.3.5* Uncertainty Analysis. An uncertainty analysis shall be performed to provide reasonable assurance that the performance criteria have been met.

Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1 This standard covers advanced light water reactors, advanced heavy water reactors, advanced gas-cooled reactors, advanced liquid metal reactors, or any and all types of advanced reactors. Advanced nuclear reactor designs include water-cooled reactors [light water and heavy water reactors (LWR/HWRs)], fast reactors [liquid metal fast reactors (LMFRs)], and gas-cooled reactors [graphite moderated high temperature gas-cooled reactors (HTGRs)]. Excluded are existing light water reactors. The fundamental elements of a fire protection program, including administrative controls, fire protection features, and so forth, can be found in NFPA 804.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction. The phrase “authority having jurisdiction,” or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.2.4 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.2 Advanced Nuclear Reactor. The two types of reactors are as follows:

(1) Evolutionary plants, which are improved versions of conventional designs employing active safety systems.
(2) Revolutionary plants, which are the result of completely rethinking the design philosophy of conventional plants. Revolutionary plants currently being proposed replace mechanical safe shutdown systems with passive features that rely on physical properties such as natural circulation, gravity flow, and heat sink capabilities.

With respect to advanced nuclear reactor passive safety features, their function will be independent of power supplies (at least following an initiation of their function) by using thermal hydraulic phenomena such as density differences due to different temperatures. Passive safety features are based on natural forces, such as convection and gravity, making safety functions independent of active systems and of components such as pumps and valves. Advanced nuclear reactor designs include LWR/HWRs, LMFRs, and HTGRs.

A.3.3.9 Fire Area. The definition provided in the body of the standard represents the preferred NFPA definition. For the purposes of this standard, the following definition is more specific as to how this term is used:

“That portion of a building or plant sufficiently bounded to withstand the fire hazards associated with the area and, as necessary, to protect important equipment within the area from a fire outside the area.”

A.3.3.10 Fire Barrier. The definition provided in the body of the standard represents the preferred NFPA definition. For the purposes of this standard, the following definition is more specific as to how this term is used:

“A continuous membrane, either vertical or horizontal, such as a wall or floor assembly, that is designed and constructed with a specified fire resistance rating to limit the spread of fire and that will also restrict the movement of smoke. Such barriers could have protected openings.”

A.3.3.11 Fire Compartment. Boundaries of a fire compartment can have open equipment hatches, stairways, doorways, or unsealed penetrations. This is a term defined specifically for fire risk analysis and maps plant fire areas and/or zones, defined by the plant and based on fire protection systems design and/or operations considerations, into compartments defined by fire damage potential. For example, the control room or certain areas within the turbine building can be defined as a fire compartment. It is noted that the term *fire compartment* is used in other contexts, such as general fire protection engineering and that the term’s meaning as used here might differ from that implied in another context. However, the term also has a long history of use in fire probabilistic risk assessment (PRA) and is used in this standard based on that history of common fire PRA practice.

A.3.3.20 Fire Zone. Both uses of the term are acceptable (and, in fact, can often be the same) but need to be clarified when used in the fire protection program or fire hazards analysis.

A.3.3.31 Reliability. See ASME RA-Sb-2007, *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications*, for more information.

A.3.3.37 Spurious Operation. These operations include but are not limited to the following:

(1) Opening or closing normally closed or open valves
(2) Starting or stopping of pumps or motors
(3) Actuation of logic circuits

(4) Inaccurate instrument reading
(5) Mechanical effects

A.4.4.1.2(6) Indication can be obtained by various means such as sampling/analysis, provided the required information can be obtained within the time frame needed.

Δ **A.4.5.1** The provisions of 4.5.1 do not require inherently noncombustible materials to be tested in order to be classified as noncombustible materials. [***101***:A.4.6.13]

A.4.5.1.1(1) Examples of such materials include steel, concrete, masonry, and glass. [***101***:A.4.6.13.1(1)]

A.4.5.2 Materials subject to increase in combustibility or flame spread index beyond the limits herein established through the effects of age, moisture, or other atmospheric condition are considered combustible. (*See NFPA 259 and NFPA 220.*) [***101***:A.4.6.14]

A.5.2 For item (1) in the list, document the specific details of the proposed plant change, including references to documents that will be revised for the change. Include all aspects of the change that could potentially impact the fire protection program.

For item (2) in the list, identify and document plant features, including fire protection program features, that potentially will be affected by the proposed change in a manner that could impact the plant's ability to meet the performance criteria. This can include, as applicable, administrative requirements; structures, systems, and components important to safety; fire detection and suppression systems; fire barriers; and fire hazards analyses (including post-fire safe-shutdown circuit analyses, fire models, etc.).

A.5.2.1 The features assessed are those approved in the fire protection program, including the fire prevention program, manual fire fighting, radiological release, non-power operations, and design of fire suppression and detection systems.

A.5.2.1.3 These analyses can include, for example, engineering evaluations, probabilistic safety assessments, or fire modeling calculations.

A.5.2.3 The fire modeling process can be used to examine the impact of the different fire scenarios against the performance criteria under consideration. Fire modeling alone should not be used to demonstrate that performance criteria have been met.

A.5.2.3.3 Refer to NUREG-1824/EPRI 1011999, *Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications*, for identification of acceptable models.

A.5.2.3.6.2 Damage thresholds should be determined for each criterion being evaluated. Damage thresholds should be categorized in terms of thermal, smoke, fire suppressant, and tenability issues. Thermal damage can result from exceeding the critical temperature or critical exposed heat flux for a given structure, system, or component. Thermal damage can result in circuit failures (e.g., open circuits, hot shorts, shorts to ground), mechanical failures, maloperation, and spurious operation of affected structures, systems, and components. Smoke damage (i.e., from particles and gases) can result in corrosion, circuit failures, mechanical failures, maloperation, and spurious operation. Fire suppressant damage from agents such as water, gaseous agents (e.g., CO_2, halon), dry chemical, dry powder, and foam discharged from automatic or manual fire suppression systems can result in circuit failures, corrosion, mechanical failures, inadvertent criticality, and spurious operation of components.

The products of combustion (smoke, heat, toxic gases, etc.) can adversely impact the personnel responsible for performing actions necessary for nuclear safety. Personnel actions that can be adversely impacted as a result of a fire include but are not limited to manual fire suppression by on-site and off-site personnel, operation and/or repair of systems and equipment, monitoring of vital process variables, performance of radiological surveys, and communications between plant personnel. Personnel actions that are adversely impacted due to a fire can result in a failure or delay in performing the correct action or the performance of an incorrect action.

Visibility can be impaired due to smoke obscuration in fire-affected areas and in non-fire-affected areas where there is the potential for smoke propagation from a fire-affected area. Visual obscuration and light obscuration/diffusion by smoke can adversely affect manual fire suppression activities by impairing the ability of plant personnel to access and identify the location of the fire. Visual obscuration or light obscuration/diffusion by smoke in the fire-affected area can impair personnel actions where operation, repair, or monitoring of plant systems or equipment is needed. Smoke propagation to non-fire-affected areas can impair personnel actions and impair access and egress paths to plant areas where those actions are performed.

Elevated ambient temperatures, radiant energy, oxygen depletion, and the toxic products of combustion (CO, HCl, etc.) can prohibit the entry of personnel into an area or require personnel to utilize special protective equipment (e.g., self-contained breathing apparatus, heat-resistant clothing) to perform actions in an area. The use of such special equipment can impair performance of the necessary actions.

Limited information is available regarding the impact of smoke on plant equipment. However, there are certain aspects of smoke impact that should be considered. Configurations should include chemical make-up of smoke, concentrations of smoke, humidity, equipment susceptibility to smoke, and so forth.

Another consideration is long-term versus short-term effects. For the purpose of this standard, consideration should focus on short-term effects. The general understanding on the issue of smoke damage includes the following:

(1) Smoke, depending on what is in it [e.g., HCl from burning polyvinyl chloride (PVC)], can cause corrosion after some time.
(2) Smoke can damage electronic equipment, especially computer boards and power supplies, on a short-term basis. Fans cooling the electronic equipment can introduce smoke into the housing, increasing the extent of the damage.
(3) Smoke can also impair the operation of relays in the relay cabinet by depositing products of combustion on the contact points. The forced cooling of the relay panel can exacerbate the situation.

A.5.2.3.6.3 An example of a limiting condition is the minimum damage threshold.

A.5.2.3.6.5(1) Examples of combustion characteristics are ignition temperature, flash point, growth rate, heat release rate, and radiant heat flux.

A.5.2.3.6.5(3) Examples of area geometry are volume, ceiling height, floor area, and openings.

A.5.2.3.6.5(4) Examples of fire protection systems and features are fire protection suppression and detection systems.

A.5.2.3.6.5(5) Examples of ventilation effects are forced air, ventilation openings from doors and windows, and ventilation-controlled fire versus fuel-controlled fire.

A.5.2.4 See A.5.2.7 regarding safety margin sufficiency.

A.5.2.4.1 A plant change evaluation can address one plant change or many plant changes. This process allows multiple changes to be considered together as a group. Further, it recognizes that some previous plant changes, for example, those that increase risk, can require consideration of their cumulative or total impact. These additional requirements are necessary to ensure that the process as a whole is consistent with the intent of evaluations of individual plant changes so that the process cannot be bypassed or inadvertently misapplied solely by sequencing unrelated plant changes in a different manner. Changes should be evaluated as a group if they affect the risk associated with the same fire scenario. See Annex D for acceptable methods used to perform the fire risk evaluation.

A.5.2.4.2 The quality of the PSA needs to be good enough to confidently determine that the proposed change is acceptable. Annex D describes fire PSA methods, tools, and data that are adequate for the evaluation of the fire risk impact for many changes. Note further that some change evaluations can require analyses that go beyond this guidance. The evaluation can require an explicit assessment of the risk from non-fire-induced initiating events.

A.5.2.4.2.2(1) For certain plant operating modes, CDF and LRF can be replaced with surrogate measures. For example, in shutdown modes, fuel outside the core (in the spent fuel pool) can be damaged and therefore must be evaluated.

A.5.2.4.2.2(2) Conservative assessments could be sufficient to show that the risk contribution is small.

A.5.2.5 An example approach for acceptance criteria for changes in risk from a plant change can be found in Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis." This process ensures that only small increases in risk are allowed. More important, the process encourages that plant changes result in either no change in risk or a reduction in risk.

A.5.2.6 Defense-in-depth is defined as the principle aimed at providing a high degree of fire protection and nuclear safety. It is recognized that, independently, no one means is complete. Strengthening any means of protection can compensate for weaknesses, known or unknown, in the other items. The fire protection program that achieves a high degree of defense-in-depth should also follow guidelines to ensure the robustness of all programmatic elements. The following list provides an example of guidelines that would ensure a robust fire protection program. Other equivalent acceptance guidelines can also be used.

(1) Programmatic activities are not overly relied on to compensate for weaknesses in plant design.
(2) System redundancy, independence, and diversity are preserved commensurate with the expected frequency and consequences of challenges to the system and uncertainties (e.g., no risk outliers).
(3) Defenses against potential common cause failures are preserved, and the potential for introduction of new common cause failure mechanisms is assessed.
(4) Independence of barriers is not degraded.
(5) Defenses against human errors are preserved.
(6) The intent of the general design criteria in 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, is maintained.

A fire protection program has certain elements that are required regardless of the unique hazards that can be present and the fire protection goals, objectives, and criteria that must be met. For example, each facility must have a water supply and an industrial fire brigade. Other requirements depend on the particular conditions at the facility and also on the conditions associated with the individual locations within the facility. An engineering analysis is performed to identify the important conditions at the facility as they apply to each location in the facility. The fire hazards analysis identifies the hazards present and the fire protection criteria that apply. Based on the engineering analysis, additional requirements can apply. For example, if a critical nuclear safety component is present in the area, additional fire protection features can be required.

A.5.2.7 The plant change evaluation needs to ensure that sufficient safety margins are maintained. An example of maintaining sufficient safety margins is the existing calculated margin between the analysis and the performance criteria compensating for the uncertainties associated with the analysis and the data. Another way that safety margins are maintained is through the application of codes and standards. Consensus codes and standards are typically designed to ensure that such margins exist. The following items are example guidelines for ensuring that safety margins remain satisfied when fire modeling and PSA are used:

(1) In the case of fire modeling, Annex C provides a method for assessing safety margins in terms of margin between fire modeling calculations and performance criteria.
(2) In the case of fire PSA, Annex D refers to material in Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," that provides for adequate treatment of uncertainty when calculated risk estimates are evaluated against acceptance criteria.

Meeting the monitoring requirements of this standard ensures that, following completion of the PSA, the plant will continue to meet the consensus level of quality for the acceptance criteria upon which the PSA is based. If other engineering methods are used, a method for ensuring safety margins would have to be proposed and accepted by the AHJ.

A.5.2.8.3 A risk-informed, performance-based engineering analysis is an acceptable means of evaluating a plant change that could impact the capability of the fire protection program to meet the performance criteria.

A.5.2.9 The fire protection program documentation shall be revised, as appropriate, to reflect the approved plant change and in accordance with the plant's design configuration control program.

A.5.3 The maintenance rule is an example of an existing availability and reliability program. A program requiring periodic self-assessments is an example of a method for monitoring overall effectiveness or performance of the fire protection program. Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," provides further guidance on acceptable monitoring programs. Assumptions that are not subject to change do not need to be monitored. The level of monitoring of assumptions should be commensurate with their risk significance.

A.5.3.4.1 Corrective actions should be implemented in a timely manner, and appropriate compensatory actions should be established and maintained until the corrective action has been completed. Compensatory actions might be necessary to mitigate the consequences of fire protection or equipment credited for safe shutdown that is not available to perform its function. Compensatory actions should be appropriate with the level of risk created by the unavailable equipment. The use of compensatory actions needs to be incorporated into a procedure to ensure consistent application. In addition, plant procedures should ensure that compensatory actions are not a substitute for prompt restoration of the impaired system.

A.5.4.1.2 A plant's existing fire hazards analysis (FHA), NSCA, and other fire protection design basis documents can be expanded as needed. The intent of this list is not to require a rigid report format but to provide some standardization in the report format to facilitate review between stations, such as by the AHJ. Flexibility to deviate from the specific sections suggested is allowed. The design basis document should include or reference the following plant fire protection design basis information:

(1) *Plant construction:* The physical construction and layout of the buildings and equipment, including a list of fire areas and fire zones and the fire ratings of boundaries and barrier components.
(2) *Identification of hazards:* An inventory of combustible materials, flammable and reactive liquids, flammable gases, and potential ignition sources.
(3) *Fire protection systems and equipment:* A description of the fire protection features provided.
(4) *Nuclear safety equipment:* Description and location of any equipment necessary to achieve nuclear safety functions, including cabling between equipment.
(5) *Radioactive release prevention equipment:* Description and location of any equipment, including cabling between equipment, necessary to prevent release of radioactive contamination.
(6) *Fire scenarios:* The limiting and maximum expected fire scenarios established for application in a performance-based analysis. This section defines the fire scenarios established and references any engineering calculations, fire modeling calculations, or other engineering analysis that was prepared to demonstrate satisfactory compliance with performance criteria for the fire area or fire zone.
(7) *Achievement of performance criteria:* A summary of the specific performance criteria evaluated and how each performance criterion is satisfied.

A.5.4.1.3 Examples of supporting information include the following:

(1) Calculations
(2) Engineering evaluations
(3) Test reports (e.g., penetration seal qualifications, model validation)
(4) System descriptions
(5) Design criteria
(6) Other engineering documents

The following topics should be documented in an engineering analysis:

(1) *Objective.* Clearly describe the objective of the engineering analysis in terms of the performance criteria outlined in Chapter 4, including, for example, specific damage criteria, performance criteria, and impact on plant operations. Quantify the engineering objectives in terms of time, temperature, or plant conditions, as appropriate.
(2) *Methodology and performance criteria.* Identify the method or approach used in the engineering analysis and performance criteria applied in the analysis and support by appropriate references.
(3) *Assumptions.* Document all assumptions that are applied in the engineering analysis, including the basis or justification for use of the assumption as it is applied in the analysis.
(4) *References.* Document all codes, standards, drawings, and reference texts used as references in the analysis. Include references to supporting data inputs, assumptions, or scenarios to be used to support the analysis. Identify all references, including revision and/or date. Include as attachments all references that might not be readily retrievable in the future.
(5) *Results and conclusions.* Describe results of the engineering analysis clearly and concisely and draw conclusions based on a comparison of the results with the performance criteria. Document key sources of uncertainties and their impacts on the analysis results.

A.5.4.3 The sources, methodologies, and data used in performance-based designs should be based on technical references that are widely accepted and utilized by the appropriate professions and professional groups. This acceptance is often based on documents that are developed, reviewed, and validated under one the following processes:

(1) Standards developed under an open consensus process conducted by recognized professional societies, other codes and standards writing organizations, or governmental bodies
(2) Technical references that are subject to a peer review process and are published in widely recognized peer-reviewed journals, conference reports, or other similar publications
(3) Resource publications, such as the *SFPE Handbook of Fire Protection Engineering*, that are widely recognized technical sources of information

The following factors are helpful in determining the acceptability of the individual method or source:

(1) The extent of general acceptance in the relevant professional community. Indications of this acceptance include peer-reviewed publication, widespread citation in the technical literature, and adoption by or within a consensus document.

(2) The extent of documentation of the method, including the analytical method itself, assumptions, scope, limitations, data sources, and data reduction methods.
(3) The extent of validation and analysis of uncertainties, including comparison of the overall method with experimental data to estimate error rates as well as analysis of the uncertainties of input data, uncertainties and limitations in the analytical method, and uncertainties in the associated performance criteria.
(4) The extent to which the method is based on sound scientific principles.
(5) The extent to which the proposed application is within the stated scope and limitations of the supporting information, including the range of applicability for which there is documented validation. Factors such as spatial dimensions, occupant characteristics, ambient conditions, and so forth, can limit valid applications. The technical references and methodologies to be used in a performance-based design should be closely evaluated by the engineer, the stakeholders, and possibly a third-party reviewer. This justification can be strengthened by the presence of data obtained from fire testing.

A.5.4.3.2 Generally accepted calculation methods appearing in engineering handbooks are considered to be adequately validated. No additional documentation is needed.

A.5.4.3.4 Fire modeling techniques are commonly used as numerical models.

A.5.4.3.5 In order to show with reasonable assurance that a particular performance or risk criterion has been met, a full understanding of the impact of important uncertainties in the analysis should be demonstrated and documented. It should be demonstrated that the choice of alternative hypotheses, adjustment factors, or modeling approximations or methods used in the engineering analyses would not significantly change the assessment. This demonstration can take the form of well-formulated sensitivity studies or qualitative arguments.

These uncertainties can have both *aleatory* (also called *random* or *stochastic*) and *epistemic* (also called *state-of-knowledge*) components. For example, when a design basis fire is used to represent the hazard to a fire barrier, there is some probability that, due to the random nature of fire events, a more severe fire could occur to challenge that barrier. Furthermore, there is some uncertainty in the predictions of the engineering model of the design basis fire and its impact on the barrier, due to limitations in the data and current state of the art for such models. Both aleatory and epistemic components should be addressed in the documentation where relevant. Parameter, model, and completeness uncertainties are typically sources of epistemic uncertainty. For example, in a typical fire risk assessment, there are completeness uncertainties in the risk contribution due to scenarios not explicitly modeled (e.g., smoke damage), model uncertainties in the assessment of those scenarios that are explicitly modeled (e.g., uncertainties in the effect of obstructions in a plume), and parameter uncertainties regarding the true values of the model parameters (e.g., the mass burning rate of the source fuel). All these uncertainties can, in principle, be reduced with additional information.

Aleatory uncertainties, on the other hand, cannot be reduced. Since the purpose of the formal quantitative uncertainty analysis is to support decision making, probabilities should be interpreted according to the "subjective probability" framework — that is, a probability is an internal measure of the likelihood that an uncertain proposition is true. In the context of this standard, two typical propositions are of the form "Parameter X takes on a value in the range $-(,x)$" and "Parameter X takes on a value in the range $(x,x + dx)$." The functions quantifying the probability of these two propositions are the cumulative distribution function and the probability density function, respectively. Bayes' theorem provides the tool to update these distribution functions when new data are obtained; it states that the posterior probability distribution for X, given new data, is proportional to the product of the likelihood of the data (given X) and the prior distribution for X. Bayes' theorem can also be used to update probabilities when other types of new evidence (e.g., expert judgment) are obtained. There are numerous textbooks on Bayesian methods.

Annex B Nuclear Safety Capability Assessment

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex is extracted from NFPA 805, Annex B.

B.1 Special Considerations for Non-Power Operational Modes. In order to assess the impact of fire originating when the plant is in a shutdown mode, the same basic methodology utilized for the nuclear safety capability assessment is used when assessing the impact of fire on nuclear safety during non-power operational modes. The set of systems and equipment are those required to support maintaining shutdown conditions. Additionally, the criteria for satisfying the performance criteria while shut down can be more qualitative in nature and have less reliance on permanent design features. For example, existing licensing basis might have allowed redundant success paths required for long-term cooling to be damaged due to a single fire and subsequently repaired. For a fire originating while in a shutdown mode, this can result in a loss of long-term decay heat removal capability. This insight should be factored into outage planning by limiting or restricting work activities in areas of vulnerability, ensuring operability of detection and suppression systems and control of transient combustible loading.

Shutdown or fuel pool cooling operations are categorized as either low or high risk evolutions. Fire protection requirements for equipment needed or credited for these operations would depend upon the categorization of the evolution the equipment supports. The categorization of the various shutdown or fuel pool cooling plant operational states (POSs) should be performed to determine whether the POS is considered as a high or low risk evolution. Industry guidance, such as NUMARC 91-06, can be used in this determination.

In general, POSs above or near the risk level of full power operations are considered high risk evolutions. High risk evolutions for shutdown would include all POSs where the fuel in the reactor and residual heat removal (RHR)/shutdown cooling is not being used [i.e., for a pressurized water reactor (PWR) this would be modes 3 and 4, when steam generator cooling is being used]. In addition, high risk evolutions would include RHR POSs where reactor water level is low and time to boil is short. POSs where the water level is high and time to boil is long are considered low risk evolutions.

An example categorization for a PWR would be the following:

(1) High risk evolutions: All modes 2 through 5; Mode 6 with water level below reactor flange

(2) Low risk evolutions: Mode 6 with water level above the reactor flange fuel in the fuel pool, core loading or unloading

[**805:**B.1]

B.1.1 General. The following is a general guidance/discussion on the applicability of the major nuclear safety capability assessment steps to non-power operational modes, shutdown cooling, or spent fuel pool cooling.

The same methodology used for fires originating at power should be used for equipment required in high risk evolutions. For shutdown cooling, many of the systems and equipment analyzed to maintain safe and stable conditions (cold shutdown) for non-power operational [fuel coolant temperature <200°F (93.3°C)] conditions should be sufficient. For spent fuel pool cooling, any systems, equipment, and associated instrumentation should be identified and interrelationships identified in order to properly assess susceptibility to fire damage in high risk evolutions. Any additional equipment (including instrumentation for process monitoring when the plant is in an abnormal condition) should be identified to supplement the cold shutdown cooling systems and equipment. Power sources necessary to support the shutdown cooling and spent fuel cooling should be identified, similar to the method used for power operations. [**805:**B.1.1]

B.1.2 Nuclear Safety Capability Circuit Analysis. The same methodology used to evaluate fire-induced circuit failure for fires originating at power should be used for equipment required in high risk evolutions. [**805:**B.1.2]

B.1.3 Nuclear Safety Equipment and Cable Location and Identification. The same methodology used to evaluate fire-induced circuit failure for fires originating at power should be used for equipment required in high risk evolutions. [**805:**B.1.3]

B.1.4 Fire Area Assessment. Following the identification of systems and equipment, a review of allowed and actual plant operational modes and allowed outage times and practices should be used for equipment required in high risk evolutions. This review will help to identify areas of vulnerability to ensure that the nuclear safety performance criteria are met for fires originating during these modes.

The nuclear capability assessment for non-power operational modes will be performance-based and should clearly demonstrate that the nuclear safety performance criteria are adequately satisfied. This capability assessment should consist of a review of the plant's technical specifications (TS) and administrative control practices, outage planning and assessment processes, and discussions with plant outage and operations staff. A review of fire protection system operability requirements and transient combustible control programs should be performed to identify practices during shutdown modes. Compliance strategies for achieving the nuclear safety performance criteria can include one or more of the following:

(1) Verifying vulnerable areas free of intervening combustibles during shutdown cooling
(2) Providing fire patrols at periodic intervals when in periods of increased vulnerability due to postulated equipment out of service and physical location of equipment and cables
(3) Staging of backup equipment, repair capabilities, or contingency plans to account for increased vulnerability
(4) Prohibition or limitation of work in vulnerable areas during periods of increased vulnerability
(5) Verification of operable detection and/or suppression in the vulnerable plant areas during periods of increased vulnerability
(6) Verifying that the quantity of combustible materials in the area remains below the heat release level that would challenge equipment required to maintain shutdown cooling

[**805:**B.1.4]

Annex C Application of Fire Modeling in Nuclear Power Plant Fire Hazard Assessments

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

C.1 Fundamental Principles. Fire modeling is one method used to approximate the conditions within an enclosure as a result of an internal fire. This technique typically involves a mathematical description of a fire scenario and the physical parameters of the enclosure. The estimated effects of the fire conditions within the enclosure are the typical output. [**805:**C.1]

Fire models can be used as engineering tools to assist in the development of a performance-based design. The models themselves do not provide the final solution but rather assist engineers in selecting the most appropriate fire protection systems and features for a performance-based design. The models are based on the physics that attempt to describe the fire phenomenon. The proper selection and application of fire models are an important part of this process and require the engineer to be familiar with model features and limitations. [**805:**C.1]

The engineer performing the analysis should have, at minimum, a basic understanding of fire dynamics to effectively utilize a fire model in a nuclear power plant and to employ the results. Fire models, whether single equations, zone, finite element, or field models, are based on the conservation equations for energy, mass, momentum, and species. A conceptual understanding of the conservation equations is necessary to effectively understand and utilize the various fire modeling techniques. [**805:**C.1]

The nondimensional conservation equations can be written in vector form as follows: Fire models are divided into two broad classifications: physical fire models and mathematical fire models. Physical fire models typically experiment with the ability to reduce the physical fire phenomena into simpler physical parameters. Mathematical fire modeling generally employs a series of equations that attempt to predict the fire behavior in a physical system. Many of the currently available fire models are a combination of these two classifications. Simplified versions of some of the equations in scalar form (usually the energy or mass equations), with empirical correlation for some phenomena (such as the air entrainment into the fire plume), provide the basis for most fire modeling methods. In most models, the heat release rate (HRR) and growth of the fire over time are entered directly by the user. These parameters typically have the most significant impact on the results of the fire model; therefore, the selection of representative HRR characteristics (i.e., design fire) is critical in obtaining valid predictions for a potential fire environment. Likewise, many of the fire models have internal assumptions/simplifications that are necessary for the model to run. The engineer must keep these two sources of inherent uncertainty in mind when stating the results of the analysis and the level of confidence in those results.

C.2 Fire Models.

C.2.1 Selection of an Appropriate Fire Model. A variety of fire modeling tools employing different features are currently available. The most appropriate model for a specific application often depends on the objective for modeling and fire scenario conditions.

Fire models have been applied in nuclear power plants in the past to predict environmental conditions inside a compartment or room of interest. The models typically try to estimate parameters such as temperature, hot smoke gas layer height, mass flow rate, toxic species concentration, heat flux to a target, and the potential for fire propagation in the preflashover stage of a compartment fire. Current fire models do not accurately predict post-flashover conditions, and any results after flashover should be considered indeterminate. Therefore, fire modeling calculations should be limited to the preflashover period of the fire. Flashover is generally considered to occur when the upper gas layer temperature in the compartment reaches approximately 1112°F (600°C) or the incident heat flux at the floor reaches 2.2 (Btu/s)/ft^2 (25 kW/m^2).

Δ **C.2.2 Fire Model Features and Limitations.** Fire models are generally limited both by their intrinsic algorithms and coding and by other factors impacting the range of applicability of a given model or model feature. These features are inherent in the model's development and should be taken into consideration in order to produce reliable results that will be useful in decision making. Some models might not be appropriate for certain conditions and can produce erroneous results if applied incorrectly. For example, some current fire models have difficulty predicting the environmental conditions inside compartments with large floor areas and low ceiling heights (such as corridors), compartments with high ceilings with respect to floor area (such as reactor buildings in BWRs), and compartments where mechanical ventilation is present (such as rooms in the auxiliary building of a PWR). Current models typically do not address the ignition of combustible materials or the bidirectional flow of gases through a horizontal (ceiling) vent.

A thorough understanding by the engineer of a model's features and the sensitivity of the model to the various input parameters, experimental benchmarking, and the limitations and uncertainties associated with the particular model selected is essential. The degree of confidence and level of accuracy in the model are determined during the validation and verification of the model as conducted by the developer or an independent party. This information can be obtained from the user's guide, other documentation provided with the model, or available public literature. Table C.2.2(a) and Table C.2.2(b) provide a brief summary and example of various model features for some common fire models.

The engineer must bear in mind that most fire models were developed for general application and not specifically for the conditions and scenarios presented in nuclear power plants. A fire model's features and ability to address these conditions should be considered when selecting an appropriate fire model. These conditions can affect the accuracy or appropriateness of the fire dynamics algorithms used for a unique analysis of a given space. [**805:**C.2.3]

The conditions can include but are not limited to the following:

(1) The types of combustibles and heat release rates
(2) Types and location of ignition sources
(3) The quantity of cables in cable trays and other in-situ fire loads in compartments
(4) Location of fire sources with respect to targets in the compartments
(5) High-energy electrical equipment
(6) Ventilation methods
(7) Concrete building construction, large metal equipment, and cable trays that will influence the amount of heat lost to the surroundings during a fire
(8) Compartments that vary in size but typically have a large volume with high ceilings
(9) Transient combustibles associated with normal maintenance and operations activities

[**805:**C.2.3]

Azarm, Dey, Travis, Martinez-Guridi, and Levine reviewed and provided descriptions of some of the current state-of-the-art computer codes used in the US building industry and overseas in the USNRC's NUREG 1521 [C.5.2(1)]. An overview of the features from these computer codes is presented in Table C.2.2(a). [**805:**C.2.3]

The following list gives short descriptions of the columns found in Table C.2.2(b):

(1) *Wall Heat Transfer.* Refers to whether the heat lost to the wall is calculated in the program. Some programs use only an empirical estimate of the heat remaining in the gas, thus greatly reducing the amount of calculation per time step.
(2) *Lower Level Gas Temp.* Refers to whether there is provision for upper layer gas to mix with or radiate to heat the lower layer of gas.
(3) *Heat Targets.* Except for the field models, the codes do not do an adequate job of calculating the impact of a fire on heating and then igniting such targets as cables in cable trays, and no code accurately predicts the heat loss in the upper gas layer due to the large amounts of heat transfer and the thermal capacity of, for example, cable tray surfaces in that layer. Most programs that do the calculation consider only the walls and ceiling as heat loss surfaces, ignoring the effect of other structures in the hot gas layer, such as cable trays.
(4) *Fire.* In all cases, except for COMPBRN IIIe, the "Fire" is entered as input. This column refers to whether it has a constant heat generation rate or can vary with time and whether there can be more than one fire in a compartment.
(5) *Gas Concentration.* Must be specified as emissions from the fire versus time if the program is expected to keep track of them from compartment to compartment. Most of the programs listed on Table C.2.2(b) will perform that task.
(6) *O_2 (Oxygen) Depletion.* Refers to whether the program will shut off or otherwise diminish the fire if the oxygen concentration gets too low for combustion to take place. However, the data for modeling the effect oxygen depletion has on the burning rate are generally not available.
(7) *Vertical Connections.* Refers to whether a model can cause gas to flow vertically from a room to one above or below it. It is assumed that any multiroom model has connections (doors) horizontally on the same level between

rooms and doors or windows from rooms to the outside. However, only some of the models can cause gas to flow vertically from a room to one above or below it.

(8) *HVAC Fans and Ducts.* Likewise, any multiroom model (except the smoke flow models) has buoyant flow of gas from one room to another. But only some of those models can add forced flow from the heating, ventilation, and air conditioning (HVAC) system(s).

(9) *Detectors.* Refers to whether the model will calculate the time at which a thermal detector (including the actuating strut in a sprinkler) or a smoke detector will actuate.

(10) *Sprinklers.* Refers to whether the model will throttle the fire as the sprinkler water impinges on it after the sprinkler strut actuates.

[**805:**C.2.3]

C.2.3 Fire Modeling Tools. Techniques used to model the transfer of energy, mass, and momentum associated with fires in buildings fall into four major categories:

(1) Single equations
(2) Zone models
(3) Field models
(4) Finite element analysis models

[**805:**C.2.1]

C.2.3.1 Single Equations. Single equations are used to predict specific parameters of interest in nuclear power plant applications such as adiabatic flame temperature, heat of combustion of fuel mixtures, flame height, mass loss rate, and so forth. These equations can be steady state or time dependent. The results of the single equation(s) can be used either directly or as input data to more sophisticated fire modeling techniques. [**805:**C.2.1.1]

C.2.3.2 Zone Models. Zone models assume a limited number of zones, typically two or three zones, in an enclosure. Each zone is assumed to have uniform properties such as temperature, gas concentration, and so forth. Zone models solve the conservation equations for mass, momentum, energy, and, in some examples, species. However, zone models usually adopt simplifying assumptions to the basic conservation equations to reduce the computational demand for solving these equations. A personal computer (PC) is usually sufficient to carry out implementation of the model. [**805:**C.2.1.2]

C.2.3.3 Field Models. Field or computational fluid dynamics (CFD) models divide an enclosure into a large number of cells and solve the Navier-Stokes equations in three dimensions for the flow field. Field models also require the incorporation of submodels for a wide variety of physical phenomena, including convection, conduction, turbulence, radiation, and combustion. The resulting flow or exchange of mass, energy, and momentum between computational cells is determined so that the three quantities are conserved. Accordingly, field models need intensive computational power, but these models can be run on high-end PCs. The field models can provide detailed information on the fluid dynamics of an enclosure fire in terms of three-dimension field, pressure, temperature, enthalpy, radiation, and kinetic energy of turbulence. These models have been used to model a variety of complex physical phenomena such as the impact of a suppression system (e.g., a sprinkler system or water mist system) on a specific type of fire or smoke movement in a large compartment with complex details such that detection can be optimized. Field models can provide a fundamental understanding of the flow field for a known compartment geometry, along with the physical phenomena that interact with the flow field. [**805:**C.2.1.3]

C.3 Fire Scenarios.

C.3.1 General. A fire scenario is a description of all or a portion of a postulated fire event. This description can be qualitative, quantitative, or a combination of the two. It can start before combustion occurs by dealing with the ignition and fuel sources, and it can carry through incubation, spread, detection, suppression, damage, and even cleanup and restoration activities. The description contained in a fire scenario can be used in a variety of ways to postulate the potential effects of the fire and to plan effective mitigation. [**805:**C.3.1]

It is important to understand that the term *fire scenario* as used in this standard has a specific meaning. It refers only to the quantitative input to and output from fire modeling calculations. Depending on the particular fire model utilized, input will include the following:

(1) Physical values related to the enclosure geometry and boundary characteristics
(2) Nature and location of ignition sources
(3) Fuel arrays (initial combustible and intermediate combustibles)
(4) Heat release and fire growth rates
(5) Ventilation conditions
(6) Target locations and damage characteristics
(7) Detection and suppression device location and operating characteristics
(8) Other data required for the model calculations

The output of interest will typically relate to target damage and the response of fire detection and suppression systems. [**805:**C.3.1]

There are two general categories of fire scenario used in this standard:

(1) Maximum expected fire scenarios (MEFS)
(2) Limiting fire scenarios (LFS)

Scenarios in each category must be modeled for each fire area/zone being analyzed. It is usually necessary to model more than one scenario for each category because the interaction between various input parameters is not always intuitively obvious and usually cannot be determined without actually performing fire modeling calculations. The ventilation variable is a good example. Most NPPs rely on manual operator actions of stopping and starting the safety-related ventilation system. Changing the one variable will generate a minimum of four separate cases, namely the following:

(1) Supply on and exhaust on
(2) Supply off and exhaust off
(3) Supply on and exhaust off
(4) Supply off and exhaust on

[**805:**C.3.1]

The total number of different scenarios required will depend on the combinations and permutations of the variables that need to be included to adequately analyze the specific conditions present. The engineer must keep in mind that due to uncertainties/approximations in the models, coupled with the variations inherent in the fire phenomena itself, a series of bounding cases are needed in order to draw reasonable engineering conclusions. [**805:**C.3.1]

Δ Table C.2.2(a) Summary of Models

	Model*			
	FIVE [C.5.1(5)]	**COMBRN IIIe [C.5.1(2)]**	**CFAST [C.5.1(1)]**	**LES [C.5.1(7)]**
General Features				
Type of model	Quasi-steady zone	Quasi-steady zone	Transient zone	Transient field
Number of layers	1	1–2	2	Multiple
Compartments	1	1	30	Multiple
Floors	1	1	30	Multiple
Vents	Wall (1)	Wall (1)	Wall (4 per room) Floor (1) Ceiling (1)	Multiple
Number of fires	Multiple	Multiple	Multiple	Multiple
Ignition of secondary fuels	No	Yes	Yes	Yes
Plume/ceiling jet sublayer	Yes	Yes/plume only	Yes	From conservation laws
Mechanical ventilation	Yes	Yes	Yes	Yes
Targets	Yes	Yes	Yes	Yes
Fire Sources				
Types	1. Gas	1. Gas 2. Pool 3. Solid	1. Gas	No specific type
Combustion factors	1. O_2 constrained (optional) 2. Yields specified	O_2 constrained	1. O_2 constrained (optional) 2. Yields specified	1. O_2 constrained (optional) 2. Yields specified
Other factors		1. Secondary ignition 2. Radiation enhancement	1. Secondary ignition	1. Secondary ignition 2. Radiation enhancement
Fire Plumes				
Types	1. Axisymmetric (Heskestad)	1. Axisymmetric (Zukoski)	1. Axisymmetric (McCaffrey)	Fluid motion equations
Modification factors	1. Wall/corner	1. Wall/corner 2. Doorway tilt	1. Wall/corner	From conservation laws
Ceiling Jets				
Types	1. Unconfined (Alpert) 2. Confined (Delichatsios)	N/A	Unconfined for detection	From conservation laws
Vents				
Types	Wall	Wall	Wall/floor/ceiling	Wall/floor/ceiling
Method	Bernoulli/orifice	Bernoulli/orifice	Bernoulli/orifice	From conservation laws
Modification factors	Flow coefficient	Flow coefficient Shear mixing	Flow coefficient Shear mixing Stack effect Wind effect	From conservation laws
Mechanical Ventilation				
Types	Injection extraction	Injection extraction	Injection extraction	Injection extraction
Method	Volumetric flow	Volumetric flow	Fan/duct network (triple connection)	User-specified velocity
Boundary Heat Loss				
Method	Heat loss factor	1-D conduction	1-D conduction	1-D conduction
Boundary conditions	N/A	Radiative Convective	Radiative Convective (Floor/ceiling)	Radiative Convective
Equipment heat loss	No	Yes	Yes (targets)	Yes
Targets				
Types	1. Thermally thick 2. Thermally thin	1. Thermally thick 2. Thermally thin 3. Everything between	1. Thermally thick 2. Thermally thin	1. Thermally thick 2. Thermally thin 3. Adiabatic
Heating	Radiative Convective	Radiative Convective	Radiative Convective	Radiative Convective
Damage criteria	Temperature	Temperature	Temperature Heat flux Flux-time product	Temperature

(continues)

Δ Table C.2.2(a) *Continued*

	Model*			
	FIVE [C.5.1(5)]	**COMBRN IIIe [C.5.1(2)]**	**CFAST [C.5.1(1)]**	**LES [C.5.1(7)]**
Validation				
Room sizes	18 m × 12 m × 6 m 9 m × 4 m × 3 m 9 m × 7.6 m × 3 m	3 m × 3 m × 2.2 m 4 m × 9 m × 3 m	12 m^3, 60,000 m^3 4 m × 2.3 m × 2.3 m, multiroom (100 m^3), multiroom (200 m^3), seven-story building (140,000 m^3)	37 m × 37 m × 8 m Outdoors
Ventilation	Forced, natural	Natural	Natural, forced	Natural, natural with wind
Fire sizes	500 kW, 800 kW, 1 MW, 2 MW	32 kW, 63 kW, 105 kW, 158 kW	<800 kW, 4–36 MW, 2.9 MW, 7 MW, 100 kW, 1 MW, 3 MW	4.5 MW, 410 MW, 450 MW, 820 MW, 900 MW, 1640 MW, 1800 MW
Fire types	Steady, transient	Steady	Steady, transient	Steady, transient
Fuels	Propylene gas, heptane pool, methanol pool, PMMA solid, electrical cables	Methane gas, electrical cables, and heptane pool	Furniture, natural gas burner	Crude oil, heptane burner, Group A plastic commodity

PMMA: Poly(methyl methacrylate).
*Numbers in parentheses refer to references listed in C.5.1.

C.3.2 Maximum Expected Fire Scenarios. The maximum expected fire scenarios (MEFS) are used to determine by fire modeling whether performance criteria are met in the fire area being analyzed. The input data for the fire modeling of the MEFS should be based on the following:

(1) Existing in-situ combustibles in the fire area
(2) Types and amounts of transient combustibles that industry experience and specific plant conditions indicate can reasonably be anticipated in the fire area
(3) Heat release and fire growth rates for the actual in-situ and assumed transient combustibles that are realistic and conservative based on available test data and applicable fire experience
(4) Ventilation within normal operating parameters with doors in the open or closed position
(5) Active and passive fire protection features operating as designed

[**805:**C.3.2]

C.3.3 Limiting Fire Scenarios. The limiting fire scenarios (LFS) are ones that result in unfavorable consequences with respect to the performance criteria being considered. In essence, the output for the LFS calculations is obtained by manipulating the fire model input parameters until consequences are obtained that violate the damage limits established. Thus, the LFS can be based on a maximum possible, though unlikely, value for one input variable or an unlikely combination of input variables. The goal of determining an LFS is to be able to analyze the margin between these scenarios and those used to establish the maximum expected fire scenario (MEFS). The values used for LFS input should remain within the range of possibility but can exceed that determined or judged to be likely or even probable. The actual evaluation of the margin between the MEFS and the LFS can be largely qualitative, but it provides a means of identifying weaknesses in the analysis where a small change in a model input could indicate an unacceptable change in the consequences. [**805:**C.3.3]

For example, a trash fire of 150 Btu/sec (160 kW) can be the most expected, but when change involving a barrier is evaluated, only a trash fire of 300 Btu/sec (320 kW) located under the raceway will result in failure of the barrier to provide the level of protection intended. [**805:**C.3.3]

C.3.4 Potential Fire Scenarios. Table C.3.4 provides examples of fire scenarios for various areas in a nuclear power plant, listing the ignition source and fuel for typical fire areas. Other factors associated with fire scenario definition (i.e., ventilation, heat release rate, configuration of fuel and plant equipment, fuel loading, and space configuration) are typically plant specific and should be confirmed in the plant. [**805:**C.3.4]

C.3.4.1 Ignition Sources. An ignition source of sufficient magnitude and duration will be necessary to initiate the event. The ignition source can be introduced as a human action, such as dropping slag from overhead welding/burning; equipment failure, such as overheating electrical faults in switchgear or transformers; or unwanted mechanical friction in motors or pumps. Cable-initiated failures due to fuse/breaker failure and circuit overloading can also be considered. Bags of transient materials can experience spontaneous combustion from improper disposal of oil-soaked rags. The ignition source should be realistic for the area under evaluation. [**805:**C.3.4.1]

C.3.4.2 Fuel Loading and Configuration. The fuel loading should be consistent with the in-situ combustibles in the area. The model input data can be accurately represented by field walkdowns. Special care should be given to the combustibles installed configurations. For example, vertical runs of cable trays will exhibit burning characteristics different from those of horizontal runs. Caution should be exercised when selecting HRRs and burning durations. [**805:**C.3.4.2]

C.3.4.3 Ventilation Parameters. The mechanical ventilation systems found in NPPs can influence the potential fire scenarios. Depending on the physical locations of supply discharges and exhaust inlets, ventilation can affect combustion and flame spread of materials. The injection of additional air can also influence the HRR intensity and burning duration. [**805:**C.3.4.3]

Δ Table C.2.2(b) Features of Several Fire Computer Codes

Program*	Type	No. of Rooms	Wall Heat Transfer	Lower Level Gas Temp.	Heat Targets	Fire	Gas Concen-trations	O_2 Depletion	Vertical Connec-tions	HVAC Fans and Ducts	Detectors	Sprinklers	Remarks
CFAST [C.5.1(1)]	Zone	15	Yes	Yes	No	Specified multiple	Yes	Yes	Yes	Yes	Yes	Yes	Fewer rooms if PC
FASTLITE [C.5.1(4)]	Zone	3	Yes	Yes	No	Specified	Yes	Yes	Yes	Yes	Yes	Yes	Easy input and run for PC
COMP-BRN III [C.5.1(2)]	Zone	1	Yes	No	Yes	Growth calculation	No	Yes	No	No	Yes	No	Input distributions for Monte-Carlo calculations
FIVE [C.5.1(5)]	Provides initial screen, leads to use of PRAs, look-up tables												Gathers info and keeps records — no computer necessary
FLAMME [C.5.1(9)]	Zone	Multi	Yes	Real	Yes	Specified multiple	Yes	Yes	No	Yes	No	No	French, ISPN
MAGIC [C.5.1(11)]	Zone	Multi	Yes	Yes	Yes	Specified multiple	Yes	Yes	Yes	Yes	Yes	No	French, EdF
FLOW — 3D [C.5.1(10)]	CFD	Few	Yes	Real	Yes	Specified	Yes	Yes	Yes	Yes	Yes	—	Depends on user, significant computing time, and acceptable granularity
LES [C.5.1(7)]	CFD	Few	Yes	Real	Yes	Specified	Yes	Yes	Yes	Yes	Yes	Yes	—
FPETOOL [C.5.1(6)]	Zone	2½	No	No	No	Specified	Yes	Yes	No	No	Yes	No	Easy inputs for PC, has "TOOLS"
ASCOS [C.5.1(8)]	Network flow	Multi	No	N/A	No	N/A	No	N/A	Yes	No	N/A	N/A	ASHRAE document (for smoke flow)
CONTAM [C.5.1(3)]	Network flow	Multi	No	N/A	No	N/A	Yes	N/A	Yes	No	N/A	N/A	Superior numerics, front end, and graphics (for smoke flow)

*Numbers in parentheses refer to references listed in C.5.1.

Δ Table C.3.4 Potential Fire Scenarios

Fuel	Ignition Source	Type Area
Lube oil[a]	Contact with hot piping surface	Containment
Fuel oil	Contact with hot piping surface	EDG room or building
Turbine lube oil[b]	Contact with hot piping surface	Turbine generator building
Electrical cable insulation[c]	Internal cable fault	Cable spreading room, cable tunnel, or cable penetration area
Electrical wiring, cables, and circuit boards[d]	Electrical fault inside a cabinet or behind vertical control boards	Control room
Charcoal in filter[e]	Spontaneous combustion due to being wetted then heated	Main safeguards filter area
Electrical cable insulation	Electrical circuit fault in switchgear cabinets	Rooms with electrical switchgear
General combustibles	Smoking, hot work, or portable heater malfunction	Warehouse (at beginning of refueling outage)
Transformer oil	Internal electrical fault causing rupture of transformer casing and release of oil that becomes ignited	Yard transformers
Hydrogen, cable insulation, and plastic battery cases	Electrical arc	Battery rooms
Core expansion material	Hot work	Seismic rattle space between two buildings
Office supplies, furnishings, and internal wiring	Smoking or electrical circuit fault	Computer room next to control room
Pump motor windings	Overheating	Various areas
Hydrogen	Electrical arc	Turbine building or outdoor hydrogen storage tanks
General Class A combustibles	Smoking, hot work, or portable heater malfunction	Temporary office trailer
Transient material associated with construction or maintenance	Hot work	Various areas
Lube oil	Contact with hot pipes	Steam-driven pumps
Lube oil	Hot work	Storage tank room or area within turbine building
Fuel oil	Contact with hot metal surface	Diesel fire pump house

[a]Reactor coolant pump lube oil system piping or fitting failure causes release of oil.
[b]A machine imbalance results in movement of the machine in relation to lube oil system piping, causing pipe failure and release of oil at more than one point along the machine. Oil sprays down from the upper elevation as a three-dimensional fire. Oil accumulates on the floor spreading as a two-dimensional pool fire.
[c]High-energy internal cable fault in a fully loaded vertical cable tray ignites cable insulation within that tray and propagates to involve adjacent trays.
[d]Fire produces a large quantity of smoke and potentially toxic combustion products, causing untenable conditions and damage to sensitive computer and electronic components.
[e]The filter is in service providing radioactive ventilation filtration, with its charcoal at the end of its service life (contaminated), leading to the products of combustion having radioactive contamination.

A systematic methodology should be followed for developing potential fire scenarios. The potential fire scenarios can vary widely between areas in the NPP. The suggested key elements used to develop the scenario are ignition source, fuel loading and configuration, ventilation parameters, targets and failure mechanisms, and suppression activities.
[**805:**Table C.3.4]

C.3.4.4 Targets and Failure Mechanisms. The fire model can be used to estimate a number of thermal transients from the fire inside the area under evaluation. Examples include but are not limited to the approximated temperature on essential cables located in the area, the actuation temperature at fire detection and suppression devices, and the thermal exposure to fire barriers and structural members. [**805:**C.3.4.4]

C.3.4.5 Suppression System Actuation and Manual Suppression Activities. The fire model can be time-stepped to correspond with automatic and or manual suppression activities. In evaluating the maximum expected and limiting fire scenarios, the engineer might choose to arbitrarily fail the automatic suppression system and examine the impact on the other elements of defense-in-depth, such as fire barrier ratings. [**805:**C.3.4.5]

C.3.4.6 Number of Case Runs. There is no defined maximum number of model runs that are to be performed for an area. The number of cases analyzed will depend on the physical parameters of the area, the number of different variables, and the object of study in the analysis. The engineer can provide a series of bounding case runs (possibly from multiple models) to define the fire scenario for an area. [**805:**C.3.4.6]

C.3.5 Fire Event Tree and Other Analytical Tools. In the context of this standard, a fire scenario should not be confused with a fire event tree, which can be used to illustrate the various pathways along which a particular fire could develop. NFPA 550 contains a detailed discussion of the development and utilization of the fire event tree. [**805:**C.3.5]

A fire event tree can be a useful analytical tool without being as elaborate or complete as that outlined in NFPA 550. It can provide a graphic summary of the potential sequence and variations of a fire event from initiation to conclusion. It can also be a framework for the utilization of probability data associated with such factors as frequency, reliability, and availability. [**805:**C.3.5]

For a given fire area, there can be several different potential fires that can be analyzed using a fire event tree. For example, Figure C.3.5(a) depicts a fire area containing a Train A oil-filled pump, associated motor, and electrical cabinet; a Train B cable tray; automatic sprinklers in one portion, and automatic carbon dioxide in another.

There are several potential fire events that could be considered for this fire area. Initiating events could include the following:

(1) Cable insulation fire
(2) Electrical cabinet components fire
(3) Pump lube oil leak fire
(4) Electric motor insulation fire
(5) Electric motor bearing grease fire
(6) Transients (various types, quantities, and locations)

An event tree can be developed for each of these fires. Figure C.3.5(b) illustrates such a tree for a fire involving a leak of the pump lube oil. [**805:**C.3.5]

There are other analytical tools available that are useful in certain situations. These include failure analysis, failure modes and effects analysis (FEMA), HAZOP analysis, various checklists, and similar methodologies. These tools can be included as part of a performance-based assessment of fire protection, depending on the particular situation involved. [**805:**C.3.5]

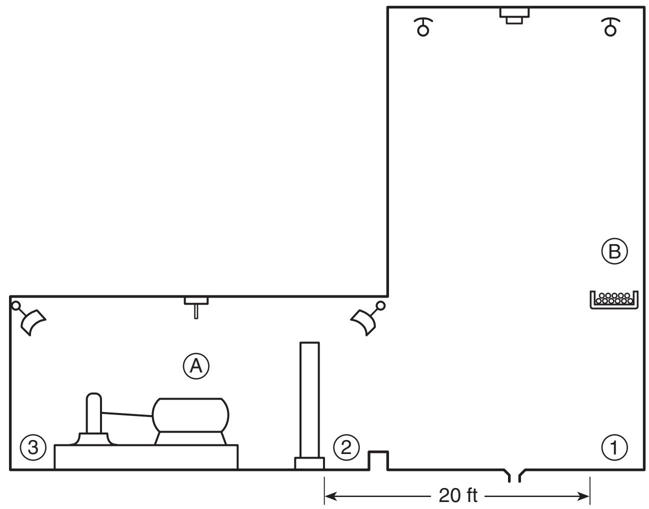

FIGURE C.3.5(a) Fire Area. [805:Figure C.3.5(a)]

C.4 Uncertainties in Fire Modeling. Uncertainty results from the specification of the problem being addressed (fire size, location, exposures, etc.). Limitations associated with the fire models used for problem analysis can produce additional uncertainties. Specifically, limitations in the number of physical processes considered and the depth of consideration can produce uncertainties concerning the accuracy of fire modeling results. Other uncertainties can be introduced due to limitations related to the input data required to conduct a fire simulation. Other sources of uncertainty include specification of human tenability limits, damage thresholds, and critical end point identifiers (e.g., flashover). [**805:**C.4]

The uncertainties associated with fire modeling can be addressed in several ways. A primary method for 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. Experimental data obtained from fire tests, statistical data from actual fire experience, and other expert judgments can be used to refine the approximation and potentially decrease the level of uncertainty. However, the data and expert opinions can introduce new uncertainties into the problem.

Experimental data used for verification or validation of fire models as well as for input to the models can generate uncertainties. The International Organization for Standardization (ISO) has drafted a guidance document that provides information on assessment and verification of mathematical fire models and discusses the issue of test data uncertainty. Typically, a measurement is not exact but is only a result of an approximation or an estimate. Therefore, a measurement is not complete unless a quantitative statement of the uncertainty

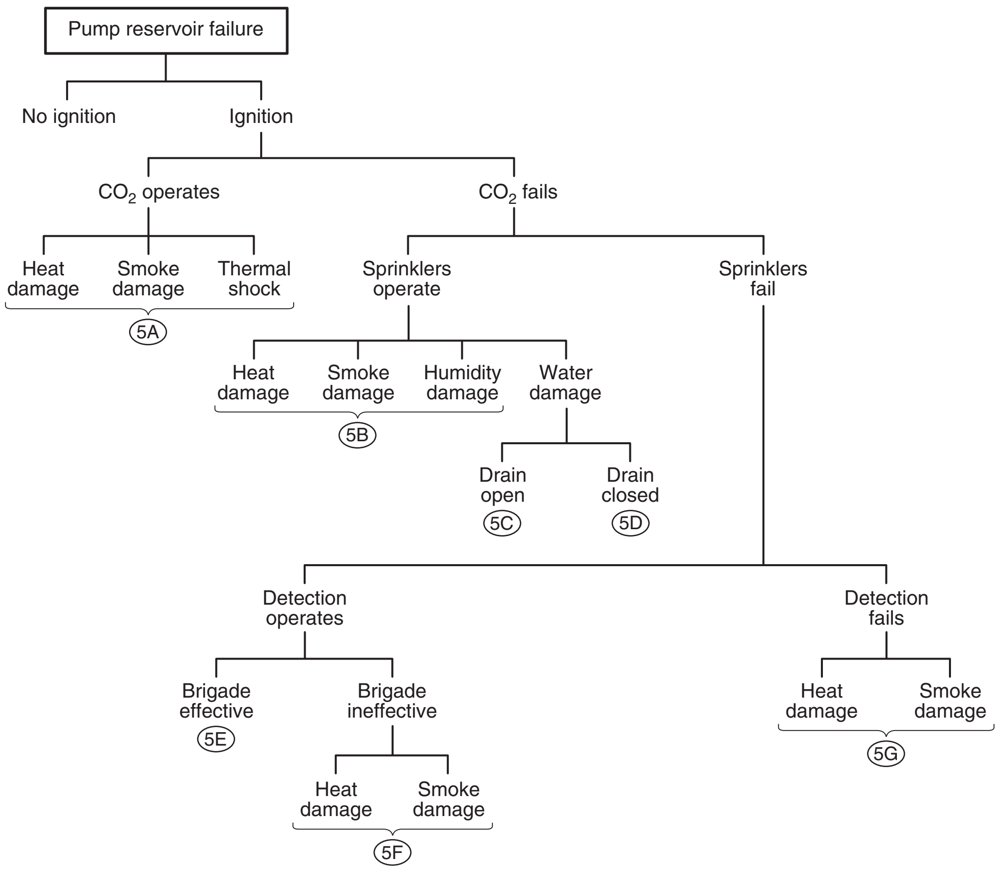

FIGURE C.3.5(b) Fire Event Tree. [805:Figure C.3.5(b)]

accompanies it. A sensitivity analysis can be conducted to evaluate the impact of uncertainties associated with various aspects of a fire model.

A sensitivity analysis should identify the dominant variables in the model, define acceptable ranges of input variables, and demonstrate the sensitivity of the output. This analysis can point out areas where extra caution is needed in selecting inputs and drawing conclusions. A complete sensitivity analysis for a complex fire model is a sizable task. Again, engineering judgment is required to select an appropriate set of case studies to use for the sensitivity analysis. The American Society for Testing and Materials (ASTM) also has a guide for evaluating the predictive capabilities of fire models. The recommendations in the ASTM guide should be reviewed and applied as appropriate when utilizing fire modeling. [**805:**C.4]

C.4.1 Source of Heat Release Rates (HRRs) and Fire Growth Rates. A significant source of uncertainty in fire models is associated with the HRRs and fire growth rates. The modeling of the combustion process and heat release is extremely complex.

Experimental data are widely used and provided as input to fire models, and large uncertainties are associated with this input because of the inability to accurately correlate experimental data to the fire source of concern. The HRR is the driving force for the plume mass flow rate, the ceiling jet temperature, and, finally, the hot gas layer temperature that is driven by the energy balance. The HRR is dependent on the heat of combustion of the fuel, mass loss rate of the fuel, and the fuel surface area. The mass loss rate is dependent upon the fuel type, fuel geometry, and ventilation. [**805:**C.4.1.]

C.4.2 Effects of Ventilation. In certain applications, the effects of mechanical ventilation are important. Most fire models have difficulty in accurately predicting the effects of mechanical ventilation on fire development and the corresponding effects on the fire compartment(s) and contents; therefore, uncertainty is introduced and is addressed by conservative assumptions. Nuclear power plants in the United States are typically multiroom, windowless structures of various sizes and are provided, exclusively, with forced ventilation systems that provide supply air and exhaust at different locations and elevations within the compartment(s). Mechanical ventilation can vary with weather and operating conditions. [**805:**C.4.2]

C.4.3 Structural Cooling Effects. Considerable cooling effects can come from the masses of cable trays, ventilation ducts, and piping in the upper part of compartments in nuclear power plants. Most zone models do not have the ability to calculate the heat transfer by convection from the gas in the hot gas layer to these structures as a function of time. [**805:**C.4.3]

C.4.3.1 Some models currently in use assume a constant heat loss factor between 0.5 and 0.7, which is consistent with the reported data.

C.4.4 Threshold for Thermal Damage to Equipment. Failures of equipment exposed to the harsh environment of a fire and the subsequent suppression activities are typically modeled by a threshold value of an appropriate parameter. This threshold value is referred to as the *equipment damage criterion*. As an example, a threshold surface temperature is usually considered a damage criterion for cables. [**805:**C.4.4]

Establishing damage criteria is a complex process and is a source of uncertainty. Equipment exposed to the thermal environment of a fire can fail either temporarily or permanently. As an example, an electronic circuit can temporarily fail (not respond or respond incorrectly) when exposed to high temperature; however, it can recover performance when the temperature drops. The failure criteria for equipment are also dependent on equipment function. As an example, small insulation leakage current can cause failure of an instrument cable, whereas the same amount of leakage in low-voltage power cable could be inconsequential. [**805:**C.4.4]

C.4.5 Effects of Smoke on Equipment. Smoke from a fire that starts in one zone can propagate to other zones and potentially damage additional equipment. Currently, fire PSAs do not treat the question of smoke propagation to other areas and their effect on component operability in a comprehensive manner. The extent to which the issue is addressed depends on the analyst, and if it is addressed, it is typically addressed qualitatively. [**805:**C.4.5]

C.4.6 Compartment and Fuel Geometry. Properly evaluating the unique or complex compartment and/or fuel geometry typical of a nuclear power plant can be a significant limitation of the model and a source for uncertainty in the results obtained. The interaction with and effect of adjacent compartments on the fire environment cannot be evaluated with models that are limited to a single compartment. In nuclear power plants, most combustibles (e.g., cable trays) are located well above the floor level. There is limited experimental data available for this type of fuel configuration. For most compartments of interest, the overhead areas in nuclear power plants are obstructed with cable trays, ventilation ducts, conduit banks, and piping. These obstructions are typically not evaluated for effect on the compartment environment by most zone models. [**805:**C.4.6]

C.5 Fire Model References.

C.5.1 Technical References for Specific Fire Model Codes in Annex C.

(1) Peacock, R. D., et al., "CFAST, the Consolidated Model of Fire Growth and Smoke Transport," NIST Technical Note 1299, National Institute of Standards and Technology, Gaithersburg, MD, February 2005.

(2) Ho, V., et al., eds., University of California at Los Angeles, "COMPRN IIIe: An Interactive Computer Code for Fire Risk Analysis," EPRI NP-7282, Electric Power Research Institute, Palo Alto, CA, December 1992.

(3) Walton, G., "CONTAM 93 User Manual," NISTIR 5385, National Institute of Standards and Technology, Gaithersburg, MD, March 1994.

(4) Department of Commerce, "FASTLite," Special Publication 889, National Institute of Standards and Technology, Building and Fire Research Laboratory, Fire Modeling and Applications Group, Gaithersburg, MD, 1996.

(5) Electric Power Research Institute, "Fire Modeling Guide for Nuclear Power Plant Applications," TR-1002981, Palo Alto, CA 2005.

(6) Deal, S., "Technical Reference Guide for FPETOOL Version 3.2," NISTIR 5486-1, National Institute of Standards and Technology, Gaithersburg, MD, 1995.

(7) McGrattan, K. B., and Forney, G. P., "Fire Dynamics Simulator (Version 4), User's Guide," NIST Special Publication 1019, National Institute of Standards and Technology, Gaithersburg, MD, July 2004.

(8) ASCOS is one of the best-known models for smoke travel between interconnecting rooms. ASCOS is described in the ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) publication "Design of Smoke Management Systems," Atlanta, GA, 1993.

(9) FLAMME is a computer fire model developed by the Institute of Protection and Nuclear Safety (IPSN) of the French Atomic Energy Commission (CEA). The FLAMME code was developed to quantify the thermal response to the environment and equipment and use the results of this analysis in fire PRAs. The objective of this code is to predict the damage time for various safety-related equipment. The FLAMME-S version can simulate the development of fire in one of several rooms in a parallelopedic form with vertical or horizontal openings, confined or ventilated, containing several targets and several combustible materials.

(10) FLOW-3D is a computational fluid dynamics (CFD Field) model used at the British Harwell Laboratory.

(11) Gay, L., and Epiard, C., "User guide of the MAGIC Software V4.1.1," EDF HI82/04, December 2004.

MAGIC is computer fire code used by the French utility Electricité de France (EdF). MAGIC, a multicompartment zone model, is used by safety engineers at EdF as a basis for discussions of fire safety provisions. Heat transfer through the walls is one-dimensional conduction, with the heat going into the next compartment. There can be several (up to about nine) fires in a compartment, each with a separate plume. Radiation can be calculated between the flame, walls, and gases; gases are treated as semitransparent and the walls as "gray." The fire can be limited by lack of oxygen, in which case the unburned gas in the next compartment flames.

Δ C.5.2 Comparison of Fire Model Codes in Annex C.

(1) Azarm, M. A., Dey, M., Travis R., Martinez-Guridi, G., and Levine, R., "Technical Review of Risk-Informed, Performance-Based Methods for Nuclear Power Plant Fire Protection Analyses," Draft NUREG 1521, US Nuclear Regulatory Commission, Washington, DC, July 1998.

Δ C.5.3 Other References Relating to Fire Modeling in Annex C.

(1) Hurley M.J, et al., eds., *The SFPE Handbook of Fire Protection Engineering,* 5th edition, SFPE, Gaithersburg, MD, 2016.

(2) Electric Power Research Institute, "Fire Modeling Guide for Nuclear Power Plant Applications," TR-1002981, Palo Alto, CA, 2005.

(3) "Fire-Induced Vulnerability Evaluation (FIVE)," EPRI TR-100370, Palo Alto, CA, December 1992.

(4) Deal, S., "Technical Reference Guide for FPETOOL Version 3.2," NISTIR 5486-1, National Institute of Standards and Technology, Gaithersburg, MD, 1995.

(5) McGrattan, K.B., and Forney, G.P., "Fire Dynamics Simulator (Version 4), User's Guide," NIST Special Publication 1019, National Institute of Standards and Technology, Gaithersburg, MD, July 2004.

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Annex D Use of Fire PSA Methods in NFPA 806

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

D.1 Introduction.

D.1.1 Objectives and Scope. The objective of this annex is to describe acceptable fire probabilistic safety assessment (PSA) methods and data that can be used to perform the fire risk evaluations discussed in 5.2.4. The scope of this annex covers fire PSA methods and tools used to evaluate nuclear safety goals for full power operation.

Other modes of plant operation and core and spent fuel pool accidents should be considered qualitatively, but at this time detailed fire PSA methodologies do not exist. As they become available, they should be considered for inclusion.

NOTE: The risk due to non-fire accident initiators might need to be quantified if the change evaluation requires consideration of baseline risk. Methods for evaluating non-fire initiators are not covered explicitly by this annex.

D.1.2 Elements of Fire PSA. Fire PSA is a process to develop a plant's fire risk and fire safety insights based on the plant's design, layout, and operation. The process contains analysis elements that correspond directly to the elements of fire protection defense-in-depth. An acceptable method for fire PSA is included in NUREG/CR 6850.

Δ **D.2 Shutdown Fire Risk Evaluation.** As described in Section B.1, shutdown or fuel pool cooling operations are categorized as either low- or high-risk evolutions. Fire protection requirements for equipment needed or credited for these operations would depend on the categorization of the evolution the equipment supports. The categorization of the various shutdown or fuel pool cooling plant operational states (POSs) should be performed to determine whether the POS is considered a high-risk or a low-risk evolution. Industry guidance, such as NUMARC 91-06, *Guidelines for Industry Actions to Assess Shutdown Management,* can be used in this determination. In general, POSs at or near the risk level of full power operations are considered high-risk evolutions. POSs at risk levels significantly below the full power risk are considered low-risk evolutions. High-risk evolutions for shutdown would typically include all POSs where there is fuel in the reactor and residual heat removal (RHR)/shutdown cooling is not being used. Where the fire protection features, nuclear safety systems, and administrative program elements are similar to those used in power operations, the fire PSA guidance in Section D.3 should be used. If the features, nuclear safety systems, or administrative program elements are different, other methods acceptable to the AHJ can be used.

D.3 Application of Fire PSA Methods to Change Analysis. NUREG/CR 6850, *Fire PRA Methodology for Nuclear Power Facilities,* provides guidance for performing a detailed fire PSA. However, the portion of the PSA corresponding to fire protection elements not affected by the plant change might not require the level of quality established in NUREG/CR 6850. It is anticipated that in this latter case, many practical applications will be sufficiently simple or of limited scope such that an adequate change evaluation can be done with a fire PSA of less overall quality but high quality in the area of application. This section provides guidance concerning this and other application issues that can arise when a fire PSA in support of a change analysis is being performed.

One type of application requiring less overall PSA quality is a plant change that is limited to a single aspect of a single element of the fire protection program. For example, evaluating a change in a fire protection feature could be demonstrated if the feature's reliability (to meet its design and performance objectives) remains the same. Therefore, the quality requirements for fire modeling or plant response analysis are limited to issues related to system reliability.

Another application where fire PSA quality can be focused is a plant change that impacts only a single element of fire protection defense-in-depth, where it can be demonstrated that plant performance following the change is essentially equivalent to the performance before the change. The analysis should ensure that the change affects only the single element and that potential effects on other elements are not masked by the modeling approach used (see the following discussion on model scope). While lower levels of fire PSA quality might be acceptable, as noted previously, some applications will also require improvements to quality of the fire PSA. The change evaluation should examine the extent to which the fire protection elements affected by the change are modeled in the fire PSA. The evaluation of some changes can require models that are not explicitly covered in the plant base fire risk model. This can, in turn, require some refinement of the plant risk model to suit the needs of the change evaluation. Some examples are as follows:

(1) The change affects fire areas/zones/scenarios that are screened on the basis of low risk. In these cases, the