NFPA 805

Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants

2001 Edition

NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

IMPORTANT NOTICE ABOUT THIS DOCUMENT

NFPA codes, standards, recommended practices, and guides, of which the document contained herein is one, are developed through a consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on fire and other safety issues. While the NFPA administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its codes and standards.

The NFPA disclaims liability for any personal injury, property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document. The NFPA also makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this document available, the NFPA is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the NFPA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The NFPA has no power, nor does it undertake, to police or enforce compliance with the contents of this document. Nor does the NFPA list, certify, test or inspect products, designs, or installations for compliance with this document. Any certification or other statement of compliance with the requirements of this document shall not be attributable to the NFPA and is solely the responsibility of the certifier or maker of the statement.

See inside back cover for additional important notices and information.

NOTICES

All questions or other communications relating to this document and all requests for information on NFPA procedures governing its codes and standards development process, including information on the procedures for requesting Formal Interpretations, for proposing Tentative Interim Amendments, and for proposing revisions to NFPA documents during regular revision cycles, should be sent to NFPA headquarters, addressed to the attention of the Secretary, Standards Council, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

Users of this document should be aware that this document may be amended from time to time through the issuance of Tentative Interim Amendments, and that an official NFPA document at any point in time consists of the current edition of the document together with any Tentative Interim Amendments then in effect. In order to determine whether this document is the current edition and whether it has been amended through the issuance of Tentative Interim Amendments, consult appropriate NFPA publications such as the *National Fire Codes*® Subscription Service, visit the NFPA website at www.nfpa.org, or contact the NFPA at the address listed above.

A statement, written or oral, that is not processed in accordance with Section 6 of the Regulations Governing Committee Projects shall not be considered the official position of NFPA or any of its Committees and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

The NFPA does not take any position with respect to the validity of any patent rights asserted in connection with any items which are mentioned in or are the subject of this document, and the NFPA disclaims liability for the infringement of any patent resulting from the use of or reliance on this document. Users of this document are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Users of this document should consult applicable federal, state, and local laws and regulations. NFPA does not, by the publication of this document, intend to urge action that is not in compliance with applicable laws, and this document may not be construed as doing so.

Licensing Policy

This document is copyrighted by the National Fire Protection Association (NFPA). By making this document available for use and adoption by public authorities and others, the NFPA does not waive any rights in copyright to this document.

1. Adoption by Reference—Public authorities and others are urged to reference this document in laws, ordinances, regulations, administrative orders, or similar instruments. Any deletions, additions, and changes desired by the adopting authority must be noted separately. Those using this method are requested to notify the NFPA (Attention: Secretary, Standards Council) in writing of such use. The term "adoption by reference" means the citing of title and publishing information only.

2. Adoption by Transcription—**A.** Public authorities with lawmaking or rule-making powers only, upon written notice to the NFPA (Attention: Secretary, Standards Council), will be granted a royalty-free license to print and republish this document in whole or in part, with changes and additions, if any, noted separately, in laws, ordinances, regulations, administrative orders, or similar instruments having the force of law, provided that: (1) due notice of NFPA's copyright is contained in each law and in each copy thereof; and (2) that such printing and republication is limited to numbers sufficient to satisfy the jurisdiction's lawmaking or rule-making process. **B.** Once this NFPA Code or Standard has been adopted into law, all printings of this document by public authorities with lawmaking or rule-making powers or any other persons desiring to reproduce this document or its contents as adopted by the jurisdiction in whole or in part, in any form, upon written request to NFPA (Attention: Secretary, Standards Council), will be granted a nonexclusive license to print, republish, and vend this document in whole or in part, with changes and additions, if any, noted separately, provided that due notice of NFPA's copyright is contained in each copy. Such license shall be granted only upon agreement to pay NFPA a royalty. This royalty is required to provide funds for the research and development necessary to continue the work of NFPA and its volunteers in continually updating and revising NFPA standards. Under certain circumstances, public authorities with lawmaking or rule-making powers may apply for and may receive a special royalty where the public interest will be served thereby.

3. Scope of License Grant—The terms and conditions set forth above do not extend to the index of this document.

(For further explanation, see the Policy Concerning the Adoption, Printing, and Publication of NFPA Documents, which is available upon request from the NFPA.)

NFPA 805

Performance-Based Standard for

Fire Protection for Light Water Reactor Electric Generating Plants

2001 Edition

This edition of NFPA 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, was prepared by the Technical Committee on Fire Protection for Nuclear Facilities and acted on by the National Fire Protection Association, Inc., at its November Meeting held November 12–15, 2000, in Orlando, FL. It was issued by the Standards Council on January 13, 2001, with an effective date of February 9, 2001.

This edition of NFPA 805 was approved as an American National Standard on February 9, 2001.

Origin and Development of NFPA 805

The 2001 edition of NFPA 805 is the first edition of this standard. NFPA 805 replaces NFPA 803, *Standard for Fire Protection for Light Water Nuclear Power Plants.* NFPA 805 is a performance-based standard that describes the methodology for applying performance-based requirements, fundamental fire protection program design and elements, determination of fire protection systems and features, and fire protection during decommissioning and permanent shutdown.

Technical Committee on Fire Protection for Nuclear Facilities

Wayne D. Holmes, *Chair*
HSB Professional Loss Control, CT [I]

Richard B. Alpert, Triad Fire Protection Engr Corp., PA [SE]
Mario A. Antonetti, Gage-Babcock & Assoc., Inc., NY [SE]
James B. Biggins, Marsh USA, Inc., IL [I]
William G. Boyce, U.S. Dept. of Energy, DC [E]
David J. Buell, Black & Veatch Corp., KS [SE]
Thomas C. Carlisle, Virginia Power, VA [U]
Harry M. Corson IV, Siemens Cerberus Division, NJ [M]
Rep. Nat'l Electrical Mfrs. Assn.
Stanford E. Davis, PP & L, PA [U]
Edgar G. Dressler, American Nuclear Insurers, PA [I]
Franklin D. Garrett, Arizona Public Service Co., AZ [U]
Rep. Nuclear Energy Inst.
Arie T. P. Go, Bechtel Corp., CA [SE]
Dennis Wayne Henneke, Southern California Edison, CA [U]
Robert Kalantari, EPM Inc., MA [SE]
Robert P. Kassawara, Electric Power Research Inst., CA [U]
Donald J. Kohn, Kohn Engr, PA [SE]
Christopher A. Ksobiech, Wisconsin Electric Power Co., WI [U]
Patrick M. Madden, U.S. Nuclear Regulatory Commission, DC [E]
David P. Notley, Science Applications Int'l Corp., MD [SE]
Clifford R. Sinopoli II, Peco Energy, PA [U]
Rep. Edison Electric Inst.
Wayne R. Sohlman, Nuclear Electric Insurance Ltd., DE [I]
William M. Sullivan, Contingency Mgmt. Assoc., Inc., MA [SE]
Raymond N. Tell, Los Alamos Nat'l Laboratory, NM [U]
Steven F. Vieira, Tyco Int'l, Ltd., RI [M]
Rep. Nat'l Fire Sprinkler Assn.
Michael J. Vitacco, Jr., Westinghouse Savannah River Co., SC [U]

Alternates

Amir Afzali, Pacific Gas and Electric Co., CA [U]
(Alt. to D. W. Henneke)
Edward A. Connell, U.S. Nuclear Regulatory Commission, DC [E]
(Alt. to P. M. Madden)
Frank Czysz, Pennsylvania Power & Light, Inc., PA [U]
(Alt. to S. E. Davis)
Thomas K. Furlong, Nuclear Service Organization, DE [I]
(Alt. to W. R. Sohlman)
L. Paul Herman, HSB Professional Loss Control, IL [I]
(Alt. to W. D. Holmes)
Neal W. Krantz, Nat'l Time & Signal Corp., MI [M]
(Alt. to H. M. Corson)
Dennis J. Kubicki, U.S. Dept. of Energy, MD [E]
(Alt. to W. G. Boyce)
Andrew R. Ratchford, Ratchford Diversified Services (RDS), CA [SE]
(Voting Alt.)
Ronald Rispoli, Entergy Corp., AR [U]
(Alt. to F. D. Garrett)
Thomas A. Storey, Science Applications Int'l Corp., VA [SE]
(Alt. to D. P. Notley)
James R. Streit, Los Alamos Nat'l Laboratory, NM [U]
(Alt. to R. N. Tell)
William B. Till, Jr., Westinghouse Savannah River Co., SC [U]
(Alt. to M. J. Vitacco)

Nonvoting

Leonard R. Hathaway, Alpharetta, GA [I]
(Member Emeritus)
Donald J. Keigher, Los Alamos, NM
(Member Emeritus)
James E. Lechner, Nebraska Public Power District, NE [U]
Walter W. Maybee, Bothell, WA
(Member Emeritus)
Nathan O. Siu, U.S. Nuclear Regulatory Commission, DC [E]

Richard P. Bielen, NFPA Staff Liaison

This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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

Chapter 1 Introduction 805– 4
1.1 Scope 805– 4
1.2 Defense-in-Depth. 805– 4
1.3 Goals. 805– 4
1.4 Performance Objectives 805– 4
1.5 Performance Criteria 805– 4
1.6 Definitions 805– 5
1.7 Equivalency 805– 7
1.8 Code of Record 805– 7

Chapter 2 Methodology 805– 7
2.1 Intent 805– 7
2.2 General Approach. 805– 7
2.3 Assumptions. 805– 9
2.4 Engineering Analyses 805– 9
2.5 Evaluating the Damage Threshold. 805–12
2.6 Monitoring. 805–12
2.7 Program Documentation, Configuration Control, and Quality 805–12

Chapter 3 Fundamental Fire Protection Program and Design Elements. 805–13
3.1 General. 805–13
3.2 Fire Protection Plan 805–13
3.3 Prevention 805–13
3.4 Industrial Fire Brigade 805–14
3.5 Water Supply 805–15
3.6 Standpipe and Hose Stations 805–16
3.7 Fire Extinguishers 805–17
3.8 Fire Alarm and Detection Systems 805–17
3.9 Automatic and Manual Water-Based Fire Suppression Systems 805–17
3.10 Gaseous Fire Suppression Systems 805–17
3.11 Passive Fire Protection Features 805–18

Chapter 4 Determination of Fire Protection Systems and Features 805–19
4.1 Methodology 805–19
4.2 Nuclear Safety 805–19
4.3 Radiation Release 805–20
4.4 Life Safety. 805–21
4.5 Plant Damage/Business Interruption 805–21

Chapter 5 Fire Protection During Decommissioning and Permanent Shutdown 805–21
5.1 Intent 805–21
5.2 Fire Protection Plan 805–21
5.3 Maintaining Fire Protection Capability 805–21

Chapter 6 Referenced Publications 805–22

Appendix A Explanatory Material 805–22

Appendix B Nuclear Safety Analysis 805–33

Appendix C Application of Fire Modeling in Nuclear Power Plant Fire Hazard Assessments 805–43

Appendix D Use of Fire PSA Methods in NFPA 805 805–53

Appendix E Deterministic Approach — Plant Damage/Business Interruption 805–58

Appendix F Referenced Publications 805–64

Index 805–65

NFPA 805

Performance-Based Standard for

Fire Protection for Light Water Reactor Electric Generating Plants

2001 Edition

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

Information on referenced publications can be found in Chapter 6 and Appendix F.

Chapter 1 Introduction

1.1 Scope. This standard specifies the minimum fire protection requirements for existing light water nuclear power plants during all phases of plant operation, including shutdown, degraded conditions, and decommissioning.

1.2 Defense-in-Depth. 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. The fire protection standard shall be based on the concept of defense-in-depth. Defense-in-depth shall be achieved when an adequate balance of each of the following elements is provided:

(1) Preventing fires from starting
(2) Rapidly detecting fires and 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 essential plant safety functions from being performed

1.3 Goals.

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

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

1.3.3* Life Safety Goal. The life safety goal shall be to provide reasonable assurance that loss of life in the event of fire will be prevented for facility occupants.

1.3.4 Plant Damage/Business Interruption Goal. The plant damage/business interruption goal is to provide reasonable assurance that the risks of fire are acceptable with regard to potential economic consequences.

1.4 Performance Objectives.

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

(1) *Reactivity Control.* Capable of rapidly achieving and maintaining subcritical conditions.
(2) *Fuel Cooling.* Capable of achieving and maintaining decay heat removal and inventory control functions
(3) *Fission Product Boundary.* Capable of preventing fuel clad damage so that the primary containment boundary is not challenged

1.4.2 Radioactive Release Objective. Either of the following objectives shall be met during all operational modes and plant configurations.

(1) Containment integrity is capable of being maintained.
(2) The source term is capable of being limited.

1.4.3 Life Safety Objectives. The life safety objectives shall be to protect occupants not intimate with the initial fire development from loss of life and improve the survivability of those who are intimate with the fire development, as well as to provide adequate protection for essential and emergency personnel.

1.4.4 Plant Damage/Business Interruption Objectives. In order to meet the plant damage/business interruption goals, the following objectives shall be met during all operational modes and plant configurations.

(1) Potential property damage due to fire shall be limited to an acceptable level as determined by the owner/operator.
(2) Potential business interruption (plant downtime) due to fire shall be limited to an acceptable level as determined by the owner/operator.

1.5 Performance Criteria.

1.5.1 Nuclear Safety Performance Criteria. 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. To demonstrate this, the following performance criteria shall be met.

(a) *Reactivity Control.* Reactivity control shall be capable of inserting negative reactivity to achieve and maintain subcritical conditions. Negative reactivity inserting shall occur rapidly enough such that fuel design limits are not exceeded.

(b) *Inventory and Pressure Control.* With fuel in the reactor vessel, head on and tensioned, inventory and pressure control shall be capable of controlling coolant level such that subcooling is maintained for a PWR and shall be capable of maintaining or rapidly restoring reactor water level above top of active fuel for a BWR such that fuel clad damage as a result of a fire is prevented.

(c) *Decay Heat Removal.* Decay heat removal shall be capable of removing sufficient heat from the reactor core or spent fuel such that fuel is maintained in a safe and stable condition.

(d) *Vital Auxiliaries.* Vital auxiliaries shall be capable of providing the necessary auxiliary support equipment and systems to assure that the systems required under (a), (b), (c), and (e) are capable of performing their required nuclear safety function.

(e)**Process Monitoring.* Process monitoring shall be capable of providing the necessary indication to assure the criteria addressed in (a) through (d) have been achieved and are being maintained.

1.5.2 Radioactive Release Performance Criteria. Radiation release to any unrestricted area due to the direct effects of fire suppression activities (but not involving fuel damage) shall be as low as reasonably achievable and shall not exceed applicable 10 *CFR*, Part 20, Limits.

1.5.3 Life Safety Criteria. The following performance criteria shall be met during all operational modes and plant configurations:

(1) Provide safe egress and/or area of refuge for occupants other than essential personnel
(2) Provide adequate protection, including emergency lighting, for essential personnel to perform necessary safety functions as a result of a fire event
(3) Provide adequate protection for essential personnel, providing necessary emergency services during or following a fire

1.5.4* Plant Damage/Business Interruption Criteria. In order to meet the individual plant damage/business interruption objectives, the following criteria shall be satisfied as described below.

(a) The probable maximum loss (PML) shall not exceed an acceptable level as determined by the owner/operator.

(b) The business interruption (plant downtime) due to a PML fire event shall not exceed an acceptable level as determined by the owner/operator.

1.6 Definitions.

1.6.1 Acceptable. Considered by the authority having jurisdiction (AHJ) as adequate for satisfying the goals, performance objectives, and/or performance criteria.

1.6.2* Approved. Acceptable to the authority having jurisdiction.

1.6.3* Authority Having Jurisdiction. The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

1.6.4 Availability. The probability that the system, structure, or component of interest is functional at a given point in time.

1.6.5 BWR. Boiling water reactor.

1.6.6* Combustible. Capable of undergoing combustion.

1.6.7 Combustible Liquid. A liquid having a flash point at or above 100°F (37.8°C). *(See NFPA 30, Flammable and Combustible Liquids Code.)*

1.6.8 Compensatory Actions. 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.

1.6.9 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.

1.6.10 Containment. Structures, systems, or components provided to prevent or mitigate the release of radioactive materials.

1.6.11 Deterministic Approach. A deterministic approach establishes requirements for engineering margin and quality assurance in design, manufacture, and construction. It involves implied, but unquantified, elements of probability in the selection of the specific accidents to be analyzed as design basis events. It does not integrate results in a comprehensive manner to assess the overall impact of postulated initiating events.

1.6.12 Electrical Raceway Fire Barrier System (ERFBS). Nonload-bearing partition-type envelope system installed around electrical components and cabling that have withstood a fire exposure as established in accordance with an approved test procedure and are rated by a test laboratory in hours of fire resistance and are used to maintain specified nuclear safety functions free of fire damage.

1.6.13 Essential Personnel. Personnel who are required to perform functions to mitigate the effects of a fire including but not limited to industrial fire brigade members, operations, health physics, security, and maintenance.

1.6.14* 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.

1.6.15* Fire Barrier. A continuous vertical or horizontal construction assembly designed and constructed to limit the spread of heat and fire and to restrict the movement of smoke.

1.6.16 Fire Door. A door assembly rated in accordance with NFPA 252, *Standard Methods of Fire Tests of Door Assemblies*, and installed in accordance with NFPA 80, *Standard for Fire Doors and Fire Windows*.

1.6.17 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.

1.6.18 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.

1.6.19 Fire Prevention. Measures directed towards reducing the likelihood of fire.

1.6.20 Fire Protection Feature. Administrative controls, fire barriers, means of egress, industrial fire brigade personnel, and other features provided for fire protection purposes.

1.6.21 Fire Protection System. Fire detection, notification, and fire suppression systems designed, installed, and maintained in accordance with the applicable NFPA codes and standards.

1.6.22 Fire-Rated Cable Encapsulation Systems. See 1.6.12, Electrical Raceway Fire Barrier System.

1.6.23 Fire-Rated Penetration. See 1.6.62, Through Penetration Fire Stop.

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

1.6.25 Fire Scenario. 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 and locations of occupants, condition of the supporting structure, and conditions and status of operating equipment.

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

1.6.27 Flame Spread Rating. A relative measurement of the surface burning characteristics of building materials when tested in accordance with NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials*.

1.6.28 Flammable Liquid. Any liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 psi (276 kPa) absolute pressure at 100°F (37.8°C).

1.6.29 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.

1.6.30 Fuel Damage. Exceeding the fuel design limits.

1.6.31* High-Low Pressure Interface. Reactor coolant boundary valves whose spurious opening could potentially rupture downstream piping on an interfacing system or could cause a loss of inventory that could not be mitigated in sufficient time to achieve the nuclear safety performance criteria.

1.6.32* 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.

1.6.33 In Situ Combustible. Combustible materials that are permanently located in a room or an area (e.g., cable insulation, lubricating oil in pumps).

1.6.34 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.

1.6.35 Large Early Release. Significant, unmitigated release from containment in a time frame prior to effective evacuation of the close-in population such that there is a potential for early health effects. **(Regulatory Guide 1.174)**

1.6.36 Limited Combustible. Material that, in the form in which it is used, has a potential heat value not exceeding 3500 Btu/lb (8141 kJ/kg) and either has a structural base of noncombustible material with a surfacing not exceeding a thickness of $^1/_8$ in. (3.2 mm) that has a flame spread rating not greater than 50, or has another material having neither a flame spread rating greater than 25 nor evidence of continued progressive combustion, even on surfaces exposed by cutting through the material on any plane. *(See NFPA 220, Standard on Types of Building Construction.)*

1.6.37 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. *(See Appendix C for a discussion of limiting fire scenarios and margin.)*

1.6.38* 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.

1.6.39 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. *(See Appendix C for a list of industry examples of fire scenarios for typical plant areas.)*

1.6.40 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.

1.6.41 Noncombustible Material. 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.

1.6.42 Owner/Operator. The organization(s) with fiscal responsibility for the operation, maintenance, and profitability of the nuclear plant.

1.6.43 Parameter Uncertainty. Uncertainty in the predictions of a model due to uncertainties in the numerical values of the model parameters.

1.6.44 Performance Criteria. Specific measurable or calculable parameters for systems and features that are quantified and described in engineering terms.

1.6.45 Performance-Based Approach. A performance-based approach 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 criteria, while undesirable, will not in and of itself constitute or result in an immediate safety concern.

1.6.46* Power Block. Structures that have equipment required for nuclear plant operations.

1.6.47 Prior Distribution. Probability distribution quantifying the analyst's state of knowledge regarding the parameter to be estimated prior to collection of new data.

1.6.48 Probable Maximum Loss (PML). The loss due to a single fire scenario, which assumes an impairment to one suppression system and a possible delay in manual fire-fighting response.

1.6.49 Probabilistic Safety Assessment (PSA). A comprehensive evaluation of the risk of a facility or process; also referred to as a probabilistic risk assessment (PRA).

1.6.50 PWR. Pressurized water reactor.

1.6.51 Radiant Energy Shield. A device utilized to protect components from the effects of radiant heat generated by a fire.

1.6.52 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.

1.6.53 Reliability. The probability that the system, structure, or component of interest will function without failure for a given interval of time or number of cycles. For standby systems, structures, or components, this includes the probability of success upon demand.

1.6.54 Risk. The set of probabilities and consequences for all possible accident scenarios associated with a given plant or process.

1.6.55* Risk Informed Approach. A philosophy whereby risk insights are considered 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.

1.6.56 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.

1.6.57 Shall. Indicates a mandatory requirement.

1.6.58 Site. Refers to 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.

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

1.6.60 Source Term Limitation. Limiting the source of radiation available for release.

1.6.61* 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.

1.6.62* Through Penetration Fire Stop. A tested, fire-rated construction consisting of the materials that fill the openings through the wall or floor opening around penetrating items such as cables, cable trays, conduits, ducts, and pipes and their means of support to prevent the spread of fire.

1.6.63 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 Completeness Uncertainty, Model Uncertainty, and Parameter Uncertainty.)

1.7 Equivalency. Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard. Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency. The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

1.8 Code of Record. The codes and standards referenced in this standard refer to the edition of the code or standard in effect at the time the fire protection systems or feature was designed or specifically committed to the authority having jurisdiction.

Chapter 2 Methodology

2.1 Intent. This chapter describes the general approach for establishing the fire protection requirements for a nuclear power plant. The chapter shall provide the requirements for the engineering analyses used to establish the required fire protection systems and features, including in particular the analyses used to support the performance-based fire protection design that fulfills the goals, objectives, and criteria provided in Chapter 1.

2.2 General Approach. The general approach of this standard shall involve the following steps in accordance with Figure 2.2:

(a) Establish the fundamental fire protection program *(see Chapter 3).*

(b) Identify fire areas and associated fire hazards.

(c) Identify the performance criteria that apply to each fire area *(see Section 1.5).*

(d) Identify systems, structures, and components (SSCs) in each fire area to which the performance criteria apply.

(e) Select the deterministic and/or performance-based approach for the performance criteria *(see Chapter 4).*

(f) When applying a deterministic approach, demonstrate compliance with the deterministic requirements *(see Chapter 4).*

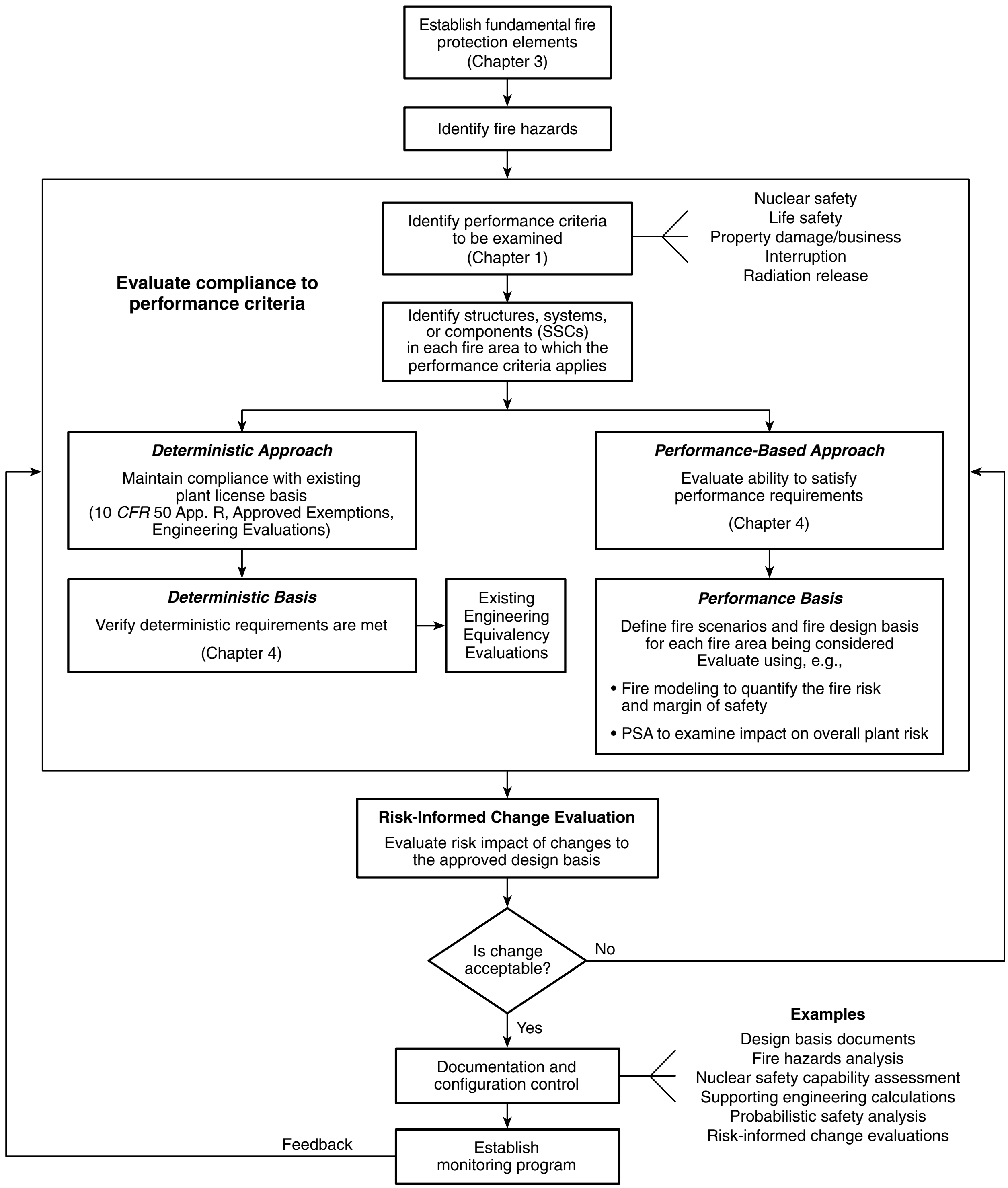
(g) When applying a performance-based approach, perform engineering analyses to demonstrate that performance-based requirements are satisfied. These analyses shall include, for example, engineering evaluations, probabilistic safety assessments, or fire modeling calculations *(see Section 2.4).*

(h)*Perform the plant change evaluation that demonstrates that changes in risk, defense-in-depth, and safety margins are acceptable *(see 2.4.4).* If any one of these is unacceptable, additional fire protection features or other alternatives shall be implemented.

(i) Develop a monitoring program to monitor plant performance as it applies to fire risk. This program shall provide feedback for adjusting the fire protection program, as necessary *(see Section 2.6).*

(j) For the resulting plant fire protection program, provide adequate documentation, ensure the quality of the analyses, and maintain configuration control of the resulting plant design and operation *(see Section 2.7).*

FIGURE 2.2 Methodology.



2.2.1 Fundamental Fire Protection Program and Design Elements. The fundamental fire protection program and design elements shall include the fire protection features and systems described in Chapter 3 of this standard.

2.2.2* Fire Hazards Identification. The fire area boundaries and fire hazards shall be identified.

2.2.3 Evaluating Performance Criteria. To determine whether plant design will satisfy the appropriate performance criteria, an analysis shall be performed on a fire area basis, given the potential fire exposures and damage thresholds, using either a deterministic or performance-based approach.

2.2.4 Performance Criteria. The performance criteria for nuclear safety, radioactive release, life safety, and property damage/business interruption covered by this standard are listed in Section 1.5 and shall be examined on a fire area basis.

2.2.5 Identify Systems, Structures, and Components (SSCs). The SSCs required to achieve the selected performance criteria shall be identified on a fire area basis.

2.2.6* Deterministic Approach. Compliance with the deterministic requirements in Chapter 4 shall be an acceptable alternative to the performance-based approach and shall be considered to satisfy the performance criteria established in Section 1.5.

2.2.7* Existing Engineering Equivalency Evaluations. When applying a deterministic approach, the user shall be permitted to demonstrate compliance with specific deterministic fire protection design requirements in Chapter 4 for existing configurations with an engineering equivalency evaluation. These existing engineering evaluations shall clearly demonstrate an equivalent level of fire protection compared to the deterministic requirements.

2.2.8* Performance-Based Approach. The performance-based approach to satisfy the nuclear safety, radiation release, life safety, and property damage/business interruption performance criteria requires engineering analyses to evaluate whether the performance criteria are satisfied. Engineering analyses shall be performed in accordance with Section 2.3.

2.2.9 Plant Change Evaluation. In the event of a change to a previously approved fire protection program element, a risk-informed plant change evaluation shall be performed and the results used as described in 2.4.4 to ensure that the public risk associated with fire-induced nuclear fuel damage accidents is low and that adequate defense-in-depth and safety margins are maintained.

2.2.10 Monitoring Program. A monitoring program shall be established to assess the performance of the fire protection program in meeting the performance criteria established in this standard. *(See Section 2.3.)*

2.2.11 Documentation and Design Configuration Control. The fire protection program documentation shall be developed and maintained in such a manner that facility design and procedural changes that could affect the fire protection engineering analysis assumptions can be identified and analyzed. *(See Section 2.3.)*

2.3 Assumptions. The following assumptions are provided to perform a deterministic analysis of ensuring the nuclear safety performance criteria are met. [Performance-based information (i.e., equipment out of service, equipment failure unrelated to the fire, concurrent design basis events) are integral parts of a PSA and shall be considered when performance based approaches are utilized.]

(1) Independent failures (i.e., failures that are not a direct consequence of fire damage) of systems, equipment, instrumentation, controls, or power supplies relied upon to achieve the nuclear safety performance criteria do not occur before, during, or following the fire. Therefore, contrary to other nuclear power plant design basis events, a concurrent single active failure is not required to be postulated.
(2) No abnormal system transients, behavior, or design basis accidents precede the onset of the fire, nor do any of these events, which are not a direct consequence of fire damage, occur during or following the fire.

2.4 Engineering Analyses. Engineering analysis is an acceptable means of evaluating a fire protection program against performance criteria. Engineering analyses shall be permitted to be qualitative or quantitative in accordance with Figure 2.4.

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 Section 2.4 for the plant area being analyzed.

2.4.1 Fire Modeling Calculations.

2.4.1.1 Application of Fire Modeling Calculations. The fire modeling process shall be permitted to be used to examine the impact of the different fire scenarios against the performance criteria under consideration.

2.4.1.2 Fire Models.

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

2.4.1.2.2 Limitations of Use. Fire models shall only be applied within the limitations of that fire model. *(See Appendix C.)*

2.4.1.2.3 Validation of Models. The fire models shall be verified and validated.

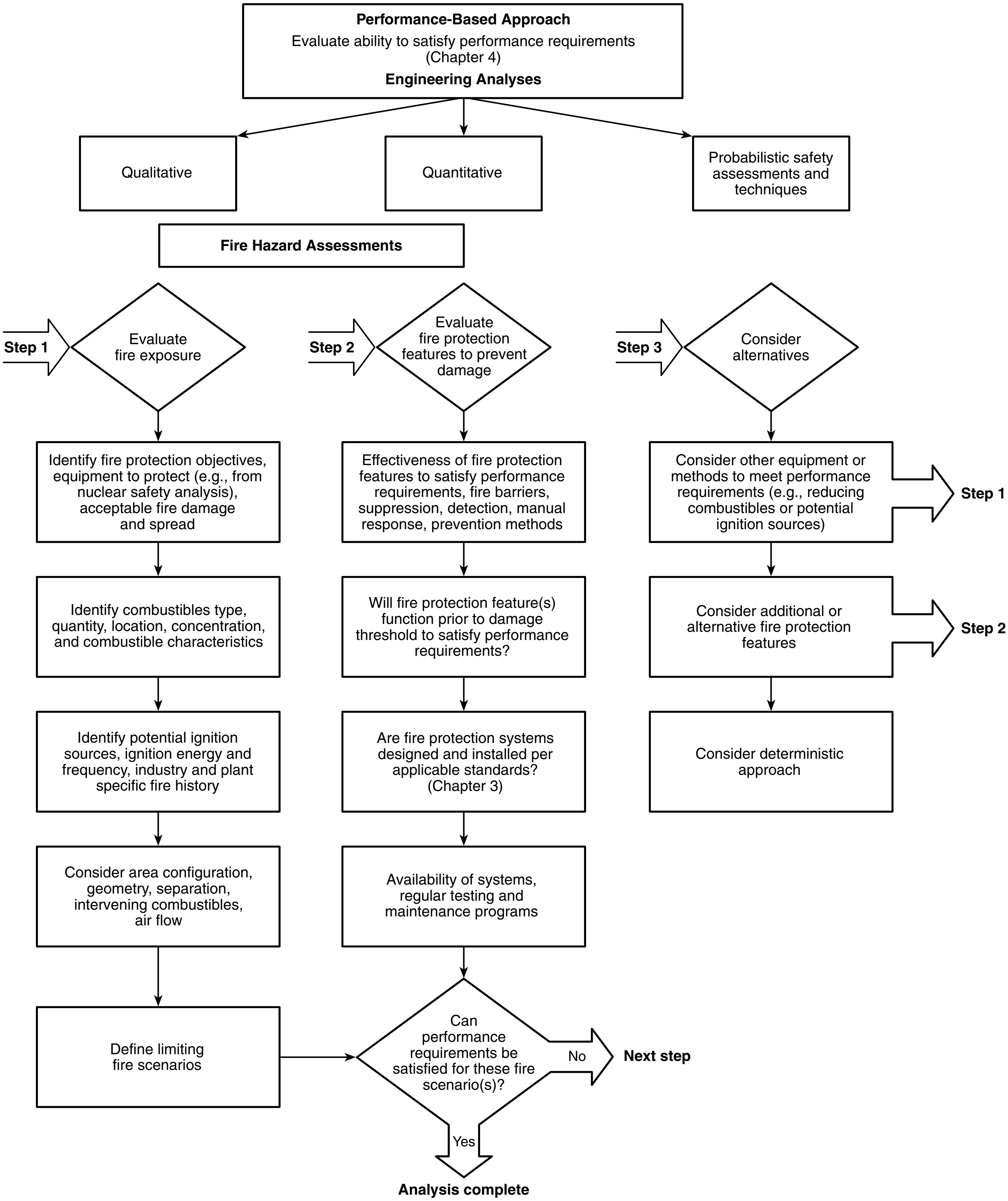
2.4.1.3 Fire Scenarios. When using fire modeling, a set of fire scenarios shall be defined for each plant area being modeled *(see Appendix C)*. The fire scenarios shall establish the conditions under which a proposed solution is expected to meet the performance criteria. These fire scenarios shall become the fire protection design basis associated with the performance objective for that area. The set of fire scenarios for each plant area shall include the following:

(1) Maximum expected fire scenarios
(2) Limiting fire scenario(s)

2.4.1.4 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.

(a) *Combustible Materials.* The type, quantity, location, concentration, and combustion characteristics (e.g., ignition temperature, flash point, growth rate, heat release rate, radiant heat flux) of in situ and expected transient combustible materials shall be considered in defining the area fire scenarios.

FIGURE 2.4 Engineering analysis.



(b) *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.

(c) *Plant Area Configuration.* The area, zone, or room configuration shall consider the plant construction surrounding the area, area geometry (e.g., volume, ceiling height, floor area, and openings), geometry between combustibles, ignition sources, targets, and surrounding barriers.

(d) *Fire Protection Systems and Features.* Those fire protection systems and features (i.e., fire protection suppression and detection systems, fire barriers, manual suppression capability) in the area that could mitigate the effects of the fire shall be evaluated.

(e) *Ventilation Effects.* Natural ventilation or forced ventilation effects (e.g., forced air, ventilation openings from doors and windows, ventilation controlled fire versus fuel controlled fire) shall be evaluated.

(f) *Personnel.* The approximate number and locations of plant personnel both within the plant area being considered and immediately adjacent to it shall be specified. Possible evacuation routes shall be identified for both nonessential and essential personnel. Personnel actions that can influence the fire scenario shall be evaluated.

2.4.2 Nuclear Safety Capability Assessment. The purpose of this section is to define the methodology for performing a nuclear safety capability assessment. The following steps shall be performed:

(1) Selection of systems and equipment and their interrelationships necessary to achieve the nuclear safety performance criteria in Chapter 1
(2) Selection of cables necessary to achieve the nuclear safety performance criteria in Chapter 1
(3) Identification of the location of nuclear safety equipment and cables
(4) Assessment of the ability to achieve the nuclear safety performance criteria given a fire in each fire area

Steps 1 through 4 shall be performed to determine equipment and cables that shall be evaluated using either the deterministic or performance-based method in Chapter 4. Other performance-based or risk-informed methods acceptable to the authority having jurisdiction (AHJ) shall be permitted.

2.4.2.1 Nuclear Safety Capability Systems and Equipment Selection. A comprehensive list of systems and equipment and their interrelationships to be analyzed for a fire event shall be developed. The equipment list shall contain an inventory of those critical components required to achieve the nuclear safety performance criteria of Section 1.5. Components required to achieve and maintain the nuclear safety functions and components whose fire-induced failure could prevent the operation or result in the maloperation of those components needed to meet the nuclear safety criteria shall be included. Availability and reliability of equipment selected shall be evaluated. *(See Appendix B for acceptable methods used to identify equipment.)*

2.4.2.2 Nuclear Safety Capability Circuit Analysis.

2.4.2.2.1 Circuits Required in Nuclear Safety Functions. Circuits required for the nuclear safety functions shall be identified. This includes circuits that are required for operation, that could prevent the operation, or that result in the maloperation of the equipment identified in 2.4.2.1. This evaluation shall consider fire-induced failure modes such as hot shorts (external and internal), open circuits, and shorts to ground, to identify circuits that are required to support the proper operation of components required to achieve the nuclear safety performance criteria, including spurious operation and signals. This will ensure that a comprehensive population of circuitry is evaluated. *(See Appendix B for considerations in analyzing circuits.)*

2.4.2.2.2 Other Required Circuits. Other circuits that share common power supply and/or common enclosure with circuits required to achieve nuclear safety performance criteria shall be evaluated for their impact on the ability to achieve nuclear safety performance criteria.

(a) *Common Power Supply Circuits.* Those circuits whose fire-induced failure could cause the loss of a power supply required to achieve the nuclear safety performance criteria shall be identified. This situation could occur if the upstream protection device (i.e., breaker or fuse) is not properly coordinated with the downstream protection device. *(See Appendix B for considerations when analyzing common power supply concerns.)*

(b) *Common Enclosure Circuits.* Those circuits that share enclosures with circuits required to achieve the nuclear safety performance criteria and whose fire-induced failure could cause the loss of the required components shall be identified. The concern is that the effects of a fire can extend outside of the immediate fire area due to fire-induced electrical faults on inadequately protected cables or via inadequately sealed fire area boundaries. *(See Appendix B for considerations when analyzing common enclosure concerns.)*

2.4.2.3* Nuclear Safety Equipment and Cable Location. Physical location of equipment and cables shall be identified. *(See Appendix B for considerations when identifying locations.)*

2.4.2.4 Fire Area Assessment. An engineering analysis shall be performed in accordance with the requirements of Section 2.3 for each fire area to determine the effects of fire or fire suppression activities on the ability to achieve the nuclear safety performance criteria of Section 1.5. *[See Chapter 4 for methods of achieving these performance criteria (performance-based or deterministic). (See Appendix B for considerations when performing the fire area assessments.)*

2.4.3* Fire Risk Evaluations. The PSA methods, tools, and data used to provide risk information for the performance-based evaluation of fire protection features (*see 4.2.4.2*) or provide risk information to the change analysis described in 2.4.4 shall conform with the requirements in 2.4.3.1 through 2.4.3.3.

2.4.3.1* The PSA evaluation shall use core damage frequency (CDF) and large early release frequency (LERF) as measures for risk.

2.4.3.2* The PSA evaluation shall address the risk contribution associated with all potentially risk-significant fire scenarios.

2.4.3.3* The PSA approach, methods, and data shall be acceptable to the AHJ. They shall be appropriate for the nature and scope of the change being evaluated, be based on the as-built and as-operated and maintained plant, and reflect the operating experience at the plant. *(See Appendix D for acceptable methods used to perform the fire risk evaluation.)*

2.4.4* Plant Change Evaluation. A plant change evaluation shall be performed to ensure that a change to a previously approved fire protection program element is acceptable. The evaluation process shall consist of an integrated assessment of the acceptability of risk, defense-in-depth, and safety margins.

The impact of the proposed change shall be monitored *(see Section 2.6)*.

2.4.4.1* Risk Acceptance Criteria. The change in public health risk from any plant change shall be acceptable to the AHJ. CDF and LERF shall be used to determine the acceptability of the change.

When more than one change is proposed, additional requirements shall apply. If previous changes have increased risk but have met the acceptance criteria, the cumulative effect of those changes shall be evaluated. 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.

2.4.4.2* Defense-in-Depth. The plant change evaluation shall ensure that the philosophy of defense-in-depth is maintained, relative to fire protection *(see Section 1.2)* and nuclear safety. The deterministic approach for meeting the performance criteria shall be deemed to satisfy this defense-in-depth requirement.

2.4.4.3* Safety Margins. The plant change evaluation shall ensure that sufficient safety margins are maintained. The deterministic approach for meeting the performance criteria shall be deemed to satisfy this safety margins requirement.

2.5* Evaluating the Damage Threshold. When using fire modeling or when doing analysis in support of the performance-based approach, damage thresholds for important SSCs and limiting conditions for plant personnel shall be defined. 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)
(4) *Tenability.* The effects of smoke and heat on personnel actions

2.6* Monitoring. A monitoring program shall be established 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. Monitoring shall ensure that the assumptions in the engineering analysis remain valid.

2.6.1 Availability, Reliability, and Performance Levels. Acceptable levels of availability, reliability, and performance shall be established.

2.6.2 Monitoring Availability, Reliability, and Performance. Methods to monitor availability, reliability, and performance shall be established. The methods shall consider the plant operating experience and industry operating experience.

2.6.3 Corrective Action. If the established levels of availability, reliability, or performance are not met, appropriate corrective actions to return to the established levels shall be implemented. Monitoring shall be continued to ensure that the corrective actions are effective.

2.7 Program Documentation, Configuration Control, and Quality.

2.7.1 Content.

2.7.1.1 General. The analyses performed to demonstrate compliance with this standard shall be documented for each nuclear power plant (NPP). The intent of the documentation is that the assumptions be clearly defined and that 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. Documentation shall be maintained for the life of the plant and be organized carefully so that it can be checked for adequacy and accuracy either by an independent reviewer or by the AHJ.

2.7.1.2* Fire Protection Program Design Basis Document. A fire protection program design basis document shall be established based on those documents, analyses, engineering evaluations, calculations, and so forth that define the fire protection design basis for the plant. As a minimum, this document shall include fire hazards identification and nuclear safety capability assessment, on a fire area basis, for all fire areas that could affect the nuclear safety or radioactive release performance criteria defined in Chapter 1.

2.7.1.3* Supporting Documentation. Detailed information used to develop and support the principal document shall be referenced as separate documents if not included in the principal document.

2.7.2 Configuration Control.

2.7.2.1 Design Basis Document. The design basis document shall be maintained up-to-date as a controlled document. Changes affecting the design, operation, or maintenance of the plant shall be reviewed to determine if these changes impact the fire protection program documentation.

2.7.2.2 Supporting Documentation. Detailed supporting information shall be retrievable records. Records shall be revised as needed to maintain the principal documentation up-to-date.

2.7.3* Quality.

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

2.7.3.2* Verification and Validation. Each calculational model or numerical method used shall be verified and validated through comparison to test results or comparison to other acceptable models.

2.7.3.3 Limitations of Use. Acceptable engineering methods and numerical models shall only be used for applications to the extent these methods have been subject to verification and validation. These engineering methods shall only be applied within the scope, limitations, and assumptions prescribed for that method.

2.7.3.4 Qualification of Users. Cognizant personnel who use and apply engineering analysis and numerical models (e.g., fire modeling techniques) 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.

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

Chapter 3 Fundamental Fire Protection Program and Design Elements

3.1* General. This chapter contains the fundamental elements of the fire protection program and specifies the minimum design requirements for fire protection systems and features. These fire protection program elements and minimum design requirements shall not be subject to the performance-based methods permitted elsewhere in this standard. Previously approved alternatives from the fundamental protection program attributes of this chapter by the AHJ take precedence over the requirements contained herein.

3.2 Fire Protection Plan.

3.2.1 Intent. A site-wide fire protection plan shall be established. This plan shall document management policy and program direction and shall define the responsibilities of those individuals responsible for the plan's implementation. This section establishes the criteria for an integrated combination of components, procedures, and personnel to implement all fire protection program activities.

3.2.2* Management Policy Direction and Responsibility. A policy document shall be prepared that defines management authority and responsibilities and establishes the general policy for the site fire protection program.

3.2.2.1* The policy document shall designate the senior management position with immediate authority and responsibility for the fire protection program.

3.2.2.2* The policy document shall designate a position responsible for the daily administration and coordination of the fire protection program and its implementation.

3.2.2.3* The policy document shall define the fire protection interfaces with other organizations and assign responsibilities for the coordination of activities. In addition, this policy document shall identify the various plant positions having the authority for implementing the various areas of the fire protection program.

3.2.2.4* The policy document shall identify the appropriate AHJ for the various areas of the fire protection program.

3.2.3* Procedures. Procedures shall be established for implementation of the fire protection program. In addition to procedures that could be required by other sections of the standard, the procedures to accomplish the following shall be established:

(1)* Inspection, testing, and maintenance for fire protection systems and features credited by the fire protection program
(2)* Compensatory actions implemented when fire protection systems and other systems credited by the fire protection program and this standard cannot perform their intended function and limits on impairment duration
(3)* Reviews of fire protection program — related performance and trends
(4) Reviews of physical plant modifications and procedure changes for impact on the fire protection program
(5) Long-term maintenance and configuration of the fire protection program
(6) Emergency response procedures for the plant industrial fire brigade

3.3 Prevention. A fire prevention program with the goal of preventing a fire from starting shall be established, documented, and implemented as part of the fire protection program. The two basic components of the fire prevention program shall consist of both of the following:

(1) Prevention of fires and fire spread by controls on operational activities
(2) Design controls that restrict the use of combustible materials

The design control requirements listed in the remainder of this section shall be provided as described.

3.3.1 Fire Prevention for Operational Activities. The fire prevention program activities shall consist of the necessary elements to address the control of ignition sources and the use of transient combustible materials during all aspects of plant operations. The fire prevention program shall focus on the human and programmatic elements necessary to prevent fires from starting or, should a fire start, to keep the fire as small as possible.

3.3.1.1 General Fire Prevention Activities. The fire prevention activities shall include but not be limited to the following program elements:

(1) Training on fire safety information for all employees and contractors including, as a minimum, familiarization with plant fire prevention procedures, fire reporting, and plant emergency alarms
(2)* Documented plant inspections including provisions for corrective actions for conditions where unanalyzed fire hazards are identified
(3)* Administrative controls addressing the review of plant modifications and maintenance to ensure that both fire hazards and the impact on plant fire protection systems and features are minimized

3.3.1.2* Control of Combustible Materials. Procedures for the control of general housekeeping practices and the control of transient combustibles shall be developed and implemented. These procedures shall include but not be limited to the following program elements:

(1)* Wood used within the power block shall be listed pressure-impregnated or coated with a listed fire-retardant application.

Exception: Cribbing timbers 6 in. by 6 in. (15.2 cm by 15.2 cm) or larger shall not be required to be fire-retardant treated.

(2) Plastic sheeting materials used in the power block shall be fire-retardant types that have passed NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films*, large-scale tests, or equivalent.
(3) Waste, debris, scrap, packing materials, or other combustibles shall be removed from an area immediately following the completion of work or at the end of the shift, whichever comes first.
(4)* Combustible storage or staging areas shall be designated, and limits shall be established on the types and quantities of stored materials.
(5)* Controls on use and storage of flammable and combustible liquids shall be in accordance with NFPA 30, *Flammable and Combustible Liquids Code*, or other applicable NFPA standards.
(6)* Controls on use and storage of flammable gases shall be in accordance with applicable NFPA standards.

3.3.1.3 Control of Ignition Sources.

3.3.1.3.1* A hot work safety procedure shall be developed, implemented, and periodically updated as necessary in accordance with NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work,* and NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations.*

3.3.1.3.2 Smoking and other possible sources of ignition shall be restricted to properly designated and supervised safe areas of the plant.

3.3.1.3.3 Open flames or combustion-generated smoke shall not be permitted for leak or air flow testing.

3.3.1.3.4* Plant administrative procedure shall control the use of portable electrical heaters in the plant. Portable fuel-fired heaters shall not be permitted in plant areas containing equipment important to nuclear safety or where there is a potential for radiological releases resulting from a fire.

3.3.2 Structural. Walls, floors, and components required to maintain structural integrity shall be of noncombustible construction, as defined in NFPA 220, *Standard on Types of Building Construction.*

3.3.3 Interior Finishes. Interior wall or ceiling finish classification shall be in accordance with NFPA *101*®, *Life Safety Code*®, requirements for Class A materials. Interior floor finishes shall be in accordance with NFPA *101* requirements for Class I interior floor finishes.

3.3.4 Insulation Materials. Thermal insulation materials, radiation shielding materials, ventilation duct materials, and soundproofing materials shall be noncombustible or limited combustible.

3.3.5 Electrical.

3.3.5.1 Wiring above suspended ceiling shall be kept to a minimum. Where installed, electrical wiring shall be listed for plenum use, routed in armored cable, routed in metallic conduit, or routed in cable trays with solid metal top and bottom covers.

3.3.5.2 Only metal tray and metal conduits shall be used for electrical raceways. Thin wall metallic tubing shall not be used for power, instrumentation, or control cables. Flexible metallic conduits shall only be used in short lengths to connect components.

3.3.5.3* Electric cable construction shall comply with a flame propagation test as acceptable to the AHJ.

Exception: Existing cable in place prior to the adoption of this standard shall be permitted to remain as is.

3.3.6 Roofs. Metal roof deck construction shall be designed and installed so the roofing system will not sustain a self-propagating fire on the underside of the deck when the deck is heated by a fire inside the building. Roof coverings shall be Class A as determined by tests described in NFPA 256, *Standard Methods of Fire Tests of Roof Coverings.*

3.3.7 Bulk Flammable Gas Storage. Bulk compressed or cryogenic flammable gas storage shall not be permitted inside structures housing systems, equipment, or components important to nuclear safety.

3.3.7.1 Storage of flammable gas shall be located outdoors, or in separate detached buildings, so that a fire or explosion will not adversely impact systems, equipment, or components important to nuclear safety. NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites,* shall be followed for hydrogen storage.

3.3.7.2 Outdoor high-pressure flammable gas storage containers shall be located so that the long axis is not pointed at buildings.

3.3.7.3 Flammable gas storage cylinders not required for normal operation shall be isolated from the system.

3.3.8 Bulk Storage of Flammable and Combustible Liquids. Bulk storage of flammable and combustible liquids shall not be permitted inside structures containing systems, equipment, or components important to nuclear safety. As a minimum, storage and use shall comply with NFPA 30, *Flammable and Combustible Liquids Code.*

3.3.9* Transformers. Where provided, transformer oil collection basins and drain paths shall be periodically inspected to ensure that they are free of debris and capable of performing their design function.

3.3.10* Hot Pipes and Surfaces. Combustible liquids, including high flashpoint lubricating oils, shall be kept from coming in contact with hot pipes and surfaces, including insulated pipes and surfaces. Administrative controls shall require the prompt cleanup of oil on insulation.

3.3.11 Electrical Equipment. Adequate clearance, free of combustible material, shall be maintained around energized electrical equipment.

3.3.12* Reactor Coolant Pumps. For facilities with non-inerted containments, reactor coolant pumps with an external lubrication system shall be provided with an oil collection system. The oil collection system shall be designed and installed such that leakage from the oil system is safely contained for off normal conditions such as accident conditions or earthquakes. All of the following shall apply.

(1) The oil collection system for each reactor coolant pump shall be capable of collecting lubricating oil from all potential pressurized and nonpressurized leakage sites in each reactor coolant pump oil system.
(2) Leakage shall be collected and drained to a vented closed container that can hold the inventory of the reactor coolant pump lubricating oil system.
(3) A flame arrestor is required in the vent if the flash point characteristics of the oil present the hazard of a fire flashback.
(4) Leakage points on a reactor coolant pump motor to be protected shall include but not be limited to the lift pump and piping, overflow lines, oil cooler, oil fill and drain lines and plugs, flanged connections on oil lines, and the oil reservoirs, where such features exist on the reactor coolant pumps.
(5) The collection basin drain line to the collection tank shall be large enough to accommodate the largest potential oil leak such that oil leakage does not overflow the basin.

3.4 Industrial Fire Brigade.

3.4.1 On-Site Fire-Fighting Capability. All of the following requirements shall apply.

(a) A fully staffed, trained, and equipped fire-fighting force shall be available at all times to control and extinguish all fires on site. This force shall have a minimum complement of five persons on duty and shall conform with the following NFPA standards as applicable:

(1) NFPA 600, *Standard on Industrial Fire Brigades* (interior structural fire fighting)
(2) NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*
(3) NFPA 1582, *Standard on Medical Requirements for Fire Fighters and Information for Fire Department Physicians*

(b)*Industrial fire brigade members shall have no other assigned normal plant duties that would prevent immediate response to a fire or other emergency as required.

(c) During every shift, the brigade leader and at least two brigade members shall have sufficient training and knowledge of nuclear safety systems to understand the effects of fire and fire suppressants on nuclear safety performance criteria.

Exception to (c): Sufficient training and knowledge shall be permitted to be provided by an operations advisor dedicated to industrial fire brigade support.

(d)*The industrial fire brigade shall be notified immediately upon verification of a fire.

(e) Each industrial fire brigade member shall pass an annual physical examination to determine that he or she can perform the strenuous activity required during manual fire-fighting operations. The physical examination shall determine the ability of each member to use respiratory protection equipment.

3.4.2* Pre-Fire Plans. Current and detailed pre-fire plans shall be available to the industrial fire brigade for all areas in which a fire could jeopardize the ability to meet the performance criteria described in Section 1.5.

3.4.2.1* The plans shall detail the fire area configuration and fire hazards to be encountered in the fire area, along with any nuclear safety components and fire protection systems and features that are present.

3.4.2.2 Pre-fire plans shall be reviewed and updated as necessary.

3.4.2.3* Pre-fire plans shall be available in the control room and made available to the plant industrial fire brigade.

3.4.2.4* Pre-fire plans shall address coordination with other plant groups during fire emergencies.

3.4.3 Training and Drills. Industrial fire brigade members and other plant personnel who would respond to a fire in conjunction with the brigade shall be provided with training commensurate with their emergency responsibilities.

(a) *Plant Industrial Fire Brigade Training.* All of the following requirements shall apply.

(1) Plant industrial fire brigade members shall receive training consistent with the requirements contained in NFPA 600, *Standard on Industrial Fire Brigades*, or NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*, as appropriate.
(2) Industrial fire brigade members shall be given quarterly training and practice in fire fighting, including radioactivity and health physics considerations, to ensure that each member is thoroughly familiar with the steps to be taken in the event of a fire.
(3) A written program shall detail the industrial fire brigade training program.
(4) Written records that include but are not limited to initial industrial fire brigade classroom and hands-on training, refresher training, special training schools attended, drill attendance records, and leadership training for industrial fire brigades shall be maintained for each industrial fire brigade member.

(b) *Training for Non-Industrial Fire Brigade Personnel.* Plant personnel who respond with the industrial fire brigade shall be trained as to their responsibilities, potential hazards to be encountered, and interfacing with the industrial fire brigade.

(c)**Drills.* All of the following requirements shall apply.

(1) Drills shall be conducted quarterly for each shift to test the response capability of the industrial fire brigade.
(2) Industrial fire brigade drills shall be developed to test and challenge industrial fire brigade response, including brigade performance as a team, proper use of equipment, effective use of pre-fire plans, and coordination with other groups. These drills shall evaluate the industrial fire brigade's abilities to react, respond, and demonstrate proper fire-fighting techniques to control and extinguish the fire and smoke conditions being simulated by the drill scenario.
(3) Industrial fire brigade drills shall be conducted in various plant areas, especially in those areas identified to be essential to plant operation and to contain significant fire hazards.
(4) Drill records shall be maintained detailing the drill scenario, industrial fire brigade member response, and ability of the industrial fire brigade to perform as a team.
(5) A critique shall be held and documented after each drill.

3.4.4 Fire-Fighting Equipment. Protective clothing, respiratory protective equipment, radiation monitoring equipment, personal dosimeters, and fire suppression equipment such as hoses, nozzles, fire extinguishers, and other needed equipment shall be provided for the industrial fire brigade. This equipment shall conform with the applicable NFPA standards.

3.4.5 Off-Site Fire Department Interface.

3.4.5.1 Mutual Aid Agreement. Off-site fire authorities shall be offered a plan for their interface during fires and related emergencies on site.

3.4.5.2* Site-Specific Training. Fire fighters from the off-site fire authorities who are expected to respond to a fire at the plant shall be offered site-specific training and shall be invited to participate in a drill at least annually.

3.4.5.3* Security and Radiation Protection. Plant security and radiation protection plans shall address off-site fire authority response.

3.4.6* Communications. An effective emergency communications capability shall be provided for the industrial fire brigade.

3.5 Water Supply.

3.5.1 A fire protection water supply of adequate reliability, quantity, and duration shall be provided by one of the two following methods.

(a) Provide a fire protection water supply of not less than two separate 300,000-gal (1,135,500-L) supplies.

(b) Calculate the fire flow rate for 2 hours. This fire flow rate shall be based on 500 gpm (1892.5 L/min) for manual hose streams plus the largest design demand of any sprinkler or fixed water spray system(s) in the power block as determined in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems,* or NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection.* The fire water supply shall be capable of delivering this design demand with the hydraulically least demanding portion of fire main loop out of service.

3.5.2* The tanks shall be interconnected such that fire pumps can take suction from either or both. A failure in one tank or its piping shall not allow both tanks to drain. The tanks shall be designed in accordance with NFPA 22, *Standard for Water Tanks for Private Fire Protection.*

Exception No. 1: Water storage tanks shall not be required when fire pumps are able to take suction from a large body of water (such as a lake), provided each fire pump has its own suction and both suctions and pumps are adequately separated.

Exception No. 2: Cooling tower basins shall be an acceptable water source for fire pumps when the volume is sufficient for both purposes and water quality is consistent with the demands of the fire service.

3.5.3* Fire pumps, designed and installed in accordance with NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*, shall be provided to ensure that 100 percent of the required flow rate and pressure are available assuming failure of the largest pump or pump power source.

3.5.4 At least one diesel engine-driven fire pump or two more seismic Category I Class IE electric motor-driven fire pumps connected to redundant Class IE emergency power buses capable of providing 100 percent of the required flow rate and pressure shall be provided.

3.5.5 Each pump and its driver and controls shall be separated from the remaining fire pumps and from the rest of the plant by rated fire barriers.

3.5.6 Fire pumps shall be provided with automatic start and manual stop only.

3.5.7 Individual fire pump connections to the yard fire main loop shall be provided and separated with sectionalizing valves between connections.

3.5.8 A method of automatic pressure maintenance of the fire protection water system shall be provided independent of the fire pumps.

3.5.9 Means shall be provided to immediately notify the control room, or other suitable constantly attended location, of operation of fire pumps.

3.5.10 An underground yard fire main loop, designed and installed in accordance with NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*, shall be installed to furnish anticipated water requirements.

3.5.11 Means shall be provided to isolate portions of the yard fire main loop for maintenance or repair without simultaneously shutting off the supply to both fixed fire suppression systems and fire hose stations provided for manual backup. Sprinkler systems and manual hose station standpipes shall be connected to the plant fire protection water main so that a single active failure or a crack to the water supply piping to these systems can be isolated so as not to impair both the primary and backup fire suppression systems.

3.5.12 Threads compatible with those used by local fire departments shall be provided on all hydrants, hose couplings, and standpipe risers.

Exception: Fire departments shall be permitted to be provided with adapters that allow interconnection between plant equipment and the fire department equipment if adequate training and procedures are provided.

3.5.13 Headers fed from each end shall be permitted inside buildings to supply both sprinkler and standpipe systems, provided steel piping and fittings meeting the requirements of ANSI B31.1, *Code for Power Piping*, are used for the headers (up to and including the first valve) supplying the sprinkler systems where such headers are part of the seismically analyzed hose standpipe system. Where provided, such headers shall be considered an extension of the yard main system. Each sprinkler and standpipe system shall be equipped with an outside screw and yoke (OS&Y) gate valve or other approved shutoff valve.

3.5.14* All fire protection water supply and fire suppression system control valves shall be under a periodic inspection program and shall be supervised by one of the following methods.

(a) Electrical supervision with audible and visual signals in the main control room or other suitable constantly attended location.

(b) Locking valves in their normal position. Keys shall be made available only to authorized personnel.

(c) Sealing valves in their normal positions. This option shall be utilized only where valves are located within fenced areas or under the direct control of the owner/operator.

3.5.15 Hydrants shall be installed approximately every 250 ft (76 m) apart on the yard main system. A hose house equipped with hose and combination nozzle and other auxiliary equipment specified in NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances,* shall be provided at intervals of not more than 1000 ft (305 m) along the yard main system.

Exception: Mobile means of providing hose and associated equipment, such as hose carts or trucks, shall be permitted in lieu of hose houses. Where provided, such mobile equipment shall be equivalent to the equipment supplied by three hose houses.

3.5.16* The fire protection water supply system shall be dedicated for fire protection use only.

Exception No. 1: Fire protection water supply systems shall be permitted to be used to provide backup to nuclear safety systems, provided the fire protection water supply systems are designed and maintained to deliver the combined fire and nuclear safety flow demands for the duration specified by the applicable analysis.

Exception No. 2: Fire protection water storage can be provided by plant systems serving other functions, provided the storage has a dedicated capacity capable of providing the maximum fire protection demand for the specified duration as determined in this section.

3.6 Standpipe and Hose Stations.

3.6.1 For all power block buildings, Class III standpipe and hose systems shall be installed in accordance with NFPA 14, *Standard for the Installation of Standpipe, Private Hydrant, and Hose Systems.*

3.6.2 A capability shall be provided to ensure an adequate water flow rate and nozzle pressure for all hose stations. This capability includes the provision of hose station pressure reducers where necessary for the safety of plant industrial fire brigade members and off-site fire department personnel.

3.6.3 The proper type of hose nozzle to be supplied to each power block area shall be based on the area fire hazards. The usual combination spray/straight stream nozzle shall not be used in areas where the straight stream can cause unacceptable damage or present an electrical hazard to fire-fighting personnel. Listed electrically safe fixed fog nozzles shall be provided at locations where high-voltage shock hazards exist. All hose nozzles shall have shutoff capability and be able to control water flow from full open to full closed.

3.6.4 Provisions shall be made to supply water at least to standpipes and hose stations for manual fire suppression in all areas containing systems and components needed to perform the nuclear safety functions in the event of a safe shutdown earthquake (SSE).

Exception: For existing plants that are not capable of meeting this requirement, provisions to restore a water supply and distribution system for manual fire-fighting purposes shall be made. This provisional manual fire-fighting standpipe/hose station system shall be capable of providing manual fire-fighting protection to the various plant locations important to supporting and maintaining the nuclear safety function. The provisions for establishing this provisional system shall be preplanned and be capable of being implemented in a timely manner following an SSE.

3.6.5 Where the seismic required hose stations are cross-connected to essential seismic non-fire protection water supply systems, the fire flow shall not degrade the essential water system requirement.

3.7 Fire Extinguishers. Where provided, fire extinguishers of the appropriate number, size, and type shall be provided in accordance with NFPA 10, *Standard for Portable Fire Extinguishers.* Extinguishers shall be permitted to be positioned outside of fire areas due to radiological conditions.

3.8 Fire Alarm and Detection Systems.

3.8.1 Fire Alarm. Alarm initiating devices shall be installed in accordance with NFPA 72, *National Fire Alarm Code®*. Alarm annunciation shall allow the proprietary alarm system to transmit fire-related alarms, supervisory signals, and trouble signals to the control room or other constantly attended location from which required notifications and response can be initiated. Personnel assigned to the proprietary alarm station shall be permitted to have other duties. The following fire-related signals shall be transmitted:

(1) Actuation of any fire detection device
(2) Actuation of any fixed fire suppression system
(3) Actuation of any manual fire alarm station
(4) Starting of any fire pump
(5) Actuation of any fire protection supervisory device
(6) Indication of alarm system trouble condition

3.8.1.1 Means shall be provided to allow a person observing a fire at any location in the plant to quickly and reliably communicate to the control room or other suitable constantly attended location.

3.8.1.2 Means shall be provided to promptly notify the following of any fire emergency in such a way as to allow them to determine an appropriate course of action:

(1) General site population in all occupied areas
(2) Members of the industrial fire brigade and other groups supporting fire emergency response
(3) Off-site fire emergency response agencies. Two independent means shall be available (e.g., telephone and radio) for notification of off-site emergency services.

3.8.2 Detection. If automatic fire detection is required to meet the performance or deterministic requirements of Chapter 4, then these devices shall be installed in accordance with NFPA 72, *National Fire Alarm Code,* and its applicable appendixes.

3.9 Automatic and Manual Water-Based Fire Suppression Systems.

3.9.1* If an automatic or manual water-based fire suppression system is required to meet the performance or deterministic requirements of Chapter 4, then the system shall be installed in accordance with the appropriate NFPA standards including the following:

(1) NFPA 13, *Standard for the Installation of Sprinkler Systems*
(2) NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*
(3) NFPA 750, *Standard on Water Mist Fire Protection Systems*
(4) NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*

3.9.2 Each system shall be equipped with a water flow alarm.

3.9.3 All alarms from fire suppression systems shall annunciate in the control room or other suitable constantly attended location.

3.9.4 Diesel-driven fire pumps shall be protected by automatic sprinklers.

3.9.5 Each system shall be equipped with an OS&Y gate valve or other approved shutoff valve.

3.9.6 All valves controlling water-based fire suppression systems required to meet the performance or deterministic requirements of Chapter 4 shall be supervised as described in 3.5.14.

3.10 Gaseous Fire Suppression Systems.

3.10.1 If an automatic total flooding and local application gaseous fire suppression system is required to meet the performance or deterministic requirements of Chapter 4, then the system shall be designed and installed in accordance with the following applicable NFPA codes:

(1) NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*
(2) NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*
(3) NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*

3.10.2 Operation of gaseous fire suppression systems shall annunciate and alarm in the control room or other constantly attended location identified.

3.10.3 Ventilation system design shall take into account prevention from over-pressurization during agent injection, adequate sealing to prevent loss of agent, and confinement of radioactive contaminants.

3.10.4* In any area required to be protected by both primary and backup gaseous fire suppression systems, a single active failure or a crack in any pipe in the fire suppression system shall not impair both the primary and backup fire suppression capability.

3.10.5 Provisions for locally disarming automatic gaseous suppression systems shall be secured and under strict administrative control.

3.10.6* Total flooding carbon dioxide systems shall not be used in normally occupied areas.

3.10.7 Automatic total flooding carbon dioxide systems shall be equipped with an audible pre-discharge alarm and discharge delay sufficient to permit egress of personnel. The carbon dioxide system shall be provided with an odorizer.

3.10.8 Positive mechanical means shall be provided to lock out total flooding carbon dioxide systems during work in the protected space.

3.10.9 The possibility of secondary thermal shock (cooling) damage shall be considered during the design of any gaseous fire suppression system, but particularly with carbon dioxide.

3.10.10 Particular attention shall be given to corrosive characteristics of agent decomposition products on safety systems.

3.11 Passive Fire Protection Features. This section shall be used to determine the design and installation requirements for passive protection features. Passive fire protection features include wall, ceiling, and floor assemblies, fire doors, fire dampers, and through fire barrier penetration seals. Passive fire protection features also include electrical raceway fire barrier systems (ERFBS) that are provided to protect cables and electrical components and equipment from the effects of fire.

3.11.1 Building Separation. Each major building within the power block shall be separated from the others by barriers having a designated fire resistance rating of 3 hours or by open space of at least 50 ft (15.2 m) or space that meets the requirements of NFPA 80A, *Recommended Practice for Protection of Buildings from Exterior Fire Exposures.*

Exception: Where a performance-based analysis determines the adequacy of building separation, the requirements of 3.11.1 shall not apply.

3.11.2 Fire Barriers. Fire barriers required by Chapter 4 shall include a specific fire-resistance rating. Fire barriers shall be designed and installed to meet the specific fire resistance rating using assemblies qualified by fire tests. The qualification fire tests shall be in accordance with NFPA 251, *Standard Methods of Tests of Fire Endurance of Building Construction and Materials*, or ASTM E 119, *Standard Test Methods for Fire Tests of Building Construction and Materials.*

3.11.3* Fire Barrier Penetrations. Penetrations in fire barriers shall be provided with listed fire-rated door assemblies or listed rated fire dampers having a fire resistance rating consistent with the designated fire resistance rating of the barrier as determined by the performance requirements established by Chapter 4. *(See 3.11.3.4 for penetration seals for through penetration fire stops.)* Passive fire protection devices such as doors and dampers shall conform with the following NFPA standards, as applicable:

(1) NFPA 80, *Standard for Fire Doors and Fire Windows*

(2) NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*

(3) NFPA *101, Life Safety Code*

Exception: Where fire area boundaries are not wall-to-wall, floor-to-ceiling boundaries with all penetrations sealed to the fire rating required of the boundaries, a performance-based analysis shall be required to assess the adequacy of fire barrier forming the fire boundary to determine if the barrier will withstand the fire effects of the hazards in the area. Openings in fire barriers shall be permitted to be protected by other means as acceptable to the AHJ.

3.11.4* Through Penetration Fire Stops. Through penetration fire stops for penetrations such as pipes, conduits, bus ducts, cables, wires, pneumatic tubes and ducts, and similar building service equipment that pass through fire barriers shall be protected as follows.

(a) The annular space between the penetrating item and the through opening in the fire barrier shall be filled with a qualified fire-resistive penetration seal assembly capable of maintaining the fire resistance of the fire barrier. The assembly shall be qualified by tests in accordance with a fire test protocol acceptable to the AHJ or be protected by a listed fire-rated device for the specified fire-resistive period.

(b) Conduits shall be provided with an internal fire seal that has an equivalent fire-resistive rating to that of the fire barrier through opening fire stop and shall be permitted to be installed on either side of the barrier in a location that is as close to the barrier as possible.

Exception: Openings inside conduit 4 in. (10.2 cm) or less in diameter shall be sealed at the fire barrier with a fire-rated internal seal unless the conduit extends greater than 5 ft (1.5 m) on each side of the fire barrier. In this case the conduit opening shall be provided with noncombustible material to prevent the passage of smoke and hot gases. The fill depth of the material packed to a depth of 2 in. (5.1 cm) shall constitute an acceptable smoke and hot gas seal in this application.

3.11.5* Electrical Raceway Fire Barrier Systems (ERFBS). ERFBS required by Chapter 4 shall be capable of resisting the fire effects of the hazards in the area. ERFBS shall be tested in accordance with and shall meet the acceptance criteria of NRC Generic Letter 86-10, Supplement 1, "Fire Endurance Test Acceptance Criteria for Fire Barrier Systems Used to Separate Safe Shutdown Trains Within the Same Fire Area." The ERFBS needs to adequately address the design requirements and limitations of supports and intervening items and their impact on the fire barrier system rating. The fire barrier system's ability to maintain the required nuclear safety circuits free of fire damage for a specific thermal exposure, barrier design, raceway size and type, cable size, fill, and type shall be demonstrated.

Exception No. 1: When the temperatures inside the fire barrier system exceed the maximum temperature allowed by the acceptance criteria of Generic Letter 86-10, "Fire Endurance Acceptance Test Criteria for Fire Barrier Systems Used to Separate Redundant Safe Shutdown Training Within the Same Fire Area," Supplement 1, functionality of the cable at these elevated temperatures shall be demonstrated. Qualification demonstration of these cables shall be performed in accordance with the electrical testing requirements of Generic Letter 86-10, Supplement 1, Attachment 1, "Attachment Methods for Demonstrating Functionality of Cables Protected by Raceway Fire Barrier Systems During and After Fire Endurance Test Exposure."

Exception No. 2: ERFBS systems employed prior to the issuance of Generic Letter 86-10, Supplement 1, are acceptable providing that the system successfully met the limiting end point temperature requirements as specified by the AHJ at the time of acceptance.

Chapter 4 Determination of Fire Protection Systems and Features

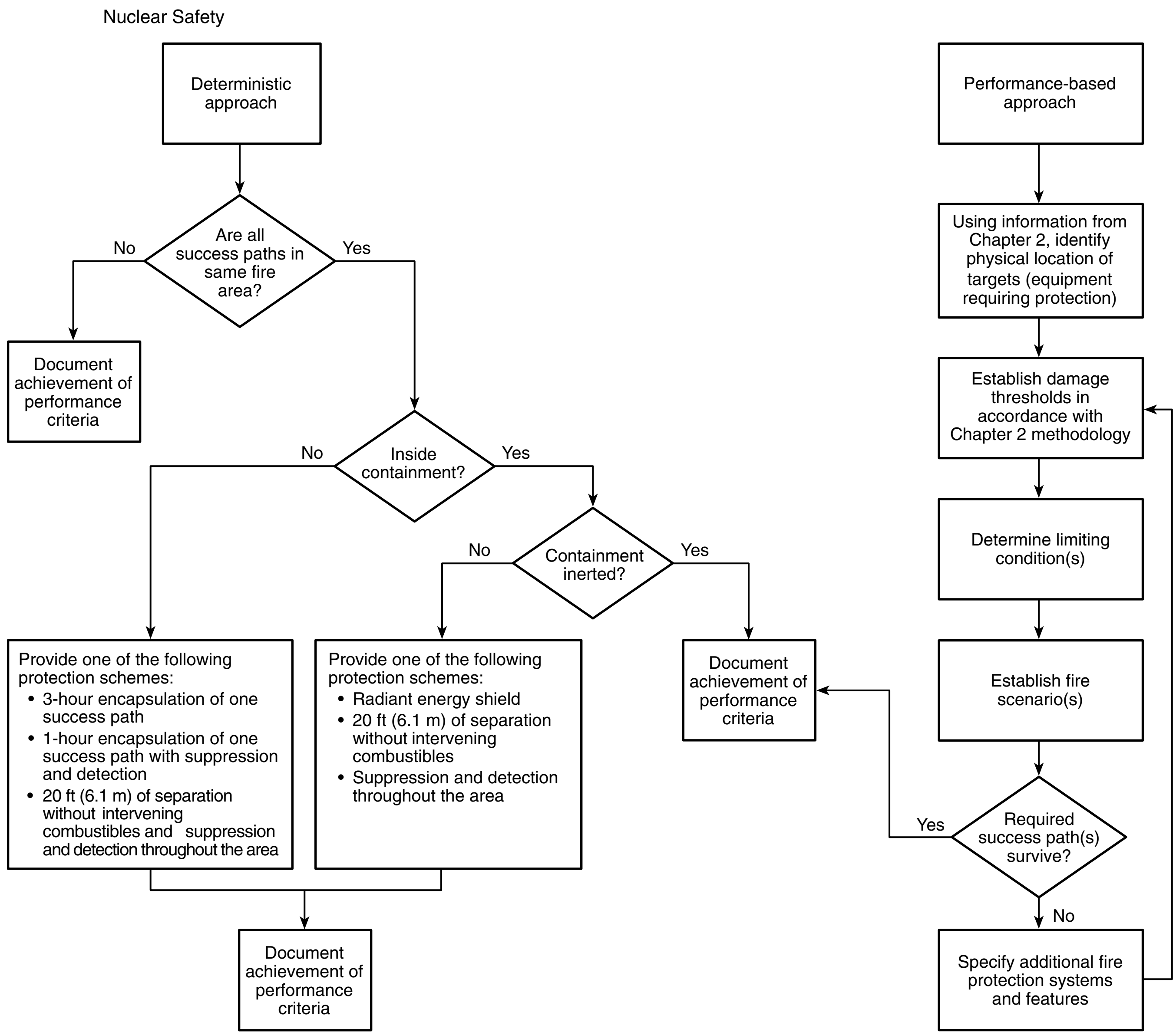
4.1 Methodology. Chapter 4 shall establish the methodology to determine the fire protection systems and features required to achieve the performance criteria outlined in Section 1.5. The methodology shall be permitted to be either deterministic or performance-based. Deterministic requirements shall be "deemed to satisfy" the performance criteria and require no further engineering analysis. Once a determination has been made that a fire protection system or feature is required to achieve the performance criteria of Section 1.5, its design and qualification shall meet the applicable requirement of Chapter 3.

4.2 Nuclear Safety.

4.2.1 Free of Fire Damage. One success path necessary to achieve and maintain the nuclear safety performance criteria shall be maintained free of fire damage by a single fire. The effects of fire suppression activities on the ability to achieve the nuclear safety performance criteria shall be evaluated.

4.2.2 Selection of Approach. For each fire area either a deterministic or performance-based approach shall be selected in accordance with Figure 4.2.2. Either approach shall be deemed to satisfy the nuclear safety performance criteria. The performance-based approach shall be permitted to utilize deterministic methods for simplifying assumptions within the fire area.

FIGURE 4.2.2 Nuclear safety capability assessment flowchart.



4.2.3 Deterministic Approach. This section shall provide deterministic methods to meet the nuclear safety performance criteria described in Section 1.5.

4.2.3.1 One success path of required cables and equipment to achieve and maintain the nuclear safety performance criteria without the use of recovery actions shall be protected by the requirements specified in either 4.2.3.2, 4.2.3.3, or 4.2.3.4, as applicable. Use of recovery actions to demonstrate availability of a success path for the nuclear safety performance criteria automatically shall imply use of the performance-based approach as outlined in 4.2.4.

4.2.3.2* One success path of required cables and equipment shall be located in a separate area having boundaries consisting of fire barriers with a minimum fire resistance rating of 3 hours. Every opening in the fire barriers forming these boundaries shall be protected with passive fire protection features having a fire-resistive rating equivalent to the fire barrier.

Exception: Fire resistance rating, if any, of exterior walls shall be determined by a fire hazard analysis.

4.2.3.3 Where required cables or equipment of redundant success paths of systems necessary to achieve and maintain the nuclear safety performance criteria are located within the same fire area outside of primary containment, one of the following means of ensuring that at least one success path is free of fire damage shall be provided.

(a) Separation of required cables and equipment of redundant success paths by a fire barrier having a 3-hour fire resistance rating. Enclosure of cable and equipment and associated non-safety circuits of a redundant success path in a fire barrier or ERFBS having a 3-hour fire resistance rating.

(b) Separation of required cables and equipment of redundant success paths by a horizontal distance of more than 20 ft (6.1 m) with no intervening combustible materials or fire hazards. In addition, automatic fire detectors and an automatic fire suppression system shall be installed throughout the fire area.

(c) Enclosure of cable and equipment and associated non-safety circuits of one redundant success path in a fire barrier or ERFBS having a 1-hour fire resistance rating. In addition, automatic fire detectors and an automatic fire suppression system shall be installed throughout the fire area.

4.2.3.4 Inside noninerted containments one of the fire protection means specified in 4.2.3.3 or one of the following fire protection means shall be provided:

(a) Separation of required cables and equipment of redundant success paths by a horizontal distance of more than 20 ft (6.1 m) with no intervening combustibles or fire hazards.

(b) Separation of required cables and equipment of redundant success paths by a noncombustible radiant energy shield. These assemblies shall be capable of withstanding a minimum $^{1}/_{2}$-hour fire exposure when tested in accordance with NFPA 251, *Standard Methods of Tests of Fire Endurance of Building Construction and Materials*.

(c) Installation of automatic fire detectors and an automatic fire suppression system throughout the fire area.

4.2.4* Performance-Based Approach. This subsection shall provide for a performance-based alternative to the deterministic approach provided in 4.2.3. When the use of recovery actions has resulted in the use of this approach, the additional risk presented by their use shall be evaluated. When the fire modeling or other engineering analysis, including the use of recovery actions for nuclear safety analysis, is used, the approach described in 4.2.4.1 shall be used. When fire risk evaluation is used, the approach described in 4.2.4.2 shall be used.

4.2.4.1 Use of Fire Modeling. The approach in 4.2.4.1.1 through 4.2.4.1.6 shall be used.

4.2.4.1.1 Identify Targets. The equipment and required circuits within the physical confines of the fire area 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 Chapter 2.

4.2.4.1.2 Establish Damage Thresholds. Within the fire area under consideration, the damage thresholds shall be established in accordance with Section 2.5 for the equipment and cables needed to achieve the nuclear safety performance criteria.

4.2.4.1.3 Determine Limiting Condition(s). The limiting conditions are the combination of equipment or required cables with the highest susceptibility (e.g., minimum damage threshold) to any fire environment.

4.2.4.1.4 Establish Fire Scenarios. Fire scenarios shall establish the fire conditions for the fire area under consideration. The fire scenario(s) for the fire area under consideration shall be established in accordance with Chapter 2.

4.2.4.1.5 Protection of Required Nuclear Safety Success Path(s). The effectiveness of fire protection systems and features shall demonstrate that the circuits and components required to achieve the nuclear safety performance criteria are maintained free of fire damage, and there is sufficient margin between the maximum expected fire scenarios and the limiting fire scenarios. Fire suppression activities in the fire area of concern shall not prevent the ability to achieve the nuclear safety performance criteria.

4.2.4.1.6 Operations Guidance. Guidance shall be provided to plant personnel that details the credited success path(s) for each fire area, including the performance of recovery actions and repairs. Recovery actions credited to achieve the nuclear safety performance criteria shall be feasible. *(See Appendix B for considerations when assessing the feasibility of recovery actions.)*

4.2.4.2 Use of Fire Risk Evaluation. Use of fire risk evaluation for the performance-based approach shall consist of an integrated assessment of the acceptability of risk, defense-in-depth, and safety margins.

The evaluation process shall compare the risk associated with implementation of the deterministic requirements with the proposed alternative. The difference in risk between the two approaches shall meet the risk acceptance criteria described in 2.4.4.1. The fire risk shall be calculated using the approach described in 2.4.3.

The proposed alternative shall also ensure that the philosophy of defense in depth and sufficient safety margin are maintained.

4.3* Radiation Release. To fulfill the criteria for radiation release described in Chapter 1, 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. Designs that balance source term limitation and containment shall also be acceptable.

4.3.1 Deterministic Approach. The protection specified in 4.2.3.4 shall provide an acceptable deterministic method for radiation release.

4.3.2 Performance-Based Approach. The performance-based approach specified in 4.2.4 shall provide an acceptable performance-based approach for radiation release.

4.4 Life Safety. Life safety shall be provided for both nonessential and essential facility occupants in accordance with the life safety performance criteria of 1.5.3.

4.4.1* NFPA *101*, *Life Safety Code*, and applicable local building codes related to life safety provide deterministic and performance-based requirements for life safety for occupants in various occupancies. Facilities within the power block that are in compliance with NFPA *101, Life Safety Code*, or applicable local building codes related to life safety shall be deemed to be in compliance with this chapter for protecting the life safety of nonessential personnel.

4.4.2 Additional features to protect the life safety of essential personnel who must remain or must access various areas of the facility while providing nuclear safety functions shall be provided for the time required to restore safe plant conditions and a safe environment for essential personnel. *(See Section 4.2 and Appendix B for requirements and guidance regarding life safety for essential personnel.)*

4.5 Plant Damage/Business Interruption.

4.5.1 Performance-Based Approach to Limit Plant Damage. The performance criteria shall be met by incorporating active design measures such as fire detection and fixed fire suppression systems and passive fire protection features. These measures shall be designed to complement the fundamental fire protection program required in Chapter 3. Incorporation of such design measures shall be considered sufficient if acceptable to the owner/operator.

4.5.2 Performance-Based Approach to Limit Business Interruption Due to a Probable Maximum Loss (PML).

4.5.2.1* Equipment critical to operations or safety shall be identified. Plans shall be developed to repair or replace this equipment and return the plant to operation within the time frame of the maximum allowable downtime.

4.5.2.2 Additional fixed fire suppression systems, fire-rated separation, or spatial separation to protect equipment and structures critical to power generation shall be provided as necessary to meet the performance criteria. The potential impact of exposure fires shall also be considered. Incorporation of such systems shall be considered sufficient if acceptable to the owner/operator.

4.5.3 Deterministic Approach to Plant Damage and Business Interruption. Deterministic criteria for plant damage and business interruption shall be established by the owner/operator. *(See Appendix E.)*

Chapter 5 Fire Protection During Decommissioning and Permanent Shutdown

5.1 Intent. This chapter applies to the power block areas of generating plants that have permanently ceased operations. As decommissioning progresses and the spent fuel is moved to an independent storage facility or permanent location, the fire protection systems and features necessary to meet the performance criteria of Chapter 1 shall be maintained.

5.2* Fire Protection Plan. The plant shall continue to maintain a fire protection plan as specified by Section 3.1. This plan shall establish a fire protection program that supports the decommissioning plan. The fire protection plan, commensurate with the changes in fire hazards and the potential release of hazardous and radiological materials to the environment, shall establish the following:

(1) Controls governing the identification of fire hazards and the changes in fire mitigation strategies resulting from decommissioning
(2) Controls governing fire area boundaries or barriers used to isolate areas with significant hazards
(3) Controls governing the testing, maintenance, and operability of fire protection systems and features required
(4) Administrative controls governing general fire prevention activities such as control of combustibles and ignition sources
(5) Controls governing plant features important to life safety and plant evacuation in the event of a fire
(6) Controls governing fire detection and notification, fire-fighting capability, and emergency response

5.3 Maintaining Fire Protection Capability. The following fire protection program elements shall be established and maintained during plant decommissioning, commensurate with the changes in fire hazards and the potential release of hazardous and radiological materials to the environment.

5.3.1 Water Supply. The on-site fire protection water supply and distribution system requirements shall be met. Sufficient heat shall be provided to protect fire-fighting water supply, distribution, and delivery systems (e.g., sprinklers and standpipes) from freezing.

5.3.2* Automatic Sprinkler Systems. For those plant areas protected by automatic sprinkler systems, automatic sprinkler systems shall be maintained as primary protection. The sprinkler protection for a given plant area shall not be rendered inoperable until it is no longer relied upon to meet the performance criteria of Chapter 1 and the fire hazards associated with decommissioning activities have been significantly minimized.

5.3.3 Portable Fire Extinguishers. Where provided, portable fire extinguishers, in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*, shall remain in plant areas included in the decommissioning plan until combustibles and ignition sources have been removed.

5.3.4* Standpipes and Hose Stations. Existing hose and standpipe systems shall remain functional to support the decommissioning plan.

5.3.5 On-Site and Off-Site Fire-Fighting Response.

5.3.5.1* The on-site industrial fire brigade requirements as specified by Chapter 3 shall be met. When the nuclear safety and the radioactive release criteria of Chapter 1 are no longer applicable to the power block, a plant industrial fire brigade and the provisions of 5.3.5.2, 5.3.5.3, and 5.3.5.4 shall no longer be required.

5.3.5.2 The pre-fire plans requirements specified by Chapter 3 shall be met. Revisions to the pre-fire plans shall be made when the occupancy or fire risk for the area has substantially changed.

5.3.5.3 On-site industrial fire brigade equipment requirements as specified by Chapter 3 shall be met.

5.3.5.4 Industrial fire brigade drills and training shall be performed commensurate with the hazard. The off-site department interface requirements shall also be commensurate with the hazard.

5.3.6* Fire Detection and Notification. During decommissioning a reliable means of detecting a fire, providing notification to a constantly attended location, and alerting the industrial fire brigade and plant personnel of the pending condition shall be maintained.

5.3.7 Fire Confinement. Fire barriers and fire area boundaries shall be evaluated to address changes resulting from plant decommissioning. Fire barriers and fire area boundaries shall be maintained as necessary to isolate fire hazards; aid in the ability to effectively contain, fight, and control a fire; protect personnel evacuation routes; and minimize the spread of radioactive contamination.

5.3.8 Life Safety. Egress and evacuation routes shall be established and maintained. The changing plant configurations shall consider the emergency lighting and evacuation alarm requirements.

Chapter 6 Referenced Publications

6.1 The following documents or portions thereof are referenced within this standard as mandatory requirements and shall be considered part of the requirements of this standard. The edition indicated for each referenced mandatory document is the current edition as of the date of the NFPA issuance of this standard. Some of these mandatory documents might also be referenced in this standard for specific informational purposes and, therefore, are also listed in Appendix F.

6.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 10, *Standard for Portable Fire Extinguishers*, 1998 edition.

NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*, 2000 edition.

NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*, 1997 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 1999 edition.

NFPA 14, *Standard for the Installation of Standpipe, Private Hydrant, and Hose Systems*, 2000 edition.

NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*, 1996 edition.

NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*, 1999 edition.

NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*, 1999 edition.

NFPA 22, *Standard for Water Tanks for Private Fire Protection*, 1998 edition.

NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*, 1995 edition.

NFPA 30, *Flammable and Combustible Liquids Code*, 2000 edition.

NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*, 1999 edition.

NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*, 1999 edition.

NFPA 72, *National Fire Alarm Code®*, 1999 edition.

NFPA 80, *Standard for Fire Doors and Fire Windows*, 1999 edition.

NFPA 80A, *Recommended Practice for Protection of Buildings from Exterior Fire Exposure*, 1996 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 1999 edition.

NFPA *101®*, *Life Safety Code®*, 2000 edition.

NFPA 220, *Standard on Types of Building Construction*, 1999 edition.

NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations*, 2000 edition.

NFPA 251, *Standard Methods for Tests of Fire Endurance of Building Construction and Materials*, 1999 edition.

NFPA 252, *Standard Methods of Fire Tests of Door Assemblies*, 1999 edition.

NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials*, 2000 edition.

NFPA 256, *Standard Methods of Fire Tests of Roof Coverings*, 1998 edition.

NFPA 600, *Standard on Industrial Fire Brigades*, 2000 edition.

NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films*, 1999 edition.

NFPA 750, *Standard on Water Mist Fire Protection Systems*, 2000 edition.

NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*, 1997 edition.

NFPA 1582, *Standard on Medical Requirements for Fire Fighters and Information for Fire Department Physicians*, 2000 edition.

NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, 2000 edition.

6.1.2 ANSI Publication. American National Standards Institute, Inc., 11 West 42nd Street, 13th floor, New York, NY 10036.

ANSI B31.1, *Code for Power Piping*, 1998.

6.1.3 ASTM Publication. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, 1997.

6.1.4 NRC Publications. Public Document Room, Washington, DC.

Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes to the Licensing Basis."

Generic Letter 86-10, Supplement 1, "Fire Endurance Test Acceptance Criteria for Fire Barrier Systems Used to Separate Safe Shutdown Trains Within the Same Fire Area."

Appendix A Explanatory Material

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

A.1.3.3 The life safety goal is to provide reasonable assurance that, for facility occupants, loss of life will not occur in the event of either a fire or the actuation of a fire suppression system.

A.1.5.1(e) Indication can be obtained by various means such as sampling/analysis, provided the required information can be obtained within the time frame needed.

A.1.5.4 Determination of the acceptable levels of damage and downtime for systems and structures that are not related to nuclear safety and that do not impact the plant's ability to achieve the nuclear safety criteria is largely a matter of economics. These values will be site-specific based on financial criteria established by the owner/operator. The owner/operator's analysis should consider factors such as the cost of installing and maintaining protection, the potential damage from the hazard or exposures (combustible load), the replacement cost of damaged equipment, and the downtime associated with replacement/repair of damaged equipment. Risk-informed data for the frequency of ignition sources, transient combustibles, or fires associated with the hazard should be considered.

A.1.6.2 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.1.6.3 Authority Having Jurisdiction. The phrase "authority having jurisdiction" 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.1.6.6 Combustible. Any material that in the form in which it is used and under the conditions anticipated will ignite and burn. A material that does not meet the definition of noncombustible or limited-combustible.

A.1.6.14 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.1.6.15 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.1.6.26 Fire Zone. Both uses 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.1.6.31 High-Low Pressure Interface. It should be noted that spurious opening of reactor coolant boundary valves that could potentially rupture downstream piping on an interfacing system or the loss of inventory that could not be mitigated in sufficient time to achieve the nuclear safety performance criteria are classified as high-low pressure interfaces [e.g., residual heat removal (PWR), pressurizer power-operated relief valves (PORVs) at PWRs, and shutdown cooling system at boiling water reactors (BWR)] and are subjected to the more restrictive criteria for circuit analysis and subsequent additional fire protection features.

A.1.6.32 Industrial Fire Brigade. Plant industrial fire brigades can either be incipient or structural as required by the authority having jurisdiction.

A.1.6.38 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.1.6.46 Power Block. Containment, auxiliary building, service building, control building, fuel building, rad waste, water treatment, turbine building, and intake structure are examples of power block structures.

A.1.6.55 Risk Informed Approach. A risk-informed approach enhances the deterministic approach by the following methods:

(1) Allowing explicit consideration of a broader set of potential challenges to safety
(2) Providing a logical means for prioritizing these challenges based on risk significance, operating experience, and/or engineering judgment
(3) Facilitating consideration of a broader set of resources to defend against these challenges
(4) Explicitly identifying and qualifying sources of uncertainty in the analysis
(5) Leading to better decision-making by providing a means to test the sensitivity of the results to key assumptions

A.1.6.61 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

A.1.6.62 Through Penetration Fire Stop. Through penetration fire stops should be installed in a tested configuration. These installations should be tested in accordance with ASTM E 814 or an equivalent test.

A.2.2(h) 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.

For fire protection, defense-in-depth is accomplished by achieving a balance of the following:

(1) Preventing fires from starting
(2) Detecting fires quickly and suppressing those fires that occur, thereby limiting damage
(3) Designing the plant to limit the consequences of fire relative to life, property, environment, continuity of plant operation, and nuclear safety capability

For nuclear safety, defense-in-depth is accomplished by achieving a balance of the following:

(1) Preventing core damage
(2) Preventing containment failure
(3) Mitigating consequence

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, 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. For example, a fire area or zone in the control building could contain a high concentration of cables and high-voltage electrical equipment. The fire area or zone can contain nuclear safety equipment (nuclear safety criteria), can be part of an important access path for the industrial fire brigade or egress path for plant personnel (life safety criteria), and can have components that if damaged could cause an extended plant shutdown (business interruption criteria).

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. This standard provides both a deterministic approach and a performance-based approach to determining the additional features required. The deterministic approach indicates that a 3-hour barrier is an adequate way to meet the standard. The performance-based approach indicates that a barrier adequate for the hazard is sufficient.

A.2.2.2 A thorough identification of the fire potential is necessary to incorporate adequate fire protection into the facility design. Integrated design of systems is necessary to ensure the safety of the plant and the operators from the hazards of fire and to protect property and continuity of production.

The following steps are recommended as part of the process to identify the fire hazards.

(a) Prepare a general description of the physical characteristics of the power facilities and plant location that will outline the fire prevention and fire protection systems to be provided. Define the potential fire hazards and state the loss-limiting criteria to be used in the design of the plant.

(b) List the codes and standards that will be used for the design of the fire protection systems. Include the published standards of NFPA.

(c) Define and describe the potential fire characteristics for all individual plant areas that have combustible materials, such as maximum fire loading, hazards of flame spread, smoke generation, toxic contaminants, and fuel contributed. Consider the use and effect of noncombustible and heat-resistant materials.

(d) List the fire protection system requirements and the criteria to be used in the basic design for such items as water supply, water distribution systems, and fire pumps.

(e) Describe the performance requirements for the detection systems, alarm systems, automatic suppression systems, manual systems, chemical systems, and gas systems for fire detection, confinement, control, and extinguishing.

(f) Develop the design considerations for suppression systems and for smoke, heat, and flame control; combustible and explosive gas control; and toxic and contaminate control. Select the operating functions of the ventilating and exhaust systems during the period of fire extinguishing and control. List the performance requirements for fire and trouble annunciator warning systems and the auditing and reporting systems.

(g) Consider the qualifications required for the personnel performing the inspection checks and the frequency of testing to maintain a reliable alarm detection system.

(h) The features of building and facility arrangements and the structural design features generally define the methods for fire prevention, fire extinguishing, fire control, and control of hazards created by fire. Carefully plan fire barriers, egress, fire walls, and the isolation and containment features that should be provided for flame, heat, hot gases, smoke, and other contaminants. Outline the drawings and list of equipment and devices that are needed to define the principal and auxiliary fire protection systems.

(i) Prepare a list of the dangerous and hazardous combustibles and the maximum amounts estimated to be present in the facility. Evaluate where these will be located in the facility.

(j) Review the types of fires based on the quantities of combustible materials, the estimated severity, intensity, and duration, and the hazards created. For each fire scenario reviewed, indicate the total time from the first alert of an actual fire emergency until safe control and extinguishment is accomplished. Describe in detail the plant systems, functions, and controls that will be provided and maintained during the fire emergency.

(k) Define the essential electric circuit integrity needed during a fire emergency. Evaluate the electrical and cable fire protection, the fire confinement control, and the fire extinguishing systems that will be required to maintain their integrity.

(l) Carefully review and describe the control and operating room areas and the protection and extinguishing systems provided thereto. Do not overlook the extra facilities provided for maintenance and operating personnel, such as kitchens, maintenance storage, and supply cabinets.

(m) Evaluate the actual and potential fire hazards during construction of multiple units and the additional fire prevention and control provisions that will be required during the construction period where one unit is in operation. This evaluation can disclose conditions that require additional professional fire department type of coverage.

(n) Analyze what is available in the form of "backup" or "public" fire protection to be considered for the installation. Review the "backup" fire department, equipment, manpower, special skills, and training required.

(o) List and describe the installation, testing, and inspection required during construction of the fire protection systems that demonstrate the integrity of the systems as installed. Evaluate the operational checks, inspection, and servicing required to maintain this integrity.

(p) Evaluate the program for training, updating, and maintaining competence of the station fire-fighting and operating crew. Provisions should be required to maintain and upgrade the fire-fighting equipment and apparatus during plant operation.

(q) Review the qualification requirements for the fire protection engineer or consultant who will assist in the design and selection of equipment.

A.2.2.6 The deterministic approach involves implied but unquantified elements of probability in the assumption of specific scenarios to be analyzed as fire events. It then requires that the design include systems and features capable of preventing or mitigating the consequences of those fire events in order to meet the goals related to nuclear safety, radiological release, life safety, and property damage/business interruption.

A.2.2.7 Refer to existing engineering equivalency evaluations (previously known as Generic Letter 86-10 evaluations, exemptions, deviations) performed for fire protection design variances such as fire protection system designs and fire barrier component deviations from the specific fire protection deterministic requirements.

Once NFPA 805 is adopted for a facility, future equivalency evaluations (previously known as Generic Letter 86-10 evaluations) are to be conducted using a performance-based approach. The evaluation should demonstrate that the specific plant configuration meets the performance criteria in the standard.

A.2.2.8 The performance-based approach can apply qualitative engineering judgment, supported by quantitative methods, as necessary, using acceptable numerical methods, probabilistic and/or fire models, and calculations to determine how specific plant performance criteria are achieved.

A.2.4.2.3 Equipment and cables should be located by the smallest designator (room, fire zone, or fire area) for ease of analysis.

A.2.4.3 Regarding the needs of the change analysis, this standard requires the assessment of the risk implications of any proposed change and the acceptability of these implications. The latter assessment can require quantitative assessments of total plant CDF, LERF, and changes in these quantities. Paragraph 2.4.3 discusses the requirements for the PSA methods, tools, and data used to quantify risk and changes in risk. Paragraph 2.4.4 discusses the requirements for the risk-informed methods used to determine the acceptability of a change.

If risk is judged to be low with a reasonable degree of certainty, then the PSA supporting analysis can be either quantitative or qualitative, based upon the guidance in Appendix D. The preferred and most complete analysis method is quantitative analysis. If risk is potentially high, quantitative analysis should be performed.

A.2.4.3.1 For certain plant operating modes, CDF and LERF 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.2.4.3.2 Conservative assessments could be sufficient to show that the risk contribution is small.

A.2.4.3.3 The quality of the PSA analysis needs to be good enough to confidently determine that the proposed change is acceptable. Appendix 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 nonfire–induced initiating events.

A.2.4.4 A plant change evaluation could 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.

A.2.4.4.1 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 importantly, the process encourages that plant changes result in either no change in risk or a reduction in risk.

A.2.4.4.2 The intent of this requirement is not to prevent changes in the way defense-in-depth is achieved. The intent is to ensure defense-in-depth is maintained.

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.

For fire protection, defense-in-depth is accomplished by achieving a balance of the following:

(1) Preventing fires from starting
(2) Detecting fires quickly and suppressing those fires that occur, thereby limiting damage
(3) Designing the plant to limit the consequences of fire relative to life, property, environment, continuity of plant operation, and nuclear safety capability

For nuclear safety, defense-in-depth is accomplished by achieving a balance of the following:

(1) Preventing core damage
(2) Preventing containment failure
(3) Mitigating consequence

Where a comprehensive fire risk analysis can be done, it can be used to help determine the appropriate extent of defense-in-depth (e.g., the balance among core damage prevention, containment failure, and consequence mitigation as well as the balance among fire prevention, fire detection and suppression, and fire confinement). With the current fire risk analysis state of the art, traditional defense-in-depth considerations should be emphasized. For example, one means of ensuring a defense-in-depth philosophy would be providing adequate protection from the effects of fire and fire suppression activities for one train of nuclear safety equipment (for the nuclear safety element) and ensuring basic program elements are present for fire prevention, fire detection and suppression, and fire confinement (for the fire protection element).

Consistency with the defense-in-depth philosophy is maintained if the following acceptance guidelines, or their equivalent, are met.

(1) A reasonable balance among prevention of fires, early detection and suppression of fires, and fire confinement is preserved.
(2) Overreliance on programmatic activities to compensate for weaknesses in plant design is avoided.
(3) Nuclear safety 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).
(4) Independence of defense-in-depth elements is not degraded.
(5) Defenses against human errors are preserved.

An example of when a risk acceptance criterion could be met but when the defense-in-depth philosophy is not occurs when it is assumed that one element of defense-in-depth is so reliable that another is not needed. For example, a plant change would not be justified solely on the basis of a low fire initiation frequency or a very reliable suppression capability.

A.2.4.4.3 The plant change evaluation needs to ensure that sufficient safety margins are maintained. An example of maintaining sufficient safety margins occurs when the existing calculated margin between the analysis and the performance criteria compensates for the uncertainties associated with the analysis and 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 such margins exist.

The following provides an example guideline for ensuring safety margins remain satisfied when using fire modeling and for using probabilistic safety analysis (PSA). In the case of fire modeling, Appendix C provides a method for assessing safety margins in terms of margin between fire modeling calculations and performance criteria. In Chapter 3, fire protection features are required to be designed and installed according to NFPA codes. In the case of fire PSA, Appendix 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 evaluating calculated risk estimates against acceptance criteria. Meeting the monitoring requirements in Section 2.4 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.2.5 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., 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 the 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 the 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 is described as follows.

(a) Smoke, depending on what is in it [such as HCl from burning polyvinyl chloride (PVC) insulation], causes corrosion after some time. A little smoke has been shown to cause damage days later if the relative humidity is 70 percent or higher. Navy experience has shown that corrosion can be avoided if the equipment affected by smoke is cleaned by a forceful stream of water containing non-ionic detergent and then rinsed with distilled water and dried.

(b) 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.

(c) Smoke can also impair the operation of relays in the relay cabinet by depositing products of combustion on the contact points. Again, the forced cooling of the relay panel can exacerbate the situation.

A.2.6 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. Regulation 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.2.7.1.2 A plant's existing fire hazards analysis (FHA) and safe shutdown analysis 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 authority having jurisdiction. 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:

(a) *Plant Construction.* The physical construction and layout of the buildings and equipment, including listing of fire areas and fire zones, and the fire ratings of boundaries and barrier components.

(b) *Identification of Hazards.* An inventory of combustible materials, flammable and reactive liquids, flammable gases, and potential ignition sources.

(c) *Fire Protection Systems and Equipment.* A description of the fire protection features provided.

(d) *Nuclear Safety Equipment.* A description and location of any equipment necessary to achieve nuclear safety functions, including cabling between equipment.

(e) *Radioactive Release Prevention Equipment.* A description and location of any equipment, including cabling between equipment, necessary to prevent release of radioactive contamination.

(f) *Life Safety Considerations.* A description and location of any equipment necessary to achieve life safety criteria, including cabling between equipment.

(g) *Plant Damage and Plant Downtime.* A description and location of any equipment necessary to achieve plant damage and downtime criteria, including cabling between equipment.

(h) *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.

(i) *Achievement of Performance Criteria.* Summarize the specific performance criteria evaluated and how each of these performance criteria are satisfied.

A.2.7.1.3 Examples of supporting information include the following:

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

The following topics should be documented when performing an engineering analysis.

(a) *Objective.* Clearly describe the objective of the engineering analysis in terms of the performance criteria outlined in Section 1.5, 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.

(b) *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.

(c) *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.

(d) *References.* Document all codes, standards, drawings, or reference texts used as a reference in the analysis. Include any reference to supporting data inputs, assumptions, or scenarios to be used to support the analysis. Identify in this section all references, including revision and/or date. Include all references that might not be readily retrievable in the future in the engineering analysis as an attachment.

(e) *Results and Conclusions.* Describe results of the engineering analysis clearly and concisely and draw conclusions based on a comparison of the results to the performance criteria. Document key sources of uncertainties and their impacts on the analysis results.

A.2.7.3 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 code and standard 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) 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) Extent of documentation of the method, including the analytical method itself, assumptions, scope, limitations, data sources, and data reduction methods.
(3) 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) Extent to which the method is based on sound scientific principles.
(5) 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 and stakeholders, and possibly by a third-party reviewer. This justification can be strengthened by the presence of data obtained from fire testing.

A.2.7.3.2 Generally accepted calculational methods such as friction loss equations are considered to be adequately validated. No additional documentation is needed.

A.2.7.3.5 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 using a design basis fire 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 of 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.

A.3.1 Fire protection systems that deviate from applicable NFPA design codes and standards should be supported by an engineering analysis acceptable to the authority having jurisdiction that demonstrates satisfactory compliance with the performance objectives.

A.3.2.2 The policy document that defines the management authority and responsibility should be consistent with other upper tier plant policy documents.

A.3.2.2.1 The senior plant management position responsible for fire protection should be the plant general manager or equivalent position. Fire protection needs the support of the highest level of management. This support is particularly important where various fire protection programmatic responsibilities go across organizational lines (i.e., operations, system engineering, design engineering, security, training).

A.3.2.2.2 The individual responsible for the day-to-day administration of the fire protection program on site should be experienced in nuclear fire protection. Preference should be given to an individual with qualifications consistent with member grade status in the Society of Fire Protection Engineers.

A.3.2.2.3 Fire protection impacts and is impacted by virtually all aspects of plant operations. These interfaces need to be considered on a plant-by-plant basis. Typically these interfaces include but are not limited to the following:

(1) Plant operations
(2) Security
(3) Maintenance
(4) System engineering
(5) Design engineering
(6) Emergency planning
(7) Quality assurance
(8) Procurement
(9) Corporate fire protection (insurance)
(10) Chemistry
(11) Health physics
(12) Licensing

A.3.2.2.4 A nuclear power plant is typically under the jurisdiction of several authorities, which vary depending on the area of the fire protection program being considered. A federal authority will likely be the AHJ for portions of the program addressing nuclear safety, and a building code official at a local level could be responsible for life safety. The insurance coverage provider or the owner/operator can be the AHJ for plant damage/business interruption aspects of the program. To eliminate future confusion it is important to identify the appropriate AHJ for the various aspects of the program in the program or policy document.

A.3.2.3 Most plants have procedure formats and hierarchies for controlling various operations and activities. Fire protection–related procedures should be consistent with other plant procedures to the extent possible.

A.3.2.3(1) Inspection, testing, and maintenance procedures should be developed and the required actions performed in accordance with the appropriate NFPA standards. Some AHJs such as insurers could have additional requirements that should be considered when developing these procedures. Performance-based deviations from established inspection, testing, and maintenance requirements can be granted by the AHJ. Where possible, the procedures for inspection, testing, and maintenance should be consistent with established maintenance procedure format at the plant.

A.3.2.3(2) 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.3.2.3(3) In order to measure the effectiveness of the fire protection program, as well as to collect site-specific data that can be used to support performance and risk-informed considerations, a process to identify performance and trends is needed. Specific performance goals should be selected and performance measured. A procedure that establishes how to set goals and how to consistently measure the performance is a critical part of this process.

A.3.3.1.1(2) Fire prevention inspections are an important part of the overall fire protection program. Use of fire protection personnel to perform these inspections should be only one part of the inspection program. Maintenance and operations supervisors should be trained on fundamentals of fire prevention that they can incorporate into their field walkdowns. In fact, training the general plant population to recognize and report on correct fire hazards is recommended. Not only does this increase the number of people looking for hazards, it also educates the employees to avoid creating the hazards in the first place. NFPA 601, *Standard for Security Services in Fire Loss Prevention*, provides a method for developing and implementing a fire prevention surveillance plan.

A.3.3.1.1(3) In addition to reviews of maintenance activities, adequate controls need to be placed in the appropriate plant procedures to make sure that fire prevention considerations are included in the modification and maintenance process. These considerations should include not only information on hot work and combustible materials controls, but also the impact of modification and maintenance activities on fire protection systems, including blocking sprinklers, detection devices, extinguishers, hose stations, and emergency lights with scaffolding or staged equipment. The effect of hot work on detection in the area (smoke or flame) as well as on suppression systems should also be considered, as well as the effect on fire barriers due to open doors or breached barriers.

A.3.3.1.2 Combustible materials in this section refer to transient-type combustibles. In-situ combustibles are addressed as part of the specific equipment. Control of transient combustibles can be accomplished in a variety of ways. Some plants have used a permit system. Other plants have used procedural controls with oversight by supervision. Controls should not only consider quantities of combustibles but also the actual location of the transient combustible. For example, 1000 lb (454 kg) of transient Class A combustible materials can be permitted and have only a small effect on the equivalent fire severity. However, if this 1000 lb (454 kg) is placed in the vicinity of critical cables or equipment, then there is a significant impact on the level of risk.

A.3.3.1.2(1) Use of fire-retardant paint requires special care. Inconsistent application and exposure to weather can reduce the effectiveness of fire-retardant coatings. Large timbers are occasionally used to support large pieces of equipment during storage or maintenance. The size of these timbers make them difficult to ignite, and they do not represent an immediate fire threat.

A.3.3.1.2(4) The limits permitted in designated storage areas should be based on the type of materials being stored, the type, if any, of fire suppression in the area, and separation from equipment necessary to meet the goals defined in Chapter 1 of this standard. Storage inside a power block building, such as the auxiliary building, turbine building, reactor or containment building, control building, diesel generator building, or radioactive waste storage or processing buildings, should be limited to that needed in a short period of time. Typically, one week's worth of supplies is appropriate.

A.3.3.1.2(5) For plant areas containing equipment important to nuclear safety or where there is a potential for radiological release resulting from a fire, additional controls over flammable and combustible liquids above those required by applicable NFPA standards should be considered. Power plants typically use a number of flammable and combustible liquids and gases as part of the operation of the plant. The type of chemical and the quantities used also change over time. The administrative control procedures should be flexible enough to handle all types of gases and liquids.

A.3.3.1.2(6) For plant areas containing equipment important to nuclear safety or where there is a potential for radiological release resulting from a fire, additional controls over flammable gases above those required by applicable NFPA standards should be considered.

A.3.3.1.3.1 Hot work controls should include a permit that is approved by the appropriate level of management prior to the start of work. Permit duration should be limited to one shift. Training on the hot work control procedure as well as the appropriate level of hands-on fire extinguisher training should be provided to all who are assigned hot work responsibilities, including both the persons performing the hot work as well as the person assigned hot work fire watch responsibilities. The administrative procedure should also include instructions for handling use and storage of oxygen and acetylene cylinders used for hot work.

A.3.3.1.3.4 The administrative procedures should include a method to control the use of electric heaters so that only those that have been inspected and approved for use will be used. NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations,* should be utilized for guidance when considering the use of temporary heating equipment.

A.3.3.5.3 Electric cable insulation should be of a type that has been tested using a recognized flame spread test. An example of such a test is IEEE 817, *Standard Test Procedure for Flame-Retardant Coatings Applied to Insulated Cables in Cable Trays,* and IEEE 1202, *Standard for Flame Testing of Cables for Use in Cable Tray and Industrial and Commercial Occupancies.*

A.3.3.9 Overflowing oil collection basins have spread fires in some incidents. In addition, upon overflow, the oil can go directly to a water source, such as a bay, lake, and so forth, which involves environmental concerns. Periodic inspections by appropriate personnel are necessary. Also, draining the oil collection basins following heavy rains should be incorporated into plant procedures.

A.3.3.10 There have been a number of fires within the industry that have occurred when high-temperature lube oil has contacted hot pipes. Ignition has occurred, even though there has been no pilot fire source and the auto-ignition temperature of the lube oil has been above that of the pipe. This ignition is believed to be caused in part by the distillation of the oil at the pipe surface after wicking through the insulation. The lighter ends that are driven off by the distillation process then ignite since they have a lower auto-ignition temperature. Immediate clean-up of the oil is important to avoid such fires.

A.3.3.12 Potential pressurized and unpressurized leakages should be considered in designing a lube oil collection system. Leakage points that should be evaluated to determine if protection is warranted include the lift pump and piping, overflow lines, lube oil coolant, oil fill and drain lines, plugs, flanged connections, and lube oil reservoirs where such features exist on the reactor coolant pumps. Lack of protection for any potential leakage point should be justified by analysis and should be documented for review by the AHJ.

A.3.4.1(b) Immediate response as listed in these sections is considered to be achieved if nominal actions are taken to put associated equipment in a safe condition.

A.3.4.1(d) Verification of a fire should result in a prompt notification of the industrial fire brigade. Immediate dispatching of the industrial fire brigade should occur upon verbal notification of a fire, two or more fire detectors being activated in a zone, or receipt of a fire suppression system flow alarm.

A.3.4.2 As a minimum, the pre-fire plans should include a description of the following:

(1) Available fire protection systems
(2) Fire barriers
(3) Fire doors
(4) Locked doors
(5) Inaccessible or limited access areas
(6) Safe shutdown equipment
(7) Fire extinguisher locations
(8) Ventilation capabilities
(9) Communication equipment
(10) Radiological hazards
(11) Special hazards
(12) Areas subject to flooding

A.3.4.2.1 Pre-fire plans should detail radiologically hazardous areas and radiation protection barriers. Methods of smoke and heat removal should be identified for all fire areas in the pre-fire plans. These can include the use of dedicated smoke and heat removal systems or use of the structure's heating, ventilating, and air-conditioning (HVAC) system if it can operate in the 100 percent exhaust mode.

Water drainage methods should be reviewed and included in the pre-fire plan for each area.

Pre-fire plans should also contain at least minimal information on any hazardous materials located in the fire area (i.e., acids, caustics, chemicals).

A.3.4.2.3 Consideration should be given to providing the pre-fire plans to public fire departments that might respond to the site so that they can use them in the development of their own pre-plans. However, if pre-plans are provided to off-site fire departments, be aware that ensuring that these copies remain current can be difficult.

A.3.4.2.4 The pre-plans should consider coordination of fire-fighting and support activities with other plant groups. These groups include but are not limited to radiation protection, security, and operations. Coordination issues include the following:

(1) Access into normally locked or limited access areas (due to radiological or security concerns)
(2) Dosimetry (including dosimetry for the off-site fire departments)
(3) Local and remote monitoring for radiological concerns (dose, contaminated smoke, contaminated fire-fighting water runoff)
(4) Scene control by security
(5) Escort of off-site fire department personnel and equipment to the scene
(6) Equipment shutdown by operations (electrical components, ventilation)

A.3.4.3(c) Acceptable industrial fire brigade drills should be provided using realistic plant conditions to maintain industrial fire brigade proficiency. Industrial fire brigade drills should include the following.

(a) Industrial fire brigade drills are to be a simulated emergency exercise involving a credible emergency requiring the industrial fire brigade to perform planned emergency operations. The purpose of these drills is to evaluate the effectiveness of the training and education program and the competence of industrial fire brigade members in performing required duties and functions. Industrial fire brigade drills can be either announced or unannounced to the industrial fire brigade. However, the senior shift representative should be informed of all drills prior to their commencement.

(1) *Announced.* An industrial fire brigade drill, including the scenario of the drill, that is announced in advance to the industrial fire brigade and other personnel who can be alerted.
(2) *Unannounced.* An industrial fire brigade drill that is not announced in advance to the industrial fire brigade and other personnel who can be alerted.

(b) Generally, industrial fire brigade drills are not considered training evaluations. However, announced drills can incorporate a degree of training while performing an evaluation of the industrial fire brigade. Announced industrial fire brigade drills can vary in types of response, speed of response, and use of equipment. Unannounced industrial fire brigade drills are to be used specifically to evaluate the fire-fighting readiness of the industrial fire brigade, industrial fire brigade leader, and fire protection systems and equipment.

(c) At least annually, each shift industrial fire brigade should participate in an unannounced industrial fire brigade drill. Unannounced industrial fire brigade drills should be performed in a realistic manner, using real-time evolutions, full personal protective equipment (PPE) including self-contained breathing apparatus (SCBA), and, where appropriate, charged hose lines. Assessment of the following items should be performed:

(1) Fire alarm effectiveness
(2) Timeliness of notification of the industrial fire brigade
(3) Timeliness of assembly of the industrial fire brigade
(4) Selection, placement, and use of equipment, personnel, and fire-fighting strategies
(5) The brigade members' knowledge of their role in the fire-fighting strategy
(6) The brigade members' knowledge and ability to properly deploy fire-fighting equipment and proper use of PPE, SCBA, and communications equipment
(7) The brigade members' conformance with established plant fire-fighting procedures
(8) A critique of the drill performed by all of the participants, including brigade members, drill planners, and observers

A.3.4.5.2 Training of the plant industrial fire brigade should be coordinated with the local fire department so that responsibilities and duties are delineated in advance. This coordination should be part of the training course and should be included in the training of the local fire department staff. Local fire departments should be provided training in operational precautions when fighting fires on nuclear power plant sites and should be made aware of the need for radiological protection of personnel and the special hazards associated with a nuclear power plant site.

A.3.4.5.3 Items to be addressed should include overseeing the issuance of security badges, film badges, and dosimetry to the responding public fire-fighting forces and ensuring that the responding off-site fire department(s) is escorted to the designated point of entry to the plant.

A.3.4.6 The industrial fire brigade communication system should not interfere with other plant groups such as security and operations. Multichannel portable radios are used for communications at nuclear power plants. This section does not prohibit sharing of radio channels by various station groups. The use and assignment of channels should ensure that the industrial fire brigade, operations, and security all can use the radios to carry out their functions during a fire emergency.

The potential impact of fire on the plant's communication system should be considered. For example, separation of repeaters from other forms of communications to ensure that communication capability will remain following a fire is one such consideration.

In unique or unusual circumstances where equipment cannot be designed to prevent radio frequency interference, the authority having jurisdiction can permit the area around the sensitive equipment where portable radios cannot be used to be identified and marked so that fire fighters can readily recognize the condition. Training in this recognition also should be provided.

Industrial fire brigade personnel need to be aware of the use of portable radios by the off-site fire departments responding within these areas. Off-site fire department radios are typically of a higher wattage output than plant industrial fire brigade radios and can affect plant equipment in areas where plant radios would not.

A.3.5.2 Due to the 100 percent redundancy feature of two tanks, refill times in excess of 8 hours are acceptable.

A.3.5.3 For maximum reliability, three fire pumps should be provided so that two pumps meet the maximum demand including hose streams. Two fire pumps can be an acceptable alternative, provided either of the fire pumps can supply the maximum demand including hose streams within 120 percent of its rated capacity.

A.3.5.14 The inspection frequency of valves should be based on past performance. The location of the valves should also be considered. Those valves that are located outside of the protected area fence can require position inspection on a greater frequency that inside the protected area.

A.3.5.16 Mitigating severe accident events that can result in fuel-clad damage is a top priority. Since fires and other severe plant accidents are not assumed to occur simultaneously, fire protection systems do not need to be designed to handle both demands simultaneously.

A.3.9.1 An adequate capability should be provided to drain water from fire suppression systems away from sensitive equipment.

A.3.10.4 The back-up gaseous suppression system referred to in this section would be a CO_2 hose reel. This back-up system does not refer to the primary and alternate bottle banks on a halon or CO_2 system.

A.3.10.6 If total flooding carbon dioxide systems are used in rooms that require access by personnel engaged in actions to achieve and maintain safe and stable conditions, provisions within the applicable procedures should ensure that either the room is ventilated prior to entry or the response personnel are provided with self-contained breathing apparatus.

A.3.11.3 Openings in fire barriers can be protected by methods such as a combination of water and draft curtains. Such alternate protection can be used if justified by the FHA and approved by the AHJ.

A.3.11.4 Various fire test protocols are available to assess the performance of a through penetration fire stop's ability to prevent the propagation of fire to the unexposed side of the assembly. These protocols include ASTM E 814, *Standard Test Method for Fire Tests of Through Penetration Fire Stops*, IEEE 634, *Standard Cable Penetration Fire Stop Qualification Test,* and UL 1479, *Fire Tests of Through Penetration Fire Stops.*

A.3.11.5 Additional fire test protocols are available to assess the capability of a barrier system when used to separate redundant safety systems from the effects of fire exposure. Use of these test methods should be addressed with the AHJ. These test methods include ASTM E 1725, *Standard Test Methods for Fire Tests of Fire Resistive Barrier Systems for Electrical Components*, and UL 1724, *Fire Test for Electrical Circuit Protective Systems.*

The ERFBS should meet other design-basis requirements including seismic position retention and ampacity derating of electrical cables.

A.4.2.3.2 An example of criteria for evaluation of exterior wall fire resistance rating is given in Section 3.1.3, Generic Letter 86-10, Enclosure 2, "Implementation of Fire Protection Requirements."

A.4.2.4 Where recovery actions are the primary means to recover and re-establish any of the nuclear safety performance criteria (e.g., inventory and pressure control; decay heat removal), in lieu of meeting the deterministic approach as specified by 4.2.3, risk can be increased. The risk for the fire area and the risk presented by the implementation of recovery actions to recover the nuclear safety function should be compared to the risk associated with maintaining the function free of fire damage in accordance with the deterministic requirements specified in Chapter 4. Additional fire protection systems and features might have to be provided in the fire area to balance the risk.

Table A.4.5.2.1(a) Boiling Water Reactor — Spare Components List

Item	Item
High pressure bladed turbine rotor	High pressure coolant injection pump
Low pressure bladed turbine rotor	High pressure coolant injection pump motor
Generator coils	Low pressure coolant injection pump
Generator stator iron	Low pressure coolant injection pump motor
Generator rotor	High pressure core spray pump
Generator step-up transformer	High pressure core spray pump motor
Auxiliary transformer	Low pressure core spray pump
Emergency diesel — generator	Low pressure core spray pump motor
Emergency diesel — engine	Containment spray pump
Class 1E charger/inverter	Containment spray pump motor
Reactor recirculation pump	RHR removal pump
Reactor recirculation pump motor	RHR removal pump motor
Reactor recirculation pump motor MG set	RB component cooling water pump
Reactor core isolation cooling pump	RB component cooling water pump motor
Reactor core isolation cooling pump turbine/motor	Main steam code safety valve
Control rod	Main steam relief valve
Control rod mechanism	Main steam isolation valve

Source: Nuclear Electric Insurance Limited (NEIL)

A.4.3 Radioactive releases can take the form of solids, liquids, or gases generated from the combustion of radioactive material, the fire-related rupture of holding vessels, or fire suppression activities. The model used for determining the plant risk can be a bounding risk analysis, a qualitative risk analysis, or a detailed risk analysis such as a Level III PRA. Effects from radioactive releases can be estimated from comparison of source terms and do not necessarily require detailed determination of health effects.

Release of radioactivity is defined to include releases from all sources such as primary containment buildings, radioactive waste processing, and so forth.

A.4.4.1 NFPA *101*®, *Life Safety Code*®, is intended only to identify one means of assuring an acceptance level of life safety for facility occupants. Some AHJs recognize other codes and standards that address this issue. References in this standard to NFPA *101* do not intend to either supplement or supplant such other recognized standards.

A.4.5.2.1 The following tables contain examples of long-lead time equipment that should be considered depending on the downtime acceptable to the owner/operator. Table A.4.5.2.1(a) applies to boiling water reactors, and Table A.4.5.2.1(b) applies to pressurized water reactors.

Table A.4.5.2.1(b) Pressurized Water Reactor — Spare Components List

Item	Item
High pressure bladed turbine rotor	High pressure safety injection pump
Low pressure bladed turbine rotor	High pressure safety injection pump motor
Generator coils	Low pressure safety injection pump
Generator stator iron	Low pressure safety injection pump motor
Generator rotor	Containment spray pump
Generator step-up transformer	Containment spray pump motor
Auxiliary transformer	RHR/DH removal pump
Auxiliary feed pump turbine/motor	RHR/DH removal pump motor
Emergency diesel — generator	Component cooling water pump
Emergency diesel — engine	Component cooling water pump motor
Class 1E charger/inverter	Steam generator
Reactor coolant pump	Pressurizer power operated relief valve
Reactor coolant pump motor	Main steam code safety valve
Control rod	Main steam isolation valve
Control rod drive mechanism	

A.5.2 Decommissioning sites should have their procedures routinely reviewed by representatives of the industrial fire brigade response forces and cognizant fire protection engineering staff, consistent with established standard operating procedures and fire protection program criteria.

A.5.3.2 The decision to deactivate automatic fire suppression systems should reflect the possibility that emergency response forces might not be able to safely enter the facility to affect manual fire suppression. A "stand-off and protect" tactical approach, which features exterior fire attack and protection of exposures, should be approved by the AHJ and emergency response forces as part of the fire pre-plans or emergency response force standard operating procedures.

A.5.3.4 Standpipe and hose systems should be maintained in the following areas of the facility:

(1) Areas of the plant that are below grade
(2) Areas that require hose lays in excess of 200 ft (61 m) from the nearest hydrant
(3) Areas in which a fire could result in the spread of radioactive materials
(4) Areas that have a large combustible loading

It can be necessary to turn portions of the existing standpipe and hose stations into dry systems due to the lack of building heat during the decommissioning process. The prefire plans should be revised to instruct the fire-fighting personnel on how to immediately provide water to the dry standpipe system.

A.5.3.5.1 Industrial fire brigades of less than four individuals responding to a fire scene would be severely restricted in their fire-fighting activities until the arrival of additional assistance. The requirement for an industrial fire brigade while decommissioning and permanent plant shutdown is to provide manual fire-fighting capability to minimize the release and spread of radioactivity as the result of a fire. As these hazards are reduced/eliminated, industrial fire brigade minimum staffing can be reduced as justified by the FHA.

A.5.3.6 Reliable means of fire detection can include watchman rounds and *(see NFPA 601, Standard for Security Services in Fire Loss Prevention)* operator rounds as well as the use of fire detection devices. Where personnel rounds are relied upon as a means of fire detection, these personnel should be aware of and trained in these responsibilities. Communication between personnel performing rounds and the constantly attended location can include telephone, plant intercom, or radios.

Appendix B Nuclear Safety Analysis

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

B.1 Nuclear Safety Assessment. The primary purpose of the nuclear safety assessment is to demonstrate that given cable and equipment damage due to a fire postulated in any fire area, sufficient equipment remains available to achieve the following nuclear safety performance criteria (*see Section 1.5*):

(1) Reactivity control
(2) Inventory and pressure control
(3) Decay heat removal
(4) Vital auxiliaries
(5) Process monitoring

The purpose of this appendix is to identify attributes that should be considered when demonstrating this capability. Other risk informed–performance-based methods acceptable to the AHJ are permitted.

B.2 Nuclear Safety Systems and Equipment. A list of systems and equipment that ensure the nuclear safety performance criteria can be achieved during and after a plant fire, regardless of fire location, should be developed. This process can be iterative and can require revisions to incorporate fire risk significant systems and equipment, if further analysis in the circuit analysis or fire area assessment determine additional systems or equipment to be fire risk significant. The process that follows describes the initial attempt to determine which systems and equipment require evaluation. Other risk informed–performance-based methods acceptable to the AHJ can be used to refine the list of nuclear safety systems and equipment.

The set of systems and equipment to be considered for nuclear safety should address, as a minimum, the following.

(a) Systems and equipment required to place the plant in a safe and stable condition following a fire occurring while the plant is at power, or while maintaining hot standby or hot shutdown. This fire also could result in a loss of off-site power, which would require achieving safe and stable conditions using power from on-site ac sources (i.e., emergency diesel generators). This is typically a traditional Appendix R to 10 *CFR* 50 post-fire safe shutdown analysis.

(b) Systems and equipment required to maintain shutdown cooling capability following a fire originating while the plant is in the shutdown cooling mode.

B.2.1 Assumptions (Plant Conditions at Time of Postulated Fire). In addition to the assumptions in Chapter 2, the following assumptions apply to this appendix.

(a) The plant is in a standard lineup governed by operating procedures, operating modes, or administrative controls at the onset of the fire.

(b) Properly oriented check valves function to prevent reverse flow in process systems.

(c) Normally closed manual valves (hand-operated only) will remain undamaged by a fire and can be relied upon for system boundary isolation.

(d) Instruments located in a fire affected area (e.g., RTDs, thermocouples, pressure transmitters, flow transmitters, and mechanically linked remote/local indications) are assumed to be damaged unless it can be demonstrated otherwise. The instrument fluid boundary associated with these devices, with the exception of soldered fittings, is assumed to remain intact.

(e) Piping, check valves, strainers, tanks, manual valves, heat exchangers, safety relief valves, and pressure vessels are assumed to remain functional during and after a fire. The integrity of instrument tubing, with the exception of soldered fittings, is also expected to be maintained, though the accuracy of the instrument reading can be affected due to heating of the process fluid.

B.2.2 Considerations for the Selection of Nuclear Safety Systems and Equipment.

Step 1: System Identification. Based upon documentation of plant design, risk insights, and operation, plant systems required to achieve each of the nuclear safety criteria should be identified.

Step 2: System Interrelationships. The selection of systems and the documentation of how these systems fulfill the nuclear safety performance criteria should be depicted in system-level logic diagrams, fault trees, or some other method that shows equipment dependencies. The documentation should consider not only the required process systems but also the essential mechanical/environmental support and essential electrical systems required to support the nuclear safety performance criteria.

Step 3: Equipment Identification.

(a) P&IDs (piping and instrumentation diagrams)/flow diagrams should be used to identify the equipment in the flowpath and the boundary equipment within the systems that are required to achieve the nuclear safety objectives.

(b) Equipment that is not directly in a required system flowpath but whose spurious operation (undesired operation) could prevent achieving the nuclear safety objectives should be identified (e.g., boundary valve component whose spurious opening could divert flow away from critical equipment). The potential for spurious operations of equipment should be considered when determining boundary valves and equipment selection.

Loops or bypasses within a system where spurious operation would not result in a loss of flow or inadequate flow to nuclear safety success paths need not be considered.

For tanks, all outlet lines should be considered for their functional requirements. For lines not required to be functional, a means of isolation should be included when necessary to prevent unnecessary drawdown of the tank. Tank fill lines should also be considered.

For example, if two normally closed valves in series must spuriously open to result in an unrecoverable condition, then both valves should be identified on the nuclear safety equipment list (NSEL). If positive means is provided to preclude spurious operation of one valve/component for non-high-low pressure interface component [such as removing power to one of the two motor-operated valves (MOVs) during normal operation], then consideration of the additional component (the other series valve) is not required.

(c) Careful consideration should be given to equipment that could result in a fire-induced plant transient. The following is guidance on considerations that should be given in the identification of equipment that could result in a fire-induced plant transient.

(1) *Fire-induced plant initiating events [transients and loss of coolant accidents (LOCAs)].* Transients are defined as anticipated operational occurrences (e.g., inadvertent safety injection actuation, loss of off-site power, overcooling, overfilling of steam generators, spurious closure of containment isolation valves, significant loss of safety systems, station blackout, rapid cooldown, etc.) that initiate as a result of fire-induced circuit failures.

a. *Loss of primary system inventory.* The potential for fire initiated spurious actuation at reactor coolant pressure boundaries that could cause an uncontrolled loss of reactor coolant inventory [e.g., spurious actuation of primary coolant interfaces such as at the reactor head vents, normal and excess letdown at a pressurized water reactor (PWR), main steam relief valves (BWRs)] should be considered.

b. *Rapid cooldown.* Transients that could result in an uncontrolled plant cooldown due to spurious operation of boundary valves should be considered. Interaction of plant systems such as steam generator (PWR) atmospheric dump valves, power-operated relief valves, safety relief valves (BWR) feedwater, reactor trip, turbine trip, and main steam isolation should be considered as well.

c. *Uncontrolled primary injection.* Transients that could potentially result in an undesired or uncontrolled injection into the reactor coolant system should be assessed. This can include spurious actuation of high-pressure injection sources (i.e., HPCS, RCIC, HPCI, feedwater for BWRs, high-head ECCS pumps for PWRs).

d. *Electric power transients.* Transients that could result in a loss of any ac power supplies should be considered. This loss can include spurious breaker actuations, onsite generating capability spurious starts or failures, or inadvertent paralleling of ac sources due to fire-induced circuit failures.

(d) Equipment that requires support such as cooling water, instrument air, HVAC, motive power, and control power should be considered in order to understand component and system inter-relationships and sequential equipment loss impact.

(e) Off-site power can be used as a source of power for nuclear safety equipment. All equipment required to support the portion of off-site power relied upon to achieve the nuclear safety performance criteria should also be identified.

Off-site power should conservatively be considered available for those cases where availability of off-site power could adversely impact nuclear safety (i.e., reliance cannot be placed on fire causing a loss of off-site power if the consequences of off-site power availability are more severe than its presumed loss). No credit should be taken for a fire causing a loss of off-site power to prevent spurious operations.

(f) Instrument sensing lines should be considered for potential inaccurate instrument indications and/or spurious equipment actuations that could occur as a result of an instrument sensing line being exposed to a fire and increased temperatures. Any instrument sensing lines that could prevent the fulfillment of the nuclear safety performance criteria should be identified, associated with the equipment that it could impact, and included in the nuclear safety assessment for review on a fire area basis.

(g) Instrument air piping and components (e.g., accumulators) should be considered for viability during and after the fire in providing the motive force for credited components.

(h) Power supplies, including alternate power supplies, for nuclear safety equipment should be identified. Interrelationships between power supplies (such as bus-tie capability and alternate power supplies) should also be identified. This information is essential in determining nuclear safety equipment losses due to loss of a power supply.

Step 4: Equipment Interrelationships. The necessary relationships between individual nuclear safety equipment and systems should be understood and documented.

Step 5: Documentation.

(a) The bases for selection and exclusion of nuclear safety systems and equipment should be documented and maintained. Calculations and analyses that have been previously performed in support of other nuclear safety objectives (i.e., station blackout, seismic qualification) can be utilized provided the results of these analyses have properly considered the applicability to post-fire nuclear safety.

(b) To develop a nuclear safety equipment list (NSEL) in a consistent and reproducible manner, the following should be considered.

(1) Valves/dampers constituting system boundaries should be included in the NSEL. Normally closed manual valves and properly oriented check valves credited as system boundaries are not required to be listed in the NSEL.
(2) Manual drain, vent, and instrument root valves should not be included in the NSEL.
(3) Valves/dampers in the flowpath whose spurious operation could adversely affect system operation should be included in the NSEL. Manual valves/dampers requiring repositioning during the post-fire shutdown should also be included. Manual valves/dampers/check valves that do not require recovery actions during the post-fire shutdown should not be included in the NSEL.
(4) Safety/relief valves provided for equipment and piping protection should not be included. However, safety/relief valves providing an active nuclear safety function, such as the steam generator relief valves, are exceptions.
(5) Pilot solenoid valves should be listed as separate components in the NSEL. The cabling associated with the solenoid valves should be listed either under the solenoid valve or the associated process valve (e.g., the air operated valve) as dictated by the project implementation procedure.
(6) Pumps, fans, turbines, tanks, heat exchangers, and other equipment should be included on the NSEL.
(7) Instrumentation required for process monitoring of the nuclear safety systems should be identified.

B.3 Nuclear Safety Circuit Analysis. Circuit analysis for required nuclear safety equipment should be performed and documented. Circuit selection criteria include the following:

(1) Identification of all circuits that can adversely affect nuclear safety, including circuits with auxiliary contacts in the control circuits of nuclear safety equipment
(2) Exclusion of circuits that cannot prevent nuclear safety equipment from performing its nuclear safety function

Other risk informed–performance-based methods acceptable to the authority having jurisdiction can be used to refine the circuit analysis or its assumptions on circuit failure modes. This can include methods that quantify the credibility or likelihood of circuit failure modes and their correlation to spurious component operation.

The equipment listed in the nuclear safety equipment list should be reviewed to determine all circuits (cables) that could prevent the equipment from performing their nuclear safety performance criteria. This analysis is focused on cables, typically either directly associated with component operation or associated with the component via auxiliary relays and contacts.

Other required circuits are defined as cables whose failure due to fire damage can affect nuclear safety capability. The following are three types of other required circuits:

(a) *Spurious Actuations.* The concern is fire damage to a cable whose failure could result in the spurious operation or maloperation of equipment that could affect nuclear safety. Identification of cables that could cause spurious component operation is an integral part of the circuit analysis methodology described in B.3.1.

(b) *Common Power Supply.* The concern is fire damage to a cable that could result in a loss of power to a power source required to support nuclear safety equipment. This damage could occur if the upstream breaker/fuse for a nuclear safety power supply is not properly coordinated with a downstream breaker/fuse for the cable that is damaged. This is discussed in B.3.2.

(c) *Common Enclosure.* The concern is fire damage to a cable whose failure could propagate to other nuclear safety cables in the same enclosure either because the circuit is not properly protected by an isolation device (breaker/fuse) or the fire could somehow propagate along the cable and impact nuclear safety equipment. This situation is discussed in B.3.3.

B.3.1 Definitions. The following circuit failure modes should be considered in the evaluation:

(1) *Open Circuit.* A condition that is experienced when an individual conductor within a cable loses electrical continuity
(2) *Shorts-to-Ground.* A condition that is experienced when an individual conductor comes in electrical contact with a grounded conducting device, such as a cable tray, conduit, or metal housing
(3) *Hot Short.* A condition that is experienced when individual conductors of the same or different cables come in contact with each other

B.3.2 Considerations for Performing Nuclear Safety Circuit Analysis. The following describes a process and the guidelines for performing the nuclear safety circuit analysis.

Step 1: Equipment Parameter Input. All equipment requiring circuit analysis and their functional parameters *(see Step 5, Section B.2)* should be identified in the NSEL *(see Section B.2).* The functional parameters include normal and desired positions and failure position/status upon loss of power and air (if applicable). These parameters establish the framework for circuit analysis.

Step 2: Electrical Drawing Review. For each component to be analyzed, applicable elementary diagrams, single-line drawings, connection diagrams, instrument loop drawings, and vendor drawings should be reviewed as necessary to identify all circuits connected to the component, including control cables associated with the component via auxiliary contacts in the component's control circuit.

Step 3: Considerations for Circuit Identification. Each circuit should be evaluated to determine which cables are necessary to support the nuclear safety function of the component. If a fire-induced circuit failure of the cable can place the component in a position/condition other than any desired position/condition necessary by that component in any mode of operation required to achieve the nuclear safety performance criteria, the cable should be identified as a required cable. If a fire-induced circuit failure of the cable cannot spuriously reposition or prevent the desired operation of the component, it is not a required cable.

The following provides general evaluation guidelines for identification of required circuits.

(a) For spurious actuations and signals, all possible failure states, including all possible consequential damage, should be evaluated — that is, the component could be energized or de-energized by one or more fire-induced circuit failure modes (e.g., hot shorts, shorts-to-ground, and open circuits). Therefore, valves could fail open or closed, pumps could fail running or not running, and electrical distribution breakers could fail open or closed. Multiple spurious actuations or signals originating from fire-induced circuit failures could occur as the result of a fire in a given fire area.

(b) During the process of identifying required nuclear safety circuits, a hot short circuit failure on the appropriate conductor(s) should conservatively be assumed to cause spurious equipment operation. This will ensure that a comprehensive population of circuitry is evaluated for the impact of fire on meeting the nuclear safety performance criteria.

(c) A cable fault is a maintained condition that exists for the duration of the fire until a recovery action has been taken to isolate the given circuit from the fire area or other recovery actions have been taken to negate the effects of the spurious actuation. It cannot be assumed that the fault condition should terminate to a ground or open circuit condition that should stop the spurious actuation. Generally upon clearing of a fault, the equipment would return to its desired state (if the de-energized state is the safe state of the safe shutdown component). An example is a dc solenoid valve or air-operated valve (AOV) with dc solenoid pilot that would fail to its safe position on a loss of control power to the solenoid. This would not be applicable to an MOV, which, if spuriously operated, would remain in that position following a loss of control power.

(d) When evaluating a component failure (e.g., required nuclear safety component or a related component), all circuits that are associated with the component's operation and all those circuits whose failure could affect the component's operation should be considered as required.

(e) A single hot short from an external source could affect any and all conductors, one at a time, within a cable that is required or is associated with a required nuclear safety component. In addition to evaluating the effects of a hot short circuit failure, these failures could occur, in conjunction with other simultaneous individual or multiple fire-induced circuit failures (i.e., shorts-to-ground, open circuits, internal conductor to conductor shorts) on other conductors associated with the circuit or cable of concern. For high-low pressure interfaces, properly aligned three-phase and proper polarity dc hot shorts should be postulated to occur and these circuits should be included in the analysis.

(f) For multi-conductor cables, energized conductor(s) could short to individual or multiple conductors within the cable that is required or is associated with a required nuclear safety component.

(g) Plant-specific design features can preclude certain circuit failures from occurring. For example, the use of grounded, metallic, armored cable or dedicated conduit would preclude external hot shorts from further consideration. However, multiple ground faults might still energize conductors within a grounded conduit, shield or armor if those conductors are associated with ungrounded circuits. See Figure B.3.3(g) for an example involving multiple shorts to ground. For ease of analysis when analyzing an ungrounded DC circuit for the effects of a short to ground, it should be assumed that an existing ground fault from the same power source is present.

Step 4: Documentation. The circuit analysis for each component analyzed should clearly document the designated nuclear safety cables and, more importantly, document and justify excluded cables and circuits. The rationale for selection or exclusion of a cable should also be documented. The circuit analysis should list required power supplies and identify those cables associated that must remain functional following a control transfer (i.e., valve control cables that remain functional following control transfer from a remote shutdown panel). Any use of risk-informed methods to reduce the scope of circuit analysis should be adequately documented.

B.3.3 Specific Circuit Failure Scenarios. The following are examples of typical circuit failure modes (simplified circuits figures have been used for illustrative purposes only).

(a) *Low-Voltage dc (1 V dc–48 V dc).* These circuits are typically instrument signal cables for monitoring, protection systems, or control valve circuits (sensor to I/P converter). Shielded, grounded signal cables are typically used. Note that a conductor-to-conductor short on instrument cable or an intermediate resistance ground can result in a false instrument signal (same failure consequences as cable hot short, a fire-induced high signal). See Figure B.3.3(a) for an example of this failure mode.

Many plant protection circuits have logic circuitry that requires multiple input signals in order to actuate (i.e., one out of two taken twice, two out of three, etc.). In these instances, multiple failures on instrument input signal cables (or in some specific designs, multiple conductors within the same cable) could cause a fire-induced protection system actuation.

(b) *Medium Voltage Single Phase ac (115 V ac–220 V ac).* These circuits are typically used for secondary side control transformers of motor control center (MCC) loads (e.g., MOV control, fan and small pump controls, ac solenoid operated valves and dampers).

For grounded ac circuits, a hot short "source" can be from any energized circuit internal or external. For ungrounded ac, external and internal hot short "source" should be from same the same power supply.

See Figures B.3.3(b) through B.3.3(e) for examples of open circuits, shorts to ground, and hot shorts on typical grounded 120 V ac control circuit.

(c) *Medium Voltage dc (125 V dc–250 V dc).* These circuits are typically used for breaker controls for large pumps, switchgear, diesel generators, dc distribution, controls for solenoid-actuated air-operated valves, solenoid valves, dc MOVs, and so forth.

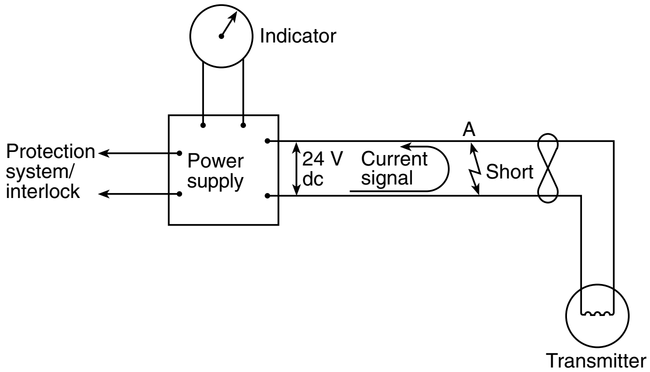
For an external hot short, the hot short "source" (other than a two-conductor proper polarity hot short) should be from the same dc source (battery) as the dc circuit under evaluation in order to provide a complete circuit path.

For high-low pressure interface valves, removing power at dc panel during normal operation does not prevent two-conductor proper polarity dc hot shorts from causing spurious actuation. *[See Figure B.3.3(f).]*

Multiple shorts to ground on an ungrounded dc system on circuits from the same battery (or on ungrounded ac circuits from the same transformer) could spuriously energize a normally de-energized circuit [*see Figures B.3.3(g) and B.3.3(h)*]. In addition, a hot short on an ungrounded dc circuit could also result in a protective device actuation (blowing a fuse or tripping a breaker) if a positive conductor shorts to a negative conductor from the same dc source or vice versa.

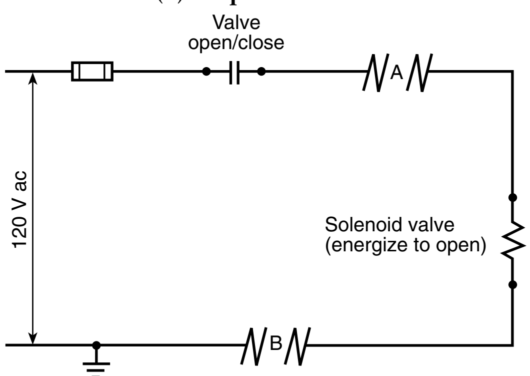
It should be noted that for high-low pressure interface valves, removing power at the motor control center (MCC) during normal power operations does not eliminate the potential three-phase proper phase ac hot shorts [*see Figure B.3.3(i)*]. Involving the power cable from the MCC to the valve could cause spurious operation of the valve.

FIGURE B.3.3(a) Instrumentation circuits.



Note: An internal short at point A could result in an erroneous instrument signal, which could cause erratic indication or related equipment malfunction such as protection system actuation or actuation of system interlocks.

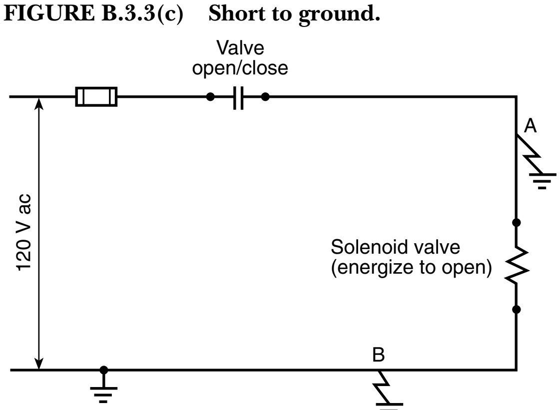
FIGURE B.3.3(b) Open circuit.



Notes:
1. An open circuit at points A and B will not affect the valve position if the control switch is open. However, it will not permit the operation of the valve.

2. An open circuit at points A or B will de-energize the valve and change its position if the control switch is closed. In addition, the open circuit will not permit the operation of the valve.

FIGURE B.3.3(c) Short to ground.

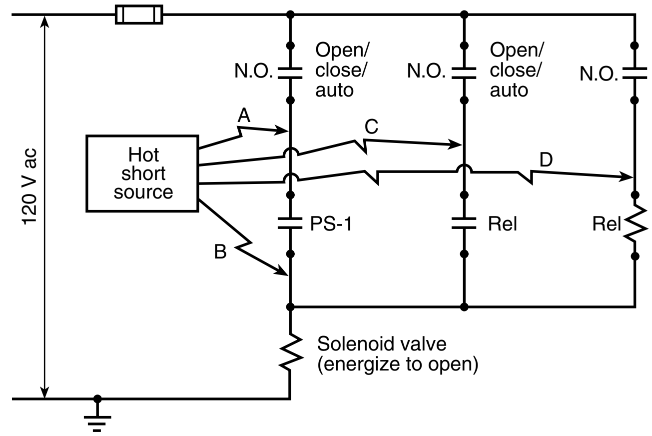


Notes:
1. Short-to-ground at point A will not affect the valve position if the control switch is open.

2. Short-to-ground at point A will affect the valve position if the control switch is closed by de-energizing the solenoid.

3. Short-to-ground at point B will not affect the valve position irrespective of the control switch position.

FIGURE B.3.3(d) Hot short example (external cable).

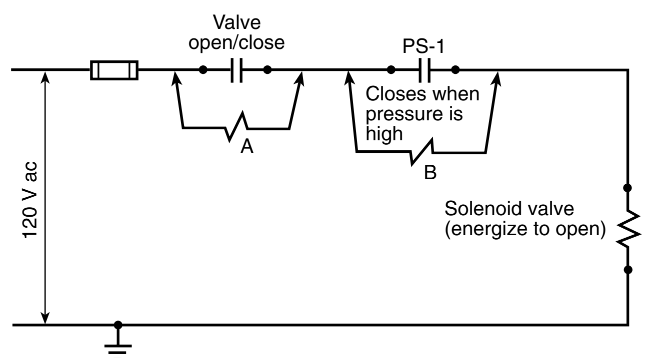


Notes:
1. A hot short at point A (from internal or external source) and an internal short inside the cable connecting to PS-1 will energize the valve and change its position.

2. A hot short at point B will energize the valve and change its position.

3. A hot short at C and D (from an external source) need not be postulated as fire-induced circuit failure for this valve, except for high-low pressure interface valves.

FIGURE B.3.3(e) Hot short example (conductor-to-conductor within same cable).



Note: Internal short inside the cable connecting to PS-1 and a short across the valve's control switch at point A will energize the valve and change its position.

FIGURE B.3.3(f) Two-conductor proper polarity dc hot short example (solenoid valve or solenoid pilot valve for AOV).

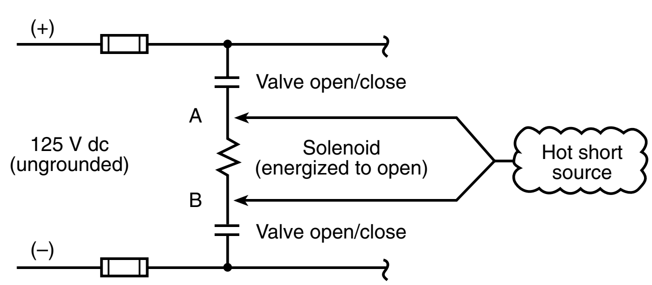
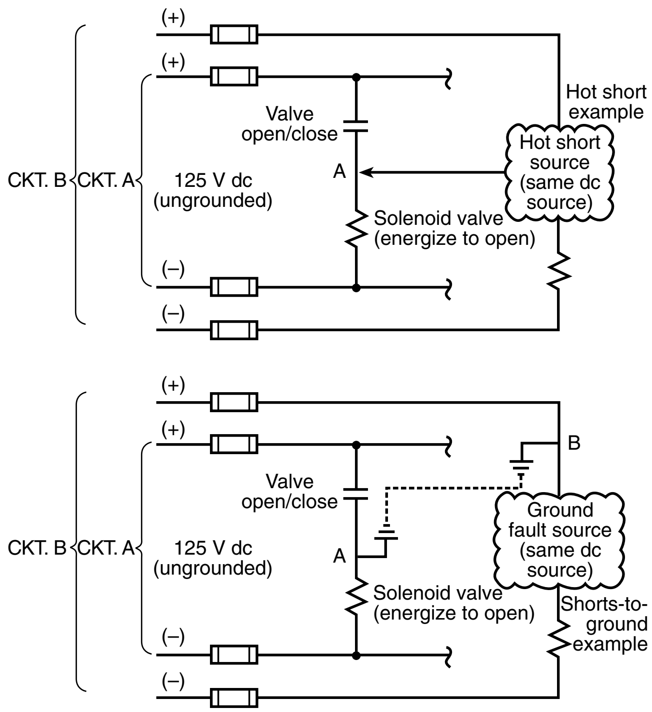


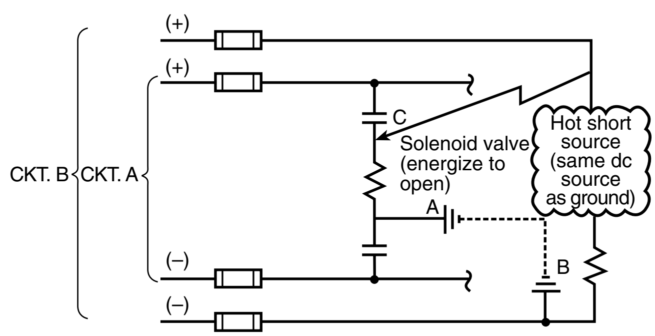
FIGURE B.3.3(g) Ungrounded system — multiple shorts to ground — Part 1.



Notes:
1. A short at point A (from an internal or external source) will energize the valve and change its position (top figure).

2. A short-to-ground at point A and a short to ground at point B will energize the valve and change its position (bottom figure).

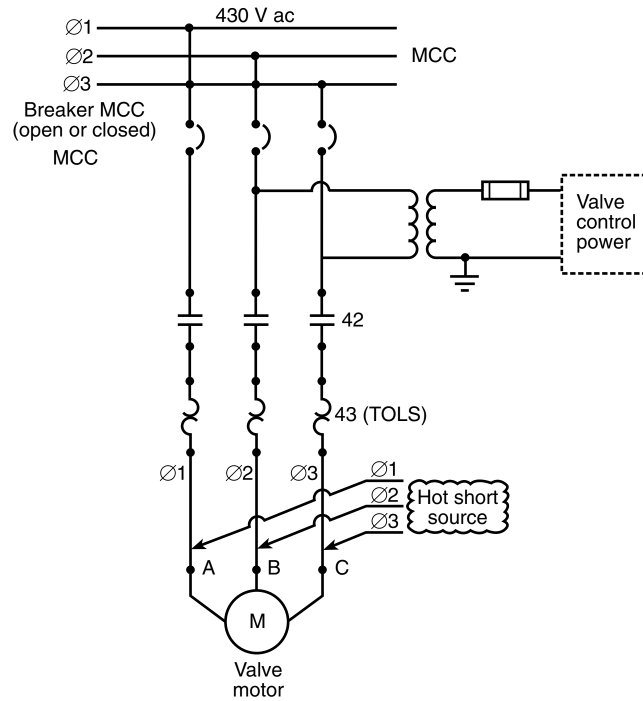
FIGURE B.3.3(h) Underground system — multiple shorts to ground — Part 2.



Notes:
1. A short-to-ground at point A and a short-to-ground at point B will not affect the valve position.

2. A short-to-ground at point A and a ground at point B and a simultaneous hot short at point C need not be postulated as a fire-induced failure for this valve except for high-low pressure interface valves.

FIGURE B.3.3(i) Three-phase ac hot short example (MOV).



Note: Hot shorts at points A, B, and C (from an external source, such as adjacent power cables in the cable tray or raceway) will energize the valve motor and change its position. This type of fire-induced circuit failure needs only be postulated for a high-low pressure interface valve.

B.3.4 Other Required Circuits (Formerly Known as Associated Circuits). This section contains a description of additional circuits that should be considered for their impact on the ability to achieve the nuclear safety criteria. These circuits are divided into the following two categories:

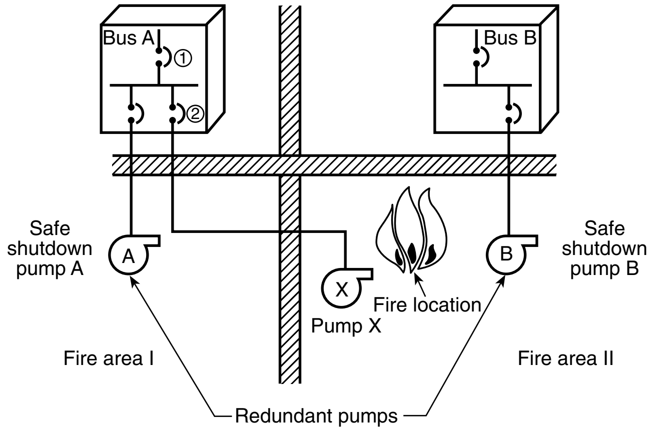
(1) Common power supply
(2) Common enclosure

These categories are described in the following paragraphs. (Note that circuits required due to spurious operation considerations are addressed in B.3.2.)

(a) *Common Power Supply Issues.* The concern is fire damage to a cable that could result in a loss of power to a power source required to support nuclear safety equipment. This situation could occur if the upstream breaker/fuse for a nuclear safety power supply is not properly coordinated with a downstream breaker/fuse for the cable that is damaged. Circuits associated by common power supply are circuits that are powered from nuclear safety power supplies whose overcurrent protection device is not properly coordinated with the overcurrent protection of the power supply feeder *[see Figure B.3.4(a)]*.

In Figure B.3.4(a), the postulated fire could render nuclear safety pump B inoperable. Fire-induced electrical faults affecting pump X or its power cable could cause breaker 1 to trip, thereby rendering pump A inoperable if the two respective overcurrent isolation devices (breaker 2 and breaker 1) are not properly coordinated. This situation results in the interruption of power to redundant nuclear safety pumps.

FIGURE B.3.4(a) Common power supply issues.



(b) *Common Enclosure Issues.* Circuits, which share enclosures with nuclear safety equipment circuits, should be analyzed to determine their effect on redundant nuclear safety equipment. The concern is that the effects of the fire can extend outside of the immediate area by means of fire-induced faults on inadequately protected cables and could cause an overcurrent condition resulting in secondary ignition. This situation could result in remote damage that could disable the redundant train of equipment.

A type of common enclosure failure mode is that of secondary ignition. As shown in Figure B.3.4(b), the fire at instrument Bus B induces a fault on a cable that is not adequately electrically protected. The fault then results in the ignition of a secondary fire in the vicinity of the instrument A cables due to an overcurrent condition resulting in cable jacket ignition. Again, the result could be the loss of the two redundant trains.

A special type of common enclosure issue involves current transformers. Current transformers are used throughout the electrical distribution system to monitor bus current and provide differential protection. The current transformers are physically located on the electrical conductor (i.e., bus bar) and provide a signal through their secondary winding that is proportional to the current flowing through the conductor. Current transformers are designed to transform high primary current into low secondary current. Theoretically, the secondary voltage is as high as required to maintain a constant primary-to-secondary current ratio. An opening in the secondary circuit causes excessively high voltages in the current transformer secondary circuit in an attempt to maintain this ratio, which can result in an ignition of the transformer materials.

One type of current transformer circuit scheme is provided in Figure B.3.4(c). A fire in the control room could cause a fire-induced opening in the secondary circuit of the current transformers, causing an electrical fault at the current transformers in both nuclear safety Buses A and B. This situation could result in a fire within each bus, thereby disabling both buses and the redundant nuclear safety pumps powered from them.

FIGURE B.3.4(b) Common enclosure issues — secondary ignition.

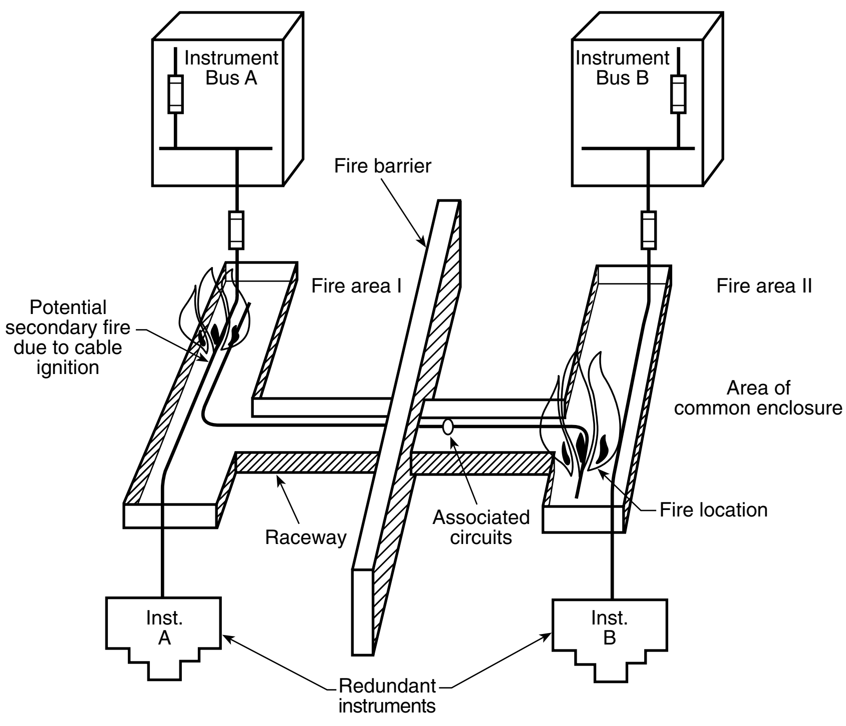
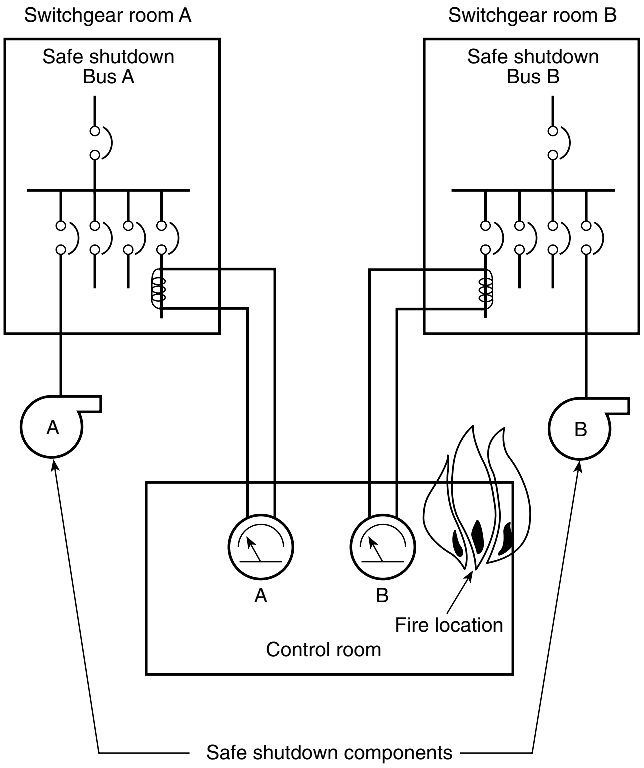


FIGURE B.3.4(c) Common enclosure issues — current transformer secondaries.



B.3.4.1 Considerations When Evaluating Common Power Supply Issues. The nuclear safety equipment list will be used to identify the electrical distribution buses, switchgear, load centers, and panels required to provide electrical power to nuclear safety equipment. The following steps describe the process recommended to evaluate those circuits (nuclear and non-nuclear safety) that share a common power supply with nuclear safety equipment.

Step 1: Identification of Required Power Supplies. A listing of all the electrical distribution system buses, switchgear, load centers, panels, and so forth, should be prepared utilizing the nuclear safety equipment list (*see B.2.2*).

Step 2: Evaluation of Electrical Protective Device and Coordination. Each load on the nuclear safety power supplies for circuit coordination should be reviewed per accepted design practices. A list of the circuits that are not properly coordinated should be prepared.

Step 3: Disposition and Documentation. The results of the common power supply issues should be documented. For cases in which coordination between series protective devices cannot be demonstrated, a common power supply other than the required circuit should be assumed to exist. These circuits should be dispositioned by one of the following means:

(a) Demonstrate coordination by refining the available short circuit current and/or trip device characteristics.

(b) Identify protective device setpoint changes (including changes in fuse size and/or clearing characteristics) that should establish coordination.

(c) Incorporate the cables of concern into the nuclear safety analysis as required circuits for the affected power supply. This procedure should ensure that, on a fire area basis, the impact of common power supply circuits is evaluated.

B.3.4.2 Considerations When Evaluating Common Enclosure Issues.

Step 1: Common Enclosure — Secondary Ignition. As described previously, secondary ignition has the potential to be a concern due to fire-induced electrical faults on inadequately protected cable resulting in secondary ignition. This concern can be addressed by evaluating the plant electrical design criteria to ensure that adequate overcurrent protection for all conductors exists throughout the plant.

Step 2: Current Transformer Secondary Ignition. Current transformers that are constructed such that an open secondary circuit could cause ignition of the transformer should be considered. Current transformers that are susceptible to ignition due to open secondary windings and have secondary circuits extending outside the fire area that are not isolated by transducers should have their circuits included in the nuclear safety assessment.

Step 3: Disposition and Documentation. The results of the common enclosure issues should be documented and maintained. Calculations and analyses that have been performed in support of other issues can be utilized provided the results of these analyses have properly considered the applicability to post-fire nuclear safety.

B.4 Nuclear Safety Equipment and Cable Location. The purpose of this step is to identify the location of the nuclear safety equipment and cables identified in Sections B.2 and B.4. Equipment and cables should be located utilizing available information from existing databases, plant layout drawings, and, if necessary, plant walkdowns. Equipment and cables should be located by the smallest designator (room, fire zone, or fire area) for ease of analysis.

The cable and raceway database (or the hard copy drawings) establish the relationship between cables and their routing. Based on this information, supplemented as necessary by plant walkdowns, the location of each required circuit can be identified. The process usually entails the following process:

(1) Cable-to-raceway relationship (what conduit, cable trays, junction boxes, pullboxes that a cable is routed through)
(2) Raceway-to-fire zone/room relationship (what fire zones, rooms, or fire areas that a raceway is routed through)
(3) Cable endpoint location (fire zones, rooms, or sub-fire areas, where a cable terminates; this can be necessary since cable endpoints can exist in plant areas with no raceways containing the cable, i.e., a cable terminating in the control room, coming up through the floor of a cable spreading room.)
(4) Fire zone/room to fire area relationship (what sub-fire areas comprise a fire area)

B.5 Fire Area Assessment. In Sections B.2, B.4, and B.5, the interdependencies of nuclear safety systems, equipment, and cables have been established. An assessment for each fire area should be performed in order to demonstrate achievement of the nuclear safety performance criteria. The nuclear safety equipment and their interrelationships should be analyzed for each area to ensure that success path(s) are available based upon the postulated equipment and cable losses in that fire area. Other risk informed–performance-based methods acceptable to the authority having jurisdiction can be used to refine the fire area assessments and the assumptions made regarding the impact on a success path. A success path should be identified that ensures each of the nuclear safety performance criteria is met.

B.5.1 Methodology.

Step 1: Identification of Affected Systems and Components. All unprotected cables and equipment within a fire area could be affected by the fire. This does not imply that the fire instantaneously spreads throughout the fire area, but rather is intended as a conservative method to address the fact that, for this analysis, neither the fire size nor the fire intensity is rigorously determined. As a minimum, this should include the following:

(1) Nuclear safety equipment affected by either the equipment, its associated cables, or associated instrument tubing located in the area
(2) Equipment affected by loss of a support system (cooling water, ventilation) or loss of power supply

Using the equipment interrelationship tool (logic diagrams, fault trees, etc.), identify the equipment affected by a fire in the area and the reason for the equipment loss (i.e., equipment located in the area, cable located in the area, power supply lost, etc.).

Step 2: Success Path Determination. The following guidelines should be considered in the determination of success path(s).

(a) Support systems should be reviewed first in order to assess the impact on the systems being supported. For example, it is recommended that the impact on the electric power distribution system be reviewed first. This review is performed so that an unnecessary amount of time is not spent analyzing process systems (i.e., charging, auxiliary feedwater, residual heat removal) that might not have necessary power to support the specific train of components to support safe shutdown.

(b) Similarly, cooling systems such as service water and component cooling water should be reviewed for the systems that they support.

(c) The impact of a particular fire on process monitoring instrumentation should be reviewed prior to assessing other system availability, to ensure that process monitoring instrumentation is available for the equipment relied upon to meet the success path.

(d) Note that some equipment can perform more than one function, such as RHR isolation valves that are normally closed during plant operation at power and during the initial phases of plant cooldown but are required to be open to support RHR operation and the safety function of long-term decay heat removal.

(e) An acceptable alternative to the methods described above is the performance of an exclusionary analysis. This analysis would assure that cables and components for at least one success path are not located in the area.

(1) In taking the performance-based approach, factors discussed in (d) should again be considered in the event equipment (or its cables) required for a success path to achieve and maintain the nuclear safety performance criteria are in the fire area of concern.
(2) Although an exclusionary analysis uses a different approach from the Step 2 success path determination process described in items (a) through (f), all of the fundamentals, such as component interrelationships, recovery action feasibility, and so forth, should be considered. Potential losses of equipment due to common power supply, common enclosure concerns, and spurious actuations and signals should also be addressed. Success paths relied upon for achieving the nuclear safety performance criteria using the exclusionary analysis method should be clearly documented for each fire area in order to ensure future changes do not invalidate the results of the analysis.

(f) The basis for successful demonstration of the nuclear safety performance criteria for a fire in each fire area should be documented for equipment potentially affected by a fire in the area. This documentation is particularly important when redundant nuclear safety equipment is located in the area and reliance is placed on physical separation, fire protection systems and features, or recovery actions, in order to achieve and maintain the nuclear safety performance criteria.

B.5.2 Methodology Success Path Resolution Considerations.

Considerations should be as follows.

(a) The magnitude, duration, or complexity of a fire cannot be foreseen to the extent of predicting the timing and quantity of fire-induced failures. Nuclear safety circuit analysis is not intended to be performed at the level of a failure modes and effects analysis since it is not conceivable to address every combination of failures. Rather, for all potential spurious operations in any fire area, focus should be on assessing each potential spurious operation and mitigating the effects of each individually. Multiple spurious actuations or signals originating from fire-induced circuit failures could occur as the result of a given fire. The simultaneous equipment or component maloperations resulting from fire-induced failures, unless the circuit failure affects multiple components, is not expected to initially occur. However, as the fire propagates, any and all spurious equipment or component actuations, if not protected or properly mitigated in a timely manner, could occur. Spurious actuations or signals that can prevent a required component from accomplishing its nuclear safety function should be appropriately mitigated by fire protection features.

(b) An assumption of only a single spurious operation without operator intervention (i.e., having two normally closed MOVs in series with cables routed through an area, and assuming only one of the valves could spuriously open) should not be relied upon for ensuring a success path remains available. Therefore, in identifying the mitigating action for each potential spurious operation in any given fire area, an assumption such as that stated above should not be relied upon to mitigate the effects of one spurious operation while ignoring the effects of another potential spurious operation.

(c) Where a single fire can impact the cables for high-low pressure interface valves in series, the potential for valves to spuriously operate simultaneously should be considered. Removing power to two or more normally closed high-low pressure interface valves in series during normal operation (which reduces credible spurious operations to multiple three-phase ac hot shorts or multiple proper polarity dc hot shorts on multiple valves) is an acceptable method of ensuring RCS integrity without additional analysis or fire protection features. This criterion applies to all fire areas, including the control room, and to all circuits regardless of whether or not they can be isolated from the control room by the actuation of an isolation transfer switch.

(d) The performance-based approach should consider the fire protection systems and features of the room and what effects the fire scenarios would have on the nuclear safety equipment within the area under consideration.

(e) Recovery actions can be performed as part of a performance-based, risk-informed approach subject to the limitations of Chapter 4 of the standard to mitigate a spurious actuation or achieve and maintain a nuclear safety performance criterion. For the equipment requiring recovery actions, information regarding the fire areas requiring the recovery action, the fire area in which the recovery action is performed, and the time constraints to perform the recovery actions should be obtained to assess the feasibility of the proposed recovery action.

(1) The proposed recovery actions should be verified in the field to ensure the action can be physically performed under the conditions expected during and after the fire event.
(2) When recovery actions are necessary in the fire area under consideration, the analysis should demonstrate that the area is tenable for the actions to be performed and that fire or fire suppressant damage will not prevent the recovery action from being performed.
(3) The lighting should be evaluated to ensure sufficient lighting is available to perform the intended action.
(4) Walk-through of operations guidance (modified, as necessary, based on the analysis) should be conducted to determine if adequate manpower is available to perform the potential recovery actions within the time constraints (before an unrecoverable condition is reached).
(5) The communications system should be evaluated to determine the availability of communication, where required for coordination of recovery actions.
(6) Evaluations for all actions, which require traversing through the fire area or an action in the area of the fire, should be performed to determine acceptability.
(7) Sufficient time to travel to each action location and perform the action should exist. The action should be capable of being identified and performed in the time required to support the associated shutdown function(s) such that an unrecoverable condition does not occur. Previous action locations should be considered when sequential actions are required.
(8) There should be a sufficient number of essential personnel to perform all of the required actions in the times required, based on the minimum shift staffing. The use of essential personnel to perform actions should not interfere with any collateral industrial fire brigade or control room duties.
(9) Any tools, equipment, or keys required for the action should be available and accessible. This includes consideration of SCBA and personal protective equipment if required.

B.6 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 capability safety 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, *Guidelines for Industry Actions to Assess Shutdown Management*, 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 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

B.6.1 General. The following is 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 *(see Section B.2)*. 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) conditions should be sufficient. For spent fuel pool cooling, any systems, equipment, and associated instrumentation should be identified and their interrelationships identified in order to properly assess their 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.

B.6.2 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 (*see Section B.3*).

B.6.3 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 (*see Section B.4*).

B.6.4 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 area free of intervening combustibles while on 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

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

This appendix 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.

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 is an important part of this process and requires the engineer to be familiar with model features and limitations.

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. The nondimensional conservation equations can be written in vector form as follows:

Energy:

$$\left[\omega\rho\left(\frac{\partial}{\partial t}\right)+(\rho\boldsymbol{v}\bullet\nabla)\right]\left[\left(\int C_p dT\right)+\alpha\Sigma h\boldsymbol{Y}+\left(\gamma-\frac{1}{\gamma}\right)M^2\left(\frac{\mathrm{v}^2}{2}\right)\right]=$$
$$\left(\gamma-\frac{1}{\gamma}\right)\omega\left(\frac{\partial\rho}{\partial t}\right)+\nabla\bullet\frac{(\lambda\nabla T)}{PR}-\alpha\Sigma h[\nabla\bullet(\rho Y\boldsymbol{V})]$$
$$+\frac{(\nabla\bullet\boldsymbol{q})}{B}+\frac{(\gamma-1)}{\gamma}\left(\frac{M^2}{R}\right)\nabla\bullet(\boldsymbol{v}\bullet S)$$
$$+\frac{(\gamma-1)}{\gamma}\left(\frac{M^2}{F}\right)(\rho\boldsymbol{v}\bullet f-\rho\Sigma Y\boldsymbol{V}\bullet\boldsymbol{f})$$

Mass:

$$\omega\left(\frac{\partial\rho}{\partial t}\right)+\nabla\bullet(\rho\boldsymbol{v})=0$$

Momentum:

$$\omega\left(\frac{\partial\rho\boldsymbol{v}}{\partial t}\right)+\nabla\bullet(\rho\boldsymbol{v}\boldsymbol{v})=-\frac{(\nabla p)}{M^2}+\frac{(\rho\boldsymbol{f})}{F}+\frac{(\nabla\bullet S)}{R}$$

Species:

$$\omega\left(\partial\frac{(\rho\boldsymbol{Y})}{\partial t}\right)+\nabla\bullet(\rho\boldsymbol{v}Y)=-\nabla\bullet(\rho Y\boldsymbol{V})+\Sigma vDf(p,T)e^{-\beta/T}$$
$$\times\Pi\boldsymbol{X}^n\left[1-\left(g\frac{(p,T)}{K}\right)e^{-\gamma/T}\Pi\boldsymbol{X}^{m-n}\right]$$

where:

ω = ratio of flow time to evolution time
ρ = density
t = time
$\boldsymbol{v}$ = velocity vector
p = pressure
M = Mach number
$\boldsymbol{f}$ = body force per unit mass
F = Froude number
R = Reynolds number
C_p = specific heat
α = nondimensional heat release
h = enthalpy of formation
$\boldsymbol{Y}$ = mass fraction
$\boldsymbol{X}$ = mole fraction
γ = ratio of specific heat at constant pressure to specific heat at constant volume
λ = thermal conductivity
P = Prandtl number
$\boldsymbol{V}$ = diffusion of species
q = radiant energy flux
S = shear stress
T = temperature
B = Boltzmann number
D = Damkohlet number
v = stoichiometric coefficient
β = activation energy
m = order of backward reaction
n = order of forward reaction
f_k = nondimensional pressure and secondary temperature dependencies of foward rate at step k
g_k = nondimensional pressure and secondary temperature dependencies of equilibrium constant at step k
K = nondimensional equilibrium constant

Fire models are divided into two broad classifications: physical fire models and mathematical fire models. Physical fire models typically experiment with the ability of reducing 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 above 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 is entered directly by the user. This parameter typically has the most significant impact on the results of the fire model; therefore, the selection of representative heat release rate characteristic (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 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 pre-flashover 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 pre-flashover 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 25 kW/m^2.

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 is determined during the validation and verification of the model as conducted by the developer or independent party. This information can be obtained from the user's guide, other documentation provided with the model, or from available public literature. Tables C.2.2(a) and 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.

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

Table C.2.2(a) Summary of Model Features

Model	Five [C-6.1 (6)]	COMBRN IIIe [C-6.1 (2)]	CFAST [C-6.1 (1)]	LES [C-6.1 (8)]
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

Table C.2.2(a) Summary of Model Features ***(Continued)***

Model	Five [C-6.1 (6)]	COMBRN IIIe [C-6.1 (2)]	CFAST [C-6.1 (1)]	LES [C-6.1 (8)]
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
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, multi-room (100 m^3), multi-room (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

Source: USNRC — NUREG 1521 [C-6.2 (1)]

Table C.2.2(b) Summary of Model Features

Program	Type	Number of Rooms	Wall Heat Transfer	Lower Level Gas Temp	Heat Targets	Fire	Gas Concen-trations	O_2 Depletion	Vertical Connections	HVAC Fans and Ducts	Detectors	Sprinklers	Remarks
CFAST **[C-6.1 (1)]**	Zone	15	Yes	Yes	No	Specified multiple	Yes	Yes	Yes	Yes	Yes	Yes	Fewer rooms if PC
FASTLITE **[C-6.1 (5)]**	Zone	3	Yes	Yes	No	Specified	Yes	Yes	Yes	Yes	Yes	Yes	Easy input and run for PC
COMP-BRN III **[C-6.1 (2)]**	Zone	1	Yes	No	Yes	Growth calcula-tion	No	Yes	No	No	Yes	No	Input distributions for Monte-Carlo calculations
FIVE **[C-6.1 (6)]**	Provides initial screen, leads to use of PRAs, look up tables												Gathers info and keeps records — no computer necessary
FLAMME **[C-6.1 (10)]**	Zone	Multi	Yes	Real	Yes	Specified multiple	Yes	Yes	No	Yes	No	No	French, ISPN
MAGIC **[C-6.1 (12)]**	Zone	Multi	Yes	Yes	Yes	Specified multiple	Yes	Yes	Yes	Yes	Yes	No	French, EdF
FLOW – 3D **[C-6.1 (11)]**	CFD	Few	Yes	Real	Yes	Specified	Yes	Yes	Yes	Yes	Yes	—	Depends on user, significant computing time, and acceptable granularity
LES **[C-6.1 (8)]**	CFD	Few	Yes	Real	Yes	Specified	Yes	Yes	Yes	Yes	Yes	Yes	
FPETOOL **[C-6.1 (7)]**	Zone	$2^1/_2$	No	No	No	Specified	Yes	Yes	No	No	Yes	No	Easy inputs for PC, has "TOOLS"
ASCOS **[C-6.1 (9)]**	Net-work flow	Multi	No	N/A	No	N/A	No	N/A	Yes	No	N/A	N/A	ASHRAE document (for smoke flow)
CONTAM **[C-6.1 (3)]**	Net-work 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)

M. A. Azarm Dey, R. Travis, G. Martinez-Guridi, and R. Levine reviewed and provided descriptions of some of the current state-of-the-art computer codes used in the U.S. building industry and overseas in the USNRC's, NUREG 1521 [C-6.2 (1)]. An overview of the features from these computer codes is presented in Table C.2.2(a).

The following is a short description of the columns found in Table C.2.2(b):

Wall Heat Transfer. Refers to whether the heat lost to the wall is calculated in the program. Some programs only use an empirical estimate of the heat remaining in the gas, thus greatly reducing the amount of calculation per time step.

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.

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. As mentioned above, 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.

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.

Gas Concentration. Must be specified as emissions from the fire vs. 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.

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.

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.

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 them can add forced flow from the heating, ventilation, and air conditioning (HVAC) system(s).

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.

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

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
(3) Field
(4) Finite element analysis models

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.

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 PC is usually sufficient to carry out the implementation of the model.

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 PC computers. 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.

C.2.3.4 Finite Element Analysis Models. Finite element analysis (FEA) models allow the engineer to evaluate the impact of a fire on a two- or three-dimensional surface such as a fire barrier, steel beam, and/or column. FEA models break the surface to be modeled into a two- or three-dimensional grid and solve the general heat conduction equation. General heat transfer finite element programs have been available for many years and can provide very good heat flux and temperature profile results assuming adequate thermal property data for the materials being modeled are available. In the application of FEA models to fires, special attention should be given to characterizing the conditions (radiant and convective heat flux) to which the surface being modeled is exposed. This characterization is often based on other fire modeling results or experimental data.

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 either 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.

It is important to understand that the term *fire scenario* as used in this standard has a very 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.

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:

(1) Supply and exhaust on

(2) Supply and exhaust off

(3) Supply on exhaust off

(4) Supply off exhaust on

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.

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

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 very 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.

For example, a trash fire of 150 Btu/sec can be the most expected, but when evaluating change involving a barrier only a trash fire of 300 Btu/sec located under the raceway will result in failure of the barrier to provide the level of protection it is intended.

C.3.4 Potential Fire Scenarios. Table C.3.4 provides a list of example 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.

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, or equipment failure such as overheating electrical faults in switchgear, transformers, or unwanted mechanical friction in motors/pumps. Cable initiated failures can also be considered due to fuse/breaker failure and circuit overloading. 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.

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 different burning characteristics than horizontal runs. Caution should be exercised when selecting HRRs and burning durations.

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.

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.

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.

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.

Table C.3.4 Potential Fire Scenarios

Fuel	Ignition Source	Type Area	Fuel	Ignition Source	Type Area
Lube oil[1]	Contact with hot piping surface	Containment	Core expansion material	Hot work	Seismic rattle space between two buildings
Fuel oil	Contact with hot piping surface	EDG room or building	Office supplies, furnishing, and internal wiring	Smoking or electrical circuit fault	Computer room next to control room
Turbine lube oil[2]	Contact with hot piping surface	Turbine generator building	Pump motor windings	Overheating	Various areas
Electrical cable insulation[3]	Internal cable fault	Cable spreading room, cable tunnel, or cable penetration area	Hydrogen	Electrical arc	Turbine building or outdoor hydrogen storage tanks
Electrical wiring, cables, and circuit boards[4]	Electrical fault inside a cabinet or behind vertical control boards	Control room	General Class A combustibles	Smoking, hot work, or portable heater malfunction	Temporary office trailer
Charcoal in filter[5]	Spontaneous combustion due to being wetted then heated	Main safeguards filter area	Transient material associated with construction or maintenance	Hot work	Various areas
Electrical cable insulation	Electrical circuit fault in switchgear cabinets	Rooms with electrical switchgear	Lube oil	Contact with hot pipes	Steam-driven pumps
General combustibles	Smoking, hot work, or portable heater malfunction	Warehouse (at beginning of refueling outage)	Lube oil	Hot work	Storage tank room or area within turbine building
Transformer oil	Internal electrical fault causing rupture of transformer casing and release of oil that becomes ignited	Yard transformers	Fuel oil	Contact with hot metal surface	Diesel fire pump house
Hydrogen, cable insulation, and plastic battery cases	Electrical arc	Battery rooms			

Notes:
[1]Reactor coolant pump lube oil system piping or fitting failure causes release of oil.
[2]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.
[3]High-energy internal cable fault in a fully loaded vertical cable tray ignites cable insulation within that tray and propagates to involve adjacent trays.
[4]Fire produces a large quantity of smoke and potentially toxic combustion products, causing untenable conditions and damage to sensitive computer and electronic components.
[5]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.

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, *Guide to the Fire Safety Concepts Tree,* contains a detailed discussion of the development and utilization of the fire event tree.

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.

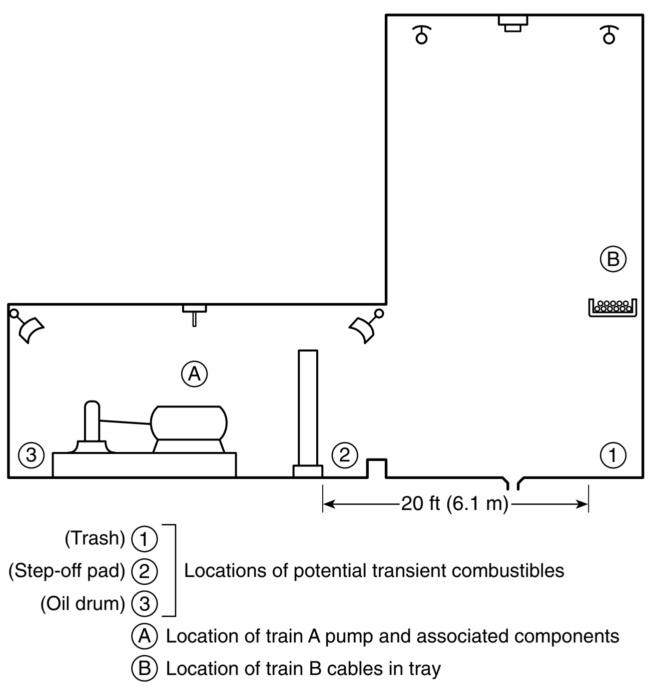
For a given fire area, there can be several different potential fires that can be analyzed using a fire event tree. For example, Figure C.3.5(a) depicts a fire area containing a Train A oil-filled pump, associated motor, and electrical cabinet; a Train B cable tray; automatic sprinklers in one portion,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

There are several potential fire events that could be considered for this fire area. *[See Figure C.3.5(b).]* 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.

FIGURE C.3.5(a). Fire area.

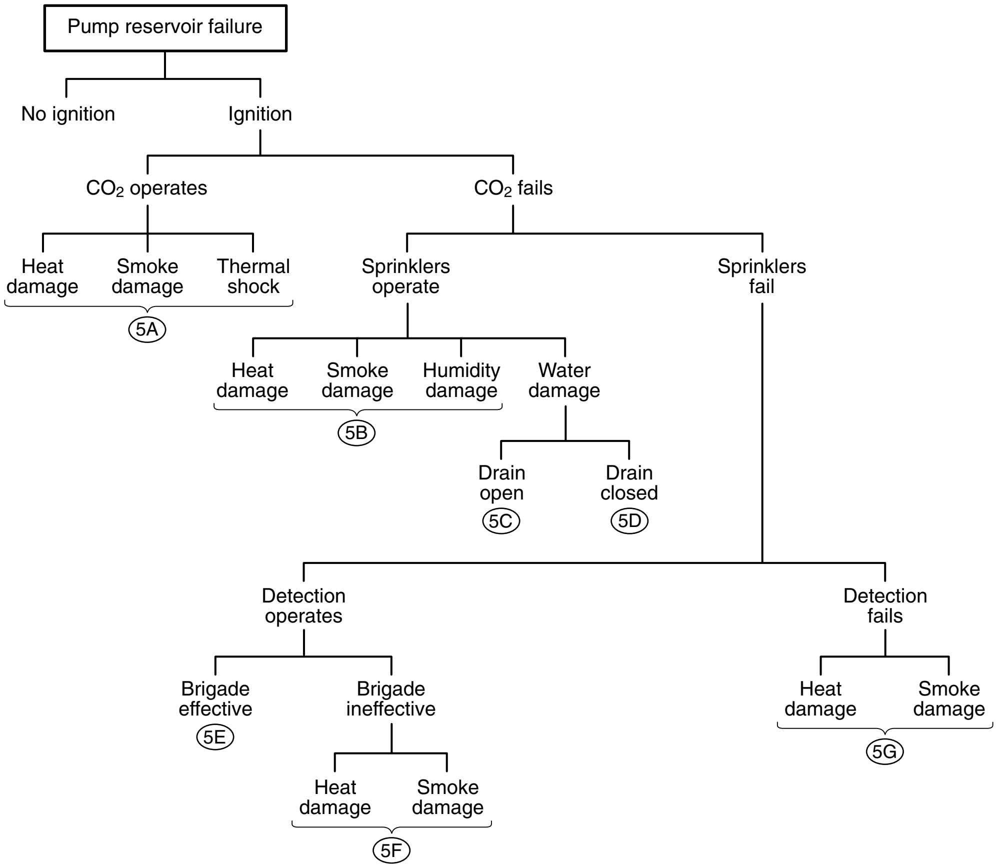


There are other analytical tools available that are useful in certain situations. These include failure analysis, failure modes and effects analysis (FEMA), HAZOP analysis, various checklists, and similar methodologies. These tools can be included as part of a performance-based assessment of fire protection,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

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).

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. These safety factors 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 experts' judgment 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.

FIGURE C.3.5(b) Fire Event Tree.



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 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 estimate. Therefore, a measurement is not complete unless a quantitative statement of the uncertainty accompanies it.

Finally, 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 also has a guide for evaluating the predictive capabilities of fire models. The recommendations in this guide should be reviewed and applied as appropriate when utilizing fire modeling.

C.4.1 Source of Heat-Release and Fire Growth Rates. A significant source of uncertainty in fire models is associated with the heat-release 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.

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 U.S. 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.

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. Some models in use at present 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 as a damage criterion for cables.

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.

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.

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.

C.5 Fire Model References.

C.5.1 Technical References for Specific Fire Model Codes.

(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 1993.

(2) Ho, et al., 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) Peacock, R.D., P.A. Reneke, W.W. Jones, R.W. Bukowski, and G.P. Forney, "A User's Guide for FAST: Engineering Tools for Estimating Fire Growth and Smoke Transport," Special Publication 921, National Institute of Standards and Technology, Gaithersburg, MD, October 1997.

(5) 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.

(6) Electric Power Research Institute, "Fire-Induced Vulnerability Evaluation (FIVE)," EPRI TR-100370, Palo Alto, CA, December, 1992.

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

(8) McGrattan, K.B., R.G. Rehm, H.C. Tang, and H.R. Baum, "A Boussinesq Algorithm for Buoyant Convection in Polygonal Domains," NISTIR 4831, National Institute of Standards and Technology, Gaithersburg, MD, April 1992.

(9) 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.

(10) 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.

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

(12) MAGIC is computer fire code used by the French utility Electricité de France (EdF). MAGIC is a multicompartment zone model, and it 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 semi-transparent 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.

C.5.2 Comparisons of Fire Model Codes.

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

(2) Deal, S., "A Review of Four Compartment Fires with Four Compartment Fire Models," Fire Safety Developments and Testing, Proceedings of the Annual Meeting of the Fire Retardant Chemicals Association, pp. 33–51, 1990.

(3) Duong, D.Q., "Accuracy of Computer Fire Models: Some Comparisons With Experimental Data From Australia," *Fire Safety Journal*, 16:6, pp. 415–431, 1990.

(4) Friedman, R., "International Survey of Computer Models of Fire and Smoke," *Journal of Fire Protection Engineering*, vol. 4, pp. 81–92, 1992.

(5) "Assessment and Verification of Mathematical Fire Models," ISO/CD 13387-3, International Organization for Standardization, April 1996.

(6) Mowrer, F.W., and D.W. Stroup, "Features, Limitations, and Uncertainties in Enclosure Fire Hazard Analyses — Preliminary Review," NISTIR 6152, National Institute of Standards and Technology, Gaithersburg, MD, March 1998.
(7) Mowrer, F.W., and B. Gautier, "Fire Modeling Code Comparisons," EPRI TR-108875, Electric Power Research Institute, Palo Alto, CA, September 1998.
(8) Mingchun Luo and Yaping He, "Verification of Fire Models for Fire Safety System Design," *Journal of Fire Protection Engineering*, vol. 9, no. 2, pp. 1–13, 1998.
(9) Simcox, S., N. Wilkes, and I. Jones, "Computer Simulation of the Flows of Hot Gases From the Fire at King's Cross Underground Station," Institution of Mechanical Engineers, King's Cross Underground Fire: Fire Dynamics and the Organization of Safety, London, pp. 19–25, 1989.

C.5.3 Other References Relating to Fire Modeling.

(1) Society of Fire Protection Engineers, "The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design," National Fire Protection Association, Quincy, MA. 1999.
(2) Wade, C.A., "A Performance-Based Fire Hazard Analysis of a Combustible Liquid Storage Room in an Industrial Facility," *Journal of Fire Protection Engineering*, vol. 9, no. 2, pp. 36–45, 1998.
(3) Mowrer, F.W., "Methods of Quantitative Fire Hazard Analysis," EPRI TR-100443, Electric Power Research Institute, Palo Alto, CA, May 1992.
(4) Meacham, B.J., "SFPE Focus Group on Concepts of a Performance-Based System for the United States," Summary of Consensus Focus Group Meeting, Society of Fire Protection Engineers, April 1996.
(5) DiNenno, P., ed. *The SFPE Handbook of Fire Protection Engineering*, 2nd edition, National Fire Protection Association, Quincy, MA, 1995.
(6) "National Fire Protection Association's Future in Performance-Based Codes and Standards," Report of the NFPA in-house task group, National Fire Protection Association, Quincy, MA, July 1995.
(7) "Design Fire Scenarios and Design Fires," ISO/CD 13387-2, International Organization for Standardization, 1997.
(8) Taylor, B.N. and C.E. Kuyatt, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," NIST Technical Note 1297, National Institute of Standards and Technology, Gaithersburg, MD, January 1994.
(9) "Standard Guide for Evaluating the Predictive Capability of Fire Models," ASTM E 1355, American Society for Testing and Materials, Philadelphia, PA, 1992.
(10) Gallucci, R., and R. Hockenbury, "Fire-Induced Loss of Nuclear Power Plant Safety Functions," *Nuclear Engineering and Design*, vol. 64, pp. 135–147, 1981.
(11) Electric Power Research Institute, "Fire PRA Implementation Guide," EPRI TR-105928, Palo Alto, CA, December 1995.
(12) Stroup, D.W., "Using Field Models to Simulate Enclosure Fires," *SFPE Handbook of Fire Protection Engineering*, 2nd ed., National Fire Protection Association, Quincy, MA, pp. 3-152–3-159, 1995.
(13) Lee, B.T., "Heat Release Rate Characteristics of Some Combustible Fuel Sources in Nuclear Power Plants," NBSIR 85-3195, NIST, Gaithersburg, MD, July 1985.
(14) Nowlen, S.P. "Heat and Mass Release for Some Transient Fuel Source Fires: A Test Report," NUREG/CR-4680, October 1986.

Appendix D Use of Fire PSA Methods in NFPA 805

This appendix 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 appendix is to describe acceptable fire probabilistic safety assessment (PSA) methods and data that can be used to perform the fire risk evaluations discussed in 2.4.3.

The scope of this appendix covers fire PSA methods and tools used to evaluate nuclear safety goals for the following purposes:

(1) All modes of plant operation
(2) Core and spent fuel pool accidents

Life safety or business interruption/property damage goals are not covered in this discussion.

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 appendix.

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, as follows:

(1) Fire initiation
(2) Fire growth (including detection, suppression, and confinement) and consequential equipment/circuit damage
(3) Post-fire safe shutdown

D.1.3 Organization of the Fire PSA Section. A general description of the fire PSA process is provided in Section D.2. This process is consistent with general industry methods and practice. Section D.3 provides guidance for conducting a fire PSA. This guidance is focused on describing the attributes of an acceptable fire PSA rather than the procedure. Guidance for performing a shutdown fire PSA is documented in Section D.4. Section D.5 contains issues specific to change analysis. A discussion of the quality necessary to support the objectives of the standard and the engineering evaluations is provided in Section D.6.

D.2 Fire PSA Process. A number of fire PSA approaches have been published over the past decades (*see references 1 through 9 in Section D.6*). These approaches have generally the same structure. Their differences lie primarily in the underlying assumptions, analytical methods, tools, and data used. The following discussion provides an overview of this common structure. It is intended to provide context for the fire PSA guidance provided in Sections D.3 and D.4. It is not intended to serve as a fire PSA procedure guide. References 1 through 9 in Section D.6 can be consulted for specific discussions on the process for performing a fire PSA.

A fire PSA is a process by which fire-induced contributions to plant risk are identified and quantified. During this process the plant is divided into fire areas and/or fire zones. In each fire area/zone, fire event scenarios are postulated and analyzed. In a direct quantification of fire risk, each fire area/zone is either screened from further consideration or quantified to estimate the fire risk. When a fire PSA is used for a change analysis, the risk difference between two (sets of) postulated plant configurations or conditions is assessed.