NFPA 551

Guide for Evaluation of Fire Risk Assessments

2004 Edition

NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471
An International Codes and Standards Organization

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Guide for the

Evaluation of Fire Risk Assessments

2004 Edition

This edition of NFPA 551, *Guide for the Evaluation of Fire Risk Assessments*, was prepared by the Technical Committee on Fire Risk Assessment Methods and acted on by NFPA at its November Association Technical Meeting held November 15–19, 2003, in Reno, NV. It was issued by the Standards Council on January 16, 2004, with an effective date of February 5, 2004.

This edition of NFPA 551 was approved as an American National Standard on January 16, 2004.

Origin and Development of NFPA 551

In the mid-1990s, it was recognized that the application of fire risk assessment methods in developing fire and life safety solutions was continuing to increase. However, a set of rules or a framework that described the properties of an acceptable fire risk assessment method was lacking. Additionally, there were no guidance documents available to those responsible for approving or evaluating fire and life safety solutions based on a fire risk assessment. In response, NFPA established the Technical Committee on Fire Risk Assessment Methods in 1999. NFPA 551 is the first document prepared by the committee in response to the growing need for guidance documents on fire risk assessment methods.

Technical Committee on Fire Risk Assessment Methods

J. Kenneth Richardson, *Chair*
Ken Richardson Fire Technologies Inc., Canada [SE]

David M. Barreres, Bechtel SAIC, LLC, NV [U]
James P. Begley, Schirmer Engineering Corporation, NV [I]
D. Allan Coutts, Westinghouse Safety Management Solutions, LLC, SC [U]
Douglas Crawford, Office of the Fire Marshal of Ontario, Canada, Canada [E]
William W. Doerr, Factory Mutual Research Corporation, MA [I]
Rep. FM Global/FM Research
Kenneth W. Dungan, Risk Technologies, LLC, TN [SE]
Russell P. Fleming, National Fire Sprinkler Association, NY [M]
Rep. National Fire Sprinkler Association
Simon Foo, Public Works & Government Services Canada (PWGSC), Canada [U]
Daniel F. Gemeny, The RJA Group, Inc., CA [SE]
George V. Hadjisophocleous, Carleton University, Canada [SE]
Morgan J. Hurley, Society of Fire Protection Engineers, MD [U]
Robert F. Layton, U.S. Department of Energy, TX [U]
Kenneth W. Linder, GE Global Asset Protection Services, CT [I]
Rep. GE Global Asset Protection Services
Brian J. Meacham, Arup Risk, MA [SE]
Kathy A. Notarianni, U.S. National Institute of Standards & Technology, MD [RT]
Michael E. G. Schmidt, Weatogue, CT [SE]
Nathan O. Siu, North Potomac, MD [E]
Rep. US Nuclear Regulatory Commission
Kuma Sumathipala, American Forest & Paper Association, DC [M]
Rep. American Forest & Paper Association
John M. Watts, Jr., Fire Safety Institute, VT [SE]
David T. L. Yung, CSIRO, Australia [RT]
Robert G. Zalosh, Worcester Polytechnic Institute, MA [RT]

Alternates

Kumar R. Bhimavarapu, Factory Mutual Research Corporation, MA [I]
(Alt. to W. W. Doerr)
Joseph A. Cappuccio, The RJA Group, Inc., VA [SE]
(Alt. to D. F. Gemeny)
Erica D. Kuligowski, U.S. National Institute of Standards & Technology, MD [RT]
(Alt. to K. A. Notarianni)
Victoria B. Valentine, National Fire Sprinkler Association, NY [M]
(Alt. to R. P. Fleming)
Armin Wolski, Arup Fire, CA [SE]
(Alt. to B. J. Meacham)

Nonvoting

Alan Charles Parnell, Fire Check Consultants, England [SE]

Milosh T. Puchovsky, 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 that cover the following: (1) frameworks that identify the relationships of fire safety concepts used for fire prevention and fire control, including codes, standards, recommended practices, and guides, and (2) frameworks that describe the properties of risk assessment methods for use in regulations.

Contents

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

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

Chapter 1 Administration

1.1 Scope. This guide is intended to provide assistance, primarily to authorities having jurisdiction (AHJs), in evaluating the appropriateness and execution of a fire risk assessment (FRA) for a given fire safety problem. While this guide primarily addresses regulatory officials, it also is intended for others who review FRAs, such as insurance company representatives and building owners.

1.2 Purpose. This guide is intended to assist with the evaluation of FRA methods used primarily in a performance-based regulatory environment. While the primary audience is anticipated to be authorities having jurisdiction, it is expected that the guide will be a useful resource for anyone conducting an FRA. This guide does not mandate the methods for use in demonstrating acceptable risk; rather, it describes the technical review process and documentation that are needed in evaluating an FRA.

1.3 Application. This guide is intended to be applied to the assessment of performance-based solutions, studies, code equivalencies, or regulatory compliance evaluations developed using FRA methods.

1.4 Qualifications for Practitioners. Persons undertaking FRAs, as anticipated by this guide, should document their qualifications and make them available to the authority having jurisdiction. Depending on the FRA being undertaken, the documentation could include educational background, past experience with FRAs, and professional registration. The form of the documentation should meet the needs of the authority having jurisdiction within the context of applicable laws and regulations.

1.5* Risk.

1.5.1 The perception of risk, and therefore the acceptance of risk, is influenced by the values of the stakeholders. Thus, the values of the stakeholders should be established in the risk metrics, which may include life safety, property, business interruption, and intangibles. The metrics associated with these values may be people affected, dollars of loss, acreage, and so forth. The expression of the metric is usually rate based (e.g., frequency, or probability of occurrence over a specified time period). The stakeholders may attach different weights to a given risk, based on their perspective. Each AHJ may have its own weighting, depending on its role.

1.5.2 For fire safety, the hazards are generally fire, explosion, smoke, and toxicity associated with fire products. The likelihoods and corresponding consequences are derived from fire scenarios associated with these hazards. The impacts or harm from the fire scenarios are expressed in the metrics associated with the values, such as number of people affected per location per year.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this guide and should be considered part of the recommendations of this document.

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

NFPA 101A, *Guide on Alternative Approaches to Life Safety,* 2004 edition.

NFPA 550, *Guide to the Fire Safety Concepts Tree,* 2002 edition.

Fire Protection Handbook, 18th edition, 2003.

SFPE Handbook of Fire Protection Engineering, 3rd edition, 2002.

NFPA Fire Incident Data Organization (FIDO).

NFPA Survey of Fire Departments.

2.3 Other Publications.

2.3.1 Bornhuetter, R. L., and R. E. Ferguson. 1972. "The Actuary and IBNR," PCAS LIX.

2.3.2 FEMA/USFA Database. U.S. Fire Administration, 16825 S. Seton Avenue, Emmitsburg, MD 21727.

National Fire Incident Reporting System (NFIRS). March 3–7, 1997.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter apply to the terms used in this guide. Where terms are not included, common usage of the terms applies.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

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

3.2.3 Guide. A document that is advisory or informative in nature and that contains only nonmandatory provisions. A guide may contain mandatory statements such as when a guide can be used, but the document as a whole is not suitable for adoption into law.

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

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

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

3.3 General Definitions.

3.3.1 Acceptance Criteria. Acceptance criteria are the units and threshold values against which a fire risk assessment is judged.

3.3.2 Consequence. The outcome of an event, which may be expressed qualitatively or quantitatively.

3.3.3* Deterministic Model. A model whose outputs are not probabilities or probability distributions, that is, they do not quantify uncertainty.

3.3.4 Event. The occurrence of a particular set of circumstances, whether certain or uncertain and whether singular or multiple.

3.3.5 Fire Risk Assessment (FRA). A process to characterize the risk associated with fire that addresses the fire scenario or fire scenarios of concern, their probability, and their potential consequences. Other documents may use other terms, such as *fire risk analysis*, *fire hazard*, *hazard analysis*, and *fire hazard analysis assessment*, to characterize fire risk assessment as used in this guide.

3.3.6* Fire Scenario. A set of conditions that defines the development of fire, the spread of combustion products, the reactions of occupants, and the effect of combustion products.

3.3.7 Frequency. The average number of times an event is repeated in a given period.

3.3.8 Likelihood. Frequency, probability, or their combination.

3.3.9 Method. A process or technique to help resolve a model.

3.3.10 Model. A simulation of an event.

3.3.11* Probabilistic Model. A model whose outputs are probabilities or probability distributions.

3.3.12 Probability. The extent to which an event is likely to occur.

3.3.13* Risk. The paired probabilities and consequences for possible undesired events associated with a given facility or process.

3.3.14 Stakeholder. Any individual, group, or organization that might affect, be affected by, or perceive itself to be affected by the risk.

3.3.15 Validation. The process of determining the correctness of the assumptions and governing equations implemented in a method.

3.3.16 Verification. The process of determining the correctness of the calculations or the solution of governing equations in a method.

Chapter 4 Evaluating a Fire Risk Assessment (FRA)

4.1 General. This chapter addresses evaluating a fire risk assessment (FRA) by discussing the stakeholders, an overview of the review process by the authority having jurisdiction (AHJ), scope of FRAs, bounding the FRA, and uncertainty.

4.1.1 FRAs may be used as tools for making risk-informed decisions.

4.1.2 FRAs have broad applicability in addressing fire safety issues. Examples of applications are shown in Table 4.1.2.

Table 4.1.2 Examples of Applications

Category	Example
Building project evaluation	Demonstrate compliance of a performance-based design Demonstrate adequacy of an existing facility Demonstrate adequacy of an alternative design Demonstrate improvement in facility fire safety
Class-of-use problems	Demonstrate adequacy of a new material use (e.g., chair fabric) Determine required protection for an alternative-fuel vehicle Establish necessary protection to be required by a code or standard Demonstrate improvement in fire safety
General application	Establish emergency response needs (e.g., fire department staffing) Establish fire risk (typical facility or overall locale) for a city, county, or state in establishing regulations

4.2 Stakeholders. The stakeholders with interest in the scope and application of the FRA should be identified early in the process. The stakeholders include all those who have a financial, personnel safety, public safety, or regulatory interest in the fire risk. Stakeholders whose interests may apply include, among others, the following:

(1) Regulators
(2) Facility owners and operators
(3) Employees
(4) Emergency responders
(5) Insurers
(6) Neighbors
(7) Community
(8) Investors
(9) Design and construction team
(10) FRA preparers
(11) Tenants

4.2.1 It is important to consider all possible stakeholders during planning, particularly when stakeholder influences conflict.

4.2.2 The stakeholders should participate in the establishment of the objectives of the FRA to ensure that the results provide proper and credible bases for decision making.

4.3 Role of the Authority Having Jurisdiction in the Process. For the purposes of this guide, it is anticipated that the review of a project will proceed using an FRA as provided in 4.3.1 through 4.3.2.3. The process is exemplified in Figure 4.3.

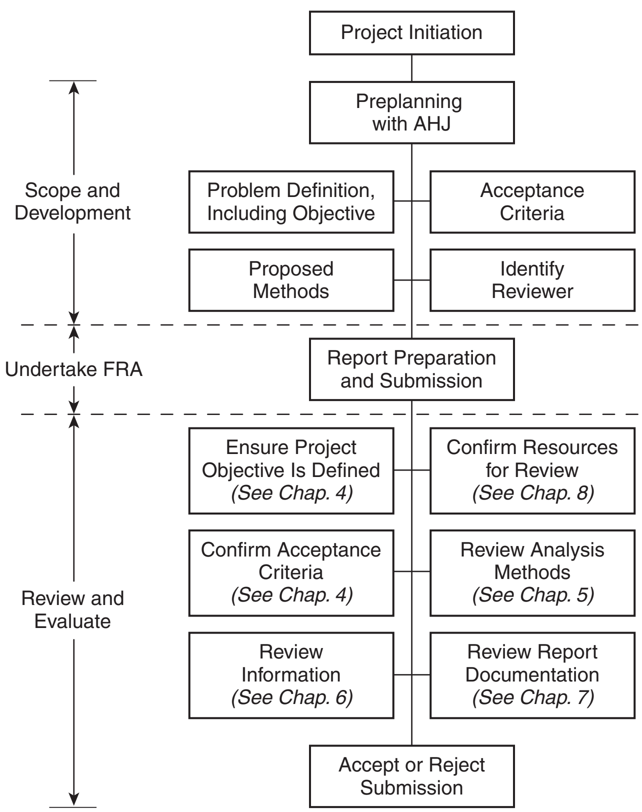

FIGURE 4.3 Overview of Review Process.

4.3.1 FRA Evaluation. The evaluation of an FRA should be a collaborative process among stakeholders. To evaluate an FRA properly, the reviewer should be introduced to the project as early as possible.

4.3.2 AHJ Participation. The AHJ should be involved in the following steps of the process: defining the problem, acceptance criteria, choice of method, review process, detailed review, and final approval.

4.3.2.1 Defining the Review Process. The AHJ should define its role in the direct review of the FRA. Depending on the FRA-related experience and resources of the AHJ, the AHJ may perform the review. Alternatively, the AHJ may utilize a third party to perform the review.

4.3.2.2 Detailed Review. When reviewing an FRA, the AHJ should check whether the assumptions, building characteristics, occupant characteristics, and fire characteristics used in the analysis acceptably reflect the actual conditions. The types of items that should be checked are identified in Section 8.3. Additionally, the modeling that was used in the FRA should be reviewed.

4.3.2.3 Final Approval. Final approval of the FRA rests with the AHJ.

4.4 Scope of FRAs.

4.4.1 Defining the Problem.

4.4.1.1 The purpose of conducting the FRA should be identified and documented. The purpose might be to identify the level of risk present in an existing building or facility, to identify methods of lowering the risk in an existing building or facility, or to identify methods of providing a level of risk deemed acceptable in a new or renovated building or facility. The objectives of the FRA may be associated with the risk to life (occupants or fire fighters), the risk to property, the risk to operations (e.g., cost of business interruption), or the risk to the environment. Fire safety objectives and appropriate performance, which are generally based on the building's characteristics and functions as well as the owner's fire safety expectation over a specific period of time or throughout the design life of the building, should be clearly stated for new and existing construction.

4.4.1.2 Collateral issues beyond the scope of the FRA or exclusions from the FRA may become the questions of additional FRAs but should not divert the FRA from its specific objectives.

4.4.2 Elements of Risk. The following elements that affect the fire risk should be characterized.

4.4.2.1 The exposed target at risk should be identified. This may include any or all of the following:

(1) People (occupants, employees, general public, emergency responders)
(2) Property (structures, systems, components of the built environment)
(3) Environment (national parks, monuments, hazardous materials)
(4) Mission (heritage, business continuity, information/communication)

4.4.2.2 The fire stimuli to which the target is vulnerable should be characterized. These may include any or all of the following:

(1) Heat (radiant flame, convective gases)
(2) Smoke (obscuration, corrosive/conductive aerosols)
(3) Gases (toxic, corrosive)

4.4.2.3 The transport phenomena, which bring the fire stimuli into contact with the exposed target, should be characterized.

4.4.2.4 The response of the exposed target to the resulting fire stimuli should be assessed to determine whether the defined acceptance criteria have been met.

4.4.3 Acceptance Criteria.

4.4.3.1 Metrics should be established that document the results in a way that facilitates decision making.

4.4.3.2 Results may be either relative (e.g., compared to a baseline or comparing alternative options) or absolute (e.g., deaths per year). Within this context, they may be qualitative or quantitative.

4.4.3.3 The acceptance criteria may be in the form of a quantitative risk value, a comparative value, or other values as agreed to by the stakeholders and the AHJ. The form of the acceptance criteria should be dependent on the risk problem and should influence the selection of appropriate FRA methods.

4.4.3.4* Acceptance criteria should be established during preplanning.

4.4.3.5 Acceptance criteria may be based on one of the following:

(1) Prescriptive regulations
(2) Performance regulations
(3) Other agreed-to criteria
(4) Standards and guides

4.4.3.6 The FRA should present its conclusions in terms that meet its objectives. For project evaluation, the criteria should specify all the risks that are to be addressed and how those risks are to be measured. The criteria may be specified in terms of absolute values or comparisons to a benchmark. They may further specify limits on probability, consequence, or risk.

4.4.4 Methods.

4.4.4.1 Choice of Methods. The method that was used should be outlined, and its appropriateness to the objectives of the FRA should be documented. The documentation should include a brief description of method of solution, numerical computations (including identification of units used), and identification of the source or derivation of all equations that are not in common usage.

4.4.4.2 Methods may include a variety of elements based on the problem definition. These elements may be qualitative or quantitative and may involve deterministic or probabilistic models.

4.4.4.3 Each element of the method should be applied properly within its scope and limitations. *(See Chapter 5.)*

4.4.5 Data.

4.4.5.1 Data used with the selected method should be appropriate and of sufficient quality to support decision making for the defined problem *(See Chapter 6.)*

4.4.5.2 The scope and the limitation of input data should be expressly documented.

4.4.5.3 Sources of data should be identified.

4.4.5.4 Any assumption or default values used in the absence of data should be explained clearly.

4.4.5.5 The FRA methods, data, and results should be documented to allow review and to provide for changes in management or conditions that could affect the fire risk. *(See Chapter 6.)*

4.5* Uncertainty and Variability Analysis. The FRA should include an assessment of uncertainties in the models and methods and of the uncertainties and variability in the assumptions and data used. This assessment should provide reasonable assurance that the acceptance criteria have been met.

Chapter 5 Selection and Evaluation: FRA Methods

5.1 General. This chapter presents the different types of FRA methods, including guidance on the appropriate selection and application of the various types of risk methods and models.

5.1.1 FRA Concepts. In evaluating FRA methods, the following FRA concepts should be considered: risk in terms of likelihood and consequences and the scope of the FRA in terms of systems and fire scenarios.

5.1.1.1 Likelihood and Consequences. FRAs should evaluate the likelihood and consequences of fire scenarios.

(1) The evaluation of likelihood may be based on past experience (e.g., statistics) for well understood events or on a combination of available knowledge and accepted mathematical treatment (subjective) for less understood events and where uncertainty and variability are high.
(2) The evaluation of consequences may be based on expert knowledge (e.g., risk indices), probabilistic modeling (e.g., life safety tree to arrive at safe or unsafe conditions), or deterministic modeling (e.g., fire growth, smoke spread, and occupant evacuation to arrive at safe or unsafe conditions).

5.1.1.1.1 Depending on the FRA objectives, the evaluation of likelihood and/or consequences may focus on relative changes associated with different design alternatives, rather than absolute values.

5.1.1.1.2 Some methods may attempt to assess or compare the change in the likelihood of certain events (i.e., the design alternatives may attempt to alter the probability of the event occurring), others may attempt to assess the impact of different design solutions on the consequences (i.e., they assume the event will happen), and others may attempt to assess both.

5.1.1.1.3 Some methods, such as risk indices, provide a measure of relative risk that only implicitly identifies likelihood and consequences.

5.1.1.2 Scope of an FRA: Concepts and Systems. Depending on the goal, FRAs may involve the assessment of one fire protection concept or system on the overall level of risk, or they may involve the assessment of multiple concepts or systems on the overall level of risk, as follows:

(1) A single-system FRA involves assessing the impact on risk, given changes to one fire protection system, such as the presence or absence of a sprinkler system or of a fire alarm system.
(2) A multisystem FRA involves assessing the impact on risk, given changes to a number of fire protection systems, both active and passive, as well as factors such as the egress system, alarm systems, occupant characteristics, training, and education.

5.1.1.2.1 Single-system FRAs may be conducted at various levels. For example, one level of sophistication involves the comparison of one fire protection system to other similar systems, looking at the impact on risk of changing system attributes (e.g., water density or sprinkler head type). Another level of sophistication is needed to compare the effectiveness of one type of automatic fire suppression system to another, based on their ability to extinguish a fire in a certain period of time.

5.1.1.2.2 Multisystem comparisons often require relatively sophisticated methods in which the overall impact on fire risk is assessed based on the availability, reliability, and operation of both passive and active fire protection systems and on other factors that may affect the overall risk.

5.1.1.2.3 The fire safety concepts tree in NFPA 550, *Guide to the Fire Safety Concepts Tree*, provides a comprehensive overview of the concepts or systems that may need to be considered in the FRA.

5.1.1.3 Scope of an FRA: Fire Scenarios. The FRA should address the risk contribution from all potentially significant fire scenarios. When approximations are used (e.g., the risk contribution from a single fire scenario is used as a basis for estimating the risk from a wider range of fire scenarios), the approximations should be justified in the context of the decision problem.

5.1.1.4 Fire Scenario. Depending on the defined problem and the FRA objectives, the FRA method may need to explicitly assess the effect of a design alternative on each event in the fire scenario, in order to assess the risk associated with the alternative. The following are examples for a typical life safety fire scenario:

(1) *Fire ignition.* Often based on the most probable event in a particular setting, for example, cigarette ignition of a couch in a living room. Prevention education would reduce the probability of occurrence of this event and the consequential risks.
(2) *Fire growth.* Based on all probable developments of a fire, from smoldering to flashover fires. Fire protection systems such as sprinklers, compartmentation, and door closers may help to contain these fires and to reduce their consequential risks. The reduction in risk depends on the reliability and effectiveness of the fire control systems.
(3) *Smoke spread.* Based on smoke spread to critical egress routes and other parts in a building. Fire protection systems such as smoke control and stairwell pressurization may help to contain the smoke and to reduce its consequential risks. The reduction in risk depends on the reliability and effectiveness of the smoke control systems.
(4) *Exposure of occupants.* Based on smoke and fire blocking egress routes. Fire protection systems such as fire alarms, voice communication, clear egress routes, and refuge areas may help to provide early warning to occupants and to direct them either to evacuate the building or to seek refuge in certain areas. The reduction in risk depends on the reliability and effectiveness of the warning and evacuation systems.
(5) *Failure of fire department to respond.* Based on no response or late response. Proper notification procedure and adequate fire department resources would help to rescue the trapped occupants or to control the fire. The reduction in risk depends on the reliability of the notification procedure and the adequacy of fire department resources.

5.1.2* FRA Methods: Categories.

5.1.2.1 Table 5.1.2.1 defines five categories of FRA methods. In order of increasing complexity, those methods are as follows:

(1) Qualitative method
(2) Semiquantitative likelihood method
(3) Semiquantitative consequence method
(4) Quantitative method
(5) Cost-benefit risk methods

5.1.2.2 The tabulation provides definitions, types of output, and examples for all five categories.

5.1.3 Selection of Methods. The selection of an FRA method for a particular application should consider the following factors: stakeholder objectives and acceptance criteria, scope of the FRA, intended audience and decision makers, regulatory and/or litigation considerations, precedents for similar applications, available resources and data, cost and time constraints, personnel capabilities, and the possible need to address uncertainties. A brief elaboration on these factors is given in 5.1.3.1 through 5.1.3.7.

5.1.3.1 FRA Objectives. The FRA objectives should be stated explicitly before a particular method or category is selected. For example, if an objective is to provide some preliminary evaluation of fire risk for screening purposes, then a simple qualitative method may suffice. At the other extreme, if the FRA is to provide a definitive evaluation of the overall fire risk, then a quantitative method would be appropriate. The particular quantitative method to be used would depend on whether only one measure or multiple measures of risk are to be considered and whether costs are to be an explicit part of the FRA.

5.1.3.2 Scope of the FRA. The FRA scope is addressed in 5.1.1.2. It should dictate how the FRA deals with multiple fire scenarios (e.g., whether the FRA should explicitly include calculations for various fire scenarios and associated risks or be confined to assessing a conservative fire scenario or the most probable fire scenario).

5.1.3.3 Intended Audience. The FRA output, and therefore the FRA method selected, should be consistent with the knowledge and needs of the intended audience.

5.1.3.4 Regulatory Considerations. Government regulations may require certain FRA methods. For example, there are regulations with maximum allowable risk for certain types of special hazard facilities, such as nuclear power plants, liquefied natural gas import terminals, and processing facilities with more than a threshold amount of certain flammable gases and vapors. These regulations delineate the types of risk measures to be evaluated and often describe the type of method to be used for the evaluation.

5.1.3.5 Precedents. Appropriate precedents established by successful FRAs may be used to support the selection of FRA methods. These precedents ease the burden of selecting an appropriate FRA category for similar applications. For example, probabilities of fire-initiated reactor core melt at nuclear power plants have been evaluated using combinations of fault tree and event tree analyses. These analyses are usually conducted and presented as quantitative FRAs.

5.1.3.6 Personnel Capabilities. The qualifications of the team performing the FRA should be addressed in the evaluation of the FRA. Personnel expertise and experience in understanding the risk problem and in implementing an appropriate type of FRA are important considerations. Just because someone understands the risk problem very well does not necessarily mean that he or she is expert in FRA methods. Likewise, expertise in FRA method application in a particular field does not necessarily translate to expertise on risk problems in another field. For example, mathematical expertise is critical in the case of qualitative methods requiring subjective evaluations of consequences and expected frequencies of occurrence but may not help in adequately defining the risk problem. For the successful implementation and interpretation of quantitative methods and cost-benefit risk methods, a broad knowledge base is required, because those categories require comprehensive analyses aimed at accounting for all relevant factors influencing the overall risk.

5.1.3.7 Uncertainties. FRAs should account for the uncertainty and variability associated with the risk determinations. Sometimes uncertainty and variability are addressed qualitatively (perhaps in terms of confidence level), and at other times they are addressed quantitatively. The need for a quantitative estimate is particularly important for those methods in which the outcome is a simple, single measure of risk, that is, for quantitative methods and for cost-benefit risk methods.

Table 5.1.2.1 Categories of FRA Methods

Category	Definition	Type of Output*	Examples
Qualitative method	Treats both likelihood and consequences qualitatively	Tabulations of outcome and relative likelihood of various fire scenarios and how they are affected by various protection options	What-if analyses Risk matrices Risk indices Fire safety concepts tree
Semiquantitative likelihood method	Treats likelihood quantitatively and consequences qualitatively	Determination of frequency of occurrence of different types of fires and/or fires with different types of protection	Actuarial/loss statistical analyses Stand-alone event tree analyses
Semiquantitative consequence method	Treats consequences quantitatively and likelihood qualitatively	Deterministic fire model outputs with qualitative representation of likelihood	Enclosure fire models for worst credible fire scenarios
Quantitative method	Combines quantitative estimates of likelihood and consequences	(1) Determination of loss expectancy OR (2) Determination of probability of flashover OR (3) Determination of probability of fatalities in other rooms or floors of building OR (4) Plot of frequency versus number of fatalities OR (5) Plot of frequency versus size of loss OR (6) Determination of likelihood of injuries, fatalities, property damage, and business interruption OR (7) Determination of individual risk (to building occupants) and of societal risk (to entire population)	FRAs to determine probability of reactor-core-melt due to fire at a nuclear power plant Event tree analysis combined with fire models
Cost-benefit risk methods	Include determination of costs of alternative approaches to limit consequences and/or likelihoods	(1) Determination of costs required to achieve various levels of risk reduction OR (2) Determination of "optimum" level of fire protection based on minimizing "overall risk" or some other risk criterion	Computational models that incorporate probability, consequences and cost data in an integrated manner

*Types of output listed are representative rather than all-inclusive.

5.1.4 FRA Methods: Considerations. Several considerations should be addressed in the evaluation of the appropriate application of various FRA methods. These factors are generally defined and discussed in 5.1.4.1 through 5.1.4.9.

5.1.4.1 Types and Common Traits of Methods. The methods include the consideration of a comprehensive set of probable fire scenarios. Fire scenarios include the various types of fires that may occur in a compartment, the various locations where a fire compartment might occur, the distribution and characteristics of the occupants, and the type and reliability of the fire protection systems that are installed. Each fire scenario has a different probability of occurrence and poses a different level of hazard to the occupants. A true FRA, therefore, should include all probable fire scenarios. The methods should also include the assessment of the capital and maintenance costs of the fire protection system, as well as fire losses as a result of probable fire spreads in the building.

5.1.4.2 Availability, Quality, and Applicability of Methods. Availability is defined as how a method may be obtained by a user. Quality is defined as how well a method is based on fire engineering (usually by documentation and reviews). Applicability is defined as the condition (such as the type of occupancy) under which a method may be applied.

5.1.4.3 Inputs. Inputs are values (such as the size of a room) that are required before a method may be implemented.

5.1.4.4 Assumptions. Assumptions are conditions (such as a two-zone model) based on which a method is developed and may be applied. Methods should describe clearly the assumptions that are in the model. The assumptions help guide a user to see whether the model and the associated method may be used for a certain application.

5.1.4.5 Assessment of Reliability, Availability, and Efficacy. Reliability is the ability of a feature (e.g., a sprinkler system) to perform its intended function when called on (e.g., a valve opens when actuated). Availability is defined as having the feature in place to act when needed (e.g., a sprinkler system cannot be considered available if the water supply is shut off). Efficacy (effectiveness) relates to the ability of a feature to perform as desired (e.g., the system as designed is able to control the expected fire). Methods of analysis should address reliability, availability, and efficacy of fire protection and other key systems as part of the FRA.

5.1.4.6 Uncertainty and Variability. FRAs should include a discussion of uncertainty and variability in the values that are used in the method. Sensitivity checks should have been conducted to ensure that the uncertainty of the values does not pose a significant variation in the predicted outcome.

5.1.4.7 Output. Output is defined as the predictions of a method.

5.1.4.8 Completeness, Robustness, and Depth of Models. Completeness is defined as how well a model covers all the controlling parameters. Robustness is defined as how well a method based on the model may be run without a problem. Depth is defined as how well a model and the associated method cover the fire and the human phenomena and other factors involved.

5.1.4.9 Validation of Method. It is often difficult to validate a risk prediction because it is a prediction of an unlikely event that requires a large database and a long time scale. Nevertheless, a method may be validated by comparing its probability modeling with statistical data or experience and its consequence modeling with experimental data or mathematical modeling.

5.2* Qualitative Methods. The qualitative tools outlined in this section are often used in the FRA process. However, they do not constitute FRA methods as envisioned by this guide unless consequence and likelihood are both addressed.

5.2.1 What-If Analysis. What-if analysis is an unstructured brainstorming approach to identifying events that could produce adverse consequences. The method involves examination of possible deviations from design, construction, modification, or operation criteria. What-if questions are formulated based on a fundamental understanding of what is intended to occur and what may go wrong, for example, what if the fire pump doesn't work? The purpose is to identify possible accident event sequences and thus identify hazards, consequences, and sometimes potential methods of risk reduction. It is distinguished from other techniques of hazard identification by its inherently unstructured format and the use of the questioning form "What if?" Output is usually a tabular, narrative listing of potential accidents with no ranking or quantitative implication.

5.2.2 Checklists. A checklist is an enumeration of specific items to identify known types of hazards, design deficiencies, and the likeliness and consequences of potential fires. The identified items are compared to appropriate standards.

5.2.3 NFPA Fire Safety Concepts Tree. NFPA 550, *Guide to the Fire Safety Concepts Tree*, uses a branching diagram to show relationships of fire prevention and fire damage control strategies. It provides an overall structure with which to analyze the potential impact of fire safety strategies such as construction, combustibility of contents, protection devices, and occupant procedures. It may identify gaps and areas of redundancy in fire protection as an aid in making fire safety design decisions.

5.2.3.1 The fire safety concepts tree shows all the elements that may be considered in evaluating fire safety and the interrelationships among those elements. By progressively moving through the various concepts in a logical manner, the tree examines all aspects of fire safety and demonstrates how each may influence the achievement of fire safety objectives.

5.2.3.2 FRA is qualitative, but the tree distinguishes between likelihood (the "Prevent fire ignition" branch of the tree) and consequence (the "Manage fire impact" branch). Output is one or more sets of fire safety strategies that intuitively meet objectives.

5.2.4 Risk Indexing. Fire risk indexing systems are heuristic models of fire safety. They comprise various processes of analyzing and scoring hazards and other system attributes to produce a rapid and simple estimate of relative fire risk. Fire risk indexing systems are also called rating schedules, point schemes, ranking, numerical grading, and scoring. Using professional judgment and past experience, fire risk indexing assigns values to selected variables representing both positive and negative fire safety features. The selected variables and assigned values are then operated on by some combination of arithmetic functions to arrive at a single value, which is then compared to other similar assessments or to a standard. Perhaps the most common fire risk indexing approach is the Fire Safety Evaluation Systems (FSES) in NFPA 101A, *Guide on Alternative Approaches to Life Safety*. Numerous other forms are described in the *SFPE Handbook of Fire Protection Engineering*.

5.2.5* Risk Matrix. A risk matrix utilizes probability levels and severity categories to represent the axis of a two-dimensional risk matrix. The matrix indicates that improbable hazards with negligible consequences represent a low risk and that frequently occurring hazards with greater consequences represent high-risk levels.

5.3 Semiquantitative Likelihood Method. Semiquantitative methods are based on the ability or need to quantify either the likelihood or the consequence of a fire event or events. Some methods rely on deterministic fire model outputs with inputs based on a quantitative representation of the likelihood of different types of fires and/or fires with different types of protection and are the subject of this section. By contrast, qualitative input from a range of fire scenarios or a worst-case fire scenario into an enclosure fire model may yield quantitative results that define the consequences.

5.3.1 A semiquantitative likelihood method calculates the likelihood of the fire scenario based on an estimated consequence. An example would be an assessment that calculates the likelihood of an event (flashover, uncontrolled fire) but does not calculate the consequence. The probability of an uncontrolled fire is calculated based on ignition data, failure/success of compartmentation, or sprinklers, but in this case the effects of fire are not calculated.

5.3.2 Semiquantitative methods that rely on the quantification of the likelihood of events are presented here. These methods are actuarial/loss statistical analyses and stand-alone event tree analysis.

5.3.2.1 Statistical analyses may be undertaken to support the selection of fire scenarios in performance-based design. Statistical data may identify the likelihood and consequence of different fire scenarios in a given occupancy. The data may indicate the time of day or week that fires occur, which may define the exposed population that may be affected. The fire scenarios may be bracketed by the likelihood and used as a determinant in choosing appropriate design fire scenarios.

5.3.2.2 Three significant databases are available to analyze the fire experience in the United States: the FEMA/USFA National Fire Incident Reporting System (NFIRS), the NFPA Fire Incident Data Organization (FIDO), and the NFPA Survey of Fire Departments. It is important to remember that any data have inherent limitations and biases, which should be taken into consideration in any analysis.

5.3.2.3 A network model is a graphic representation of the paths by which information flows. It is represented by connected points, or *nodes*, and links connecting two nodes (usually passing through other nodes), or *paths*.

5.3.2.3.1 A *tree* is a special type of network model in which only one path connects two nodes. An event tree, the simplest and one of the most powerful probability models, is a model of the sequence of possible states of a system and of corresponding events that lead to those states.

5.3.2.3.2 By assigning probabilities to each path and assuming that the events are independent, the probabilities along each path are multiplied to calculate the probability of the consequences.

5.4 Semiquantitative Consequence Method. Semiquantitative methods are based on the ability to quantify either the likelihood or the consequences of a fire event or events. Some methods rely on deterministic fire model outputs with inputs based on a quantitative representation of the likelihood of different types of fires and/or fires with different types of protection. By contrast, qualitative input from a range of fire scenarios or a reasonable worst-case fire scenario into an enclosure fire model may yield quantitative results that define the consequences. The latter method is the subject of this section.

5.4.1 A semiquantitative consequence method treats the likelihood qualitatively and calculates the consequence. An example would be an assessment that estimates the likelihood of a given fire (low, medium, or high probability) and calculates the effects or consequences of the fire.

5.4.2 Semiquantitative methods that allow the analyst to quantify the consequence of fire events are presented in 5.4.2.1 through 5.4.2.3. The primary method is the use of deterministic enclosure fire models for reasonable worst-case fire scenarios.

5.4.2.1 Loss data may be analyzed to establish predicted variables for future losses. Methods such as incurred loss extrapolation, paid loss extrapolation, and "The Actuary and IBNR," by Bornhuetter and Ferguson, may be used to project ultimate losses per occurrence. The results of each method are often averaged to establish ultimate loss projections. These types of statistical analyses of specific loss data provide semiquantitative values of consequence per occurrence.

5.4.2.2 Three significant databases are available to analyze the fire experience in the United States: the FEMA/USFA National Fire Incident Reporting System (NFIRS), the NFPA Fire Incident Data Organization (FIDO) database, and the NFPA Survey of Fire Departments. It is important to remember that any data have inherent limitations and biases, which should be taken into consideration in any analysis.

5.4.2.3 In the prediction of fire development/filling time, the intent is to select design fires that provide a *worst likely* fire scenario. Enclosure fire models predict the interaction of multiple fire processes occurring at the same time in an enclosure. These models provide estimates of particular events such as fire growth, temperature rise, and smoke generation and transport. Addressing multiple rooms and confining the model to the room of origin are two approaches. These models necessitate the use of computers because of the large number of mathematical expressions.

5.4.3 Availability, Quality, and Applicability of Methods. Two general classes of computerized models for enclosure fire development are probabilistic and deterministic. Probabilistic models, also called state transition models, use mathematical rules and probabilities during a series of sequential events or states to consider fire growth. Deterministic models, also called room fire models, computer fire models, or mathematical fire models, use interrelated expressions based on physics and chemistry to evaluate discrete changes in any physical parameter in terms of the effect on fire hazard.

5.4.3.1 Two general types of deterministic models are zone models and field models. Zone, or control volume, models solve the conservation equations for distinct regions and are the most common type of physically based fire model. Field models divide the compartment space into a hypothetical, three-dimensional grid of small cubes and solve the physical conditions, using the fundamental equations of mass, momentum, and energy in each cube as a function of time. Field models allow the user to determine the conditions at any point in the compartment.

5.4.3.2* Deterministic enclosure fire models are available from several sources. Zone and field models such as CFAST and FDS may be obtained from the U.S. Department of Commerce, National Institute of Standards and Technology, at no cost. Other enclosure models, such as JASMINE, may be purchased commercially.

5.4.4 Inputs. Inputs for deterministic fire models include room and building geometry, heat release and combustion data, thermophysical properties of the bounding surfaces, species generation rates, ventilation parameters, and ambient/atmospheric conditions.

5.4.5 Assumptions. There are often limitations inherent to a particular model and limitations in the availability of specific data as input into a model. Accordingly, it is often necessary to make assumptions that bridge the gap between the limitations and the goals of the modeling exercise.

5.4.5.1 The deterministic models used to predict fire phenomena in an enclosure have limits in many areas, including how they address room geometry, interior finishes, and fire suppression. Models that predict sprinkler activation are based on a smooth, flat ceiling condition that often is not the condition in the subject case. Models may not accurately address the influence of interior finishes, either in the loss of heat to the bounding surfaces or in their fuel contribution to the fire. The effects of fire sprinkler operation in a fire enclosure are complex and not readily modeled. In all cases, it is important to recognize the limitations of each model and to explicitly state the assumptions, quantitatively or qualitatively, that are necessary to correlate the parameters of the analysis to the limits of the model.

5.4.5.2 Good data are critical to both probabilistic and deterministic modeling. Often there are not enough specific data to meet the needs of the analysis. As a result, it is necessary to make assumptions to obtain the necessary input into the model. The data assumptions may be the result of interpolation or extrapolation of other relevant data or from other correlation methods. Such assumptions in the data must be stated explicitly. Furthermore, such assumptions should be treated for sensitivity and accounted for in the uncertainty of the analysis.

5.4.6 Uncertainty.

5.4.6.1 The uncertainty of enclosure fire models is introduced in a number of ways. The numerical uncertainty introduced by the model includes the model assumptions (such as the distinct two-layer environment in zone models), the numerical solver(s) for the model, and the sensitivity of certain variables. Other uncertainty may result from users' assumptions in the input and from the use of the model beyond the stated limits of validation.

5.4.6.2 Uncertainty introduced into the statistical analysis methods results from the quality of the statistical data. Questions such as whether the data was reliably collected and recorded, whether it was all inclusive, and whether there was any influence due to subjective bias should be considered.

5.4.7 Output. Output from enclosure fire models includes temperature profiles, species concentrations, and smoke density. Depending on the model, the data may be represented numerically and/or graphically.

5.4.8 Validation of Method. Most enclosure fire models have been developed to correspond with a range of fire research data. Although the models often rely on first principles of chemistry and physics, they have been "fitted" to the data. Therefore, it is important to recognize that a model should be used to study a fire scenario that falls within the range of the data first used to develop and validate the model. The valid range may be found in the model's user manual.

5.5* Quantitative Methods. Many events may occur during the life of a facility; some have a higher probability of occurrence than others. Some events, though not typical, could have a devastating effect on the facility. A reasonable design should be able to achieve the stated goals and objectives for any typical or common design fire scenario and for some of the non-typical, potentially devastating fire scenarios up to some level commensurate with society's expectations.

5.5.1 Selecting Fire Scenarios. The challenge in selecting fire scenarios to be analyzed is in finding a manageable number that are sufficiently diverse and representative so that if the design is reasonably safe for those fire scenarios, it should be reasonably safe for all fire scenarios, except those scenarios specifically excluded as being unrealistically severe or sufficiently infrequent to be fair tests of the design.

5.5.1.1 For a single fire scenario sequence, risk is the product of the sequence consequence (i.e., loss, C_i) and the corresponding sequence frequency (F_i). For a structure, facility, or locale, the total risk (R_t) is the sum of the individual fire scenario sequence risks. This may be represented as:

$$R_t = \sum_{i=1}^{n} C_i F_i$$

where:
R_t = total risk
C_i = sequence consequence
F_i = sequence frequency

5.5.1.2 If the output includes the assessment of many risks, such as business as well as individual, then the multiple outcomes, R_{tj}, may be represented by:

$$R_{tj} = \sum_{j=1}^{m} \sum_{i=1}^{n} C_{ij} F_i$$

where:
R_{tj} = multiple outcomes
C_{ij} = multiple losses
F_i = sequence frequency

5.5.1.3 When the risk is estimated directly, accounting for each fire scenario sequence is usually not practical because each fire scenario sequence represents a detailed series of events that leads to a consequence-frequency pair. To reduce the analytical effort, it is common to group individual sequences into fire scenario sets. The fire scenario sets distill the fire scenario sequences into their most basic features by eliminating extraneous details. Thus, a fire scenario set describes only the pertinent details necessary to calculate the corresponding risk.

5.5.2 Types and Common Traits of Methods. Judicious selection of the fire scenario sets may make the FRA process manageable. If desired, the corresponding consequence-frequency pairs may be analyzed as a multiple quantitative outcome FRA. *(See Section 5.6.)* As an alternative, a consequence threshold may be adopted, which allows further simplification of the FRA process. The fire scenario set evaluation becomes one of demonstrating whether a particular fire scenario set exceeds the threshold. The frequency of those fire scenario sets that exceed the threshold may be evaluated. The sum of the frequencies would then be the frequency that a specific consequence value is exceeded.

5.5.3 Availability, Quality, and Applicability of Models. The quantitative outcome method is typically problem specific. Thus, it is common to use multiple models in developing the analysis: one or more models to estimate consequences and another to estimate frequencies. No computer software packages use the single quantitative outcome FRA method. This is to be expected, because such software packages readily produce multiple quantitative outcomes just as simply as they would a single outcome.

5.5.4 Inputs. (Reserved)

5.5.5 Assumptions. (Reserved)

5.5.6 Uncertainty. The quantitative outcome method produces results that bound the potential risks. Because of this approach, the actual risk may not be well characterized. For example, if the consequence threshold is death of one individual, the risks associated with multiple deaths are not fully characterized. To account for that, multiple consequence thresholds may be established (e.g., more than 1 death per event, more than 5 deaths per event, more than 10 deaths per event). Such variation should then produce a separate frequency-consequence pair for each discrete consequence estimate.

5.5.7 Output. (Reserved)

5.5.8 Completeness, Robustness, and Depth of Models. The completeness and robustness of the quantitative outcome method depend on the analyst's selection of the fire scenario sets. If too many fire scenario sequences are missed or not adequately represented, the analysis will be nonconservative. Thus, the sequence sets should be shown to represent all possible outcomes.

5.5.9 Validation of Method. Because there are no integrated computer software packages that produce quantitative outcome results, an overall validation of the method has to be documented. The analysis methods selected to prepare consequence or frequency estimates will strongly influence whether a validation has already been completed. In terms of overall technique, the quantitative outcome approach is well accepted; if properly constructed, it produces results that accurately represent the actual fire risk.

5.6* Cost-Benefit FRA Methods. Cost-benefit FRA methods provide not only an assessment of the expected risk to life to the occupants but also an assessment of the expected fire costs associated with a particular fire safety design. Fire costs include the capital and maintenance costs of the fire protection, as well as the expected fire losses to the building structure and contents as a result of probable fire spreads in the building. The assessment of both the expected risk to life and the expected fire costs allows the identification of cost-effective fire safety designs that provide the required level of safety with the lowest fire costs.

5.6.1 Types and Common Traits of Methods. The cost-benefit dimension of the overall FRA brings yet another parameter to the assessment. Some methods may provide a comprehensive analysis of the fire risk and a minimal assessment of the costs and benefits. Others may provide a detailed assessment of the costs of certain alternatives with minimal assessment of the alternatives' impact on the fire risk.

5.6.1.1 It is extremely important that in any cost-benefit FRA analysis it is clear what risk factors are being analyzed, whether the analysis is of a single system or a multiple system, and whether the analysis covers one fire scenario or multiple fire scenarios. The relevance of each of those parameters as well as the detail of the cost-benefit analysis must be determined for the particular project or issue being analyzed.

5.6.1.2 Some of the more sophisticated cost-benefit FRA methods provide the capability to compare alternative solutions. These methods may be used to determine both comparative levels of risk and the costs associated with the alternatives. The results allow practitioners to compare alternative solutions from both a risk basis and a cost basis. One limitation to this approach, however, is in the determination of a level of acceptable risk.

5.6.1.3 The difficulty encountered by practitioners in the safety field is in taking the current standards with their inherent level of safety and determining objective criteria against which to compare risk. The current standards may be prescriptive in nature and may contain little or no direction as to what objective they are expected to achieve or, more important, what is an acceptable level of risk. The difficulty is compounded when the desire is to assess safety from a perspective that is broader than, for example, one building component or one particular safety system.

5.6.1.4 One approach to addressing the difficulty described in 5.6.1.3 is to compare alternative solutions to a baseline case, such as a prescribed code solution or a standard acceptable to the AHJ. This procedure may then allow a comparison without the need to first establish objective criteria. Some of the more sensitive areas of risk analysis, such as determining the cost for a human life, are thereby avoided. These methods assist in determining if a proposed solution is acceptable because they may provide an objective measure of fire risk in relation to the current standard.

5.6.1.5 Regulators' Needs.

5.6.1.5.1 Regulators typically require the following:

(1) Proper documentation of the FRA process, whether simple or comprehensive
(2) Proper documentation of the assumptions, such as the fire scenario, probability of occurrence, and reliability of fire protection systems
(3) Proper documentation of how the consequences of each fire scenario are assessed and whether they are based on subjective point systems or deterministic modeling tools

5.6.1.5.2 Equivalency assessment is more suitable, based on the assumption that the risk level inherent in the current code is acceptable. Current practice is basically an equivalency assessment based on the subjective opinion of the AHJ.

5.6.1.6 Building Owners' Needs. Building owners' needs typically involve the following:

(1) Cost-effective or flexible designs
(2) Equivalency considerations, which would naturally lead to alternative designs that are more cost effective
(3) Cost assessment, such as capital and maintenance costs of installed fire protection systems and probable fire losses
(4) An equivalency approach, which avoids the difficulties of assigning a value to human life

5.6.2 Availability, Quality, and Applicability of Models. Models should describe the application for which they are suitable and what their limits are. For example, a model may be suitable for apartment buildings but not for office buildings and may limit the maximum number of floors that may be considered.

5.6.3 Inputs. Models should describe the input that is required. A computer model with a user-friendly graphical user interface (GUI) would help. To avoid the entering of incorrect input values, models should require inputs that are well defined and may be easily obtained by the user. For example, the amount of combustibles in a compartment may be a well-defined input, whereas the size of a fire may not be a well-defined input. The user would not know the size of a fire because fire growth depends on a number of parameters. If the user uses a large fire, the results will be different than if a small fire is used. In this case, the amount of combustibles may be an input, but the fire growth should not be. Instead, the fire growth should be modeled by the FRA methods, based on the amount of combustibles and other controlling parameters.

5.6.4 Assumptions. Models should clearly describe the assumptions that are in the model. The assumptions help to guide a user as to whether the model may be used for a certain application.

5.6.5 Assessment of Reliability. Models should include the consideration of the reliability of fire protection systems. They should also include the effectiveness of fire protection systems when they operate. Reliability and effectiveness are the main reasons why we have FRA. If fire protection systems worked 100 percent of the time, there would be no need for FRA.

5.6.6 Uncertainty. Models should include the discussion of uncertainty in the values that are used in the model. Sensitivity checks should have been conducted to ensure that the uncertainty of the values does not pose a significant variation in the predicted outcome.

5.6.7 Output. Output should be in a form useful to the user. It should also be in a form that may be easily documented.

5.6.8 Validation of Method. Models should have documentation that describes the scientific basis of their modeling and how good their predictions are.

Chapter 6 Information Requirements

6.1 General. This chapter provides a general guide for the AHJ as to the availability of the information (data from the literature, electronic data, technical drawings and documentation, and automated computational methods) in the FRA. This information may be needed and used by the AHJ for the evaluation of the FRA. The chapter is broken into two parts: issues of general quality associated with all methods and issues pertinent to particular current methods.

6.2* General Quality of Information. The AHJ should be concerned with the following data issues associated with any method used in an FRA: availability of the data, applicability of the data, uncertainty of the data, and automated systems requirements. The FRA should document why data sources are appropriate for input into the FRA.

6.2.1 Availability. The AHJ should be concerned about whether data used in the analysis is accessible for further evaluation by the AHJ, as well as for potential re-evaluations associated with future changes with the facility or its management.

6.2.1.1 Public Sources. Data obtained from public sources should be fully documented in a referenced manner in the project report or calculation file associated with the analysis. The documentation should include the title of the publication, the author(s), the page, table, or figure number(s), the name and location of the publisher or agency, and the date of publication. In the report or calculation file with each citation, the data or information should be identified with the citation.

6.2.1.2 Private Sources. Data obtained from private sources should be fully documented in a referenced manner as with public data in 6.2.1.1 and should include the communicator and the recipient of the data, as appropriate, and the form of the data (letter, electronic file, etc.). If data from private sources are proprietary, a notation should be made in the reference. Private, nonproprietary data should be accessible via the project file or be traceable. For proprietary data, contact information should be provided about the communicator or the recipient of the data.

6.2.1.3 "Lack of" Data. Data for which assumed or theoretical values are used because experimental or observed data do not exist should be identified clearly in the project report and the calculation files.

6.2.1.4 Records Management. The project report and its associated calculation files should be numbered for version or for cataloging (if appropriate) and dated for traceability and reproducibility. The AHJ should ensure that the data warehouse for the fire risk study is available for future needs and management of change. Records should be retained per the requirements of a jurisdiction or until there is no further interest or need for the fire risk study by all stakeholders.

6.2.1.5 Other Information. Other information (maps, procedures, hardware, manuals, vendors, etc.) should be retained for future use.

6.2.2 Applicability.

6.2.2.1 Occupancy. The risk analysis should be applicable to the occupancy being analyzed. Hospital data should not necessarily be utilized in a residential risk analysis, and petroleum plant information may not be applicable to warehouse storage facilities. In certain instances, it may be allowable to utilize more restrictive and conservative data from a different occupancy when applicable occupancy data are not available. Any variation of this sort should be documented in the risk analysis.

6.2.2.2 Context. Certain industries, for example, the commercial nuclear power industry and certain government entities, require a significant level of documentation, verification, validation, and/or peer review. In such instances, the more restrictive requirements should be applicable.

6.2.2.3 Cultural and Geographic Biases. Information may have cultural or geographic biases. For instance, risk analyses utilizing the assumption that sprinkler systems are less likely to freeze might be more applicable in more temperate environments than in northern climates such as Ottawa, Ontario. Conversely, the dry pipe system inspection, testing, and maintenance (ITM) techniques may not be as well practiced in these same temperate climates, where dry pipe systems are not utilized as often.

6.2.2.3.1 Cultural biases may be demonstrated in the following example. Some industries may have significantly more attentive ITM personnel, leading to disparities in ITM frequencies. It would be expected that ITM trending data from industries with dedicated service personnel and significant outlaying of funds for ITM activities would tend to identify fewer failures than industries without such funding and resources. Industry-specific trending data may not be applicable in all instances where cultural biases may affect information.

6.2.2.3.2 Another example of cultural biases may be demonstrated in U.S. fire loss data. The level of fire protection afforded to the United States might not be similar to that in other countries, and therefore U.S. fire loss data might not be applicable. This discrepancy can be attributed partly to the level of focus on fire protection issues from a cultural level.

6.2.2.4 Referenced Data Sources. Data utilized in FRAs should be provided with references whenever applicable. Common data sources do not necessarily need to be provided with the analysis if they are readily available (e.g., NFPA's *Fire Protection Handbook*). Reports and articles reproduced in independent publications should be provided in their entirety as an appendix to the analysis.

6.2.2.5 Quality and Experimental Context. Data utilized as inputs into the analysis should be reviewed for statistical significance, approved components, and failure or success criteria. Where experimental data are utilized, the experiment setup should be reviewed against all other applicability criteria in 6.2.2 for relevance to the risk analysis.

6.2.2.6 Administrative and Skill Requirements. All risk analyses have administrative and skill requirements for analysts, including technical and organizational requirements. Risk analysts are required to be technically capable in the field in which they are practicing, and analyses are required to be laid out in an organized manner. The requirements of other sections of this guide provide general direction for organizational outlines of the analyses and applicable input information. Further discussion is contained in Chapter 7.

6.2.2.7 Measures of Objective Function. A risk analysis should involve the proper consequence evaluation for the given application. To an isolated telecommunications facility, life safety consequences may not be as applicable as those associated with business continuity, whereas life safety consequences may take precedence in an institutional setting. Other consequence groupings include, but are not limited to, property impacts, cost, and environmental impacts.

6.2.3 Uncertainty and Variability. Although data are generally necessary to support an FRA, various aspects of the data contribute to uncertainty. Paragraphs 6.2.3.1 through 6.2.3.7 should be considered in the review of data and other supporting information.

6.2.3.1 Fire Scenario Assumptions. Event frequency or probability may be influenced by the fire scenario to which it applies. Therefore, the analyst needs to clearly identify the fire scenario on which such data are based. The fire scenario endpoint is particularly important. For example, data that are based on reported fires are likely to understate ignition probability or frequency. Conclusions that are based on fire scenarios different from the fire scenario of interest may be supportable, but only if the analyst identifies and acknowledges the differences and appropriate compensation is applied. In general, however, compensated data will be significantly less precise than uncompensated data, because such data are subject to error in both the data and the compensation.

6.2.3.2 Population Issues. The population on which data are based needs to be identified, and any statistical manipulations need to be identified and understood. If data are based on a sample, the size of the sample and the size of the population need to be known so that bounds may be placed on the statistical error. Similar information needs to be provided for data that are themselves extrapolated from samples. If the population from which the data are obtained differs in any significant way from the subject of the analysis, additional compensation may be required. Ways in which populations may differ include the following:

(1) Age of equipment (mean, median, mode)
(2) Manufacturer and model of equipment
(3) Materials, where applicable
(4) Water quality, where applicable

6.2.3.3 Bias. Data may be biased in many, often subtle ways. Insurance company data, for example, are generally “left censored” because only incidents that exceed policy deductibles are included. Insurance company data may also be more subtly biased by reflecting only one company’s insureds. In general, the probability of incident reporting tends to be directly proportional to the incident severity. Near misses generally are less likely to be reported than events that cause casualties. For that reason, if the number of events is being used as a system challenge frequency, it may need to be adjusted. Manufacturer’s data are likely to reflect only the manufacturer’s product and may reflect only failures that occur during the warranty period.

6.2.3.4 Time and Date of Data/Time Span of Interest. The interval over which data are collected may affect the quality of the data. If data are collected for too short a period of time, seasonal variation may not be fully considered. If data are collected over too long a period of time, constant conditions are unlikely. Maintenance practices and aging will affect the population directly.

6.2.3.5 Historic Context. Various factors may affect a population indirectly. Regulatory changes, particularly incident-reporting requirements, may directly affect population attributes and the likelihood that incidents will be reported. Ownership changes and other changes that affect the ambient culture during data collection may also directly affect the population and the data collection quality. Changes in standard practice may affect event consequences. For example, just-in-time inventory control may reduce direct fire exposure but increase business interruption consequences.

6.2.3.6 Numerical (Discrete Data, Range of Uncertainty). Experimental design, that is, whether data are based on experiment or gathered from actual practice, may alter the nature of the data. Data that are collected discretely may differ from data collected in ranges.

6.2.3.7 Societal Importance. The perceived importance of data is likely to affect its accuracy. This is obvious in the case of the frequency versus number curve, but it may be subtle in the case of injuries or near-misses. Cancers may be more likely to be counted in the vicinity of a facility that is perceived to be dangerous than elsewhere.

6.2.4 Automated System Requirements. Software and hardware should be fully characterized by the fire risk analyst for evaluation by the AHJ.

6.2.4.1 Written or Electronic Data. Input and output data from computational software should be fully described by case and run number, variable name, units, and any scalar values. Input and output data stream samples should be provided, if warranted, to further clarify input and output from models. All input and output from computational software used in the fire risk study should be retained by the fire risk analyst as part of records management.

6.2.4.2 Computational Models. Computer codes used by the fire risk analyst should be fully characterized by vendor, input/output forms, software version, hardware platform requirements, operating system and version, and whether the vendor has provided verification and validation for quality control. The name of the software and the name and address of the vendor who authored the software should also be provided.

6.2.4.3 Verification. The analysis verification should encompass all portions of the analysis.

6.2.4.4 Validation. The analysis validation should review the results against real-life conditions to ensure that it encompasses all applicable criteria.

6.3 Method-Specific Issues.

6.3.1 What-If Analysis. (Reserved)

6.3.2 Checklists. Criteria for acceptability should be defined and available to the AHJ for all checklists. Results of the checklists should be retained by the fire risk analyst for records management. Hazards not included in the checklist may be overlooked. The checklist approach is not appropriate for identifying hazards such as common cause failure modes and procedural issues. The fire risk analyst who uses a checklist in which results are not fully affirmative should provide an explanation and an analysis of impacts of the results on risk.

6.3.3 Fire Safety Decision Tree Fire Scenarios. Fire scenarios or deficiencies identified by the risk analyst that are derived from the use of NFPA 550, *Guide to the Fire Safety Concepts Tree*, should be documented in the calculation file of the project report. If likelihoods are associated with elements or deficiencies, then those likelihoods should also be documented in the fire scenario.

6.3.4 Semiquantitative Consequence Analysis.

6.3.4.1 Scale. The scale used in semiquantitative analysis (such as the risk matrix) should provide resolution sufficient to evaluate the fire risk problem.

6.3.4.2 Extremely Severe Consequences. If special weightings are used for extreme, severe consequence events, then the weighting scale should be clearly defined.

6.3.5 Semiquantitative Likelihood Assessment.

6.3.5.1 Scale. The scale used in semiquantitative analysis (such as the risk matrix) should provide resolution sufficient to evaluate the fire risk problem.

6.3.5.2 Low Likelihood Events. Low, improbable likelihoods should be reported not as zero but in the lowest "bin" for likelihood in the fire risk study.

6.3.6 Risk Assessment.

6.3.6.1 Scale. The scale used in semiquantitative analysis (such as the risk matrix) should provide resolution sufficient to evaluate the fire risk problem.

6.3.6.2 Low Risk Events. Low, improbable likelihood events should have risks reported not as zero but in the lowest "bin" of risk.

6.3.6.3 Extremely Severe Risk. If special weightings are used for extreme, severe risk events, then the weighting scale should be clearly defined.

6.3.7 Cost-Benefit Approach. (Reserved)

Chapter 7 Documentation (Deliverables)

7.1 General. This chapter describes the information that should be provided in the FRA report. It is permissible to prepare multiple documents to fulfill the intent of the FRA report.

7.2 Definition of Problem.

7.2.1 The project scope is an identification of the boundaries of the risk analysis. The boundaries might include a building, part of a building, individual components or pieces of equipment, processes, and so forth.

7.2.2 The purpose of conducting the risk analysis should be identified. The purpose might be to identify the level of risk present in an existing building or facility, to identify methods of lowering the risk in an existing building or facility, or to identify methods of providing a level of risk deemed acceptable in a new or renovated building or facility.

7.2.3 The objectives of the FRA may be associated with the risk to life (occupants or fire fighters), the risk to property, the risk to operations, or the risk to the environment. Fire safety objectives and appropriate performance, which are generally based on the building's characteristics and functions as well as the owner's fire safety expectation over a specific period of time or throughout the design life of the building, should be clearly stated, for both new and existing construction.

7.2.4 Performance criteria are quantitative expressions of the objectives and functional requirements of the regulations. Documentation of the assumptions made in deriving the required performance ensures that future modifications may be captured. These modifications, which may inadvertently change the key elements or features critical to the intended performance of the building and its systems, such as changes in specified maintenance procedures, have to be accounted for in order to maintain the level of safety before the implementation of the detrimental modifications.

7.2.5 Stakeholders are the parties with an interest in the risk analysis. There might be multiple parties involved in a risk analysis, with each party bringing a different perspective to the risk analysis. Possible stakeholders in the risk analysis include the risk analyst, building or facility owners and managers, authorities having jurisdiction, tenants, building operators or maintainers, emergency responders, insurance providers, and members of a construction team.

7.3 Analysis.

7.3.1 Analytical Methods and Computations.

7.3.1.1 A brief description of method of solution, numerical computations (including identification of units used), and identification of the source or derivation of all equations that are not common usage should be provided.

7.3.1.2 The method that was used should be outlined, including its appropriateness to the FRA. Any peer review of the method, in the scientific or the engineering community, should be documented.

7.3.2 Data. Data, reference to the sources of the data, and assumptions with justification should be provided.

7.3.3 Statement of Qualifications of the Risk Analyst. The qualifications of the risk analyst should be documented. The form of the documentation might depend on past working relations with the stakeholders and applicable laws or regulations. The documentation could include educational background, past experience in FRA, and professional registration.

7.3.4 Results. Paragraphs 7.3.4.1 through 7.3.4.3 provide a description of the results of an FRA.

7.3.4.1 An accurate FRA must consider the full spectrum of possible events. In many cases, however, it will not be practical to analyze every possible fire scenario or sequence. Therefore, a number of summary fire scenarios that are representative of the full spectrum should be considered. The documentation should identify which fire scenarios were selected and why they are considered representative of the full spectrum of possible fire scenarios.

7.3.4.2 Where the purpose of the risk analysis is to determine whether an "acceptable risk" is provided or to identify methods of achieving an acceptable risk, the pass/fail threshold for the risk analysis, including how the threshold was developed, should be stated clearly. This step may be omitted if the purpose of the risk analysis is to document existing risk.

7.3.4.3 The goals of a risk analysis might be associated with the risk to life safety, the risk to property, the risk to operations, or the risk to the environment. Goals are typically qualitative and should be in a form that will be easily understood by laypeople.

7.3.5 Software and Model Evaluation. See Section 8.2 in addition to the information in 7.3.5.1 and 7.3.5.2.

7.3.5.1 Verification. The verification process is intended to demonstrate that the mathematical relationships and evaluation techniques accurately produce predictable and consistent results. One or more of the following may accomplish verification:

(1) Replication by alternative calculation
(2) Check of each calculation step
(3) Selected auditing of numerical results

7.3.5.2 Validation. The validation process is intended to demonstrate that the results of the FRA accurately reflect the facility risk. One or more of the following may accomplish validation:

(1) Comparison with alternative calculation
(2) Comparison with test results
(3) Demonstration of acceptable performance with finished facility

7.3.6 Limitations and Assumptions.

7.3.6.1 Prerequisites. Prerequisites are those items that must exist to ensure the validity of the FRA results and conclusions.

7.3.6.2 Open Items. Open items are those items that must be resolved before the FRA conclusions can be considered complete.

7.3.6.3 Conclusions. The results of the FRA, including a comparison to the pass/fail threshold if applicable, should be summarized. A description should be provided of the degree to which the purpose and objectives have been met along with information on the appropriateness and completeness of the results for the intended purpose.

7.3.6.4 References. The sources of the input data and how the input data are appropriate for the FRA should be identified. Examples of references include drawings, reports, manuals, publications, codes, and standards. The revision number or the publication date should be provided, if available.

7.4 Operational Manual.

7.4.1 Listing of Limitations and Assumptions.

7.4.1.1 In the interest of time, money, and/or simplicity, the engineering methods and models used to simulate system performance or to evaluate the fire risk are usually simplified. These simplifications carry limitations, and assumptions should be explicitly listed.

7.4.1.2 The controls (administrative programs and design features) used to protect the limitations and assumptions should be described. *(See 7.4.2.)*

7.4.1.3 The following topics should be reviewed to ensure that the operation of the facility does not inadvertently violate the limitations and assumptions of the FRA during normal and emergency situations:

(1) Engineering specifications, procurement documentation, work priorities, equipment replacement practices, rigorousness of equivalency evaluations, process monitoring instrument accuracies, electrical fault design practices, fuse replacement programs, and so forth
(2) Operating procedures (both normal and emergency), communications system availability, local response for emergency, emergency plans, and respondent training
(3) Labeling and storage practices, inventory control, packing/unpacking practices, material control, and vehicle use and control
(4) Housekeeping, hot work control, and combustible and flammable material control practices
(5) Training programs
(6) System design, reliability, maintenance, testing, and configuration control

7.4.2 Change Accommodation and the Change Management Program.

7.4.2.1 Organizations and processes evolve continually. The elements of change include the following:

(1) Knowledge changes
(2) Product obsolescence
(3) Labor force mix and quality changes
(4) Increasing internationalization, which changes the character and the quality of products
(5) Formal organization changes, which produce functional efficiency changes and realign departmental interfaces
(6) Jurisdictional criteria

7.4.2.2 The FRA is usually valid only under a limited set of conditions, depending on the inputs used. Any changes in factors such as building construction, geometry, outfitting, and processes could result in the FRA no longer being valid. Therefore, documentation should be provided on the set of conditions under which the FRA is considered to be valid and what types of changes in conditions would require a new FRA. Where it is intended to ensure that a risk is acceptable, methods of monitoring for change, such as periodic inspection, should be documented in an operations and maintenance manual or equivalent document.

7.4.2.3 Implementation of the following controls should be considered to avoid changing the established risk unknowingly:

(1) Educate the building owner and operator to identify when the FRA is affected and to understand change impacts.
(2) Footnote the procedures and programs to reinforce the source of constraint or element of basis that allows for the applicable process steps to be changed.
(3) Formalize the change process to account for pertinent departments being included in evaluation of the impact to the facility/program, including risk (i.e., getting the right people involved).
(4) Pilot programs used prior to change must be broader based in evaluating the total impacts to the modifications being made.
(5) Audit the processes and programs to ensure continued support of elements such as the FRA.

7.4.2.4 Because the FRA cannot presume to address all the possible changes, it is incumbent on the analyst to incorporate the assumptions, limitations, and conclusions into the ongoing process procedures and programs to ensure adequate understanding of the key attributes affected.

7.4.3 Inspection, Testing, and Maintenance Program.

7.4.3.1 Maintenance, testing, and inspection programs will affect the operability and availability of the credited systems, components, and structures.

7.4.3.2 Statistics and frequency of failures and availability are influenced by the conditions of maintenance, testing, and inspection.

7.4.3.3 Failure rates of improperly maintained equipment are difficult to account for.

7.5 Enforcement.

7.5.1 The FRA should define any enforcement mechanisms that will be in place to ensure that credited administrative and engineered features are correctly maintained.

7.5.2 These enforcement mechanisms may be modeled after the jurisdiction's occupancy and inspection regulations.

7.5.3 Penalties for noncompliance with agreements may be part of the FRA.

7.5.4 Postinstallation discoveries (equipment recalls, unaccounted-for behaviors, etc.) may create the need to update the FRA. The FRA should describe a mechanism to address such discoveries.

Chapter 8 Review

8.1 Technical Review Approaches. There are two possible approaches that an AHJ could use to verify the soundness of an FRA: direct review and third-party review.

8.1.1 Direct Review. If the AHJ has the resources available to undertake a review of the FRA to the desired degree of thoroughness, the AHJ could review the documentation of the FRA.

8.1.2 Third Party Review. There are two possible approaches to third-party review: peer review and contract review.

8.1.2.1* In peer review, an AHJ asks a third party to review the FRA, and the third party provides a report to the AHJ that identifies the soundness of the FRA. The AHJ then makes a decision as to what action to take on the FRA (e.g., approve, request revisions, or reject), based on the peer reviewer's documentation. Peer reviewers should have the same degree of education and experience as would be necessary to perform an FRA. Peer reviewers should not be involved in the FRA and should be acceptable to the AHJ.

8.1.2.2 In contract review, an AHJ delegates responsibility for review of the FRA to a third party, and the third party makes the decision as to what action to take on the FRA (e.g., approve, request revisions, or reject). Contract reviewers should have the same degree of education and experience as would be necessary to perform an FRA.

8.2 FRA Review Techniques. When reviewing an FRA, the AHJ should check whether the assumptions, building characteristics, occupant characteristics, and fire characteristics used in the analysis acceptably reflect the actual conditions. The types of items that should be checked are identified in Section 8.3. Additionally, the modeling that was used in the FRA should be reviewed. This review may be accomplished by verification and/or validation. Validation is a more thorough review than verification.

8.2.1 Verification. The verification process is intended to demonstrate that the mathematical relationships and evaluation techniques used in the FRA accurately produce predictable and consistent results. This may be done by one of the methods in 8.2.1.1 through 8.2.1.3.

8.2.1.1 Replication by Alternative Calculation. The results of the fire risk analysis may be checked by using alternative methods and checking the results against the original submittal. When this method is used, it is often not necessary to use a method as complex as that used in the original submittal. For example, if the original submittal used complex computer models, it might be possible to use a simple hand calculation to check the results. Because the methods used might have differing degrees of precision, some difference in the results might be expected; however, if the results are not markedly different, it might verify that the original submittal was modeled appropriately.

8.2.1.2 Check of Each Calculation Step. The modeling in the submittal may be verified by checking each step of the calculation. This method is best suited to modeling that uses hand calculations or simple computer models. While this method will not determine whether the problem was modeled correctly or whether an appropriate model was used, it will provide insight as to the internal correctness of the calculation.

8.2.1.3 Selected Auditing of Numerical Results. Where it is not practical to check each calculation step, sample portions of the modeling may be checked. If a large enough sample of the calculations are checked, and no errors are found, the reviewer may reasonably assume that all the calculations were performed correctly. However, if multiple errors are found in a relatively small sample, all the calculations might be suspect. As with checking each calculation step, this method will not determine whether the problem was modeled correctly or whether an appropriate model was used.

8.2.2 FRA Validation Techniques. The validation process is intended to demonstrate that the results of the FRA accurately reflect the facility risk. The methods in 8.2.2.1 through 8.2.2.3 may be used.

8.2.2.1 Comparison with Alternative Calculations. The FRA may be validated by using alternative methods to model the fire risk. The methods chosen should be of equal or greater precision to those used in the FRA submittal, and the alternative calculation method should return results similar to those included in the FRA submittal.

8.2.2.2 Comparison with Test Results. The methods used in the FRA may be run using input that describes the conditions under which tests were run and comparing the modeling results with the test results. If the modeling results show good agreement with the test results, then the reviewer may have confidence in the predictive capability of the model.

8.2.2.3 Demonstration of Acceptable Performance with Finished Facility. Demonstration could involve a qualification test that demonstrates that the model accurately predicts a simulated fire event.

8.3 Review Questions. The following questions may be used to determine whether the FRA was performed properly. For each question, the fire risk analyst should be able either to answer how it was considered in the fire risk analysis or to describe why the question is not relevant to the fire risk analysis. Depending on the scope of the fire risk analysis, it may not be necessary to consider each item.

(1) Is the purpose for conducting the fire risk analysis identified?
(2) Is the scope of the fire risk analysis identified?
(3) Are the methods used in the fire risk analysis identified, including a statement of why the methods are appropriate?
(4) Are the limitations of the analysis identified?
(5) Are the results of the risk analysis methods included?
(6) Are the conclusions of the fire risk analysis included?
(7) Is an operations and maintenance manual, that describes what needs to be done by the facility users, included?
(8) Are there instructions for how to manage change?
(9) Was an inspection, testing, and maintenance program developed?

Annex A Explanatory Material

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

A.1.5 The risk associated with a proposal is the sum of the risks for all the possible loss fire scenarios, but in practice only a subset of the hazards and fire scenarios will be addressed. FRAs may address specific elements of risk or the risk associated with specific hazards. Risk may further be measured from the viewpoint of specific stakeholders. This section identifies risk elements, hazards, and stakeholders that the AHJ may require be addressed. Regardless of the precision with which risk is calculated or the way in which the conclusions of the FRA are presented, the acceptable risk criteria must be expressed in the same way so that a determination may be made of whether the result of the analysis meets the criteria in whole, in part (for multiple risk categories), or not at all. Other information to be reported may be established by the stakeholders.

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

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

A.3.2.5 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.3 Deterministic Model. In a deterministic model, the quantities being modeled are treated as being completely certain—the purpose of the model is to provide an estimate of these quantities. For example, in a conventional deterministic zone model for compartment fires, the average hot gas layer temperature at any given point in time is computed as having a single, known value.

A.3.3.6 Fire Scenario. See Chapter 5.

A.3.3.11 Probabilistic Model. In a probabilistic model, the quantities being modeled are treated as being uncertain—the purpose of the model is to quantify the degree of uncertainty in these quantities. For example, in addressing the availability of a fire suppression system, it is uncertain whether the system is operational at any given point in time. A state-transition model representing the various states of the suppression system may be used to quantify the time-dependent likelihood that the system is operational (or not).

A.3.3.13 Risk. See Kaplan and Garrick, "On the Qualitative Definition of Risk."

A.4.4.3.4 Depending on the stakeholder, one or more of the following items may receive focus in the acceptance criteria:

(1) Human losses
(2) Environmental damage
(3) Property damage
(4) Business interruption
(5) Risk control program implementation costs
(6) Loss of image
(7) Loss of community confidence
(8) Loss of structures and objects with heritage significance

A.4.5 The following are related to uncertainty and variability analysis:

(1) *Uncertainty and variability.* Uncertainty is characterized by incomplete knowledge, which may be addressed by further research or testing (e.g., heat of combustion for a particular wood species may be determined by testing). Variability is characterized by random or stochastic processes, which cannot necessarily be reduced or eliminated (e.g., the population distribution in a building or the fuel load in a compartment).
(2) *Theory and model uncertainty.* Models are representations of reality. Many models make simplifying assumptions, and in some fields scientific knowledge is limited. Additionally, many models are based on empirical data from tests conducted under specific conditions (e.g., ceiling heights ranging from 2.5 m to 12 m). Application of such models outside of those conditions (e.g., in areas with ceiling heights less than 2.5 m or greater than 12 m) introduces uncertainty.
(3) *Data and model inputs.* Many of the input values used in fire risk calculations are subject to uncertainty. For well-defined products, there might be acceptable tolerances (e.g., sprinkler activation temperatures might be in the range of ±5 percent of the rated temperature). Field data are subject to uncertainty, because not all events might be reported, or generalizations might be made from a small number of data points.
(4) *Calculation limitation.* Some models are more complex. While simpler models might be appropriate for relatively simple problems, some applications might require a more complex model. Therefore, the relationship between the sophistication of the model used and the complexity of the application might introduce uncertainty.
(5) *Fire scenario selection.* Fire scenarios are typically predictions of the types of events that could occur. The degree to which a fire scenario represents the types of events that could actually occur could introduce uncertainty.
(6) *Uncertainties in human behaviors.* Uncertainty is introduced when the actions that people might take in a fire scenario are predicted.

(7) *Uncertainties in risk perceptions, attitudes, and values.* Different people are willing to accept different amounts of risk. Therefore, there might be uncertainty in assessing an "acceptable" level of risk.

A.5.1.2 Qualitative measures may generally be applied in FRAs for which comparison to a standard is sufficient. Methods that use qualitative measures include checklists and "what-if" analyses. Qualitative measures may also be used for FRAs that compare the risks presented by the base case and alternative schemes.

Quantitative measures may also be used to establish and demonstrate compliance to acceptance criteria.

Examples of quantitative acceptance criteria include the following:

(1) Expected value of risk (dollars)
(2) Expected injuries per unit floor area
(3) Defined scoring systems or indices
(4) Expected risk to life (ERL)
(5) Percentage fire loss
(6) Extent of fire spread

A.5.2 What-if analysis is purely qualitative in that it purposely avoids measurement. The fire safety concepts tree is a structured graphical approach that also is nonquantitative. Fire risk indexing is a quantitative method but does not specifically distinguish between likelihood and consequence and produces a measure of relative risk. The risk matrix approach is potentially quantitative; however, it typically relies on subjective scaling estimates of likelihood and consequence that may or may not be associated with explicit numerical values.

A.5.2.5 The risk matrix method was developed in the 1960s as a systems safety technique for military systems and is presently documented as MIL-STD-882D. In this approach, each hazard is assigned a probability level and a severity category. Table A.5.2.5(a) and Table A.5.2.5(b) are adapted from corresponding tables in MIL-STD-882D.

A risk matrix utilizes the probability levels and severity categories to represent the axis of a two-dimensional risk matrix such as shown in Figure A.5.2.5.

A.5.4.3.2 A list of currently available fire models can be found at the CSE Web site *www.firemodelsurvey.com.*

A.5.5 The following is a typical fire scenario sequence. A living room lamp comes in contact with a curtain, which ignites. The smoke detector is inactive, so it does not wake the apartment occupants. The burning curtain falls onto a chair, causing fire spread. The chair heat release rate raises the room temperature sufficiently to cause flashover. The door to the bedroom is closed, thus limiting smoke migration. The breaking glass wakes the apartment occupants. The severe fire conditions in the living room prevent evacuation. The building occupants exit the apartment through their alternative escape route, a second-story window above a porch roof.

The following is a typical fire scenario set. A fire in the living room occurs when the building occupants are sleeping. The smoke detector fails to activate an alarm. Flashover occurs in the room of origin, blocking the primary exit. The bedroom door is closed, so the occupants are not directly exposed. The occupants wake during the fire and exit by the alternative escape route.

The following is a typical consequence threshold. A fire death results from a fire in which the victim was not intimate with the ignition source.

Table A.5.2.5(a) Probability Levels

Probability	Description
Frequent	Likely to occur frequently, experienced ($p > 0.1$)
Probable	Will occur several times during system life ($p > 0.001$)
Occasional	Unlikely to occur in a given system operation ($p > 10^{-6}$)
Remote	So improbable, may be assumed this hazard will not be experienced ($p < 10^{-6}$)
Improbable	Probability of occurrence not distinguishable from zero ($p \sim 0.0$)

Table A.5.2.5(b) Severity Categories

Severity	Impact
Negligible	The impact of loss will be so minor that it would have no discernible effect on the facility or its operations.
Marginal	The loss will have impact on the facility, which may have to suspend some operations briefly. Some monetary investments may be necessary to restore the facility to full operations. Minor personal injury may be involved.
Critical	The loss will have a high impact on the facility, which may have to suspend operations. Significant monetary investments may be necessary to restore to full operations. Personal injury and possibly deaths may be involved.
Catastrophic	The fire will produce death or multiple deaths or injuries, or the impact on operations will be disastrous, resulting in long-term or permanent closing. The facility would cease to operate immediately after the fire occurred.

A.5.6 This section provides a framework for understanding and evaluating cost-benefit FRA methods. It describes various parameters of the methods and attempts to provide some context to these from the perspective of a regulator and an owner.

Cost-benefit risk assessment methods can range from those that are extremely simple to those that are quite sophisticated. They provide a further dimension to each of the FRA methods already described. The determination of the costs and/or benefits of various solutions is generally included as an extension or integral component of the FRA.

Currently there is no clear consensus as to the appropriate level or rigor of FRA that is acceptable in reviewing fire protection designs. This lack of consensus poses issues for all parties who have an interest in the project (e.g., the owner, the designer, the regulator) and who wish to have some generally accepted method that identifies the costs and the benefits from a risk perspective of one or more design solutions.

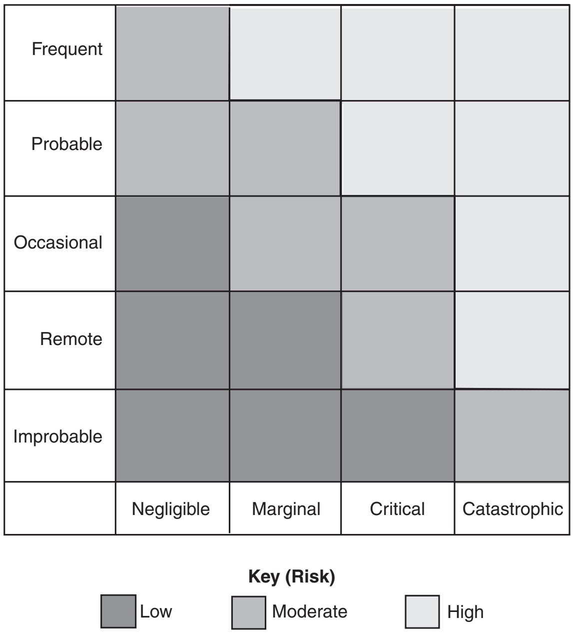

FIGURE A.5.2.5 Risk Matrix.

A.6.2 See Hall and Ahrens, "Data for Engineering Analysis."

A.8.1.2.1 For more information on peer review of fire protection designs, see the proposed SFPE "Guidelines for Peer Review in the Fire Protection Design Process."

Annex B Informational References

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

B.1 Referenced Publications. The following documents or portions thereof are referenced within the annexes of this guide.

B.1.1 NFPA Publication. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

Hall, J. R., Jr., and M. J. Ahrens. 2002. "Data for Engineering Analysis." Section 5, Chapter 5, of *SFPE Handbook of Fire Protection Engineering*, 3rd edition.

B.1.2 Other Publications.

CSE Web Site, *www.firemodelsurvey.com*. Combustion Science & Engineering, 8940 Old Annapolis Rd., Suite L, Columbia, MD 21045.

Kaplan, S., and B. J. Garrick. 1981. "On the Qualitative Definition of Risk," *Risk Analysis*, 28(1), 11–27.

MIL-STD-882D, *Standard Practice for System Safety*. U.S. Department of Defense, 10 February 2000. U.S. Government Printing Office, Washington, DC 20402.

SFPE. Forthcoming. "Guidelines for Peer Review in the Fire Protection Design Process."

B.2 Informational References. The following documents or portions thereof are listed here as informational resources only. They are not directly referenced in this guide.

B.2.1 NFPA Publication. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

Barry, T. F., et al. 1991. "Fire Loss Prevention and Control Management." *Fire Protection Handbook*, 17th edition.

Bukowski, R. 1997. "Fire Hazard Analysis." *Fire Protection Handbook*, 18th edition.

Hall, J. R., Jr. 1997. "Fire Risk Analysis." *Fire Protection Handbook*, 18th edition.

SFPE Handbook of Fire Protection Engineering, 3rd edition, 2002. Section 5 Fire Risk Analysis.

Walton, W., and E. Budnick. 1997. "Deterministic Computer Fire Models." *Fire Protection Handbook*, 18th edition.

Watts, J. M., Jr. 1997. "Probabilistic Fire Models." *Fire Protection Handbook*, 18th edition.

Watts, J. M., Jr. 2002. "Risk Indexing." Section 5, Chapter 10 in *SFPE Handbook of Fire Protection Engineering*, 3rd edition.

B.2.2 Other Publications.

"What-If Analysis." 1997. *System Safety Analysis Handbook*, 2nd edition. Albuquerque: System Safety Society, P.O. Box 70, Unionville, VA 22567-0070, 301–303.

Yung, D., G. V. Hadjisophocleous, and G. Proulx. 1997. "Modeling Concepts for the Risk-Cost Assessment Model FiRECAM™ and Its Application to a Canadian Government Office Building." *Proc. 5th International Symposium on Fire Safety Science*. Melbourne, Australia, 619–630.

B.3 References for Extracts. (Reserved)