



Performance-Based

Primer #1

Goals, Objectives and Criteria

Revision 1.1 19 SEPTEMBER 1997

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Preface

This primer (Primer 1) has been developed by the NFPA Performance-Based Support Team (PB Support Team). The PB Support Team functions under the auspices of the NFPA Standards Council, and reports directly to the Council on an on-going basis. The PB Support Team was created in 1995 to assist NFPA Technical Committees with the transition to performance-based documents.

Primer 1 is the first in a series intended to provide NFPA Technical Committees with guidance and information on how to write a performance-based NFPA code, standard, or similar document. This primer is based on the report of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models' report entitled *NFPA's Future in Performance-Based Codes and Standards*. This report, released in July 1995 and developed in conjunction with the NFPA Board of Directors, implies the need for the development of further guiding information for NFPA Technical Committees. Primer 1 is the first step to fill this need for further guiding information.

It is anticipated that this primer will undergo future changes as they are developed. Any comments on the primer should be sent to:

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NFPA Technical Committee PB Primer #1

PERFORMANCE-BASED GOALS, OBJECTIVES AND CRITERIA

Revision 1.1 19 SEPTEMBER 1997

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NFPA Performance-Based Primer 1

Goals, Objectives, and Criteria

1997 Edition

NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates explanatory material on that paragraph in Appendix A. A double asterisk (**) indicates similar information as used by other organizations and is in Appendix B.

Chapter 1 General Information

1-1 Primer Purpose. The purpose of this primer is to serve as a resource for NFPA Technical Committees during their efforts in developing performance-based provisions and incorporating them into NFPA documents. This primer can be used to develop new stand-alone performance-based documents or to develop performance-based options in existing or future documents. "Document" is used as a collective term for codes, standards, or recommended practices and may refer to one, two or all three.

1-2 Primer Scope. This primer addresses the process of developing performance-based goals, objectives, and criteria for NFPA documents. It is one of five primers that serve as resources for NFPA Technical Committees for their development of performance-based provisions.

1-3 Origin. This primer is the direct result of the efforts of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models and the report they produced [1]. This primer is based in part on that report and provides an expansion of the concepts contained therein. It is anticipated that the primer will undergo future changes as they are developed.

1-4* Process. As shown in Figure 1-4, there are two distinct, although not exclusive, approaches to developing performance-based provisions. The top-down approach is described in [1] and the bottom-up approach is taken from [3]. Four additional primers will be developed in addition to this one. One of the primers will provide an overview of the top-down approach. The remaining three will address characteristics, fire scenarios, and calculation and other verification methods. The development of goals, objectives, and criteria is discussed in detail in Chapter 6.

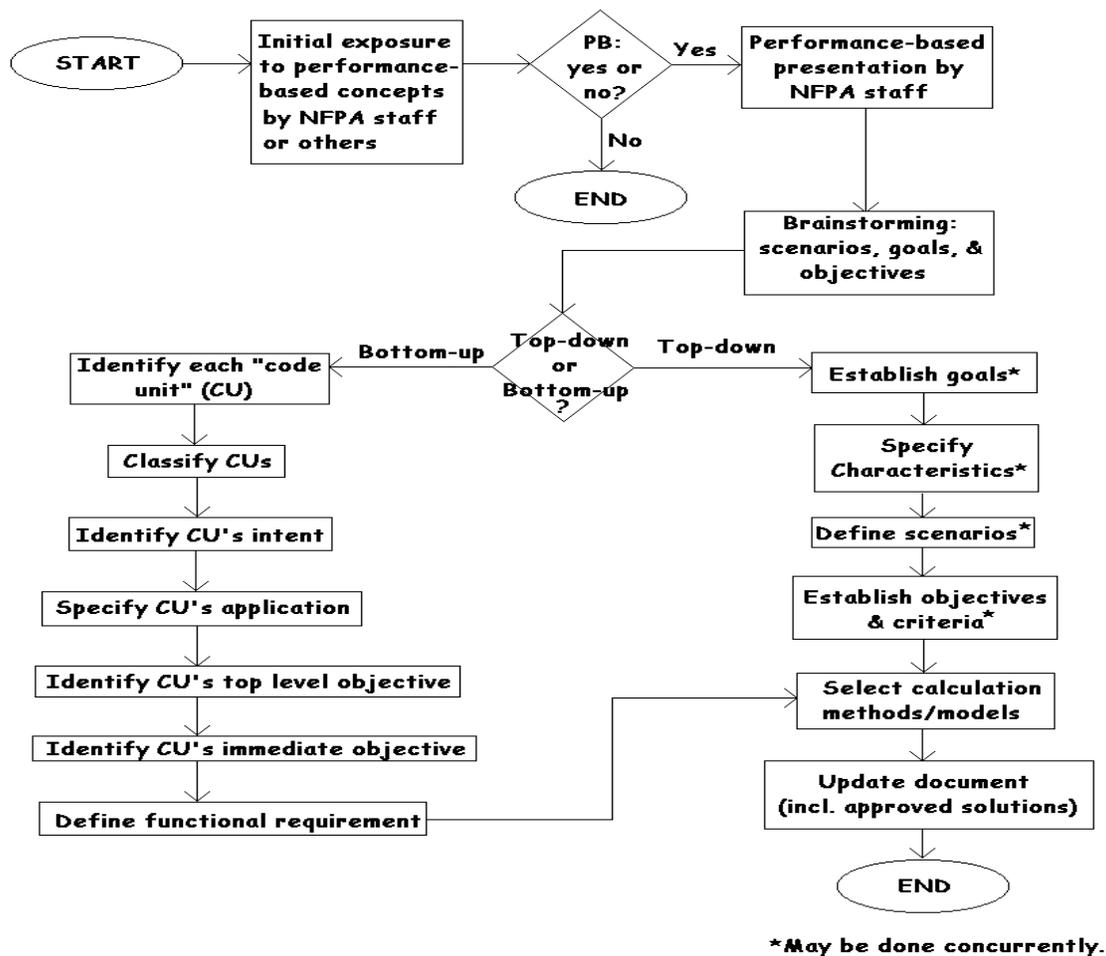


Figure 1-4 Performance-based Document Development

1-5 Clarification. Due to the wide variety of topics covered by NFPA documents, it is difficult to address each topic specifically in this primer. These topics include buildings, systems within buildings, building features, vehicles (including boats and ships), outdoor property, people, and products. Therefore, in this primer “building” will be used to generally indicate the topic of a given NFPA document.

Chapter 2 Glossary

2-1 General. The following terms are presented to help provide a consistent vocabulary. Definitions of the following terms are taken from [1], unless otherwise noted.

Approved Method. Authoritative procedure used to develop proposed solutions. Currently the only approved solutions are contained within prescriptive documents.

Bottom-Up. One approach used to develop performance-based provisions. Using this approach, the goals, objectives, characteristics, and scenarios of a document that are unstated prior to document revision processing are identified and explicitly stated [3].

Code (Document) Unit. The smallest portion of a code (i.e., a document) that can have an intent and application statement attached to it [3]. Each code unit has a type, an intent, application (i.e., “application and limitations of the application of the provision such as occupancy, building height, sprinklered/nonsprinklered building, etc.”) and one or more objectives.

Fire Model. A calculation tool that incorporates engineering and scientific principles and applies them in a logical manner. Due to the complex nature of the principles involved, models are often packaged as computer software. Included with the fire models should be all relevant input data, assumptions, and limitations needed to properly implement the model. Depending on the user, fire models may be used to develop or evaluate a proposed solution, or both.

Fire Safety Goal. Overall outcome to be achieved with regard to fire. Goals are non-specific and are measured on a qualitative basis. They should be stated in terms of conditions that are intrinsically desirable and do not rely on any assumptions. Goals should be stated in terms that are potentially measurable, even if the precise measurement scale is not specified. Thus, goals may be expressed in terms of impact on people, property, or the environment, or in terms of mission continuity. A single goal may be applicable to many different NFPA documents.

Fire Scenario. Specification of fire conditions under which a proposed solution is expected to meet the fire safety goals. The fire scenario describes factors critical to the outcome of the fire such as ignition sources, nature and configuration of the fuel, ventilation, characteristics and locations of occupants, condition of the supporting structure, applicable operating equipment (e.g., reliability and/or effectiveness), etc.

Performance-Based Characteristics. Those qualities of the occupants, building contents, potential fuel packages, process equipment, and facility features, etc. that may be present in the facility and that should be considered when developing a performance-based fire safety design or performance-based provisions for NFPA documents. Typically, these involve, but

are not limited to, the unique aspects of the facility that have lead to the decision to use a performance-based design.

Performance-Based Design Approach. A design process whose fire safety solutions are designed to achieve a specified goal for a specified use or application. This process allows performance-based documents to be implemented and insures that their goals are met.

NOTE: The following describes a performance-based design approach:

- a) Establish fire safety goals.
- b) Evaluate the condition of the occupants, building contents, process equipment, or facility in question with regard to fire safety.
- c) Establish performance objectives and performance criteria.
- d) Identify potential hazards to be protected against.
- e) Define appropriate scenarios.
- f) Select suitable calculation methods (e.g., fire models).
- g) Develop proposed solution.
- h) Assess proposed solution.
- i) Document proposed solution along with supplementary information.
- j) Obtain approval of the proposed solution.

Steps a) through f) are also part of the development of a performance-based code or standard. Only steps g) through j) are specific to performance-based design, where the intent is to find a solution for the project. Also, steps c), d), and e) are not necessarily intended to be sequential; they may in fact be concurrent. While the above is presented in a sequential order, the design approach does not necessarily need to begin with step a) and proceed consecutively through step j). Since different stakeholders (e.g., owner, designer, authorities) must be satisfied, some steps of this approach are iterative. Similarly, for performance-based document development, steps a) through e) may or may not be taken sequentially.

Performance-Based Document. A code or standard that specifically states its fire safety goals and references approved methods that can be used to demonstrate compliance with its requirements. The document may be phrased as a method for quantifying equivalencies to an existing prescriptive-based document and/or it may identify one or more prescriptive documents as approved solutions. Furthermore, the document allows the use of all solutions that demonstrate compliance using approved methods.

NOTE: A performance-based document may also include separate prescriptive provisions as a parallel, independent approach to meet the performance-based goals and objectives.

Performance Criteria. Performance objectives for individual products, systems, assemblies, or areas that are further quantified and stated in engineering terms (e.g., temperature, radiant heat flux, level of exposure to combustion products). Performance criteria provide

pass/fail threshold values which are treated as data for calculations used to develop a proposed performance-based solution.

Performance Objective. Requirement for the fire, building, or occupants (or combination thereof) which must be satisfied in order to achieve a fire safety goal. Objectives are stated in more specific terms than goals and tend to be more quantitative than qualitative. Objectives may be thought of as specific goals for individual NFPA documents

Prescriptive-Based Document. A code or standard that prescribes fire safety for a generic use or application. Fire safety is achieved by specifying certain construction characteristics, limiting dimensions, or protection systems without providing a mechanism for how these requirements achieve a desired fire safety goal. Typically these documents do not state their fire safety goals.

NOTE: Many current NFPA codes and standards are not strictly performance-based or prescriptive-based: technically, they can be referred to as prescriptive documents containing some performance provisions. For example, a requirement for a one-hour door sets a measurable performance criterion, going beyond prescription of the door's construction, but does not link the criterion explicitly to a fire safety goal.

Proposed Solution. A fire safety system design intended to achieve the stated fire safety goals and expressed in terms that make it possible to assess whether the fire safety goals and objectives have been achieved. If a fire model is used, then the proposed solution should also specify the model and input data employed.

Safety Factor. Adjustment made to reflect conservatism due to uncertainty in the methods and assumptions employed in measuring performance.

Top-Down. One approach used to develop performance-based provisions. Using this approach, the goals and objectives are developed during document revision processing without consideration of any current prescriptive requirements: a “clean sheet of paper” approach.

Verification. Confirmation that a proposed solution meets the established fire safety goals. Verification involves several steps (which, for a prescriptive-based approach, are left without guidance to the discretion of the Authority Having Jurisdiction). Verification confirms that the building is built as proposed to a design that will achieve the intended level of safety and that the building's ability to achieve the level of safety has been demonstrated by qualified people using the correct methods applied to the correct data.

Chapter 3 Goals

3-1 General. The goal statement of a performance-based document should be a broad, qualitative expression of the overall, primary concern of the document. Goals should be stated in terms that are potentially measurable, even if the precise measurement scale is not specified. Thus, goals may be stated in terms of impact on people, property or the environment, business interruption, or any combination of these. Goals should address the primary concern of the document.

3-2 Definitions. Given the nature of a performance-based approach (i.e., flexible), the definition of terms becomes an important issue. Therefore, an authoritative definition of “goal” is presented, followed by the term’s envisioned use in NFPA documents.

3-2.1 Dictionary Definition. From [2], a goal is “The purpose toward which effort is directed, an objective.” Alternatively, this could be stated as that which one plans to do or achieve. A goal may suggest an idealistic or even a remote purpose.

3-2.2 NFPA Context.** Given NFPA’s mission, the (single) goal of any NFPA performance-based provision is readily evident: to reduce the burden of fire on the quality of life. As discussed further in this document, this goal may be manifested in different ways, depending on the particular NFPA document being considered. Goals do not rely on assumptions. For example, “avoidance of flashover” would not be a goal because it relies on assumptions about what kinds of fires cause harm and how flashover is defined.

3-3 Performance-Based Fire Safety Goals. Typically, fire safety goals fall into six broad categories (“occupancy” examples shown in parentheses):

- (a) Life safety of occupants (theater);
- (b) Property protection (warehouse);
- (c) Mission continuity (shipboard engine room);
- (d) Environmental consequences (outdoor rubber tire storage);
- (e) Heritage preservation (museum gallery); and
- (f) Firefighter safety (all of the above “occupancies”).

3-3.1* Life Safety. Goals relating to life safety are the most common and arguably the most important in fire and other emergency situations. The public places trust in the built environment (i.e., in anyone involved in constructing buildings, structures, and other facilities: designers, engineers, code officials, etc.) to maintain some level of safety or protection from adverse conditions. Therefore, maintaining the health, safety and welfare of building occupants could be a goal.

3-3.2* Property Protection. Property protection considers the impact of fire on the structural elements of, as well as the equipment and contents in, a building [4]. While the natural measurement scale for this goal would seem to be monetary, available models rarely

suffice to predict monetary losses. Instead, they can predict areas and volumes affected by type of damage (e.g., flames, smoke). Thus, the goal of reducing the impact of a fire both within and without a building falls into the general category of property protection; e.g., limiting the spread of a fire. There are many issues with regard to limiting the spread and effects of fire. On a macro scale, building design should be such that a fire will not spread from one building to another. While within the building, it is desirable to limit the spread of fire before it can reach specific areas of the building, e.g., areas of refuge or other places of safety.

3-3.3* Mission Continuity. The goal of mission continuity is analogous to that of property protection. However, instead of considering the physical nature of a structure, mission continuity is more concerned with the ability of a structure to perform its intended function(s) and how that affects the structure's tenants. Business interruption is perhaps the best known example of a mission continuity loss and is also something described as "indirect loss," as contrasted with "direct loss" from damage to structure or contents. Obviously, the building must remain structurally sound for a required period of time for this to happen, so there is a link between property protection and mission continuity. But mission continuity is intended to protect an organization's ongoing mission, production, or operating capability [4]. Thus, property protection and mission continuity are not mutually exclusive.

3-3.4* Environmental Consequences. The goal of limiting the impact of a fire on the environment may be trivially easy to achieve for most fires, even some large fires, but it is a distinct goal of increasing importance to nations around the world. Air pollution in the form of the smoke released during a fire is probably the most visible damage to the environment from a fire. However, the run-off from manual fire suppression operations and/or sprinkler system discharge may also damage the environment, e.g., when non-water soluble, toxic chemicals are involved in some way.

3-3.5* Heritage Preservation. Heritage preservation is meant to keep historical and cultural "items" from harm. Items in this case are usually one-of-a-kind and could be an entire building, archaeological and other historical artifacts, works of art, manuscripts, etc. One aspect of heritage preservation is protecting items in museums. If these items are destroyed, their loss to our society and culture may be impossible to measure. In some cases, heritage preservation is similar to property protection except any resulting fire damage should be less extensive than for property protection.

3-3.6* Firefighter Safety. Typically, firefighters are not considered to be occupants of a building and therefore are not usually the subject of the life safety goal of 3-3.1. Part of the reason for this approach is that firefighting is inherently dangerous and risks associated with the job cannot be entirely eliminated. However, there are goals which, if achieved, give firefighters a reasonable chance of achieving manual extinguishment without undue threat (i.e., with minimal risk). For example, the fire department requires access to the

building itself and to specific areas within the building (e.g., parking lots and stairwells). Furthermore, maintaining the structural integrity of the building is also important to ensure firefighter life safety. Thus, the effectiveness of firefighters is a direct result of their safety: the less risk they face, the greater probability they have of suppressing a fire.

Chapter 4 Objectives

4-1 General. The fire safety objectives of performance-based codes and standards are intended to be more specific than goals. In the context of performance-based provisions, objectives provide a greater level of (qualitative) detail than goals. Objectives are stated in more specific terms than goals and are measured on a more quantitative rather than qualitative basis. Objectives are the link between fire safety goals and performance criteria. In general, objectives define a series of actions necessary to make the achievement of a goal much more likely.

4-2 Definitions. Given the nature of a performance-based approach (i.e., flexible), the definition of terms becomes an important issue. Therefore, an authoritative definition of “objective” is presented, followed by the term’s envisioned use in NFPA documents.

4-2.1 Dictionary Definition. From [2], an objective is “something worked toward or striven for; a goal.” An objective often implies that the end or goal can be achieved.

4-2.2 NFPA Context.** From [1], an objective is a requirement of the fire, building, or occupants which needs to be obtained in order to achieve a fire safety goal. Objectives are stated in more specific terms than goals and tend to be more quantitative rather than qualitative.

4-3 Difference Between Goals and Objectives. The primary difference between fire safety goals and objectives is that objectives are more specific to the problem being solved or the document being developed. The same goals may be applied to most NFPA documents, while objectives are intended to reflect the nature and intent of the document in question. For example, the goal of maintaining life safety can be used for a document dealing with smoke management systems as easily as it can be used for one dealing with an active suppression system. However, the objectives of those two documents would not be the same. Therefore, the objectives for these two documents would discuss, in quantitative terms, how life safety may be maintained by using either a smoke management system or an active suppression system. The objectives of the individual documents must be different since they are dealing with markedly different systems, components, and occupant responses. Finally, goals are always qualitative, while objectives may also be quantitative.

4-4 Performance-Based Fire Safety Objectives.

4-4.1 Since objectives are document specific, it is difficult, but not impossible, to provide general fire safety objectives. From [1] some general fire safety objectives are:

- a) Prevention of structural damage;
- b) No life loss in the room of fire origin;
- c) Separating occupants from fire effects for “a specified period of time;” and
- d) Containing the fire to the room of origin.

4-4.2 The third example helps illustrate how similar objectives may be different for different documents. Depending on the scenarios of interest, the specified time could be several minutes (e.g., patient room in a health care facility) to several hours (e.g., non-fire floor in a high-rise building).

4-4.3 As a further example, consider the prototype objectives found in Appendix C of [1], for a prototypical NFPA 13DX, *Residential Sprinkler Systems*. In this case, there are two levels of objectives; one for overall performance and another for the (sprinkler) system. From [1], the prototypical, overall performance objectives are:

Protection of Occupants. A sprinkler system shall be designed, installed, and maintained to reduce the likelihood of instantaneous or cumulative exposure to conditions that exceed the survivability criteria of 1-6.1 by occupants not intimate with ignition for the period of time necessary for occupant evacuation.

Prevention of Flashover. A sprinkler system shall be designed, installed, and maintained to reduce the likelihood of flashover in the room of fire origin for the period of time necessary for occupant evacuation.

4-4.4 The prototypical objectives for the (sprinkler) system deal with the water supply, system components (i.e., pipes, valves, etc.), design specification, testing, and repair and maintenance.

Chapter 5 Performance Criteria

5-1 General. Performance criteria tend to be the most specific parts of performance-based documents. From [1] criteria are “Performance objectives (emphasis added) for individual products, systems, assemblies, or areas [which] are further quantified and stated in engineering terms.” Thus, in essence, criteria can be thought of as quantified objectives.

5-2 Definitions. Given the nature of a performance-based approach (i.e., flexible), the definition of terms becomes an important issue. Therefore, an authoritative definition of “criterion” is presented, followed by the term’s envisioned use in NFPA documents.

5-2.1 Dictionary Definition. From [2], criterion is defined as “A standard, rule, or test on which a judgment or decision can be based; criteria (pl).”

5-2.2* NFPA Context. From [1], criteria are stated in engineering terms, which include temperature, radiant heat flux, and levels of exposure to fire products. In this sense they are directly “measurable” (i.e., by experimentation, analysis and/or calculation) objectives that, if achieved, result in attaining the specified fire safety objectives and consequently achieving the associated goals.

5-3 Performance-Based Fire Safety Criteria.

5-3.1 Depending on the document, performance criteria may or may not be document specific. Performance criteria are related to the physics of fire and the human physiology of its consequences. As such, criteria can be applied to more than one document or scenario. From [1], some examples of candidate examples of candidate fire safety criteria are:

- a) Limiting a structural steel member to less than 540°C;
- b) Limiting COHb levels to less than 25%;
- c) Limiting upper layer temperatures to less than 500°C above ambient;
- d) Limiting radiant flux at the floor to less than 20 kW/m².

5-3.1.1 Note the difficulty of choosing the right level of detail for performance criteria. If they are stated too specifically, they may oversimplify the phenomenon of fire and its effects, leading to poor guidelines that do not reflect real performance. On the other hand, if they are stated too generally, they may provide insufficient guidance to a user on how to evaluate designs.

5-3.2 As a further example, consider the prototype criteria found in Appendix C of [1], for a prototypical NFPA 13DX, *Residential Sprinkler Systems*. In this case there are, essentially, two performance criteria that relate to the two overall performance objectives: survivability and flashover prevention. From [1], the prototypical performance criteria for survivability are “measured” five feet above the floor and involves a consideration of the temperature and

various gaseous species concentrations (e.g., CO, O₂). The flashover prevention criteria also specifies an upper layer temperature and a radiant heat flux to the floor.

5-3.3 A collection of test methods, each with a pass/fail threshold, might appear to provide a set of performance criteria. However, appropriate performance criteria must quantify the higher-level goals and objectives without inappropriate assumptions about which fires matter and how fire effects occur. Few, if any, test methods can be used in isolation, without analysis for this purpose.

Chapter 6 Developing Goals, Objectives, and Criteria

6-1 General.

6-1.1 As indicated by Appendix C of [1], goals, objectives, and criteria can be written in a standard format, similar to that of current prescriptive requirements. The goals would most likely be stated in the “Document Purpose” section of the document and will apply to both the prescriptive and performance aspects of the document [1]. By having the goal(s) apply to the prescriptive requirements, the basis for equivalencies is firmly established.

6-1.2 The performance objectives and criteria should be stated in the “Performance Objectives” and “Performance Criteria” sections of the document. These provisions will apply only to the performance-based provisions of the document [1].

6-1.3 A flow chart of the document conversion or development process is shown in Figure 6-1.3. In Figure 6-1.3, the development of criteria and the finalization of scenarios and characteristics is not necessarily a linear process. Figure 6-1.3 is intended to show that any one of these items may be considered first, second, or third. When these steps have been collectively completed, suitable models and methods may be selected.

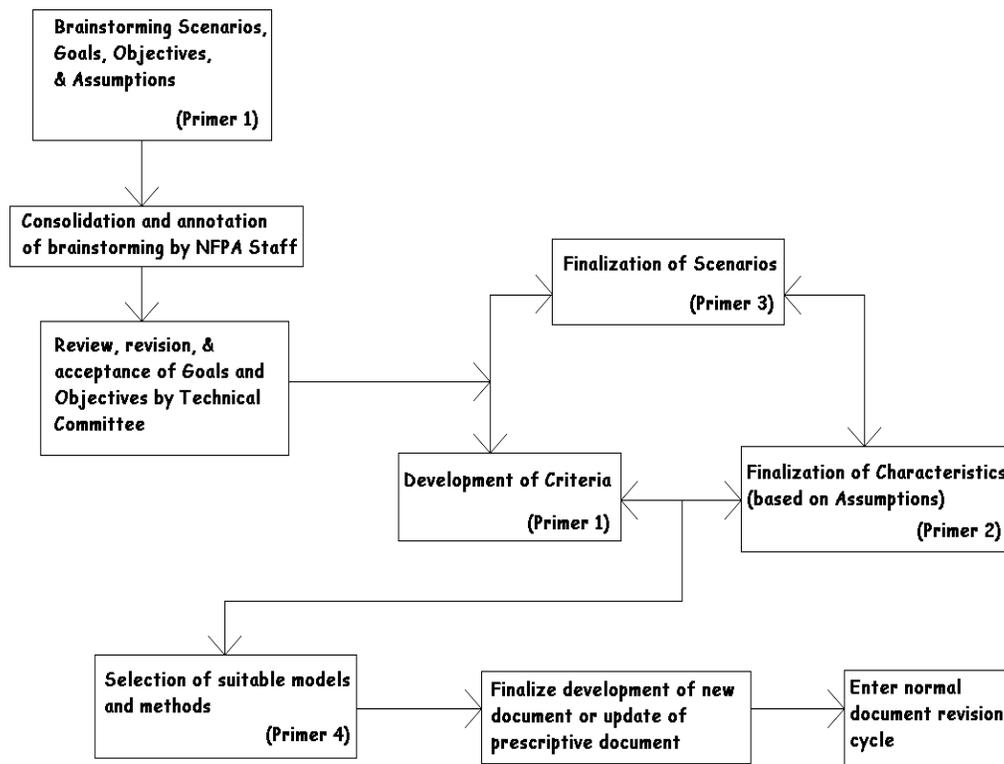


Figure 6-1.3 Document Conversion/Development Flow Chart

6-2 Development of Goals and Objectives.

6-2.1 After a Technical Committee has made the decision to pursue performance-based provisions for their document, NFPA staff facilitate a brainstorming exercise. This exercise is intended to assist committee members in not thinking prescriptively, i.e., to help them change the way they are used to thinking about developing document provisions.

6-2.2 The brainstorming exercise first addresses scenarios. The purpose of this is to highlight those unique issues that particular documents cover. Primer #3 will provide greater detail regarding scenarios.

6-2.3 Since the distinction between the two terms can be unclear, both are considered simultaneously in the next phase of the exercise. NFPA staff then review and annotate the items developed during the exercise. The annotated goals and objectives are then returned to the Technical Committee for their review, revision, and acceptance.

6-2.4 Some NFPA documents do not have explicit goals and objectives, while others do. This exercise is an opportunity to clearly define what a document is intended to achieve, if it does not currently have explicit goals and objectives. If a document does have explicit goals, and/or objectives, this provides an opportunity to either update or expand them, as desired by the Technical Committee. The decision of what to do with the results of the exercise is left to the individual Technical Committees.

6-2.5 Objectives may also be of an administrative nature. An administrative objective could involve a safe shut down (or similar) procedure or address the issue of staff training.

6-3 Development of Criteria.

6-3.1 The criteria that pertain to a particular document are based upon the objectives resulting from the brainstorming exercise. Criteria may be thought of as quantified (or quantifiable) objectives.

6-3.2 The development of criteria is less subjective than the development of goals and objectives. Since criteria are grounded in physics they are associated with the models and calculation methods which must be used to predict them. Therefore, the specification of criteria is more a matter of deciding appropriate values, than it is a matter of choosing which criteria to use.

6-3.3 Administrative objectives may result in criteria which may not be quantifiable. For example, the criteria for staff training may be on a simple pass/fail basis.

6-4 Development of Goals, Objectives, and Criteria Summary.

6-4.1 The development of goals, objectives, and criteria is one way of beginning the process of producing performance provisions for NFPA documents. Either a bottom-up, a top-down, or (more likely) combination of the two approaches may be used to define these items.

6-4.2 Since there is a small, finite set of goals, developing them should be relatively straightforward. The performance objectives will probably require a brainstorming session or two, followed by resolving those brainstorming ideas into a comprehensive set of objectives for the document in question.

6-4.3 The performance criteria follow directly from the objectives; essentially, putting the objectives into engineering terms. With these items established, subsequent performance provisions will be built on a solid foundation. Regardless of which approach is chosen, the process for producing a document will not change from the current NFPA consensus process.

Chapter 7 Conclusion

7-1 General. This document discusses the issue of developing performance goals, objectives and criteria for NFPA documents wishing to incorporate performance-based provisions.

7-2 Development Process. Developing performance-based provisions is a dynamic process and not easily delineated. Although [1] does provide a discussion on the document conversion process and provides steps for doing so, the order of those steps need not be taken literally. Some Technical Committees will most likely follow those steps as if they were gospel; others, for reasons of their own, will not. The point is not to worry about what comes first or what comes next. Goals, objectives, criteria, assumptions or characteristics, fire scenarios, and analysis methods are all part of the performance-based package. The order in which they are developed is less important than making sure all of the pieces are in place.

Chapter 8 Reference Publications

1. *NFPA's Future in Performance-Based Codes and Standards*, National Fire Protection Association, Quincy, MA, July, 1995.
2. *The American Heritage College Dictionary*, 3rd ed., Houghton Mifflin Co., Boston, 1993.
3. *Bottom-Up Analysis of National Codes*, Canadian Codes Centre, September 1996.
4. Custer, R.L.P. and Meacham, B.J., *Introduction to Performance-Based Fire Safety*, National Fire Protection Association, Quincy, MA, 1997.

Appendix A

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

A-3-3.1 Examples of fire safety goals stated in terms of impact on people might be:

- Assure risk of death due to fire is no higher than current level for similar properties,
- Assure that anyone capable of self-evacuation and not intimate with the ignition can safely escape.

A-3-3.2 Examples of fire safety goals stated in terms of property protection might be:

- Maintain structural stability,
- Ensure that a fire remains small.

A-3-3.3 Examples of fire safety goals stated in terms of mission continuity might be:

- Ensure resumption of operations as soon as possible,
- Avoid a critical loss of inventory.

A-3-3.4 Examples of environmental goals include:

- Prevent the release of any radiation to the environment,
- Ensure firefighting activities have a minimal environmental impact.

A-3-3.5 Examples of heritage preservation goals are similar to property protection goals and may include:

- Minimize damage to all museum galleries,
- Maintain structural stability,
- Ensure that a fire remains small.

A-3-3.6 Examples of firefighter safety goals may be:

- Provide adequate building/site access for firefighting apparatus and equipment,
- Provide adequate information to firefighters during an emergency.

Appendix B

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

B-1 General.

B-1-1 The International Code Council (ICC) is developing a single, prescriptive building code for the United States, the International Building Code (IBC). In addition, they are also developing a performance-based IBC. Since users of NFPA performance-based documents may also encounter the performance-based IBC, this appendix is included to provide a comparison between the two organizations' performance-based provisions. While many of the concepts are similar, nomenclature may not be.

B-1-4 Process. The structure of the performance-based IBC is shown in Figure B-1-4. As of the date of this primer, only the intent, scope, objectives, functional statements, and performance requirements will be in the performance-based IBC. The ICC Performance Committee (ICC PC) essentially used a top-down approach with the New Zealand Building Regulations 1992 as a model. The status of criteria, guidelines, and acceptable solutions is uncertain. However, it is recognized that the prescriptive IBC will provide acceptable solutions until performance-based solutions can be developed.

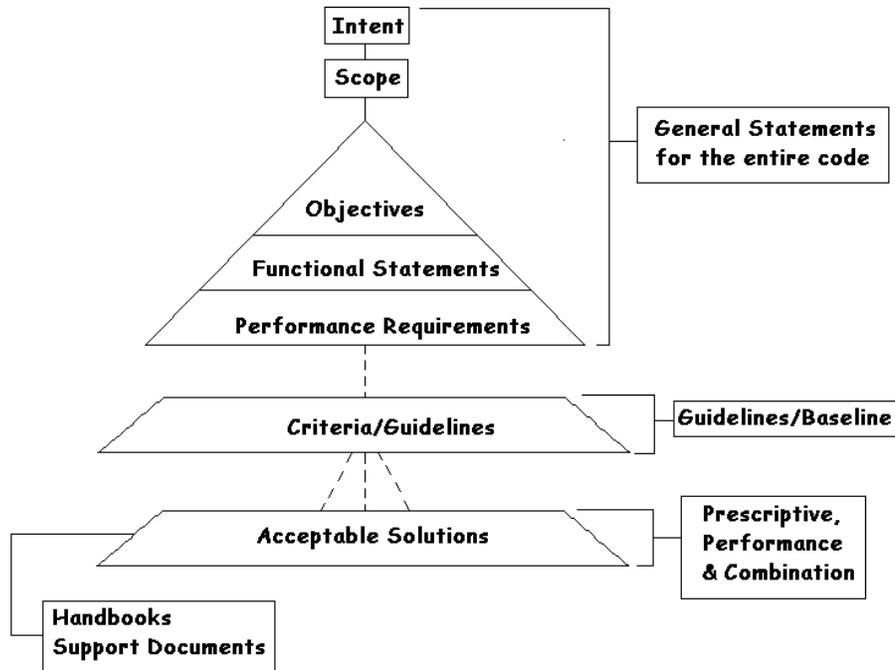


Figure B-1-4. Performance-based IBC Structure

B-3-2.2 Instead of “goal,” the performance-based IBC uses an Intent statement as shown in Figure B-1-4.

B-4-2.2

B-4-2.2.1 The term “objective” is used similarly by the ICC PC and NFPA.

B-4-2.2.2 In addition to Objectives, the ICC PC also uses a Functional Statement which are intended to answer the question, “Why this requirement?” [B-1]. From [B-1], “In the Functional Statement, always try to fill in the blank: This requirement is being provided because _____.”

Examples of Functional Statements given in [B-1] are:

- Give occupants sufficient time to escape,
- Prevent injury to building occupants due to overload of a structural element or system,

B-4-2.2.3 The ICC PC defines a Functional Statement as explaining in general terms why the objective must be met [B-2].

-1]. If this question were asked of NFPA Criteria, the answer would most likely be presented in engineering terms. When asked of an IBC Performance Requirement the answer could be “A sprinkler system shall be installed that will activate in sufficient time to contain a fire of the intensity expected for the particular building.” [B-1].

B-5-2.2.3 As shown in Figure B-1-4, the ICC PC recognizes the need for criteria (and guidelines). As of the date of this primer, these have not been addressed by the ICC PC.

Referenced Publications.

- B-1. *Performance Code Style & Format Guide*, International Code Council Performance Committee, MAR97.
- B-2. Weber, R. *Guidelines for Use ICC Performance Code*, International Code Council Performance Committee, JUN97.



**Performance-Based
Primer #2
Characteristics & Assumptions**

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Preface

This primer (Primer 2) has been developed by the NFPA Performance-Based Support Team (PB Support Team). The PB Support Team functions under the auspices of the NFPA Standards Council, and reports directly to the Council on an on-going basis. The PB Support Team was created in 1995 to assist NFPA Technical Committees with the transition to performance-based documents.

Primer 2 is the second in a series intended to provide NFPA Technical Committees with guidance and information on how to write a performance-based NFPA code, standard, or similar document. This primer is based on the report of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models' entitled *NFPA's Future in Performance-Based Codes and Standards*. This report, released in July 1995 and developed in conjunction with the NFPA Board of Directors, implies the need for the development of further guiding information for NFPA Technical Committees. Primer 2 is one step to fill this need for further guiding information.

It is anticipated that this primer will undergo future changes as they are developed. Any comments on the primer should be sent to:

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NFPA Technical Committee PB Primer # 2

PERFORMANCE-BASED CHARACTERISTICS & ASSUMPTIONS

Revision 1.0 19 October 1999

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NFPA Performance-Based Primer 2

Performance-Based Characteristics & Assumptions

1999 Edition

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

Part I - Information

This section (Part I) provides general information to the Technical Committee regarding the Primers and terms used within the Primers.

Chapter 1 General Information

1-1 *Primer Purpose. The purpose of this primer is to serve as a resource for NFPA Technical Committees during their efforts in developing performance-based provisions and incorporating them into NFPA documents. This primer can be used to develop new stand-alone performance-based documents or to develop performance-based options in existing or future documents. "Document" is used as a collective term for codes, standards, or recommended practices and may refer to one, two or all three.

1-2 Primer Scope. This primer discusses the characteristics of the occupants and the building, and assumptions, which must be specified by NFPA Technical Committees. These characteristics and assumptions are those directly related to the purpose and scope of the committee's document, which must be considered by designers and Authorities Having Jurisdiction. This primer is one of six primers that serve as resources for NFPA Technical Committees for the development of performance based provisions.

1-3 Origin. This primer is the direct result of the efforts of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models and the report they produced [1]. This primer is based in part on that report and provides an expansion of the concepts contained therein. It is anticipated that the primer will undergo future changes as they are developed.

1-4 *Process. As shown in Figure 1-4, there are two distinct, although not exclusive, approaches to developing performance-based provisions. The top-down approach is described in [1] and the bottom-up approach is taken from [2].

1-4.1 A total of six primers are either planned or completed:

Primer #	Title	Status
1	Goals, Objectives & Criteria	Available
2	Characteristics & Assumptions	Available
3	Fire Scenarios	Available
4	Performance-Based Verification Methods	Available
5	Reliability	In Process
6	Overview of Performance Approach	In Process

Additional Primers may be developed as needed to address topics, e.g., computer fire modeling, risk management, etc.

1-5 Clarification. Due to the wide variety of topics covered by NFPA documents, it is difficult to address each topic specifically in this primer. These topics include buildings, systems within buildings, building features, vehicles (including boats and ships), outdoor property, people, and products. Therefore, in this primer “building” will be used to generally indicate the topic of a given NFPA document.

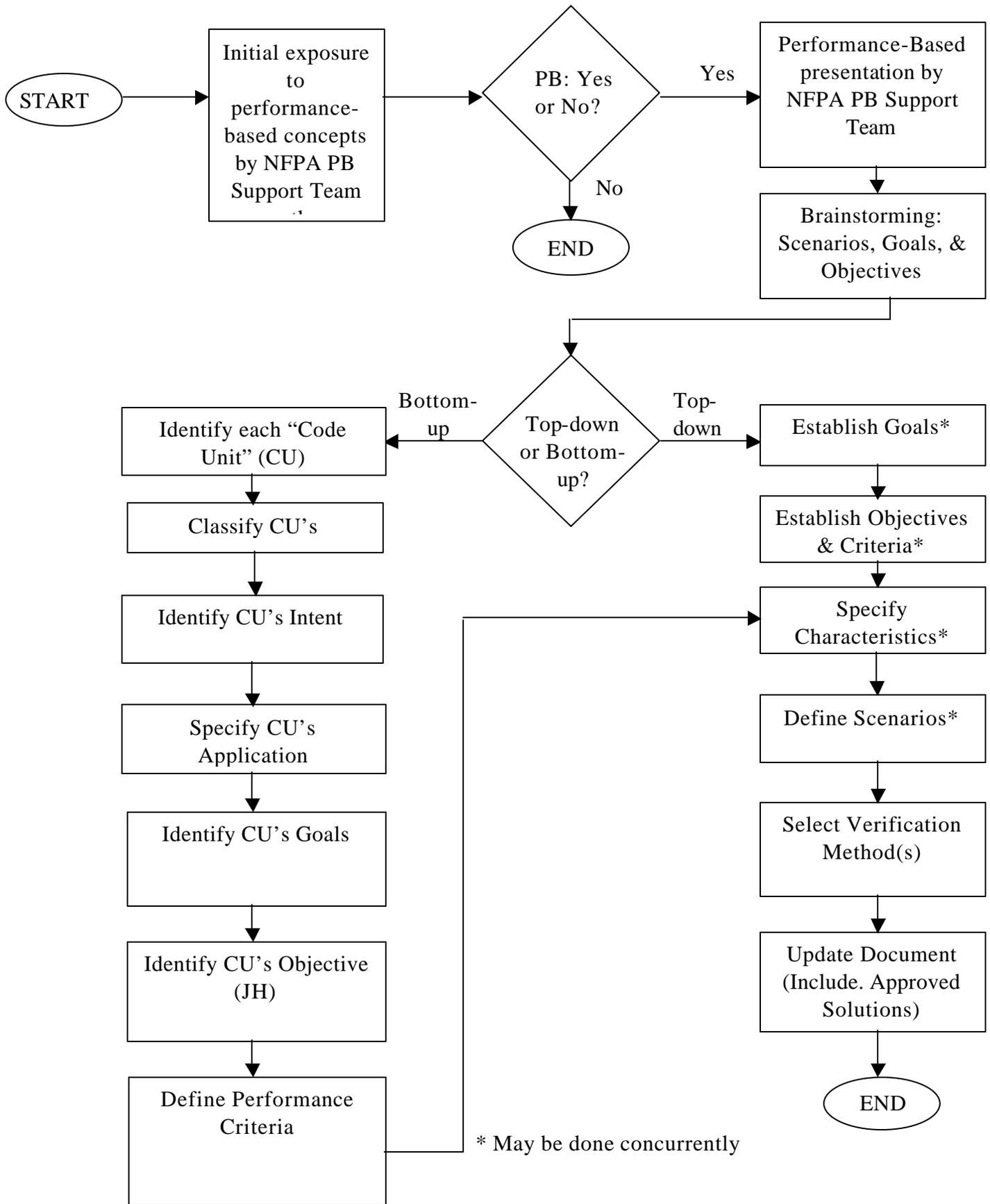


Figure 1-4. Performance-Based Document Development

Chapter 2 Glossary

2-1 General. The following terms are presented to help provide a consistent vocabulary. Definitions of the following terms are taken from [1], unless otherwise noted.

Acceptable. That which has adequately satisfied specified performance criteria. The AHJ holds the final decision on whether or not a design or portion of a design is acceptable.

Approved Method. Authoritative procedure used to develop proposed solutions. A more commonly used example of approved methods are contained within prescriptive documents.

Assumptions. Specifications related to the building, ambient conditions, and surroundings, which do not vary across individual fire scenarios. Examples include ambient pressure and temperature in the building, or fire department response.

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

NOTE: The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner because 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.

***Bottom-Up.** One approach used to develop performance-based provisions. Using this approach, the goals, objectives, characteristics, and scenarios of a document that are unstated prior to document revision processing are identified and explicitly stated.² See "Top-down".

Calculation Method. A description of a system or phenomenon in terms of relationships among elements, permitting study of how some elements vary when other elements are changed. A calculation method normally consists of one or more mathematical relationships, permitting calculation of some elements based on their relationship(s) to other elements. Note that fire science and engineering use "model" as a synonym to calculation method but also for other concepts and elements such as scale models. More specific terms including the word "model", used as a synonym for "calculation method", are differentiated below, and the more specific term will be used in this document where applicable.

Computer Model. A model that is packaged as computer software.

Fire Effects Model. A model that incorporates engineering and scientific principles and applies them in a logical manner to determine possible consequences and extent of physical effects based on an externally specified fire, expressed as heat release rate as a function of time. (Typically referred to as a "fire model", even though it may not model combustion .)

Evacuation/Egress Model. A model used to describe the behavior and movement of people during a fire situation. May be used in combination with a fire effects and typically incorporating them to determine whether or not occupants may safely escape.

Computer Fire Model. A fire model that is packaged as computer software.

Characteristics. Qualities of the occupants, building contents, potential fuel packages, process equipment, and facility features and systems. The focus is usually on those characteristics that should be considered when developing a performance-based fire protection design or performance-based provisions for NFPA documents.

Code (Document) Unit. The smallest portion of a code (i.e., a document) that can have an intent and application statement attached to it.² Each code unit is a definable concept having a type, an intent, application (e.g., "application and limitations of the application of the provision such as occupancy, building height, sprinklered/nonsprinklered building, etc.") and one or more objectives.

***Design Specification.** The aspects of the building design which will impact the fire safety analysis, such as floor area and layout, sprinkler density, building height, ventilation system flow rate, etc. expressed in engineering units.

Design Team. Group of stakeholders including, but not limited to, representatives of the architect, client, and any and all pertinent engineers and other designers. A stakeholder is an individual, or representative of same, having an interest in the successful completion of a project.

Fire Safety Goal. Overall outcome to be achieved with regard to fire. Goals are non-specific and are measured on a qualitative basis. They should be stated in terms of conditions that are intrinsically desirable and do not rely on any assumptions. Goals should be stated in terms that are potentially measurable, even if the precise measurement scale is not specified. Thus, goals may be expressed in terms of impact on people, property, or the environment, or in terms of mission continuity. A single goal may be applicable to many different NFPA documents.

Fire Scenario. Quantitative description of a fire and any factors affecting or affected by it from ignition to extinguishment; including ignition sources, nature and configuration of the

fuel, ventilation, characteristics and locations of occupants, condition of the supporting structure, and conditions and status of operating equipment. Usually used more narrowly to describe initiating conditions for use with a model, test procedure, or other method used for deriving conditions at later stages. The term "design fire" is used even more narrowly to refer to initiating conditions of the fire, those thus excluding most characteristics of the larger building environment the fire may grow into, occupants, and building systems and features.

Functional (or Performance) Requirement. A statement indicating how the building (system, etc.) must perform in order to achieve the stated objectives and goals; typically, a further refinement of an objective, if needed. For example, to achieve the life safety goal with a smoke control objective, a functional requirement could be “The level of smoke shall remain above the heads of evacuees using either a natural or forced ventilation smoke management system.”

Owner. The party who holds financial responsibility for the project and to whom professional services are rendered.

Performance-Based Design Approach. A design process whose fire protection solutions are designed to achieve a specified goal for a specified use or application. This process allows performance-based documents to be implemented and insures that their goals are met.

NOTE: The following describes a performance-based design approach:

- a) Establish fire safety goals.
- b) Evaluate the condition of the occupants, building contents, process equipment, or facility in question with regard to fire protection.
- c) Establish performance objectives and performance criteria.
- d) Identify potential hazards to be protected against.
- e) Define appropriate scenarios.
- f) Select suitable verification methods (e.g., fire models).
- g) Develop trial solutions.
- h) Assess proposed solution.
- i) Document proposed solution along with supplementary information.
- j) Obtain approval of the proposed solution.

Steps a) through f) are also part of the development of a performance-based code or standard. Only steps g) through j) are specific to performance-based design, where the intent is to find a solution for the project. Also, steps c), d), and e) are not necessarily intended to be sequential; they may in fact be concurrent. While the above is presented in a sequential order, the design approach does not necessarily need to begin with step a) and proceed consecutively through step j). Since different stakeholders (e.g., owner, designer, authorities) must be satisfied, some steps of this approach are iterative.

Similarly, for performance-based document development, steps a) through e) may or may not be taken sequentially.

Performance-Based Document. A code, standard, or similar document that specifically states its fire safety goals and references approved methods that can be used to demonstrate compliance with its requirements. The document may be phrased as a method for quantifying equivalencies to an existing prescriptive-based document and/or it may identify one or more prescriptive documents as approved solutions. Furthermore, the document allows the use of all solutions that demonstrate compliance using approved methods.

NOTE: A performance-based document may also include separate prescriptive provisions as a parallel, independent approach to meet the performance-based goals and objectives.

Performance Criteria. Performance objectives for individual products, systems, assemblies, or areas that are further quantified and stated in engineering terms (e.g., temperature, radiant heat flux, level of exposure to combustion products). Performance criteria provide pass/fail threshold values which are treated as data for calculations used to qualify a proposed performance-based solution.

Performance Objective. Requirement for the fire, building, or occupants (or combination thereof) that must be satisfied in order to achieve a fire safety goal. Objectives are stated in more specific terms than goals and tend to be more quantitative than qualitative. Objectives may be thought of as specific goals for individual NFPA documents

Prescriptive-Based Document. A code or standard that prescribes fire protection for a generic use or application. Fire protection is achieved by specifying certain construction characteristics, limiting dimensions, or protection systems without providing a mechanism for how these requirements achieve a desired fire safety goal. Typically these documents do not state their fire safety goals.

NOTE: Many current NFPA codes and standards are not strictly performance-based or prescriptive-based: technically, they can be referred to as prescriptive documents containing some performance provisions. For example, a requirement for a one-hour door sets a measurable performance criterion, going beyond prescription of the door's construction, but does not link the criterion explicitly to a fire safety goal.

Project Team. The design team and the Authority Having Jurisdiction. The AHJ may have no formal or legal responsibility for the design but should be involved at every stage of the project. This ensures the greatest chance for a successful project.

Proposed Solution. A fire protection system design intended to achieve the stated fire safety goals and which is expressed in terms that make it possible to assess whether the fire safety goals and objectives have been achieved. If models are used, then the proposed solution should also specify the models and input data employed.

Safety Factor. Adjustment made to reflect conservatism due to uncertainty in the methods and assumptions employed in measuring performance. A safety factor is not part of the process of setting acceptable levels of safety as risk but only reflects the precision of the calculation.

Scenario Data. Specific data, related to each design fire scenario and expressed in engineering terms or conditions, which can be used as input for the design tool by the designer. The development of design fire scenarios, and the related data, is discussed in *Primer 3 – Fire Scenarios*.

Top-Down. One approach used to develop performance-based provisions. Using this approach, the goals and objectives are developed during document revision processing without consideration of any current prescriptive requirements: a “clean sheet of paper” approach. See "Bottom-up".

Verification. Confirmation that a proposed solution (i.e., candidate design) meets the established fire safety goals. Verification involves several steps. Verification confirms that the building is built as proposed to a design that will achieve the intended level of safety and that the building's ability to achieve the level of safety has been demonstrated by qualified people using the correct methods applied to the correct data.

Verification Method. A model or tool or other method used to demonstrate that a proposed solution provides the level of protection specified in the criteria. The AHJ, the designer, or both are permitted to use any type and number of source material provided they produce needed output data based upon available input data. Also called "design tool".

Part II - Background

This section (Part II) discusses the use of characteristics and assumptions in engineered design. These characteristics and assumptions relate to the building, the occupants of that building, the surrounding area, and any outside forces that might act upon the building during an emergency situation. NFPA Technical Committees need to address characteristics and assumptions in their document so that AHJ's and designers can have a point of reference when approving or deciding upon characteristics or assumptions in designs. How the Technical Committees can present this information in their document is discussed in Part III.

Chapter 3 Characteristics in Performance Based Design

3.1 General. Characteristics are used in conjunction with assumptions, fire scenario data, and design specifications as input for the verification methods in order to evaluate the design against performance goals, objectives, and criteria. The characteristics are generally separated into building and occupant characteristics for the purpose of clearly expressing the design input.

3-1.1 Definitions. When referring to characteristics throughout this document the following definitions will be used:

3-1.1.1 Dictionary Definition. *The American Heritage College Dictionary* defines "characteristic" as "a feature which helps distinguish a person or thing."³

3-1.1.2 NFPA Context. In this context "characteristics" are those attributes of the building or the occupants that need to be quantified and specified to permit evaluation of a design against specified goals, objectives, and criteria, using appropriate design fire scenarios and verification methods (Discussed in detail in *Primer 3 –Fire Scenarios* and *Primer 4 – Verification Methods*). Basic examples of characteristics to be used in Performance Based Design include the physical and mental capabilities of the occupants or the flammability of the interior finishing materials.

3-1.2 Characteristics Role. Figure 3-1.2 depicts the role of characteristics as part of the evaluation of a proposed building design against specified stakeholder fire safety goals, objectives, and criteria. They are separated into building and occupant characteristics, with both of these blocks of data used as input for the verification method used in the design. The building and the occupant characteristics are developed from a combination of specific code/standard requirements and attributes of the proposed building design.

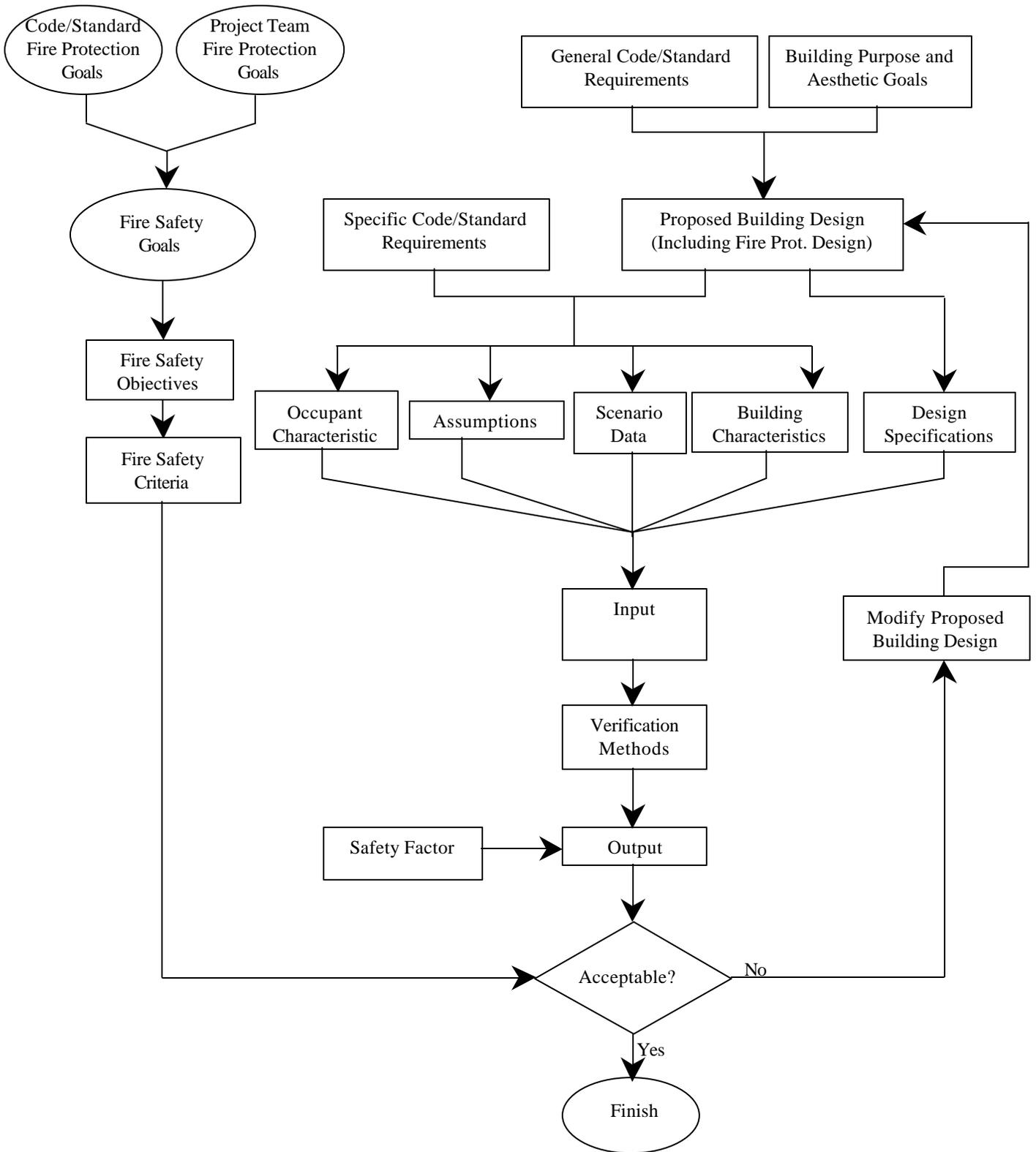
3-1.3 *Code/Standard Versus Designer Specified Characteristics. The Technical Committee must separate the characteristics into those specified or constrained by the code or standard, those required by the AHJ, and those specified or chosen by the designer either in

the design proposal or elsewhere in the analysis. Some building and occupant characteristics will be specified or constrained by the code/standard or by the AHJ as expressions of the community's judgements on acceptable risk. Conversely, the intended use of the building and the basic design specifications for building geometry and construction materials will be translatable by the design team into occupant and building characteristics. These characteristics will be part of a proposal to the AHJ, requiring his/her approval, but remaining the choice of the designer. It is very important that the Technical Committee realize that any values or attributes not specified or constrained by the code/standard are left to the interpretation of the design team, and consequently subject to the possibility of abuse. To prevent this potential abuse, the Technical Committee could seek appropriate values and references for occupant and building characteristics, which can then be implemented into or referenced by the code or standard.

3-1.4 *Characteristics Development. For those characteristics not specified by the code/standard or the AHJ, the design team will naturally be guided by the anticipated use of the building under consideration when selecting occupant and building characteristics. Additionally, the design team will have to select values for characteristics which are neither covered by the code or standard nor derived from the design, in which case they should be realistic and conservative in their selection, reflecting the best available data.

The design team may be inclined to use "typical" values for the characteristics they are developing; however, the code or standard should be written to ensure the building is designed for the entire range of occupant loading and building stresses that can reasonably be expected to occur during the life of the building, and not simply the ideal case. To ensure proper conservatism, the Technical Committee may wish to specify minimum possible values for these characteristics, or they may reference publications, for use by the designer and the AHJ, which provide acceptable, conservative values for the occupant or building characteristics. Additionally, the Technical Committee will typically have to set requirements for the documentation and substantiation of this group of characteristics, as opposed to specifying exact values.

3-1.5 Characteristics Documentation. The language of the code or standard being developed by the Technical Committee should provide requirements and guidance regarding which characteristics are to be documented in this section and which will be specified with the building design specifications. Additionally, the Technical Committee will also have to outline which of these characteristics are to be reflected in the analysis of design performance.



*Figure 3-1.2. Role of Characteristics in Design

3-2 Occupant Characteristics.

3-2.1 Definition. The occupant characteristics can be defined as any and all factors required to predict the behavior of the people in the building before and during a specific fire scenario, as well as the affects of fire and the products of combustion on these people. The occupant characteristics used in the performance design should be based upon the anticipated distribution of people whom the design team feels will occupy the building or space being considered before and during the fire scenario. The occupant characteristics should not be set by the Technical Committee in terms of typical values, but in terms of either a representative range of characteristic combinations, or a particularly challenging combination consisting of the most difficult group of occupants that might occupy the building at one time and that society would expect to be protected.

3-2.2 Purpose. The occupant characteristics will be used as input for the design tools or verification methods when evaluating the building. Each occupant characteristic must be clearly identified and listed for the AHJ, and should be presented in a form which will allow use with the design tools selected to analyze the building. Those characteristics of the occupants identified by the design team but not used as input for the verification methods should also be presented to the AHJ for review.

3-2.3 *Response. The primary occupant characteristics used during the design can be summarized in four basic response characteristics; sensibility, reactivity, mobility, and susceptibility [4]. Each of these response characteristics may be expressed as, or translated into a component of time in the occupants' required safe egress time.

3-2.3.1 Sensibility. Sensibility refers to the building occupants' ability to sense physical cues. Examples include the ability to sense, discern, and discriminate between audible, visual, and olfactory cues emanating from the fire, an alarm system, or some other notification mechanism. This concept affects the occupants' time to detection or awareness of the fire.

3-2.3.2 Reactivity. Reactivity refers to the occupants' ability to correctly interpret the sensed cues and take appropriate action. The reactivity may be a function of the occupants' cognitive capacity, speed of instinctive reaction, or group sociology and dynamics. The Technical Committee may need to consider the occupants' anticipated familiarity with the building and premises, as this may influence how they react to an alarm or emergency. This concept affects the time from occupant detection to commencement of action or evacuation.

3-2.3.3 Mobility. Mobility refers to the building occupants' speed and overall ability to move. In addition to the occupants' individual characteristics such as overall health and stamina, the Technical Committee should also consider potential crowding phenomena,

such as that which occurs at stairs and doorways. An occupant's mobility affects his/her required time for evacuation.

3-2.3.4 Susceptibility. Susceptibility refers to the vulnerability of the building occupants to the products of combustion. This susceptibility can vary depending on the occupants' metabolism, lung capacity, pulmonary disease, allergies, or other physical limitations that may affect the survivability in a fire environment. The sensitivity of the occupants affects the time to incapacitation or injury from fire products of combustion.

3-2.4 Distribution. The entire distribution of occupants at the onset of fire should be included, unless the design is conservatively evaluated as a failure if fire or any products of combustion ever reach a potentially occupied space. This general breakdown may or may not be varied for each fire scenario investigated. Regardless, the reasoning for the specified distribution in each scenario should be documented by the designer.

3-2.4.1 Location. The location of the building occupants at the beginning of the fire scenario is critical to the evaluation of egress paths and distances. A conservative approach that the Technical Committee can require or recommend is that in every normally occupied room there be at least one person located at the most remote point.

3-2.4.2 Number. The number of occupants situated in the various locations should generally be based upon the maximum number of people that each occupied area is expected to or, conservatively, can contain at any time during the building use. It may not be realistic or conservative to assume that occupancy limits on rooms or facilities will be strictly enforced. The Technical Committee should be careful to not automatically select the maximum number of occupants as the worst case. An example of when the maximum number of occupants is not the worst case would be an industrial facility relying upon staff response to deal with an incident or fire scenario.

3-3 Building Characteristics.

3-3.1 *Definition. The building characteristics are those features which are not part of the overall building design, but will have an impact on the building's performance. The building's performance may also have to be evaluated based upon its ability to protect important areas or processes located within, and in these cases the characteristics of these areas should be specified by the design team.

3-3.2 Purpose. The characteristics of the building will be used as input when evaluating the building. Each specification and characteristic, expressed as quantitative parameters, variables, and other values which can be used in engineering calculations and test specifications, should be listed by the design team for review by the AHJ. Those characteristics of the building identified by the design team but not used as input for the verification methods should also be presented to the AHJ for review. The Technical

Committee can require that the AHJ receive the documentation and approve the characteristics designated as part of a pre-approval of the proposed design.

3-3.3 *Building Contents. Building contents and furnishings are not normally specified in, or controlled by, the design specifications. However, they will have an impact on the fire and smoke spread and/or occupant behavior. The Technical Committee can require that the design team present the AHJ with a description of the expected fuel packages located in the area of fire origin in each fire scenario. The Technical Committee can also specify particular fuel sources and configurations based upon the desired scenario data; however, there are some anticipated fire scenarios which will involve fuel sources and packages chosen by the owner and designer based upon the intended use of the building. A sensitivity analysis should be performed to determine the acceptable level of variation in the fuel characteristics and configuration, as outlined in *Primer 6 – Overview of Performance Approach*.

3-3.4 Building Layout. The overall layout of the building needs to be clearly expressed by the design team. This information can often be included with the design assumptions and design specifications. Included with this section should be information not always shown on building plans, such as expected cubicle layout, temporary storage areas, and anticipated office arrangement. A sensitivity analysis should be performed to accurately determine the impact of these characteristics/assumptions, and how much these arrangements can be modified without a re-evaluation of that area. This concept of “management of change” is critical in performance based design, and is discussed in greater detail in *Primer 6 – Overview of Performance Approach*.

3-4 Documentation.

3-4.1 Purpose. It is extremely important that the design team document the characteristics of the building, the occupants, and the fuel packages that are being used in each scenario. The Technical Committee should stress that the documentation will benefit the designer, the AHJ, and any design team which has to work on the building in the future. All components of the design that are not variable across scenarios can be listed as assumptions. All of the relevant characteristics need to be identified, documented, converted into input and submitted to the AHJ in an organized fashion. Even that information that cannot be used as input in the design and converted to output should be identified, allowing the AHJ to clearly outline the characteristics of the fuel for each scenario, the reason for selecting this fuel, the area of origin characteristics and the reasoning behind them, the building design characteristics, and the occupant characteristics. In addition, the source of all of this information should be included, allowing for quick and easy reviewing of the values and variables used. Some of the information and characteristics may be repetitive, and the design team should make an effort to present the data in as clear a manner as possible to the AHJ.

3-4.2 Review. The AHJ shall review the characteristics for each component of the input outlined above, and he/she will have final approval on whether or not those characteristics are appropriate in the final design.

Chapter 4 Assumptions

4-1 Role of Assumptions. Assumptions are specifications that do not vary across scenarios and are not permitted to vary in the building design. If the assumption must be varied for a particular scenario, then it is no longer defined as an assumption, instead becoming part of that specific scenario. Examples of assumptions include the arrival time of the fire department or the availability of staff assistance in a hospital or similar building. Figure 3-1.2 depicts the role of assumptions in the building design process.

4-2 Assumption Consistency. The assumptions made by the design team during the design analysis must be the same throughout the analysis, and can include any input values which do not vary from one fire case to another. The Technical Committee can require particular assumptions be made during the analysis. Any assumptions made by the design team must be sensible and mutually consistent across the various fire scenarios, and must remain true throughout the analysis. An example of this is that the analysis can not assume that a door remains closed throughout the analysis, while also allowing this door to be used as a means of egress for the people in the building.

4-3 Assumption Regarding Prescriptive Requirements. Assumptions regarding prescriptive requirements from the code or standard being modified by the Technical Committee, or a related code and standard which will impact the building performance, must be clearly stated along with a reference to the section of the code or standard from which the information was taken and how it relates. It may be appropriate to retain a prescriptive requirement if the evaluation analysis cannot be structured to adequately assess the feature (e.g., a sprinkler system needs control valves). However, Technical Committees should resist the temptation to retain a requirement solely because they cannot imagine how a design could be safe without that piece.

4-4 Assumption Documentation. Any assumptions made by the design team before or during the analysis should be documented and presented to the AHJ under a separate heading. This will allow the AHJ to easily determine if any of the assumptions were violated during any of the design and verification procedures.

4-5 Design Assumptions. Each of the following design assumptions should be addressed by the Technical Committee, if applicable. This section does not list every possible design assumption, and the Technical Committee should address requirements for any additional design assumptions that they feel are applicable to their document.

4-5.1 *Emergency Response. Any attributes or other conditions related to the availability and response of emergency personnel shall be included in the Assumptions section of the submittal to the AHJ.

4-5.2 *Staff Assistance. Any assumption made by the design team regarding staff assistance should be included in the submittal to the AHJ. In facilities that warrant such consideration, the

Technical Committee may require that staff assistance be provided in sufficient numbers at all times to aid the building occupants in exiting the building in the event of an emergency.

4-5.3 Off-site Conditions. If the Technical Committee anticipates the need, they can require that off-site conditions that will directly or indirectly affect the ability of the building to meet the goals and objectives for any reason be specified or characterized sufficiently to evaluate the design. These assumptions would then have to be included in the submittal to the AHJ. An example would include the location and condition of the water main that the designer intends to use as the water supply for a sprinkler system.

4-5.4 Model Applicability. The designer must make assumptions regarding the applicability of the design tools and models that he/she will be using. These assumptions must be outlined for the AHJ, along with the reasoning used to select that particular verification method.

4-5.4.1 Model Input. *Primer 4 - Verification Methods* describes the process of selecting the proper design tool for the analysis. Each of these design tools requires various input parameters in order to calculate the desired output to compare to the performance criteria. The input parameters not specified with the building or occupant characteristics, or design specifications should be included with the assumptions. These assumptions must remain the same throughout the analysis. Examples include ambient temperature, pressure, time to occupant response following an alarm (assumption based upon occupant response characteristics supported by reference material or test data, and approved by AHJ), etc. The Technical Committee may specify those values and parameters imperative to that committee's goals, or they can rely upon the designer to make every relevant assumption with final approval from the AHJ. In addition, any assumptions not used in the design tool or model and not converted to output must also be specified for the AHJ.

4-5.5 Ventilation. The state of the ventilation in the building must be assumed and documented before the fire scenarios are investigated by the designer. Like all of the assumptions, the ventilation conditions shall be the same for each fire scenario, unless the ventilation equipment is actively a part of one or more of the scenarios.

4-5.6 Doors. The state of the doors within the facility is important, particularly with regard to fire and smoke spread. The state of each door which would, if deployed, serve as a barrier to fire products of combustion or have an effect on ventilation, should be documented by the designer and presented to the AHJ. Once again, these assumptions must be consistent throughout the design.

4-6 *Building Features and System Performance . The Technical Committee should specify how the building features and systems are to be designed and installed by referring to applicable NFPA codes, standards, and other appropriate documents for those components. The Technical Committee should also specify a level of performance (i.e., performance criteria, see *Primer 1 – Goals, Objectives, and Criteria*) expected from the system following installation.

Part III - Technical Committee Use

This section (Part III) is included to give general Technical Committee guidance and sources of references for their documents, including a performance-based option.

Chapter 5 Technical Committee

5-1 General. Each Technical Committee charged with or interested in producing a performance based document is going to have to decide how stringent to be with the specification of building and occupant characteristics and assumptions. Various Technical Committees may have different views of how much should be left to the designer, and each will have to find a point where they feel comfortable. Each Technical Committee has to carefully choose whether or not to retain any prescriptive requirements, with the understanding that that which isn't retained is subject to different uses, interpretations, and potential abuses. If the Technical Committee feels strongly that a particular value is pivotal and critical, it may be beneficial to retain it as a prescriptive requirement.

5-2 Project Team. For those values not retained as prescriptive requirements, the selection of characteristics and assumptions will primarily be the decision of the project design team. The Technical Committee might be best advised to list those values that are expected to be important in the building design, allowing the designer to select the actual values and to experience the flexibility sought in a performance based design.

5-3 Performance-Based Design Guide. The SFPE is currently (expected release date early 2000) developing a performance-based design guide intended to outline the performance based design process for the designer. The guide will be a resource for the designer to use when designing according to performance provisions. The guide will expand on what is required in the steps of a performance-based design.

Appendix A

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

A-1-1 The International Code Council (ICC) is developing a single, prescriptive building code for the United States, the International Building Code (IBC). In addition, they are also developing a performance-based IBC. Since users of NFPA performance-based documents may also encounter the performance-based IBC, section A-1 of this appendix is included to provide a comparison between the two organization's performance-based provisions. While many of the concepts are similar, nomenclature may not be.

A-1-4 Process. The structure of the performance-based IBC is shown in Figure A-1-4. As of the date of this primer, only the intent, scope, objectives, functional statements, and performance requirements will be in the performance-based IBC. The IBC Performance Committee (ICC PC) essentially used a top-down approach with the New Zealand Building Regulations 1992 as a model. The status of criteria, guidelines, and acceptable solutions is uncertain. However, it is recognized that the prescriptive IBC will provide acceptable solutions until performance-based solutions can be developed.

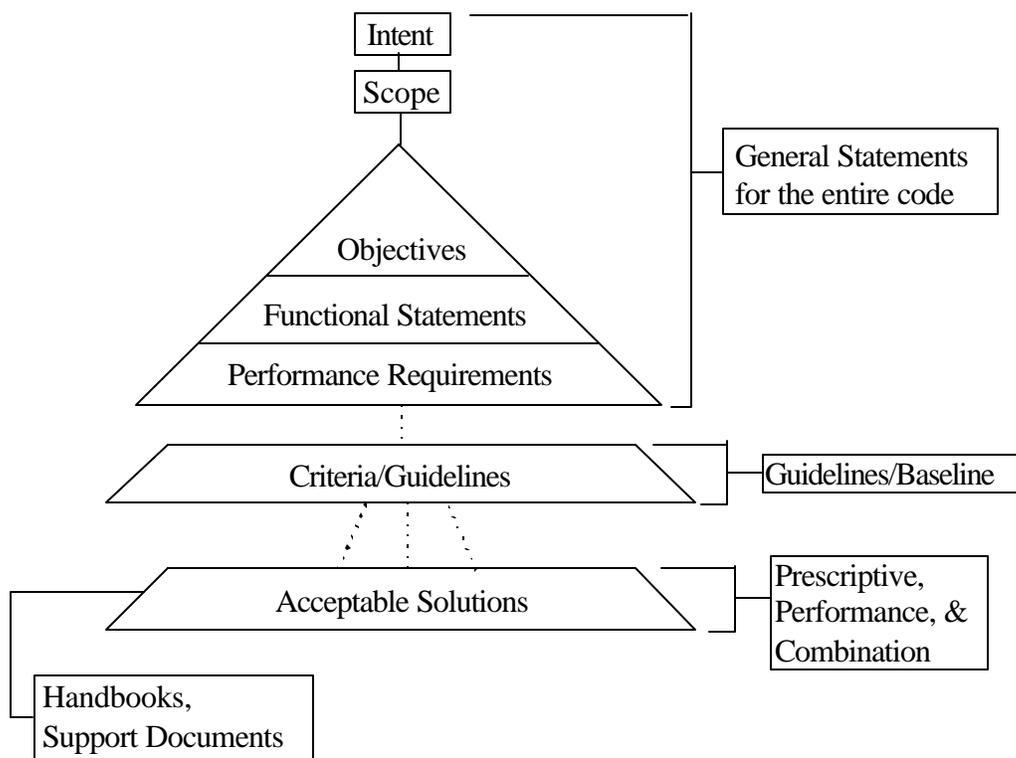


Figure A-1-4. Performance-Based IBC Structure

A-2.1 Bottom-Up. It is called "bottom-up" because it works "up" from the established prescriptive language to infer the goals, objectives, and other statements that justify the prescriptive language.

A-2.1 Design Specification. The design team should include any design specifications which can be used as input for the design tools, or will impact the assumptions made by the design team. The design specifications listed by the design team should be separated into categories of those that can be readily changed by the fire protection design team, and those that cannot be easily changed by the fire protection design team and would instead require major changes to the overall structural and architectural building design. Included in the first category would be items such as, but not limited to, the ventilation flow rate, sprinkler density, interior finish material (and consequently its flammability), whereas the second category would include items such as, but not limited to, building height, building footprint, floor height, etc.

A-Figure 3-1.2. Role of Characteristics in Design

Number	Title	Description
1	Code/Standard Fire Protection Goals	Code/Standard required fire protection outcome presented in a non-specific, qualitative basis.
2	Project Team Fire Protection Goals	Basic fire protection desires of stakeholders not specifically stated in, or required by, the code or standard.
3	Fire Safety Goals	Overall outcome to be achieved with regard to fire, measured on a qualitative basis. Discussed in greater detail in <i>Primer 1</i> .
4	Fire Safety Objectives	Requirement for the fire, building, or occupants that must be satisfied in order to achieve a fire safety goal, stated in a more quantitative manner than fire safety goals. Also discussed in <i>Primer 1</i> .
5	Fire Safety Criteria	Performance objectives, further quantified and stated in engineering terms, relating to individual products, systems, assemblies or areas. Provides pass/fail threshold values to be compared to design evaluation output. Also discussed in <i>Primer 1</i> .
6	General Code/Standard Requirements	Provisions from the code or standard relating to the building design and construction, particularly retained prescriptive requirements.
7	Building Purpose and Aesthetic Goals	Building owner's and stakeholders' overall intentions for the building, ranging from building's intended purpose to desired architectural plan.
8	Specific Code/Standard Requirements	Provisions from the code or standard directly pertaining to the occupant characteristics, assumptions, scenario data, or building characteristics. These specific requirements combine with characteristics, assumptions and scenario data specified by the design team based upon the proposed building design. These requirements for the characteristics, assumptions, and scenario data cannot be modified by the design team at any time during the evaluation.
9	Proposed Building Design (Including Fire Protection Design)	Building design to be evaluated by the fire protection engineer against the previously determined fire safety criteria. Initial proposal should include preliminary architectural and structural design, as well as proposed fire protection system design.
10	Occupant	Ability, behavior, and vulnerability of the anticipated distribution of people

	Characteristics	before and during a specific fire scenario. Important elements include response characteristics such as sensibility and mobility, occupant location, or number of occupants. Characteristics such as number and location of occupants may be dependent on the proposed building design and the fire scenario being investigated, whereas the response characteristics and any code/standard restrained characteristics must remain the same throughout the design. Discussed in greater detail in <i>Primer 2</i> .
11	Assumptions	Specifications made by the fire protection engineer regarding the building and surrounding area, which are not part of the building design, do not vary across fire scenarios, and will be used as input to evaluate the building. Examples include emergency response or staff assistance. Discussed in greater detail in <i>Primer 2</i> .
12	Scenario Data	Quantitative description of fire, and any factors affecting or affected by it, in the time from ignition to extinguishment, including ignition sources, ventilation, and configuration of fuel. Factors that do not vary across scenarios may be treated as assumptions. Any specific code/standard requirements for scenario data must be maintained throughout the analysis, regardless of the proposed building design. For example, building systems/features status (doors opened or closed) may be treated as a scenario factor or an assumption. Discussed in greater detail in <i>Primer 3</i> .
13	Building Characteristics	Features of the building which are not specifically included in overall design, but will have an impact on overall performance, including building contents and anticipated layout. Any specific code/standard requirement for the building characteristics may not be changed at any time in the evaluation. Discussed in greater detail in <i>Primer 2</i> .
14	Design Specifications	Those aspects of the building design that will have an impact on the fire safety analysis, expressed in engineering terms. Examples include floor area and barrier layout, building height, or sprinkler density.
15	Input	List of all relevant design information, expressed in engineering terms, to be used in the verification method(s) to evaluate the design. Discussed in greater detail in <i>Primer 4</i> .
16	Verification Methods	Model, tool, or similar method used to evaluate the proposed design against the level of performance specified by the fire safety criteria. Discussed in greater detail in <i>Primer 4</i> .
17	Output	Specific results obtained from verification methods and design tools. Expressed in engineering terms, which can be compared directly to fire safety criteria. Discussed in greater detail in <i>Primer 4</i> .
18	Safety Factors	Adjustment factors applied to compensate for uncertainty in the assumptions, methods, and calculations employed in evaluating engineering designs. Discussed in greater detail in <i>Primer 6</i> .
19	Acceptable?	Represents comparison of output (obtained from the design evaluation) to fire safety criteria (developed by design team from code/standard and stakeholder goals) to determine if building satisfies performance requirements.
20	Modify Proposed Building Design	If design output fails to meet all of the fire safety criteria, modifications must be made to the preliminary design. These modifications in the proposed design could lead to changes in the design assumptions, scenario data, building characteristics, and/or design specifications, producing variations in the design input. Only those aspects of the design not specified by the code/standard may be modified, and the Technical Committee should specify which, if any, of the input values cannot be changed by the designer in order to satisfy the performance requirements.
21	Finish	If the design evaluation satisfies all of the fire safety criteria, then the proposed design becomes a successful trial design. After evaluating each proposed

		design and determining those that pass all of the fire safety criteria, the design team must select the most desirable for implementation as the final design. This final design, along with all relevant design information and data sources, must be documented in full for submittal to the AHJ for approval. This documentation procedure is discussed in greater detail in <i>Primer 6</i> .
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A-3.1.3 Code/Standard Versus Designer Specified Characteristics. The Technical Committee is going to have to decide which, if any, characteristics are going to be specified or constrained by the code or standard, or the AHJ, as expressions of the community’s judgement of acceptable risk. Examples of this include a code or standard specifying a minimum number of occupants with disabilities be incorporated into the design, or an AHJ specifying that an evaluation be based on a specified degree of overcrowding, which reflects a community conservatism in requiring a robust design that is not rendered unsafe by foreseeable lapses in enforcement of operating requirements.

A-3.1.4 Characteristics Development. Examples of characteristics that are neither dictated by the code or standard nor derived from the design include, but are not limited to, speeds of reaction and travel for occupants, and type and arrangement of fuel packages in a typical office to be considered in the design as an area of origin. The Technical Committee must ensure that the design team uses safe, conservative values for their selection of characteristic values. Failure to use or consider conservative values for characteristics is the same as making a value judgement that the loss of vulnerable people or the loss of everyone when the building is not in ideal condition are acceptable losses for the community.

A-3-2.3 Response. The design team should focus on the four main response characteristics when developing the occupant characteristics. These occupant performance characteristics can be further separated into those presented in the table below.

Alertness	Are occupants awake or asleep? Dependent on time of day.
Location	Where are the occupants in relation to alarm cues and escape routes?
Responsiveness	What are occupants’ abilities to sense and react to cues?
Commitment	To what degree are the occupants committed to the activity that they are performing at the time of alarm?
Focal Point	What are the occupants focusing on at the time of the alarm (Front of classroom or stage, movie screen)?
Physical and Mental Capabilities	What are the abilities of the occupants to sense, respond, and react to cues? Are the occupants impaired or disabled?
Role	What role will the occupant play in the building

	evacuation? Leader or follower, staff or person in need of help?
Familiarity	How familiar are the occupants with the building? How much time have they spent in the building and have they performed any emergency training?
Social Affiliation	To what extent will the occupants act/react as individuals? What affect will social psychology have? Will group dynamics play a role?
Number of Occupants	How many occupants are located in the building, and how are they distributed? What affect will time of day and month of the year have on this number?
Condition	What will the physiological and psychological effects of the fire be on the occupants throughout the course of the fire.

A-3-3.1 Definition. The building characteristics include not just the building, but also that which is located inside the building. In addition to the human occupants, the Technical Committee may have to consider a particular area or process within the building that must be protected and given special consideration. As an example, a semiconductor manufacturing facility’s primary interest is to protect the manufacturing process and clean rooms, preventing any products of combustion from entering rooms and spaces outside of the area of origin. In most cases, these processes are either far more susceptible to damage from minor quantities of smoke and products of combustion than any human occupants, represent a significant hazard to the occupants, or are critical to mission continuity (i.e., facility operation). If the goals, objectives, and criteria target specialized areas or processes, then the design team must specify the characteristics of these areas or processes, which can then be used as input for the evaluation. Included in these characteristics should be the anticipated location and distribution, as well as the overall susceptibility, of these specialized areas and processes. The susceptibility terms could include, but are not limited to, smoke concentration (parts per million), incident heat flux (kW/m^2), or maximum permissible shell temperature of a storage vessel ($^{\circ}\text{C}$).

A-3-3.3 Building Contents. Examples of the building contents and furnishings characteristics that could be reported in a submittal to the AHJ include, but are not limited to, the fuel load, burning properties of materials and products, placement and geometry considerations, and special product conditions such as changes in burning properties due to aging or vandalism. Much of this information could be listed with the assumptions, and the Technical Committee should state where the information should be included in the submittal if required.

A-4.5.1 Emergency Response. Any information regarding the speed of response, effectiveness, anticipated roles, and other important characteristics of the emergency personnel should be specified or estimated.

A-4-5.2 Staff Assistance. The reasoning behind the requirements for staff assistance should be outlined in the standard. If the design team incorporates staff assistance into the analysis, they must state the staff qualifications, how many people will be available, how they are going to be deployed, what they are going to be doing, etc. The design team must present engineering calculations or credible reference data supporting their assumptions regarding staff assistance to the AHJ.

A-4-6 Building Features and System Performance. If the building features and systems are installed according to NFPA standards, then the reliability of these components can generally be assumed to be 100%, with the exception of those scenarios that explicitly state that the analysis should consider an impaired or non-operational system. If the Technical Committee feels a lower overall reliability should be used in the design, then that value, or a method to determine this reliability, should be distinctly stated or specified.

Appendix B - Reference Publications

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

1. *NFPA's Future in Performance-Based Codes and Standards*, National Fire Protection Association, Quincy, MA, July, 1995.
2. *Bottom-Up Analysis of National Codes*, Canadian Codes Centre, September 1996.
3. *The American Heritage College Dictionary*, 3rd ed., Houghton Mifflin Co., Boston, 1993.
4. *NFPA 101, Life Safety Code*, 2000 Edition – draft, Chapter 5, National Fire Protection Association, Quincy, Massachusetts, USA, 1999

Performance-Based
Primer #3
Fire Scenarios

Revision 1.1 11 SEPTEMBER 1998
National Fire Protection Association, 1998

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02269-9101 USA

Preface

This primer (Primer 3) has been developed by the NFPA Performance-Based Support Team (PB Support Team). The PB Support Team functions under the auspices of the NFPA Standards Council, and reports directly to the Council on an on-going basis. The PB Support Team was created in 1995 to assist NFPA Technical Committees with the transition to performance-based documents.

Primer 3 is the third in a series intended to provide NFPA Technical Committees with guidance and information on how to write a performance-based NFPA code, standard, or similar document. This primer is based on the report of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models' report entitled *NFPA's Future in Performance-Based Codes and Standards*. This report, released in July 1995 and developed in conjunction with the NFPA Board of Directors, implies the need for the development of further guiding information for NFPA Technical Committees. Primer 3 is one step to fill this need for further guiding information.

It is anticipated that this primer will undergo future changes as they are developed. Any comments on the primer should be sent to:

NFPA
Attn.: Standards Council Secretary
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Quincy, MA 02269-9101

NFPA Technical Committee PB Primer #3

PERFORMANCE-BASED SCENARIOS

Revision 1.1 11 SEPTEMBER 1998

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NFPA Performance-Based Primer 3

Performance-Based Scenarios

1998 Edition

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

Part I Information

This section (Part I) provides general information to NFPA Technical Committee's regarding the Primers and terms used within the Primers.

Chapter 1 General Information

1-1 *Primer Purpose. The purpose of this primer is to serve as a resource for NFPA Technical Committees during their efforts in developing performance-based provisions and incorporating them into NFPA documents. This primer can be used to develop new stand-alone performance-based documents or to develop performance-based options in existing or future documents. "Document" is used as a collective term for codes, standards, or recommended practices and may refer to one, two or all three.

1-2 Primer Scope. This primer addresses the process of developing performance-based scenarios for inclusion in NFPA documents. It is one of five primers that serve as resources for NFPA Technical Committees for their development of performance-based provisions.

1-3 Origin. This primer is the direct result of the efforts of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models and the report they produced [1]. This primer is based in part on that report and provides an expansion of the concepts contained therein. It is anticipated that the primer will undergo future changes as they are developed.

1-4 *Process. As shown in Figure 1-4, there are two distinct, although not exclusive, approaches to developing performance-based provisions. The top-down approach is described in [1] and the bottom-up approach is taken from [2]. A total of five primers are in various stages of development: from conceptual to completed. The five primers address: goals, objectives and criteria; characteristics/assumptions; scenarios; verification methods; and a process overview.

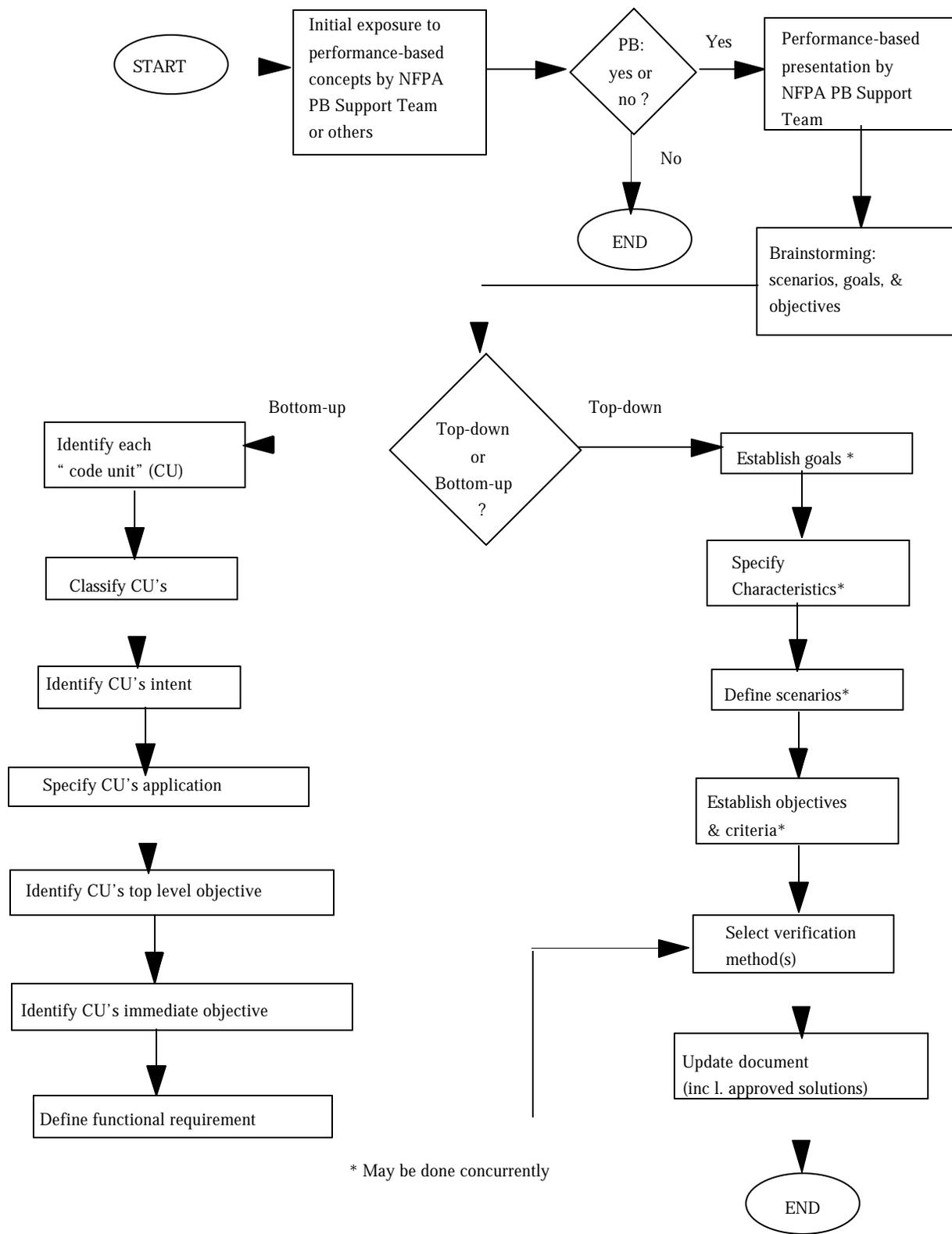


Figure 1-4. Performance-based Document Development

1-5 Clarification. Due to the wide variety of topics covered by NFPA documents, it is difficult to address each topic specifically in this primer. These topics include buildings, systems within buildings, building features, vehicles (including boats and ships), outdoor property, people, and products. Therefore, in this primer “building” will be used to generally indicate the topic of a given NFPA document.

Chapter 2 Glossary

2-1 General. The following terms are presented to help provide a consistent vocabulary. Definitions of the following terms are taken from [1], unless otherwise noted.

Acceptable. That which has adequately satisfied specified performance criteria. The authority having jurisdiction (AHJ) holds the final decision on whether or not a design or portion of a design is acceptable.

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

NOTE: The phrase “authority having jurisdiction” is used in NFPA documents in a broad manner because 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 marshall; 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.

Approved Method. Authoritative procedure used to develop proposed solutions. A more commonly used example of approved methods are contained within prescriptive documents.

Bottom-Up. One approach used to develop performance-based provisions. Using this approach, the goals, objectives, characteristics, and scenarios of a document that are unstated prior to document revision processing are identified and explicitly stated.² See "Top-down".

Calculation Method. A description of a system or phenomenon in terms of relationships among elements, permitting study of how some elements vary when other elements are changed. A calculation method normally consists of one or more mathematical relationships, permitting calculation of some elements based on their relationship(s) to other elements. Note that fire science and engineering use "model" as a synonym to calculation method but also for other concepts and elements such as scale models.

More specific terms including the word "model", used as a synonym for "calculation method", are differentiated below, and the more specific term, will be used in this document where applicable.

Computer Model. A model that is packaged as computer software.

Fire Effects Model. A model that incorporates engineering and scientific principles and applies them in a logical manner to determine possible consequences and extent of physical effects based on an externally specified fire, exposed as heat release rate as a function of time. (Typically referred to as a "fire model", even though it may not model combustion.)

Evacuation/Egress Model. A model with building egress system and physiological, and possibly psychological, principles. Typically used in combination with a fire effects model of human behavior as a function of time, in the presence of a building fire, typically incorporating them to determine whether or not occupants may safely escape.

Computer Fire Model. A fire model that is packaged as computer software.

Characteristics. Qualities of the occupants, building contents, potential fuel packages, process equipment, and facility features and systems. The focus is usually on those characteristics that should be considered when developing a performance-based fire protection design or performance-based provisions for NFPA documents.

Code (Document) Unit. The smallest portion of a code (i.e., a document) that can have an intent and application statement attached to it.² Each code unit is a definable concept having a type, an intent, application (e.g., “application and limitations of the application of the provision such as occupancy, building height, sprinklered/nonsprinklered building, etc.”) and one or more objectives.

Design Team. Group of stakeholders including, but not limited to, representatives of the architect, client, and any and all pertinent engineers and other designers. A stakeholder is an individual, representative of same, having an interest in the successful completion of a project.

Fire Safety Goal. Overall outcome to be achieved with regard to fire. Goals are non-specific and are measured on a qualitative basis. They should be stated in terms of conditions that are intrinsically desirable and do not rely on any assumptions. Goals should be stated in terms that are potentially measurable, even if the precise measurement scale is not specified. Thus, goals may be expressed in terms of impact on people, property, or the environment, or in terms of mission continuity. A single goal may be applicable to many different NFPA documents.

Fire Scenario. Quantitative description of a fire and any factors affecting or affected by it from ignition to extinguishment including ignition sources, nature and configuration of the fuel, ventilation, characteristics and locations of occupants, condition of the supporting structure, and conditions and status of operating equipment. Usually used more narrowly to describe initiating conditions for use with a model, test procedure, or other method used for deriving conditions at later stages. The term "design fire" is used even more narrowly to refer to initiating conditions of the fire, those thus excluding most characteristics of the larger building environment the fire may grow into, occupants, and building systems and features.

Performance-Based Design Approach. A design process whose fire protection solutions are designed to achieve a specified goal for a specified use or application. This process allows performance-based documents to be implemented and insures that their goals are met.

NOTE: The following describes a performance-based design approach:

- a) Establish fire safety goals;
- b) Evaluate the condition of the occupants, building contents, process equipment, or facility in question with regard to fire protection;
- c) Establish performance objectives and performance criteria;
- d) Identify potential hazards to be protected against;
- e) Define appropriate scenarios;
- f) Select suitable verification methods (e.g., fire models);
- g) Develop proposed solution;
- h) Assess proposed solution;
- i) Document proposed solution along with supplementary information; and
- j) Obtain approval of the proposed solution.

Steps a) through f) are also part of the development of a performance-based code or standard. Only steps g) through j) are specific to performance-based design, where the intent is to find a solution for the project. Also, steps c), d), and e) are not necessarily intended to be sequential; they may in fact be concurrent. While the above is presented in a sequential order, the design approach does not necessarily need to begin with step a) and proceed consecutively through step j). Since different stakeholders (e.g., owner, designer, authorities) must be satisfied, some steps of this approach are iterative. Similarly, for performance-based document development, steps a) through e) may or may not be taken sequentially.

Performance-Based Document. A code or standard that specifically states its fire safety goals and references approved methods that can be used to demonstrate compliance with its requirements. The document may be phrased as a method for quantifying equivalencies to an existing prescriptive-based document and/or it may identify one or more prescriptive documents as approved solutions. Furthermore, the document allows the use of all solutions that demonstrate compliance using approved methods.

NOTE: A performance-based document may also include separate prescriptive provisions as a parallel, independent approach to meet the performance-based goals and objectives.

Performance Criteria. Performance objectives for individual products, systems, assemblies, or areas that are further quantified and stated in engineering terms (e.g., temperature, radiant heat flux, level of exposure to combustion products). Performance criteria provide pass/fail threshold values which are treated as data for calculations used to qualify a proposed performance-based solution.

Performance Objective. Requirement for the fire, building, or occupants (or combination thereof) that must be satisfied in order to achieve a fire safety goal. Objectives are stated in more specific terms than goals and tend to be more quantitative than qualitative. Objectives may be thought of as specific goals for individual NFPA documents

Prescriptive-Based Document. A code or standard that prescribes fire protection for a generic use or application. Fire protection is achieved by specifying certain construction characteristics, limiting dimensions, or protection systems without providing a mechanism for how these requirements achieve a desired fire safety goal. Typically these documents do not state their fire safety goals.

NOTE: Many current NFPA codes and standards are not strictly performance-based or prescriptive-based: technically, they can be referred to as prescriptive documents containing some performance provisions. For example, a requirement for a one-hour door sets a measurable performance criterion, going beyond prescription of the door's construction, but does not link the criterion explicitly to a fire safety goal.

Project Team. The design team and the Authority Having Jurisdiction. The AHJ may have no formal or legal responsibility for the design but should be involved at every stage of the project. This ensures the greatest chance of a successful project.

Proposed Solution. A fire protection system design intended to achieve the stated fire safety goals and which is expressed in terms that make it possible to assess whether the fire safety goals and objectives have been achieved. If models are used, then the proposed solution should also specify the models and input data employed.

Safety Factor. Adjustment made to reflect conservatism due to uncertainty in the methods and assumptions employed in measuring performance. A safety factor is not part of the process of setting acceptable levels of safety as risk but only reflects the precision of the calculation.

Top-Down. One approach used to develop performance-based provisions. Using this approach, the goals and objectives are developed during document revision processing without consideration of any current prescriptive requirements: a "clean sheet of paper" approach. See "Bottom-up".

Verification. Confirmation that a proposed solution (i.e., candidate design) meets the established fire safety goals. Verification involves several steps. Verification confirms that the building is built as proposed to a design that will achieve the intended level of safety and that the building's ability to achieve the level of safety has been demonstrated by qualified people using the correct methods applied to the correct data.

Verification Method. A model or tool or other method used to demonstrate that a proposed solution provides the level of protection specified in the criteria. The AHJ, the designer, or both are permitted to use any type and number of source material provided they produce needed output data based upon available input data. Also called "design tool".

Part II Background

This section (Part II) discusses the use of scenarios in engineered design. NFPA Technical Committees will specify the scenarios that must be used to demonstrate that the goals and objectives of a standard or code have been met. How the Technical Committees can select scenarios for this purpose is described in Part III.

Chapter 3 The Use of Scenarios in Performance-Based Design

3-1 General. Fire scenarios define the fire challenges a building is expected to mitigate. Therefore, every imaginable fire must be either (a) addressed by a fire scenario that is explicitly defined, (b) presumed to be manageable because a similar or more severe scenario has been explicitly addressed, or (c) regarded as too unlikely and too severe for the building to be expected to handle. Figure 3-1 illustrates performance-based process.

3-2 Scenarios. A fire scenario is a detailed description of conditions or factors related to any stage of fire development critical to the outcome of the fire such as ignition sources, nature and configuration of the fuel, ventilation characteristics and location of the occupants, condition of the supporting structure, applicable operating equipment (e.g., reliability and/ or effectiveness). This allows the fire protection provisions of a building to be tested for their ability to achieve the fire safety goals, objectives, and criteria.

3-2.1. Using scenarios is a crucial step in performance-based design so it is important to be thorough and realistic when creating and selecting fire scenarios. "Realism" does not mean that only typical fires should be considered, because society expects buildings to achieve fire safety goals for nearly all fires the buildings might encounter during their lifetimes. "Thorough" does not mean that all scenarios must be explicitly addressed but rather that every fire must be either represented by a scenario that is addressed or explicitly excluded from consideration.

3-2.2. In practice, most of the outcomes regarding a scenario are either calculated using some calculation method or measured using a fire test. The scenario is defined by a small number of initial design specifications and assumptions, and the description of later steps, including consequences, is then the result of using computer modeling, other calculation methods, or tests.

3-2.3. Performance analysis based on risk requires calculation of probabilities of scenarios. A very detailed scenario represents only a small probability of occurrence. This suggests that many scenarios would need to be evaluated to achieve completeness. To avoid such unworkable situations, the design team may use the approach of selecting very detailed scenarios to set up modeling or testing, and then use less detailed scenarios (which are, therefore, groups or sets of more detailed scenarios) to calculate probabilities.⁴

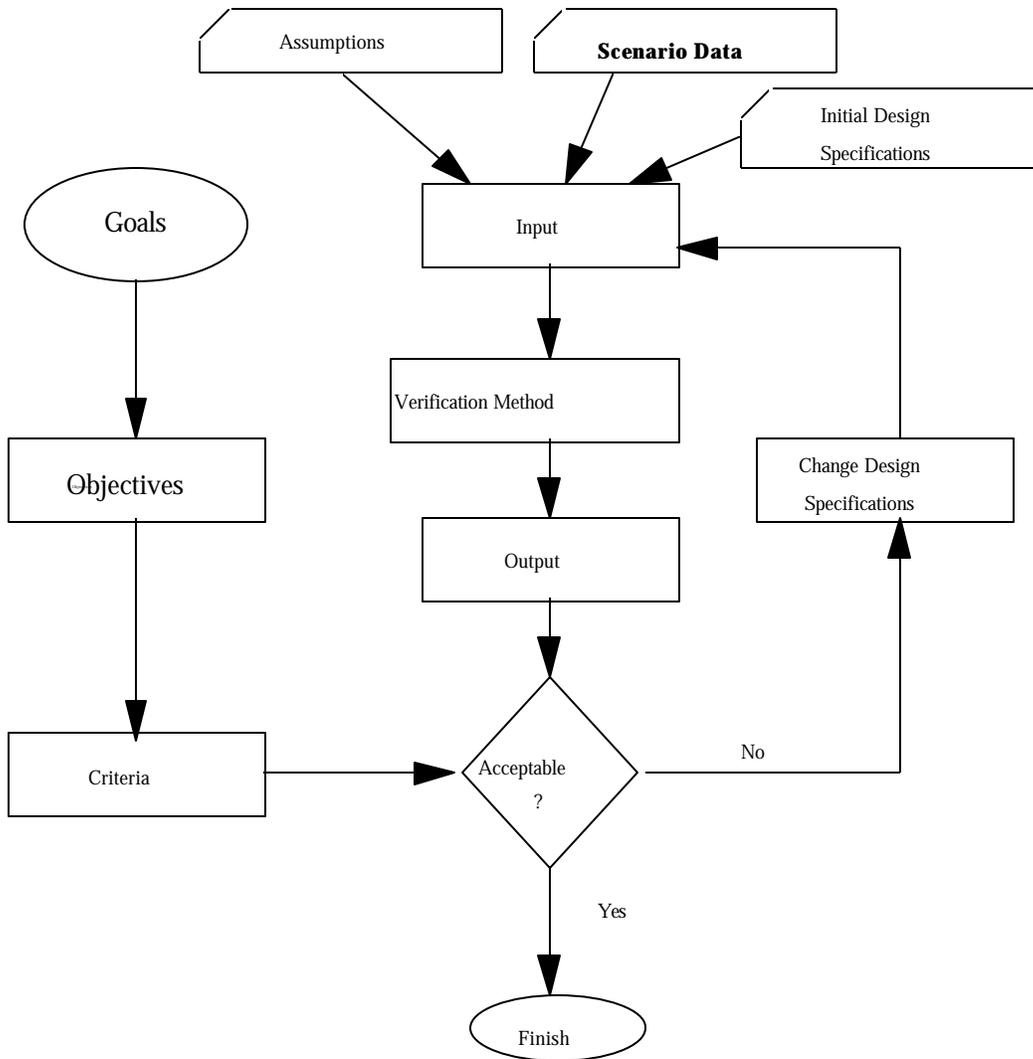


Figure 3-1. Role of Scenarios

3-3 Design Fire. A design fire is a component of the scenarios, consisting of the detailed description of the fire but excluding conditions or factors regarding the building occupants, etc., that may impact fire development and/or severity. It is the physical description of the fire including crucial information such as the fire's size, growth rate, heat release rate and other related fire properties.

The TC will generically describe the desired design fires for the scenarios it specifies (e.g., slow, medium, fast, ultrafast fire) including peak rate and duration, and decay time.

3-3.1*. The design fire parameters in each scenario must be approved by the AHJ to insure they reasonably portray the fire the scenario is describing.

If the design team's design fails a scenario, the parameters of the design fire should not be changed to a less severe fire in order for the design to pass.

3-4 *Consistency. An important step in evaluating scenarios is to check that they are consistent with the other elements of the performance-based analysis. This is to say, the scenarios should not assume conditions that are incompatible with conditions assumed elsewhere in the analysis. For example, the spread of fire effects should not be

calculated based on closed doors if the same doors are assumed to be opened repeatedly or continuously by evacuating occupants. If the scenarios are not consistent, either the scenarios or the other elements should be revised.

Chapter 4 Scenario Application

4-1 Matching Scenario Specifications to Use of Scenario. It is important that the correct type of scenario is used. If the scenarios appropriate to one application are used for a different application, then the analysis may lead to false conclusions.

4-2 Scenario Selection for Design Analysis. Fire scenarios can be used to depict an array of potential fire sources, rooms of origin, or other areas of special concern that may cause or contribute to a fire. In pre-fire situations, the building is most likely new, or at least new fire safety measures are being implemented. At this point, it is assumed that the room being considered has not experienced a fire; developing fire scenarios for that room is intended to provide a reasonable and credible challenge to the fire protection system. Applying scenarios in a pre-fire situation can be seen as a non-destructive test providing results that can be compared to the criteria and also as providing input into the verification methods.

4-2.1 Scenario Selection for Hazard Analysis. In PB design using hazard analysis, the key fire scenarios are limiting states. They represent the most severe fires for which the building design is expected to meet the fire safety goals and objectives.

In this approach a modest number of scenarios can be analyzed to establish the adequacy of the building relative to those scenarios and all less-severe fires.

4-2.2 Scenario Selection for Risk Analysis. In PB design using risk analysis, a large set of scenarios is needed, so that each scenario may be analyzed in terms of building design performance but also in terms of the probability that this or a similar scenario will occur. The set of scenarios most collectively address all possible fires, so the number of scenarios required will typically be larger than with hazard analysis.

4-2.3 Scenario Selection for Exploratory Analysis. The designer may select one or two high-probability, moderately challenging but not high-challenge scenarios to use in exploratory analysis that will indicate how the building design may typically work and how reasonably the modeling approaches and other PB analysis elements seem to work. It is important not to treat this exploratory analysis as sufficient for verification of the proposed solution.

4-3 Reconstructing of Actual Fire. Scenarios are also used after a fire has occurred, to reconstruct a fire. By developing scenarios based on theories of the fire's origin and testing them with verification methods, the theories can be scientifically narrowed down to only the most realistic and probable ones, to eventually determine the cause of the fire. Since in this situation the fire has already occurred, fewer assumptions about the fire will need to be made. Also, there will be no need to include the wide variety of scenarios that are necessary in a pre-fire situation.

Chapter 5 Scenario Selection

5-1 *General. Many situations can occur throughout the life of a building. Some have a higher potential to occur than others. Others, though not typical, could be devastating in the event they happen. A good fire protection design should be able to achieve the fire safety goals and objectives for any typical or common fire scenario and for some of the less typical, potentially devastating fire scenarios, up to some level of acceptability that reflects the values of society. The central challenge in scenario selection is finding a manageable number of fire scenarios that are sufficiently diverse and representative so that, if the design is safe for those scenarios, then it should be safe for all scenarios, except for those specifically excluded as too unrealistically severe and too unlikely to be fair tests of the design.

5-2 Define Situation. Before selecting scenarios the type of scenario being used needs to be defined. It is important to have the characteristics and assumptions of the design in place because this information will help establish accurate scenarios. Also refer to Chapter 4 for information on defining how the scenario will be applied.

5-3 *Level of Acceptable Loss. The level of acceptable loss is expressed primarily in the criteria. The criteria are quantifiable measures of the goals and objectives. (See *Primer 1 - Goals, Objectives and Criteria* for more information on criteria.) In performance-based design, it will be the project team who will determine the level of acceptable loss, subject to maximums set or implied in the performance-based code or standard. For example, the owner may state what they are willing to lose to fire (e.g., lives, property, business interruption). The designer quantifies the owner's expectations with criteria for the design to meet and the AHJ determines whether that provides adequate safety as required by society as defined by the applicable code or standard.

This is where the TC plays a role. Statements of goals, objectives, and criteria placed in their document will define society's requirements for acceptable loss.

The choice of high- challenge scenarios required in the code or standard is another place where the TC sets limits on acceptable loss. When selecting scenarios, the TC should keep in mind that initiating fires more severe than the scenarios the TC requires are, by that fact, deemed to be acceptable losses, based on presumed low probability. Considerable thought should go into drawing the line between fires which are deemed severe enough and likely enough to use in assessing a design and more severe fires deemed too unlikely to use in assessment.

5-4 *Assumptions. When selecting scenarios, many assumptions will be made. The more complex the building, the more assumptions that will most likely be made. Generally, assumptions can be categorized as one of two things. It could be the professional judgment of the designer to fill in pieces of information that are not known. This type of assumption is a variable. Or they could be fixed values set by someone other than the designer that cannot be changed. These fixed conditions could include retained prescriptive requirements, in the code or standard, that the TC feels cannot be compromised. They could be assumptions the AHJ requires in order to approve the design, even in the performance-based environment.

There is no limit to the number of assumptions that can be made when using a performance-based design. However, it is crucial that the assumptions be clearly stated and documented.

Assumptions are not varied from one scenario to the next. If they are varied, then they become part of the scenario definitions. An example is in 1-7.1 of *NFPA 101 - Draft 200*, which states the assumption that there is only a single fire source.⁵ This is an assumption that applies to all scenarios, for all candidate designs.

5-5 *Key Characteristics in Design Fires. Scenarios should address the situations listed in Table 5-5 below, plus other situations of specific concern to the TC's or the AHJ, to form a group of scenarios that are a mix of high and low challenge fire scenarios. The appendix material offers examples of two Technical Committees' scenario provisions. Although they use different approaches, both encompass the characteristics in Table 5-5.

Table 5-5. Scenario Situations

<p style="text-align: center;">Illustrative Characteristics of High Challenge Scenarios</p>

Fire in critical areas, i.e., areas where slight damage will have disproportionate impact on direct or indirect damage.

Examples includes clean rooms, computer rooms, telephone switching stations, AC/DC converters and other rooms with expensive equipment highly vulnerable to even light smoke damage or with very high costs of business interruptions.

Initiating fire close to high occupancy, high fuel load, or critical areas. Examples include storage rooms near large, fully occupied assembly rooms; offices or closets near very large product storage rooms or showrooms; and plenum space fires near computer rooms.

Fire in an egress path, such as a front entrance way or lobby.

Fire shielded from active systems or other fire fighting, e.g., concealed spaces, origin outside building.

Fire involving materials producing unusually toxic, corrosive, explosive or otherwise harmful combustion products. Examples include fires exposing pool chemicals, disposal containers, or fireworks or other pyrotechnics.

Large, high intensity or fast growing fires, e.g., high initial heat release rate, flash fires, accelerant-fed arson fires, large flammable or combustible liquid spill fires.

Impairment of fire protection systems, e.g., sprinklers with closed valves on high-piled stock.

Chapter 6 Scenario Construction

6-1 General. Typically, the TC's will require the use of certain scenarios but will not fully specify those scenarios, leaving the site-specific details to be supplied by the designer with approval by the AHJ.

For example, although the example scenarios provided in A-5-5 can be applied to many buildings they are generic and so lack needed detail for use on any particular building. For codes and standards dealing with a specific type of facility (e.g., nuclear power generating plants, furniture manufacturers using wood dust collection equipment), and even more for design proposed for specific buildings, more detailed and site specific scenarios will be needed.

6-2 Considerations. When developing a scenario(s) there are many things to consider that will shape the scenario(s). Scenarios must be compatible with the criteria, the verification methods, the assumptions, and the proposed design, so TC's and designers should review all the primers before beginning scenario construction. There may be other references and sources not listed that pertain to specific interests of individual Technical Committees.

6-2.1 Respecting Unique Properties of Each Design and Document. In every project, a designer will work on, as well as every document to which a TC might supply a performance option, there will be similar considerations and there will also be unique ones. Despite certain similarities or "core scenarios", it is important that scenarios previously used by other projects or TC's are not simply adopted without careful study of whether or not they fit the special needs of the project or document going through the performance-based process.

6-2.2 Occupant Characteristics. Description of the occupants is needed in the scenario. The project team can determine which occupant characteristics are fixed assumptions and which ones are definable in the scenario. Linked to the occupant characteristics is the time of day specific for the scenario and the design fire. A detailed discussion of occupant characteristics is found in *Primer 2 - Characteristics and Assumptions* .

6-2.3 Environment. The environment in which the fire grows is also important to include in the scenario. Environmental characteristics can alter the challenge the scenario creates for certain portions of the design. See *Primer 2 - Characteristics and Assumptions*.

6-2.4 Design Fire Details. Although the core scenarios in a code or standard will generally outline the design fire for a scenario, there will be many missing details for the designer to provide to tailor the scenario to the building being considered. Some of this information will be design specifications such as room geometry. Others will have to be assumptions based on engineering judgment such as the heat of combustion. It is important to accurately describe the design fire.

6-3 Design Characteristics. This refers to the project team's proposed solution/design, expressed as quantitative parameters, variables, and other values suitable for use in an engineering calculation or test specification. The design team needs to provide all the values required as input. (In Figure 3-1, characteristics are expressed in the three boxes contributing to "input".)

6-4 *Data Use. When developing scenarios it may be useful to review statistical data. Fire experience data that matches the detailed structure of the scenarios can be useful in defining high-challenge scenarios. High-challenge scenarios can be defined as those with high historical severity, such as high rates of death per fire.

Part III Application

This section (Part III) is included to give general guidance and sources of reference to the TC including a performance-based option to their code or standard.

Chapter 7 Performance-Based Provision Development

7-1 General. Part 2 has briefly introduced scenarios as part of the performance-based design process. The Technical Committees have the task of incorporating scenarios into the performance-based option of their documents. To do so, a process is needed that will allow needed detail to be added and make needed choices.

7-2 Consider Detailed Examples. For reference, A-5-5 briefly describes how scenarios are addressed in two NFPA standards already including a performance option.

7-3 Assistance from Support Team . Core scenarios are not intended to be in conflict with the design freedom associated with performance-based design, but, there need to be some parameters for the AHJ to evaluate the design. Overly severe scenarios mean a design meeting the prescriptive code might not pass, while insufficiently severe scenarios could allow unsafe buildings to be built. The same could also be true if scenario selection is excessively delegated to the design professional. The Performance-Based Support Team can offer more guidance to the TC on this issue.

7-4 Brainstorming. In doing this exercise it may be useful for the TC to engage in a brainstorming session to identify as many of the different fire scenarios that can occur within the scope of their document. The diverse representation on the Technical Committees is a good environment for thorough brainstorming.

7-5 Identifying Common Fires. To ensure the committee has covered everything, the committee may want to consult a fire incident data base to see if they have considered fires that statistically occur most frequently. For more information on this topic refer to 6-3 and A-6-3. These data bases are also useful to review how low the probabilities of high-challenge scenarios have been historically.

7-6 Exploratory Analysis. It can be useful to conduct exploratory modeling evaluations using a range of candidate scenario specifications, in order to examine sensitivity to parameter specification quantitatively and realistically. This brainstorming activity can be done by the Technical Committee or on its own behalf.

Chapter 8 Conclusion

8-1 General. This document discusses the issue of developing fire scenarios for inclusion in NFPA documents by Technical Committees wishing to incorporate performance-based provisions.

8-2 Development Process. Developing performance-based provisions is a dynamic process and not easily delineated. This is especially true in defining scenarios. This primer (Primer 3) is intended to give the TC background and guidance as it develops scenarios. Keep in mind that although reference is made to NFPA codes and standards already including a PB option the TC is not limited to those approaches. Each TC is unique which is why one TC cannot borrow another's approach without an understanding of its development. The Primers are not intended to replace the NFPA Performance-Based Support Team; their assistance is available to all TC's considering a performance-based option.

Appendix A

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

A-1-1 The International Code Council (ICC) is developing a single, prescriptive building code for the United States, the International Building Code (IBC). In addition, they are also developing a performance-based IBC. Since users of NFPA performance-based documents may also encounter the performance-based IBC, this appendix is included to provide a comparison between the two organizations' performance-based provisions. While some of the concepts are similar, nomenclature may not be.

A-1-4 Process. The structure of the performance-based IBC is shown in Figure B-1-4. As of the date of this primer, only the intent, scope, objectives, functional statements, and performance requirements will be in the performance-based IBC. The ICC Performance Committee (ICC PC) essentially used a top-down approach with the New Zealand Building Regulations 1992 as a model. The status of criteria, guidelines, and acceptable solutions is uncertain. However, it is recognized that the prescriptive IBC will provide acceptable solutions until performance-based solutions can be developed.

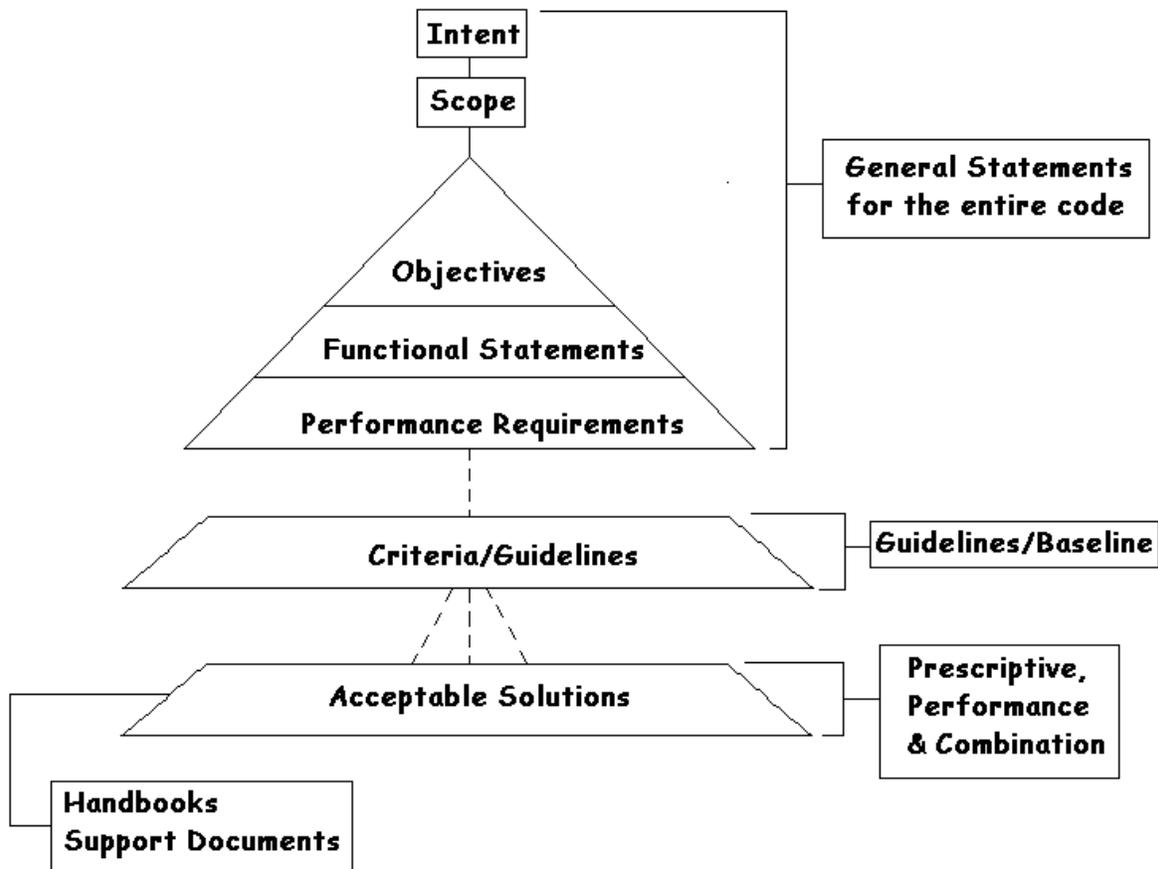


Figure B-1-4. Performance-based IBC Structure

A-3-3.1. Although the AHJ is not strictly a designer, it will be important to include the AHJ in this early part of the PB design phase. By having the design fires of the scenarios reviewed by the AHJ at this stage, a good line of communication is established between all parties. This also saves the owner the time and money of redesigning a rejected plan or fighting appeals.

A-3-4. To thoroughly evaluate the scenarios it may be helpful to use a flow chart or concept tree to follow the performance-based design process in an organized manner. *NFPA 550 - Guide to the Fire Safety Concepts Tree, 1995 Edition*, might be a useful tool to achieve consistency.

A-5-1. One must be careful to remain realistic when selecting scenarios. It is easy to be under or overly conservative; a balance must be found. For example, it would be devastating if a meteor hit the building in question, but is that realistic? Is that a problem any building is likely to face in its lifetime? Obviously not; therefore, there is no need to provide protection for the building and its occupants in that situation.

Is it possible that a building is a target for terrorist activity (e.g., bomb, arson)? That is more likely than a meteor, but how severe an incident is likely enough to be used for planning?

On the opposite side of the spectrum, there is a very good chance that a fire could block the most commonly used means of egress.

A-5-3. Each NFPA document has a goal and objectives, either implicit or explicit.. In the prescriptive version of the document they are not always clearly expressed. Rather, they are woven into the prescriptive requirements. Providing a performance option requires the TC to clearly state goals and objectives so that criteria can be set and scenarios identified. Criteria and scenarios are the places in the document where acceptable safety and risk are most clearly quantified.

Included below are excerpts from *NFPA 805 - Performance - Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants pre-ROP draft 5 for 2000 edition* so that the TC may get a general idea of how one committee addresses acceptable loss. **Note:** These are very general criteria. It is up to the user to expand on their detail.⁶:

1-7.1 Nuclear Safety Performance Criteria. Fire protection features shall be provided to demonstrate the plant is not placed in an unrecoverable condition. To demonstrate this the following performance criteria shall be met:

- a) Reactivity Control - Achieve and maintain the Effective Multiplication factor (K) less than one such that fuel damage is prevented.
- b) Fuel Cooling - Applicable fuel design limits are not exceeded.

1-7.2 Radioactive Release Performance Criteria

1-7.2.1 Deterministic Approach. Radiation release, from all sources due to fire or fire suppression activities, shall be within the limits of 10CFR20.

1-7.2.2 Performance Based Approach. Radiation releases, from all sources due to fire or fire suppression activities, shall be less than the USNRC safety goal of 1 tenth of 1 percent of the individual and societal background risk in the location of the facility.

1-7.3 Life Safety Criteria The Life Safety Objectives can be demonstrated by meeting the prescriptive criteria specified in Section 4.2.1, or the performance base criteria specified in Section 4.2.2.

1-7.4 Plant Damage/Business Interruption Criteria. In order to meet the individual Plant Damage/Business Interruption Objectives identified in 1-6.4, the following criteria shall be satisfied as described below. *See also Appendix A-1-6.4.*

1-7.4.1 Criteria to Limit Property Damage. To meet Objective 1-6.4.1, both of the following criteria shall be satisfied:

- a) The Maximum Foreseeable Loss (MFL) shall not exceed an acceptable level.

and

- b) The Probable Maximum Loss (PML) shall not exceed an acceptable level.

1-7.4.2 Criterion to Limit Business Interruption. To meet Objective

1-6.4.2, the business interruption (plant downtime) due to a PML fire event shall not exceed an acceptable level.

1-7.5* Adjustments to Calculation. Adjustments to the calculation procedure shall be approved by the authority having jurisdiction. Adjustments shall be made if required to best address effects or conditions of concern to the design professional or the authority having jurisdiction.

1-7.6 The AHJ will make the final determination as to whether the performance objectives have been met.

1-6.4* Plant Damage/Business Interruption Objectives. In order to meet the Plant Damage/Business Interruption Goal identified in 1-2.1.4, all of the following objectives shall be satisfied.

1-6.4.1 Limit property damage due to fire to an acceptable level.

1-6.4.2 Limit business interruption (plant downtime) due to fire to an acceptable level.

A-1-6.4 Determination of the acceptable levels of damage and downtime for systems and structures that are not related to nuclear safety and that do not impact the plants ability to perform safe shutdown is largely a matter of economics. These values will be site specific based on financial criteria established by the Owner/Operator. The Owner/Operators analysis should consider factors such as the cost of installing and maintaining protection, the potential damage from the hazard or exposures (combustible load), the replacement cost of damaged equipment, and the downtime associated with replacement/repair of damaged equipment. Risk-informed data for the frequency of ignition sources, transient combustibles, or fires associated with the hazard should be considered.

4-2.1 Prescriptive. NFPA 101, **Life Safety Code**, provides minimum requirements for safety to life for occupants in general occupancies. The performance-based requirements of this chapter of NFPA 805 are available for use to demonstrate alternative safety to life provisions from the **Life Safety Code** with specific application to the special occupancies to be found in light water nuclear reactors. Facilities that are fully compliant with the prescriptive requirements of NFPA 101, **Life Safety Code**, shall be deemed to be in compliance with this Chapter of NFPA 805.

4-2.2 Performance Based

4-2.2.1 Application The requirements of this chapter shall apply to life safety systems designed to the performance-based option permitted by 1.7.2.

For further discussion on level of acceptable loss refer to section 3.3 of :

Custer, R.L.P. and Meacham, B.J., *Introduction to Performance-Based Fire Safety*, National Fire Protection Association, Quincy, MA, 1997.

A-5-4. Assumptions can be varied between model runs as a part of exploratory analysis. If the design is not performing well during the verification process or analysis indicates the assumption is too conservative or not conservative enough, these input values can be changed to see what the effect may be. The designer still has to document all assumptions and justify the values ultimately chosen for the verification. Other values analyzed may be useful in a sensitivity analysis, supporting safety factor calculations.

Explanation and documentation requirements should be laid out in a way so that an AHJ or designer not familiar with the design can clearly identify assumptions from known facts and can easily trace the references the assumptions are based on.

A-5-5. Refer to *Primer 2 - Characteristics and Assumptions*, when completed, for more characteristics to consider when doing performance-based design work.

Providing core scenarios in an NFPA document is meant to limit a designer's performance options to those that will provide acceptable safety against all fires society expects a building to handle. A proper engineering analysis cannot be performed without considering certain scenarios. It may not be necessary to use every core scenario but a compelling reason for not incorporating a scenario must be given, based on hard evidence, and be well documented in the design report.

The nine scenarios presented below are the scenarios found in *NFPA 101 - The Life Safety Code*.⁵ It is understood that these specific scenarios may not be pertinent to the focus of each Technical Committee; however, each scenario addresses specific issues that are of import to many TC's, which is why they are presented in this Primer. Each TC should be encouraged to develop those scenarios it feels are necessary.

Scenario 1. An occupancy-specific scenario representative of a typical fire for the occupancy. The scenario shall explicitly account for: occupant activities, number and location; room size; furnishings and contents; fuel properties and ignition sources; and ventilation conditions. The first item ignited and its location shall be explicitly defined.

Scenario 2. An ultrafast developing flammable liquids fire, in the primary means of egress, with interior doors open at the start of the fire. This scenario shall address the concern of reducing the number of available means of egress.

Scenario 3. A fire, starting in a normally unoccupied room, that can potentially endanger a large number of occupants in a large room or other area. This scenario shall address the concern of a fire starting in a normally unoccupied room and migrating into the space that can, potentially, hold the greatest number of occupants in the building.

Scenario 4. A fire originating in a concealed wall- or ceiling-space adjacent to a large occupied room. This scenario shall address the concern of a fire originating in a concealed space that does not have either a detection system or suppression system, and the fire spreading into the room within the building that can, potentially, hold the greatest number of occupants.

Scenario 5. A slow developing fire, shielded from fire protection systems, in close proximity to a high occupancy area. This scenario shall address the concern of a relatively small ignition source causing a significant fire, either from a life safety viewpoint or from the viewpoint of delayed activation of the suppression system, if present.

Scenario 6. An ultrafast-developing fire resulting from the largest possible fuel load characteristic of the normal operation of the building. This scenario shall address the concern of a rapidly developing fire with occupants present.

Scenario 7. Outside exposure fire. This scenario shall address the concern of a fire starting remotely from the area if concern and either spreading into the area, blocking escape from the area, or developing untenable conditions within the area.

Scenario 8. A fire originating in ordinary combustibles in a large room or area with automatic suppression systems not operational. This scenario shall address the concern of a suppression system being either unreliable or unavailable.

Scenario 9. A fire originating in ordinary combustibles in a large room or area with automatic detection systems not operational. This scenario shall address the concern of a detection system being either unreliable or unavailable.

NFPA 101 uses the approach of defining nine scenarios that the TC felt adequately challenges a fire protection design. *NFPA 805 - Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants* presents the use of scenarios in a somewhat different way. After defining an area of origin and its characteristics (e.g., geometry, vent configuration, potential fuel load etc.), the designer would test the design under the conditions listed below.

(a) Fire with all existing fire protection features in place and operating. This includes assumptions that the automatic suppression system, where existing, will control and extinguish the fire.

(b) Same fire as (a) with assumption that the automatic suppression system will control fire growth but not extinguish the fire.

(c) Same fire as (a) with assumption that the suppression system will not operate.

(d) Same fire as (a) with assumption of single failure of a fire protection system or feature, other than automatic suppression, as may be applicable:

- (1) Failure to operate smoke control system.
- (2) Failure of water supply to hose connections.
- (3) Failure to operate heat actuated opening protective device (e.g., fire damper, water curtain, held-open door).
- (4) Failure of room enclosure (e.g., open door, broken glazing).

(e) Same fire as in (b) with assumption of single failure of a fire protection system or feature, other than automatic suppression as may be applicable:

- (1) Failure to operate smoke control system.
- (2) Failure of water supply to hose connections.
- (3) Failure to operate heat actuated opening protective device (e.g., fire damper, water curtain, held-open door).
- (4) Failure of room enclosure (e.g., open door, broken glazing).

Some of the above combinations constitute envelope conditions for other scenarios, so that not all scenarios need to be modeled in all cases. If it can be determined that the probability of a particular scenario occurring is 1×10^{-6} , then that one can be disregarded.

An acceptable design should afford safe conditions under scenarios (a) and (b), as well as under any of the single failure scenarios of (d). It is desirable, but not required that designs pass single system failure scenarios listed under (e) but failure does not necessarily preclude acceptability of the design.⁶

A-6-4. Use of percentages to choose likely scenarios is not as easy as it sounds. Judgment is involved in selecting the categories that define alternative scenarios.

First, remember that the dimensions and factors used to code and describe historical fires in available data bases are not always the same dimensions and factors required as input data for a fire hazard analysis model. A translation is required, and every translation involves an assumed or demonstrated relationship between fire experience data characteristics and desired input data characteristics. It is essential that these relationships be substantiated as much as possible.

For example, it would not be valid to assume that all arson fires are fast or severe fires (i.e., have a steeply rising rate of heat release or a high peak rate of heat release). Most arson fires do not involve the use of accelerants and are started by juveniles, not by individuals sophisticated in fire. For scenario purposes in a fire hazard analysis, the typical arson fire may behave like an ordinary trash fire. By contrast, it would be valid to assume that all fires starting with ignition of flammable liquids, whether accidental or deliberate, show the heat release rate curves associated with those products.

Second, when selecting likely scenarios, the analyst would like to identify scenarios that collectively account for a large share, preferably most, of the relevant fires. However, fire hazard analysis calculations typically require input data with so many characteristics defined that no one scenario can be expected to account for more than a tiny percentage of total fires. In such a situation, the selection of scenarios should be done in two stages. The first stage

would be partitioning all the fires that can occur into a manageable number of relatively homogeneous scenario classes. A scenario class would be a group of similar scenarios that are expected or known to yield similar severities when they occur. The second stage consists of selecting a typical fire within the class to represent the scenario class.

In a typical building, a manageable scenario class for analyzing home fires might consist of all fires originating in ordinary combustibles in any room that people normally occupy, i.e., excluding means of egress that people pass through but do not normally stay in and excluding service areas and concealed spaces. Then, the representative fire within the class might be an upholstered furniture fire within a living room. That is not necessarily the most likely scenario within the class (kitchen fires involving food on a stove are more common, for example), but it is a very common scenario that is easier to quantify for analysis purposes, given existing laboratory data, and is probably more typical of the fires in the class.

As the examples cited earlier suggest, high-challenge scenarios can often be defined in terms of an area of origin and a fire size, both of which are dimensions that can be assessed statistically and used as engineering specifications for an engineering analysis of a building. Other appropriate dimensions to use in defining high-challenge scenarios would include time of day (an indicator of the status of occupants).

It is possible that the fire protection design is intended to prevent fires from ever growing to the design fire size being considered. In this, assuming such a fire size would force the analyst to assume failure of any design features intended to prevent growth of the fire to the designated fire size. This in turn could show the overall design to be unacceptable when such was not the case. A high-challenge scenario could instead be defined in terms of an initial fuel package that (a) statistics show to be high-ranking in terms of probability and associated with a high rate of deaths per fire, and (b) engineering data shown to be associated with a high peak rate of heat release and a high rate of heat release. This will produce a fire tending to become severe quickly and will therefore be a good high-challenge test of the design but without prejudging the effectiveness of design elements intended to act early in the fire.

Three major data bases are available to analyze patterns in U.S. fire experience -- the annual NFPA survey of fire departments; the FEMA/USFA National Fire Incident Reporting System (NFIRS); and the NFPA Fire Incident Data Organization (FIDO). Together, these three data bases can provide valid, detailed information that is the best basis in the USA for constructing fire scenarios.

Annual NFPA Survey of Fire Departments

The NFPA survey is based on a stratified random sample of roughly 3,000 US fire departments (or roughly one of every ten fire departments in the country). The survey collects the following information that may be useful in fire hazard calculations: the total number of fire incidents, civilian deaths, and civilian injuries and the total estimated property damage (in dollars) for each of the major property-use classes defined by the NFPA 901 standard for fire incident reporting.⁷ These totals are analyzed and reported in NFPA's annual study, "Fire Loss in the United States," which traditionally appears in the September/October issue of *NFPA Journal*.

The NFPA survey is stratified by size of population protected to reduce the uncertainty of the final estimate. Small, rural communities protect fewer people per department and are less likely to respond to the survey, so a larger number must be surveyed to obtain an adequate sample of those departments. NFPA also makes follow-up calls to a sample of the smaller fire departments that do not respond, to confirm that those that did respond are truly representative of fire departments their size. On the other hand, large city departments are so few in number and protect such a large proportion of the population that it makes sense to survey all of them. Most respond, resulting in excellent precision for their part of the final estimate.

These methods have been used in the NFPA survey since 1977 and represent a state-of-the-art approach to sample surveying. Because of the attention paid to representativeness and appropriate weighting formulas for projecting national estimates, the NFPA survey provides a valid basis for measuring national trends in fire incidents, civilian deaths and injuries, and direct property loss, as well as for determining patterns and trends by community size and major region.

FEMA/USFA's National Fire Incident Reporting System (NFIRS)

The Federal Emergency Management Agency's US Fire Administration (FEMA/USFA) administers and distributes NFIRS, an annual computerized data base of fire incidents, with data classified according to a standard format based

on NFPA 901. Roughly three-fourths of all states have NFIRS coordinators, who receive fire incident data from participating fire departments and combine the data into a state data base. This data is then transmitted to FEMA/USFA. (To obtain a copy of the NFIRS data tape for a particular year, contact the National Fire Data Center, U.S. Fire Administration, 16825 South Seton Avenue, Emmitsburg, MD 21727-8995, or call 301-447-6771.) Participation by the states, and by local fire departments within participating states, is voluntary. NFIRS captures roughly one-third to one-half of all US fires each year. A larger proportion of US fire departments are listed as participants in NFIRS, but not all departments provide data every year.

NFIRS provides the most detailed incident information of any reasonably representative national data base not limited to large fires. NFIRS is the only data base capable of addressing national patterns for fires of all sizes by specific property use and specific fire cause. (The NFPA survey separates fewer than twenty of the hundreds of property use categories defined by NFPA 901 and provides no cause-related information except for incendiary and suspicious fires.) NFIRS also captures information on the construction type of the involved building, height of building, extent of flame spread and smoke spread (which are useful in estimating whether flashover occurred and whether conditions would have caused an operational smoke detector to operate, respectively), performance of detectors and sprinklers, and victim characteristics, the latter in individual casualty reports which accompany the incident reports in an NFIRS file.

One weakness of NFIRS is that its voluntary character produces annual samples of shifting composition. Despite the fact that NFIRS draws on three times as many fire departments as the NFPA survey, the NFPA survey is more suitable as a basis for projecting national estimates because its sample is truly random and is systematically stratified to be representative.

Most analysts use NFIRS to calculate percentages (e.g., the percentage of residential fires that occur in apartments, or the percentage of apartment fire deaths that involve discarded cigarettes), which are then combined with NFPA -survey-based totals, to produce estimates of numbers of fires, deaths, injuries, and dollar loss for subparts of the fire problem. This is the simplest approach now available to compensate in the area where NFIRS is weak. It has been documented as an analysis method in a 1987 article in *Fire Technology*.⁸

NFPA's Fire Incident Data Organization (FIDO)

NFPA's FIDO is a computerized index and data base that provides the most detailed incident information available, short of a full-scale fire investigation. The fires covered are those deemed by NFPA to be of major technical interest. The tracking system that identifies fires for inclusion in FIDO is believed to provide virtually complete coverage of incidents reported to fire departments involving three or more civilian deaths, one or more fire fighter deaths, or large dollar loss (redefined periodically to reflect the effects of inflation, and defined since the late 1980s as \$5,000,000 or more in direct property damage).

FIDO covers fires from 1971 to date, contains information on more than 70,000 fires, and adds about 2,000 fires per year. NFPA learns of fires that may be candidates for FIDO through a newspaper-clipping service, insurers' reports, state fire marshals, NFIRS, responses to the NFPA annual survey, and other sources. Once notified of a candidate fire, NFPA seeks standardized incident information from the responsible fire department and solicits copies of other reports prepared by concerned parties, such as the fire department's own incident report and results of any investigations.

The strength of FIDO is its depth of detail on individual incidents. Coded information that may be captured by FIDO, but never by NFIRS, includes detailed types and performance of built-in systems for detection, suppression, and control of smoke and flame; detailed factors contributing to flame and smoke spread; estimates of time between major events in fire development (e.g., ignition to detection, detection to alarm); reasons for unusual delay at various points; indirect loss and detailed breakdowns of direct loss; and escapes, rescues, and numbers of occupants. Additional uncoded information often is available in the hard-copy files, which are indexed by FIDO for use in research and analysis.

FIDO is a resource that may be used with NFIRS-based national estimates in the same manner that NFIRS is used with the NFPA survey to produce national estimates. That is, a FIDO analysis may provide reasonable estimates of how a block of fires, estimated through NFIRS-based national estimates, further subdivides into more detailed categories.

Neither FIDO nor any other special fire incident data base with detail exceeding that in NFIRS is directly available to analysts outside the organization that maintains the data base. It will be necessary to arrange with analysts in charge of the data base to obtain needed analyses, and at that time, the data base analysts can help indicate what analyses are possible with the data.

Working with the Strengths and Weaknesses of Different Data Bases

No fire data base can possibly capture all instances of unwanted fires. Few data bases cover fires that are not reported to fire departments. By their nature, fire data bases are biased in favor of "failures" rather than "successes." The fire that is controlled so quickly it does not need to be reported to a fire department is not captured by the data bases that cover reported fires. Analyses of the impact of devices and procedures that provide early detection or suppression also need to allow for the phenomenon of missing "success" stories.

There is also the issue of quality control for a data base. For data bases with limited depth of detail (like the NFPA survey) or limited breadth of coverage (like FIDO, which is primarily devoted to large fires), it is possible to invest considerable effort in ensuring that each report is as complete and accurate as possible. Follow-up calls can be used to fill gaps and check possible odd answers. For a data base with the depth and breadth of NFIRS, however, the same level of quality control effort has not been possible. Consequently, NFIRS is missing more entries and has more that are dubious. The trade-off between data quality and data quantity is never easy; an analyst needs to be aware of the strengths and limitations of the sources before conducting an analysis.

Appendix B Reference Publications

1. *NFPA's Future in Performance-Based Codes and Standards*, National Fire Protection Association, Quincy, MA, July, 1995.
2. *Bottom-Up Analysis of National Codes*, Canadian Codes Centre, September 1996.
3. *The American Heritage College Dictionary*, 3rd ed., Houghton Mifflin Co., Boston, 1993.
4. Hall, John R. Jr., "Fire Risk Analysis," *Fire Protection Handbook, 18th Edition*, NFPA, 1997. pp. 11-78 - 11-88.
5. *NFPA 101 - Life Safety Code, pre-ROP draft for 2000 edition*, National Fire Protection Association, Quincy, MA, July 1998.
6. *NFPA 805 - Performance - Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants pre-ROP draft 4 for 2000 edition*, National Fire Protection Association, Quincy, MA, June 1998.
7. *NFPA 901 - Uniform Coding for Fire Protection*, 1976 ed. (used in most fire data bases) and 1991 ed., National Fire Protection Association, Quincy, MA
8. Hall, J. R., Jr., and Harwood, Beatrice, "The National Estimates Approach to U.S. Fire Statistics," *Fire Technology*, Vol. 25, No. 2, May 1989, pp. 99-113.



Performance-Based
Verification Methods
Primer #4

Draft 9 5 JAN 1999
National Fire Protection Association, 1999

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1 Batterymarch Park
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Preface

This primer (Primer 4) has been developed by the NFPA Performance-Based Support Team (PB Support Team). The PB Support Team functions under the auspices of the NFPA Standards Council, and reports directly to the Council on an on-going basis. The PB Support Team was created in 1995 to assist NFPA Technical Committees with the transition to performance-based documents.

Primer 4 is the fourth in a series intended to provide NFPA Technical Committees with guidance and information on how to write a performance-based NFPA code, standard, or similar document. This primer is based on the report of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models' report entitled *NFPA's Future in Performance-Based Codes and Standards*. This report, released in July 1995 and developed in conjunction with the NFPA Board of Directors, implies the need for the development of further guiding information for NFPA Technical Committees. Primer 4 is one step to fill this need for further guiding information.

It is anticipated that this primer will undergo future changes as they are developed. Any comments on the primer should be sent to:

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NFPA Technical Committee PB Primer # 4 **PERFORMANCE-BASED** **VERIFICATION METHODS**

Draft 9 5 JAN 1999

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NFPA Performance-Based Primer 4

Performance-Based Verification Methods

1999 Edition

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

Part I - Information

This section (Part I) provides general information to the Technical Committee regarding the Primers and terms used within the Primers.

Chapter 1 General Information

1-1 *Primer Purpose. The purpose of this primer is to serve as a resource for NFPA Technical Committees during their efforts in developing performance-based provisions and incorporating them into NFPA documents. This primer can be used to develop new stand-alone performance-based documents or to develop performance-based options in existing or future documents. "Document" is used as a collective term for codes, standards, or recommended practices and may refer to one, two or all three.

1-2 Primer Scope. This primer addresses the process of determining acceptable verification methods used to substantiate performance-based designs. It is one of five primers that serve as resources for NFPA Technical Committees for their development of performance-based provisions.

1-3 Origin. This primer is the direct result of the efforts of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models and the report they produced [1]. This primer is based in part on that report and provides an expansion of the concepts contained therein. It is anticipated that the primer will undergo future changes as they are developed.

1-4 *Process. As shown in Figure 1-4, there are two distinct, although not exclusive, approaches to developing performance-based provisions. The top-down approach is described in [1] and the bottom-up approach is taken from [2].

1-4.1 A total of five primers are either planned or completed:

Primer #	Title	Status
1	Goals, Objectives & Criteria	Available
2	Characteristics & Assumptions	Planned
3	Fire Scenarios	Available
4	Performance-Based Verification Methods	Available
5	Overview of Performance Approach	Planned

Additional Primers may be developed as needed to address topics, e.g., computer fire modeling, risk management, etc.

1-5 Clarification. Due to the wide variety of topics covered by NFPA documents, it is difficult to address each topic specifically in this primer. These topics include buildings, systems within buildings, building features, vehicles (including boats and ships), outdoor property, people, and products. Therefore, in this primer "building" will be used to generally indicate the topic of a given NFPA document.

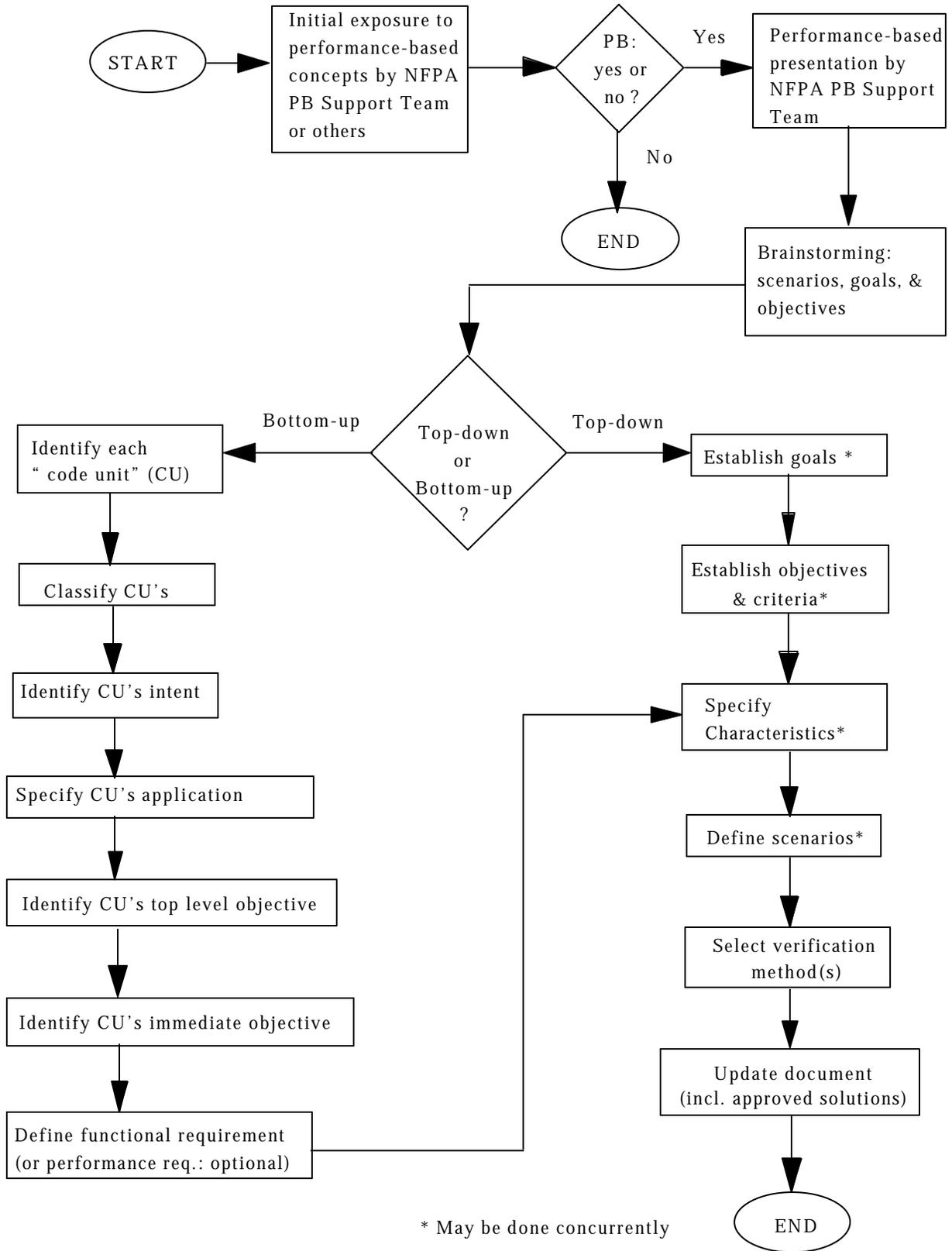


Figure 1-4. Performance-Based Document Development

Chapter 2 Glossary

2-1 General. The following terms are presented to help provide a consistent vocabulary. Definitions of the following terms are taken from [1], unless otherwise noted.

Acceptable. That which has adequately satisfied specified performance criteria. The AHJ holds the final decision on whether or not a design or portion of a design is acceptable.

Approved Method. Authoritative procedure used to develop proposed solutions. A more commonly used example of approved methods are contained within prescriptive documents.

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

NOTE: The phrase “authority having jurisdiction” is used in NFPA documents in a broad manner because 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.

Bottom-Up. One approach used to develop performance-based provisions. Using this approach, the goals, objectives, characteristics, and scenarios of a document that are unstated prior to document revision processing are identified and explicitly stated.² See "Top-down".

Calculation Method. A description of a system or phenomenon in terms of relationships among elements, permitting study of how some elements vary when other elements are changed. A calculation method normally consists of one or more mathematical relationships, permitting calculation of some elements based on their relationship(s) to other elements. Note that fire science and engineering use "model" as a synonym to calculation method but also for other concepts and elements such as scale models.

More specific terms including the word "model", used as a synonym for "calculation method", are differentiated below, and the more specific term will be used in this document where applicable.

Computer Model. A model that is packaged as computer software.

Fire Effects Model. A model that incorporates engineering and scientific principles and applies them in a logical manner to determine possible consequences and extent of physical effects based on an externally specified fire, expressed as heat release rate as a function of time. (Typically referred to as a "fire model", even though it may not model combustion.)

Evacuation/Egress Model. A model used to describe the behavior and movement of people during a fire situation. May be used in combination with a fire effects and typically incorporating them to determine whether or not occupants may safely escape.

Computer Fire Model. A fire model that is packaged as computer software.

Characteristics. Qualities of the occupants, building contents, potential fuel packages, process equipment, and facility features and systems. The focus is usually on those characteristics that should be considered when developing a performance-based fire protection design or performance-based provisions for NFPA documents.

Code (Document) Unit. The smallest portion of a code (i.e., a document) that can have an intent and application statement attached to it.² Each code unit is a definable concept having a type, an intent, application (e.g., “application and limitations of the application of the provision such as occupancy, building height, sprinklered/nonsprinklered building, etc.”) and one or more objectives.

Design Team. Group of stakeholders including, but not limited to, representatives of the architect, client, and any and all pertinent engineers and other designers. A stakeholder is an individual, or representative of same, having an interest in the successful completion of a project.

Fire Safety Goal. Overall outcome to be achieved with regard to fire. Goals are non-specific and are measured on a qualitative basis. They should be stated in terms of conditions that are intrinsically desirable and do not rely on any assumptions. Goals should be stated in terms that are potentially measurable, even if the precise measurement scale is not specified. Thus, goals may be expressed in terms of impact on people, property, or the environment, or in terms of mission continuity. A single goal may be applicable to many different NFPA documents.

Fire Scenario. Quantitative description of a fire and any factors affecting or affected by it from ignition to extinguishment including ignition sources, nature and configuration of the fuel, ventilation, characteristics and locations of occupants, condition of the supporting structure, and conditions and status of operating equipment. Usually used more narrowly to describe initiating conditions for use with a model, test procedure, or other method used for deriving conditions at later stages. The term "design fire" is used even more narrowly to refer to initiating conditions of the fire, those thus excluding most characteristics of the larger building environment the fire may grow into, occupants, and building systems and features.

Functional (or Performance) Requirement. A statement indicating how the building (system, etc.) must perform in order to achieve the stated objectives and goals; typically, a further refinement of an objective, if needed. For example, to achieve the life safety goal with a smoke control objective, a functional requirement could be "The level of smoke shall remain above the heads of evacuees using either a natural or forced ventilation smoke management system."

Performance-Based Design Approach. A design process whose fire protection solutions are designed to achieve a specified goal for a specified use or application. This process allows performance-based documents to be implemented and insures that their goals are met.

NOTE: The following describes a performance-based design approach:

- a) Establish fire safety goals.
- b) Evaluate the condition of the occupants, building contents, process equipment, or facility in question with regard to fire protection.
- c) Establish performance objectives and performance criteria.
- d) Identify potential hazards to be protected against.
- e) Define appropriate scenarios.
- f) Select suitable verification methods (e.g., fire models).
- g) Develop proposed solution.
- h) Assess proposed solution.
- i) Document proposed solution along with supplementary information.
- j) Obtain approval of the proposed solution.

Steps a) through f) are also part of the development of a performance-based code or standard. Only steps g) through j) are specific to performance-based design, where the intent is to find a solution for the project. Also, steps c), d), and e) are not necessarily intended to be sequential; they may in fact be concurrent. While the above is presented in a sequential order, the design approach does not necessarily need to begin with step a) and proceed consecutively through step j). Since different stakeholders (e.g., owner, designer, authorities) must be satisfied, some steps of this approach are iterative. Similarly, for performance-based document development, steps a) through e) may or may not be taken sequentially.

Performance-Based Document. A code or standard that specifically states its fire safety goals and references approved methods that can be used to demonstrate compliance with its requirements. The document may be phrased as a method for quantifying equivalencies to an existing prescriptive-based document and/or it may identify one or more prescriptive documents as approved solutions. Furthermore, the document allows the use of all solutions that demonstrate compliance using approved methods.

NOTE: A performance-based document may also include separate prescriptive provisions as a parallel, independent approach to meet the performance-based goals and objectives.

Performance Criteria. Performance objectives for individual products, systems, assemblies, or areas that are further quantified and stated in engineering terms (e.g., temperature, radiant heat flux, level of exposure to combustion products). Performance criteria provide pass/fail threshold values which are treated as data for calculations used to qualify a proposed performance-based solution.

Performance Objective. Requirement for the fire, building, or occupants (or combination thereof) that must be satisfied in order to achieve a fire safety goal. Objectives are stated in more specific terms than goals and tend to be more quantitative than qualitative. Objectives may be thought of as specific goals for individual NFPA documents

Prescriptive-Based Document. A code or standard that prescribes fire protection for a generic use or application. Fire protection is achieved by specifying certain construction characteristics, limiting dimensions, or protection systems without providing a mechanism for how these requirements achieve a desired fire safety goal. Typically these documents do not state their fire safety goals.

NOTE: Many current NFPA codes and standards are not strictly performance-based or prescriptive-based: technically, they can be referred to as prescriptive documents containing some performance provisions. For example, a requirement for a one-hour door sets a measurable performance criterion, going beyond prescription of the door's construction, but does not link the criterion explicitly to a fire safety goal.

Project Team. The design team and the Authority Having Jurisdiction. The AHJ may have no formal or legal responsibility for the design but should be involved at every stage of the project. This ensures the greatest chance of a successful project.

Proposed Solution. A fire protection system design intended to achieve the stated fire safety goals and which is expressed in terms that make it possible to assess whether the fire safety goals and objectives have been achieved. If models are used, then the proposed solution should also specify the models and input data employed.

Owner. The party that holds financial responsibility for the project and to which professional services are rendered.

Safety Factor. Adjustment made to reflect conservatism due to uncertainty in the methods and assumptions employed in measuring performance. A safety factor is not part of the process of setting acceptable levels of safety as risk but only reflects the precision of the calculation.

Top-Down. One approach used to develop performance-based provisions. Using this approach, the goals and objectives are developed during document revision processing without consideration of any current prescriptive requirements: a "clean sheet of paper" approach. See "Bottom-up".

Verification. Confirmation that a proposed solution (i.e., candidate design) meets the established fire safety goals. Verification involves several steps. Verification confirms that the building is built as proposed to a design that will achieve the intended level of safety and that the building's ability to achieve the level of safety has been demonstrated by qualified people using the correct methods applied to the correct data.

Verification Method. A model or tool or other method used to demonstrate that a proposed solution provides the level of protection specified in the criteria. The AHJ, the designer, or both are permitted to use any type and number of source material provided they produce needed output data based upon available input data. Also called "design tool".

Part II - Background

This section (Part II) discusses the use of verification methods in engineered design. NFPA Technical Committees need to address verification methods in their document so that AHJ's and designers can have a point of reference when approving or using verification methods in designs. How the Technical Committees can present this information in their document is discussed in Part III.

Chapter 3 Verification

3-1 Purpose.

3-1.1. Since a performance-based design, by its nature, will involve features that do not comply with prescriptive requirements, it is necessary to verify that the design will produce a building that meets the fire safety goals and objectives. Any procedure to do this is a "verification method", and Technical Committees need to provide guidelines on the selection and use of such methods.

3-1.2. Verification occurs in two stages. The first stage, described in this chapter and Chapter 4, is for the designer to verify that the design satisfies the criteria. The second stage, described in Chapters 5 and 6, is for the AHJ to approve the design. This is the final step in the performance-based design process. The manner in which this stage is carried out will likely be the decision of the municipality having jurisdiction over the project; not the designer as in the first stage.

3-2 Definitions. When referring to verification throughout this document the following definitions will be used:

3-2.1 Dictionary Definition. *Webster's Ninth New Collegiate Dictionary* defines "verification" as "the act or process of establishing the truth, accuracy or reality of." [3]

3-2.2 NFPA Context. In this context "verification" is to establish the accuracy of the designer's claim that a proposed solution meets the established fire safety goals, objectives and criteria. Verification involves several parts. Verification confirms that the building's ability to achieve the level of safety set in the criteria has been demonstrated by qualified people appropriately using sound methods applied to appropriate and accurate data.

3-3 *Verification Methods. Figure 3-3 depicts the role of verification methods in performance-based design and in developing performance-based provisions. The verification method is the point where one demonstrates whether a building built to the design specifications and assumptions, and confronted with the challenges of the fire scenarios, will perform in accordance with the goals and objectives, as measured by the performance criteria. In addition to scenario data (e.g., growth rate, fire location, fuel characteristics and ventilation) and design specifications (e.g., structural requirements, building layout and construction materials), occupant characteristics and other assumptions are required input to verification methods. As shown, the outputs of verification methods are compared to the performance criteria in order to determine the acceptability of proposed, alternate solutions.

Note: that the process of evaluating, proving or validating a verification method may itself be called verification. To avoid confusion, this primer will use terms other than "verification" to describe the process of demonstrating the appropriateness and accuracy of a verification method.

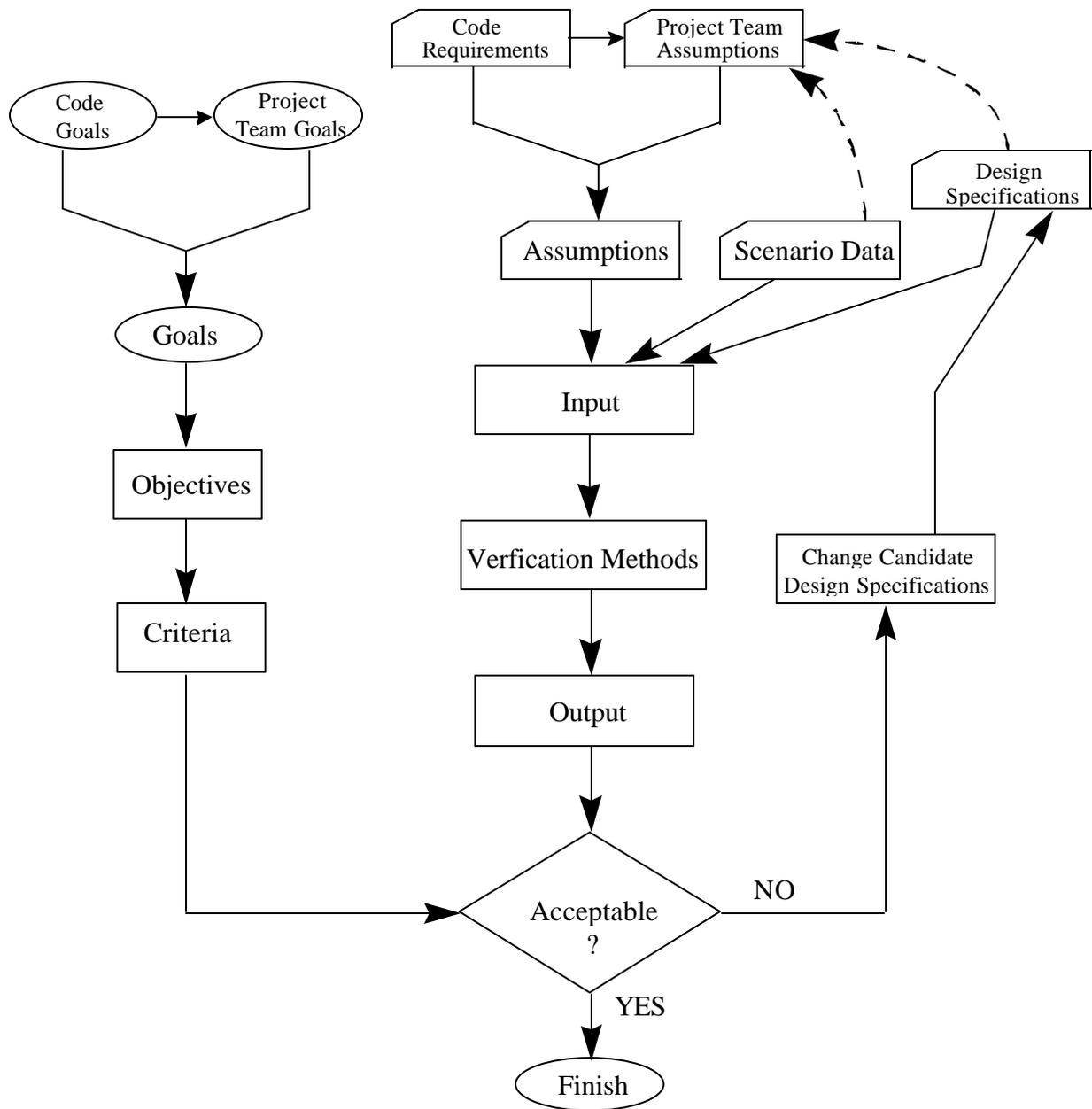


Figure 3-3. Role of Verification Methods

3-4 *Selection. There are various types of tools available to use in the verification process ranging from hand calculations to computer models. (Refer to Chapter 4 for a description of various types of tools.) Each of the many types has been created to provide results for various necessary pieces of information (e.g., system reliability or time to safe evacuation) that are required to verify a design's performance. It is important to be thorough when selecting a verification method. One must carefully consider what information the verification method needs to in order to show that the criteria are satisfied.

3-4.1 Input. When using a tool to analyze the design, the results it predicts are dependent on the input. The input to a model or other tool is based on what is specified in the scenario, design specifications and assumptions. This direct relationship between model input and model output is shown in Figure 3-4.1. Some important factors to include in the

input are the geometry of the area to be modeled, fuel characteristics, construction materials, condition of the vents, and occupant characteristics. Input parameters are not limited to those previously listed.

3-4.1.1 Characteristics, Design Specifications & Assumptions. All components of the design that are not variable need to be identified, documented and converted to input for the design tools. Those components that cannot be converted to output should still be identified and documented so that the AHJ is aware of this in his/her evaluation. This is crucial to the verification process because if input is omitted or misrepresented it will alter the results of the verification method. For more information on this refer to *Primer 2 - Characteristics and Assumptions*.

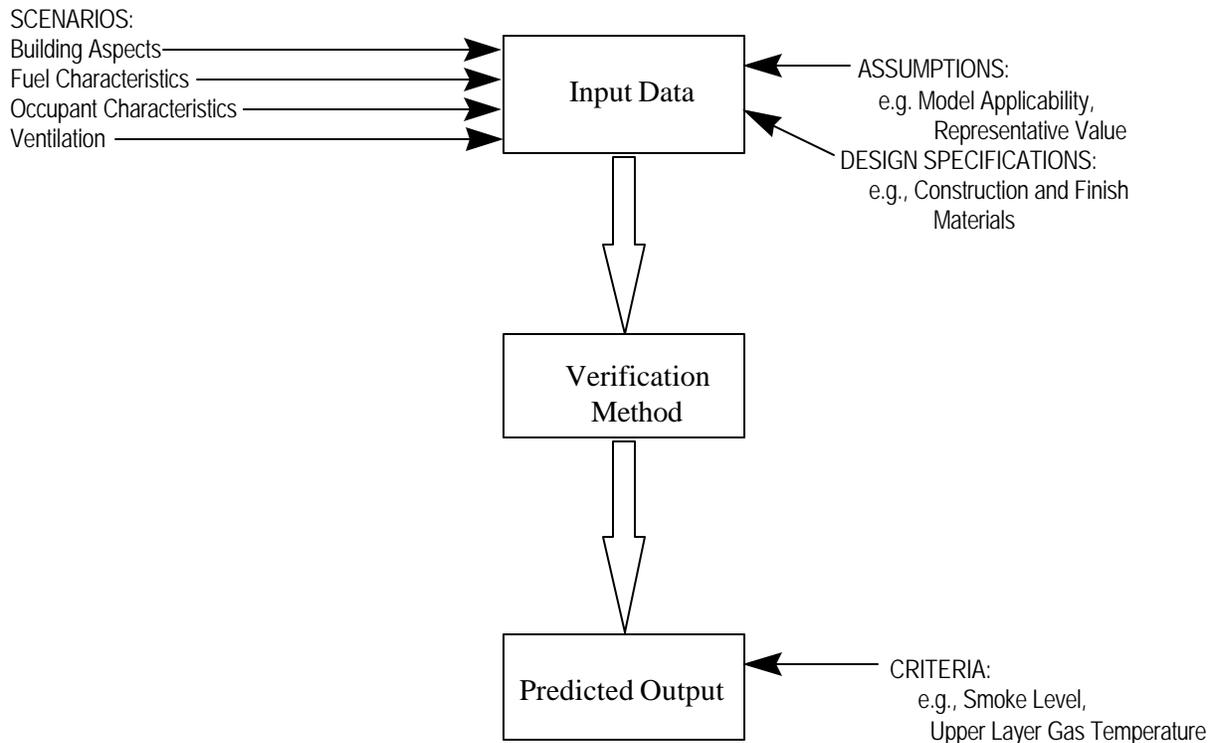


Figure 3-4.1 - Input Output Relationship

3-4.1.2 Define Problem. A complete set of goals, objectives and criteria define the problem to be solved by the proposed solution and thus dictate the output to be predicted. These are essential factors to aid the designer in choosing a verification method. See *Primer 1 - Goals, Objectives and Criteria* for more information.

3-4.1.3 Define Scenarios. As shown in Figure 3-4.1, the scenarios must be defined in terms compatible with the input data requirements of the verification methods. Any input data not provided by scenarios, characteristics or design specifications must be provided through assumptions, and any scenario or assumption details not useful by the verification method as input data raise questions as to whether the proper verification method is being employed. For more information on scenarios refer to *Primer 3 - Fire Scenarios*.

3-4.2 *Verify.

3-4.2.1 Proposed Design. After defining the problem, scenarios, assumptions and selecting a verification method, it is necessary to verify the proposed design. The method's range of output must be carefully analyzed and compared to the criteria. In doing this the designer is verifying that the method can reasonably predict or produce the appropriate results. Results are considered reasonable if they satisfy the criteria by the pre-determined factor of safety.

3-4.2.2 Factor of Safety. Presently, there is no identified way to scientifically quantify a safety factor for fire and life safety. However, a factor of safety may be explicitly or implicitly set by the project team when the criteria are defined. The levels at which the criteria are set and the diverse perspectives of the project team reflects the level of loss society is willing to accept. For this reason, the criteria may be set at a more conservative level than may be needed to satisfy the threshold limits of the building and its components.

Chapter 4 Verification Methods

4-1 Verification Methods Available. This section is intended to introduce several types of tools that can be used to evaluate proposed solutions. Verification methods incorporate the scenarios, design specifications and assumptions to show a design meets the goals and objectives as specified by the criteria. Acceptable verification methods are not limited to those mentioned in this section, however, these are most commonly used.

4-2 *Limitations. Verification methods have some limitations that designers must be aware of before analyzing a design.

4-2.1 Background. In addition to the assumptions the designer makes in the design process, the tools he/she uses have been developed based on certain assumptions or a complex mathematical theory that has been simplified. It is important that the designer be aware of the tool's background so as not to apply the verification method incorrectly.

4-2.2 Input Parameters. It is easy for a person doing an evaluation to overlook important parameters. For example, a computer model will only consider that information which is input. There are many assumptions that are required in setting up a computer model and getting it to run. Therefore, in using verification methods, if assumptions are not chosen carefully and important parameters are not included, the results may not be accurate.

4-2.3 User. It is easy to misinterpret model results. This is especially true of computer models which are capable of predicting many different parameters. Proficiency in using models comes with experience. Computer model (as all verification methods) results should always be checked by using at least one other verification method.

4-3 Deterministic Tools. Deterministic tools are based on mathematical equations which describe physical phenomena. These tools can be either dependent or independent of time, meaning they yield results over the duration of the fire or at just one point in time during that duration. Deterministic tools are more commonly used than probabilistic tools. It can be speculated that this can be attributed to the fact that these tools are most often used by people with engineering backgrounds and that these users have a better understanding of physics based models rather than those based on behavioral or management science. However, it is also easier to verify the results of a deterministic tool.

4-3.1 Hand Calculations. The simplest of deterministic tools are hand calculations. Hand calculations are mathematical equations or equation sets that can be solved using equipment no more sophisticated than a hand calculator. These equations are mostly arithmetic, algebraic or differential in form and solve for only a small number of unknowns such as physical characteristics of fire or components of egress. Various hand calculations can be found in both the *SFPE Handbook* and the *Fire Protection Handbook* as well as other professional guides and handbooks for both fire dynamics and egress calculations.

4-3.2 *Physics Models. Physics models or fire models (as they are referred to) do not model fires; they model the effects or physical response of a (user) specified fire (i.e., a heat release rate curve is input). They may be used as indicated in 4-3.6 and 4-3.6.2 or by themselves to predict the performance of the design for a given scenario. For this reason they are expected to be used in most, if not all, performance-based fire protection system designs.

4-3.2.1 Types of Fire Models. Deterministic fire models will be used to predict the performance of the design. Several types of fire models are available. In order of decreasing sophistication, they are classified as: field, zone, and purpose built.

4-3.2.2 *Field Models. Field models can provide the most detailed predictions of all the deterministic models because they divide a given space into thousands of smaller volumes. However, for other than “high end” projects, they are not practical because they are computationally intensive. These models have become more commonly known as “computational fluid dynamics (CFD) models”.

4-3.2.3 Zone Models. Zone models are more widely used than field models in the United States because they can provide reasonably accurate predictions in much less time. Zone models typically use less than ten volumes to depict a given enclosure. Because zone models sacrifice a certain degree of accuracy for ease of use, their predictions require a greater amount of scrutiny than do those of field models.

4-3.2.4 *Purpose Built Models. Purpose built models are similar to zone models in their ease of use. However, purpose built models do not provide a comprehensive model; instead, they predict the value of one variable of interest. For example, a purpose built model can predict the conditions of a ceiling jet at a specified location under a ceiling but a zone model would “transport” those conditions throughout the enclosure. The discussion below deals with zone models but much of it is also applicable to purpose built models.

4-3.3 Evacuation Models. Evacuation models are used to model the behavior and movement of people during a fire situation. They can incorporate fire model output data to predict occupant conditions based on fire effects on occupants, and thereby demonstrate the design does or does not meet the life safety criteria.

4-3.3.1 Types of Evacuation Models. There are three categories of evacuation models that can be considered: single-parameter estimation methods, movement models, and behavioral simulation models.

4-3.3.2 Single-Parameter Estimations. Single-parameter estimation models are generally used for simple estimates of movement time. They are usually based on equations derived from observations of movement in non-emergency situations. They may be hand calculations or simple computer models. Examples include calculation methods for flow times based on widths of exit paths and travel times based on travel distances. Sources for these methods include the *SFPE Handbook* and *Fire Protection Handbook*.

4-3.3.3 Movement Models. Movement models do not model the movement of individuals but rather generally handle large numbers of people in a flow network similar to water in pipes or ball bearings in chutes. They tend to optimize occupant behavior, resulting in predicted evacuation times that can be unrealistic and far from conservative. However, they can be useful in an overall assessment of a design especially in early evaluation stages where an unacceptable result with this sort of model will indicate that the design has failed to achieve the life safety objectives.

4-3.3.4 Behavioral Simulation Models. Behavior simulation models take into consideration more of the variables related to occupant movement and behavior. Occupants are treated as individuals and can have characteristics assigned to them uniquely, allowing a more realistic simulation of the design under consideration.

4-3.4 Source of Computer Fire and Evacuation Models. Compendia of computer fire models are found in [4] and [5] and the Forum for International Cooperation in Fire Research - International Survey of Fire Models web site.⁶ Also, the models described in [4] and [5] that were developed by the Building Fire Research Laboratory of National Institute of Standards and Technology may be downloaded from the Internet at <http://www.bfrl.nist.gov/864/fmabs.html>. Further discussion of various evacuation models can be found in the conference proceedings of *Interflam 96 - Seventh International Fire science and Engineering Conference*⁷ and the proceedings of the *First International Symposium on Human Behavior in Fire*⁸. Peer reviewed papers on evacuation models can be found in the proceedings of *IAFSS Fifth International Symposium - Fire Safety Science*⁹. Other calculation methods can be found in both the *SFPE Handbook* and the *Fire Protection Handbook*.

4-3.5 Validation of Computer Fire Models. Computer fire models undergo limited validation; i.e., they are applicable to either the experimental results they are based upon and/or the limited set of scenarios the model developers compared the model’s output to. The Society of Fire Protection Engineers has formed a task group to independently evaluate computer fire models. As of October 1998, they are preparing to finish their first evaluation (DETECT) and have chosen a second model (ASET) to evaluate. Until more models can be evaluated independently (i.e., not by the developer), the model user must rely on available documentation and previous experience for guidance regarding the appropriate use of a given model. By choosing a specific model, the user is tacitly assuming that the model is valid for the scenario under consideration.

4-3.6 Test Results. Test results may be used to provide special data required by a model or directly verify a proposed solution if the test conditions adequately and accurately represent the scenarios. NOTE: One must be careful not to misinterpret the scenario in order to make it conform to the test.

4-3.6.1 Data Uses. The data obtained from standardized tests has three uses for verification purposes. The test results can be used instead of a model. (This will typically be the role of full scale test results.) The test results can be used as a basis for validating the model. (If the model predictions match well with the test results, the model can be used in situations similar to the test scenario.) The test results can be used as input to models. (This is typically the use of small scale data tests.)

4-3.6.2 *Experimental Data. Experimental data may be used as a verification technique when the specified scenario and the experimental setup are similar. Typically, experimental data are applicable to a greater variety of scenarios than are standardized test results. Experimental results can also be used as input for modeling or compared to the output of a predictive model as part of a validation exercise.

4-3.6.3 Standardized Tests. Standardized tests are conducted on various systems and components to determine whether or not they meet some predetermined by their nature criteria are prescriptive criteria. Results are given on a pass/fail basis: the test specimen either does or does not meet the pre-established criteria. The specific time history performance of the test specimen is not usually recorded.

4-3.6.4 Scale. Tests can be either small, intermediate, or full scale. Small scale tests are used to test activation of detection and suppression devices, and the flammability and toxicity of materials. Usually, the item to be tested may be placed within the testing device or apparatus. Intermediate scale tests may be used to determine the adequacy of system components, e.g., doors and windows, as opposed to entire systems. The difference between small and intermediate scale is usually one of definition provided by those conducting the test. Full scale tests are typically used to test building and structural components or entire systems. The difference between intermediate and large scale is also subject to the definition of those performing the test. Full scale tests are intended to most closely depict performance of the test subject as installed in the field; i.e., most closely represent real world performance.

4-3.6.5 *Start-up Tests. Start-up test results can be used to demonstrate that the fire protection system performs as designed. The system design may be based upon modeling. The start-up test essentially verifies the system design modeling and confirms that the system performs as designed and intended. Start-up tests and system design modeling are not the same as verification methods for an entire building design of which the system is a part. If the start-up test indicates a deficiency, then the system must be adjusted and retested until it can be demonstrated the system performs as designed and intended. Only then can one ask whether system performance and the rest of the building design meet the criteria for the building. Typically, start-up tests apply only to the installation of the system component for which they are designed.

4-4 *Probabilistic Tools. A probabilistic tool is one built on probabilities of events. These tools often use statistics to estimate probabilities.

4-4.1 Expected-Value Risk Model. It is possible to use probabilities in a very restricted fashion as part of a model of risk based on expected value. Such a model can use possibilities of scenarios to weight estimates of scenario consequences, where the consequences are estimated using deterministic tools. The weighted consequences are then summed to produce the risk estimate.

4-4.2 Probabilistic Tree Model. A tree model is an example of a fully probabilistic model. A tree model can be either logic or time dependent. In a logically dependent tree model the flow can trace an event through success or failure (e.g., success or failure tree). In an event tree (time dependent), probabilities are used to indicate whether a particular event will occur, given occurrence of a prior event (e.g., people will reach the front door, given that they have moved half-way through the lobby vs. being still asleep in bed).

4-4.3 Special Sub-Model. A partially or fully probabilistic tool that can be used to provide input for a more complex deterministic model. This reflects the fact that any phenomenon can be modeled probabilistically, and some aspects (e.g., ignition, reliability) cannot be reliably and appropriately modeled deterministically, but deterministic models are generally proved by examples.

4-5 *Heuristic Tools. A heuristic tool is one that is based on investigation, problem solving techniques, experience, and engineering judgment. It is a successive process in which the decisions made at one step bear direct effect on the outcome and direction of the following step.

Chapter 5 Acceptable Solutions

5-1 Purpose. Given the flexible nature of performance-based design, it is expected that more than one solution will be developed for a given problem. These solutions may or may not be based upon different verification methods. This chapter is provided to show NFPA Technical Committees how provisions regarding verification methods may be employed to develop alternate acceptable solutions.

5-2 Definitions. The term "acceptable" is subject to vastly differing opinion. To reduce any misconception, the definitions given here are to be used when referring to this document.

5-2.1 Dictionary Definition. *Webster's Ninth New Collegiate Dictionary* defines the word "acceptable" as, "Capable or worthy of being accepted; satisfactory or adequate".³

5-2.2 *NFPA Context. Acceptable in this text is used to mean that which upholds certain criteria set forth in this guideline and as agreed upon by the AHJ.

5-3 Guidelines for Determining Acceptable Solutions. What is deemed acceptable, before submittal to the AHJ, will vary. However, at this stage if the designer can demonstrate to the AHJ that the methods used have produced results that meet the performance criteria, the owner's requirements, and will satisfy the AHJ, then the designer has selected acceptable methods. Because this is a matter of opinion, there is no guarantee that the AHJ will agree the selected methods are acceptable to the AHJ's measure.

5-3.1 *Design Development and Approval Process. Once the designer feels the design is complete, but prior to submitting the design for the AHJ's approval, the designer should be able to run through the following exercise, as a minimum:

- (a) Describe the performance criteria used in the design.
- (b) Identify the differences between the performance requirements used and the prescriptive requirements that would have been used.
- (c) Review the overall strategy followed to meet the performance requirements.
- (d) Summarize the fire engineering analysis.
- (e) Summarize the building design and its fire protection features.¹⁰

This may be used as a check method for the designer or worked into the design report submitted to the AHJ. For documentation purposes, the designer must state his or her understanding of the intent of the prescriptive requirement for which a performance-based solution is being proposed (i.e., if the equivalency option of a prescriptive document is being exercised). The designer must then document how the proposed performance-based solution is intended to meet the agreed upon performance criteria and thus achieve the stated performance goals and objectives. Presumably, achieving the performance goals and objectives is sufficient to meet the intent of the prescriptive provision and thus the proposed performance-based solution will acceptably maintain the health, safety and welfare of society.

Performance-based design is an iterative process. The results of one step may require the designer to reevaluate the steps performed previously. The approval of the AHJ is the terminal activity in the initial design phase. It is the decision of the AHJ to give approval or request further verification of the proposed solution.

5-4 Scope of AHJ Jurisdiction. An AHJ is "The organization, office or individual responsible for approving equipment, an installation or a procedure."¹¹ The AHJ reviews all designs prior to them being approved for implementation. The AHJ makes this ruling based on the structural composition of the building and the levels of protection it offers its occupants from fire and other emergency. In some jurisdictions there may be multiple authorities having jurisdiction: the building official (or someone performing a similar role) who would oversee the structural, mechanical and other features and systems of a building, and the fire marshal (or someone performing a similar role) who would oversee all fire protection features and systems.

5-5 Responsibilities. In situations where alternative prescriptive codes apply, the AHJ should approve only those performance-based designs which demonstrate, at a minimum, the full intent of the applicable prescriptive code. It is not the role of the AHJ to judge whether or not a prescriptive design could have been done in place of the performance-based design being submitted; only to evaluate the PB design. The AHJ must be able to recognize the limits of his design evaluation expertise and schedule. When a design surpasses those limits, the AHJ must be allowed to seek the services of a third party reviewer, at the owner's expense, to review the design on behalf of the AHJ.

5-6 *Training and Re-Education. Introducing a formal performance-based design document to the fire protection field creates the need to provide re-education and periodic technical updating for the AHJ. The AHJ must be capable of determining whether or not the design at least meets the intent of the prescriptive code where such a prescriptive code is also applicable. Further education and training will also ensure that the AHJ stays current with the technology.

Chapter 6 Third Party Reviewer

6-1 *General. A third party reviewer is a person or group of persons chosen by the AHJ to review performance-based designs (PBD) that have been submitted to the AHJ and assist the AHJ in determining if sufficient life and fire safety requirements have been met. Typically, the third party reviewer works for the AHJ, with the cost of a third party reviewer being the financial responsibility of the designer and/ or owner.

6-2 *Qualifications. A third party reviewer must be able to demonstrate experience in either designing or reviewing using performance-based documents, a good working knowledge of the documents within the jurisdiction, familiarity of the scope of the project, and experience in engineering design and fire protection issues. It is up to the discretion of the AHJ to determine if the reviewer is qualified. However, since the owner is financially responsible for the cost of the third party reviewer, the owner should have the right to object to the AHJ's choice. Selection may only be challenged if the owner feels that the reviewer chosen does not meet the qualifications mentioned previously or any other qualification the jurisdiction may require of a third party reviewer.

6-3 Limits and Responsibility. Whereas the third party reviewer is acting as consultant to the AHJ, the third party reviewer is obligated to make a thorough and fair evaluation of the design to the best of the reviewer's ability.

Part III - Technical Committee Use

This section (Part III) is included to give general Technical Committee guidance and sources of references for their documents, including a performance-based option.

Chapter 7 Technical Committee

7-1 General. Incorporating verification into an NFPA document may be the most challenging part of the performance-based conversion process for the Technical Committee (TC). The difficulty lies in that it is the one step that the AHJ is expected to want the most guidance from the document, and also that it is the step that has been the least clearly defined by the fire protection community.

7-2 Project Team. The selection of verification methods will largely be the decision of the project team. Other than in the small number of cases where approved calculation methods do exist, the TC might not specify the verification methods to be used so as to allow the designer to experience the flexibility sought in a PB design. The TC may choose to direct its audience to guidelines the TC feels should be considered in the verification method selection process or current widely used methods as appendix material.

7-3 Performance-Based Design Guide. The SFPE is currently developing a performance-based design guide intended to outline the PB design process for the designer. The guide will be used as a resource for the designer to use when designing according to performance provisions. The guide will expand on what is required in the steps of a performance-based design. More specifically it will be a useful resource for the designer in choosing appropriate verification methods. This guide is scheduled to be out for review on or after December 31, 1998.

Chapter 8 - Conclusion

8-1 General. In performance-based design, various methods or combination of methods are used to demonstrate compliance with a document. There is no limit to what these methods may be; however, there must be a way to prove that the method(s) chosen is based on sound engineering principles. In this primer, this issue is discussed by looking at different verification methods currently used, ways to determine acceptable solutions, and the final approval of a performance-based approach.

8-2 Development Process. Developing performance-based provisions is a dynamic process and not easily delineated. Although *NFPA's Future in Performance-Based Codes and Standards*¹ does provide a discussion on the document conversion process and provides steps for doing so, the order of those steps need not be taken literally.¹ Some TC's will most likely follow those steps as if they were gospel; others, for reasons of their own, will not. The point is not to worry about what comes first or what comes next. Goals, objectives, criteria, characteristics and assumptions, fire scenarios, and verification methods are all part of the performance-based package. The order in which they are developed is less important than making sure all of the pieces are in place.

Appendix A

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

A-1-1 The International Code Council (ICC) is developing a single, prescriptive building code for the United States, the International Building Code (IBC). In addition, they are also developing a performance-based IBC. Since users of NFPA performance-based documents may also encounter the performance-based IBC, this appendix is included to provide a comparison between the two organization's performance-based provisions. While many of the concepts are similar, nomenclature may not be.

A-1-4 Process. The structure of the performance-based IBC is shown in Figure A-1-4. As of the date of this primer, only the intent, scope, objectives, functional statements, and performance requirements will be in the performance-based IBC. The IBC Performance Committee (ICC PC) essentially used a top-down approach with the New Zealand Building Regulations 1992 as a model. The status of criteria, guidelines, and acceptable solutions is uncertain. However, it is recognized that the prescriptive IBC will provide acceptable solutions until performance-based solutions can be developed.

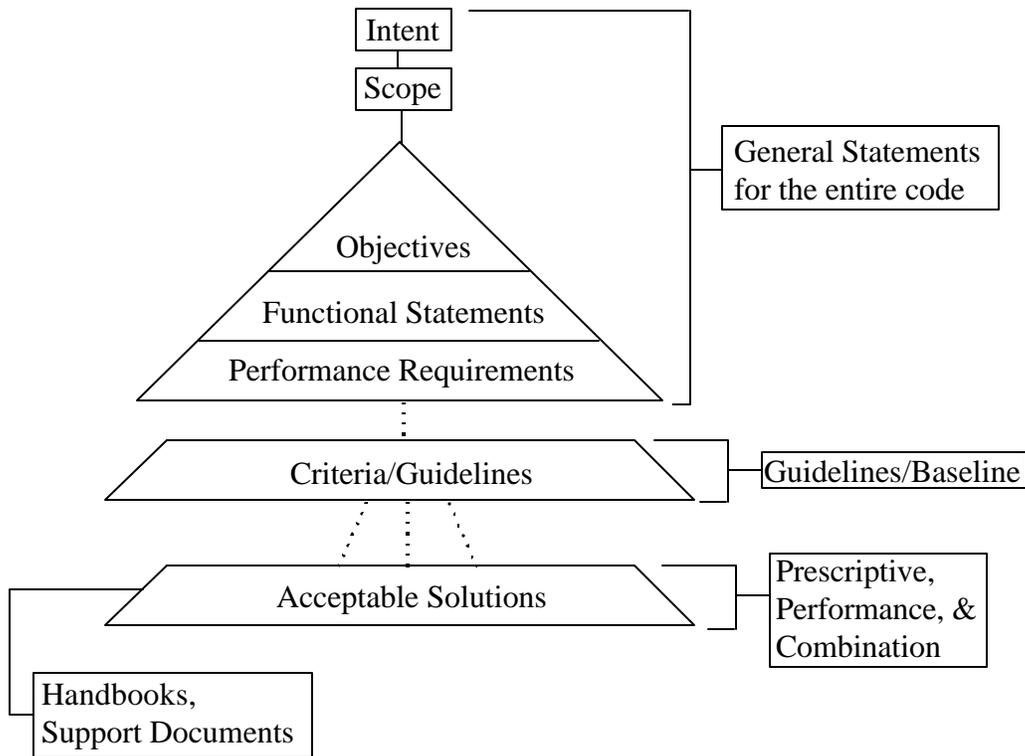


Figure A-1-4. Performance-Based IBC Structure

A-2.1 Bottom-Up. It is called "bottom-up" because it works "up" from the established prescriptive language to infer the goals, objectives, and other statements that justify the prescriptive language.

A-3.4 Because of the specified scope of some of the Technical Committee's there may not be a verification method listed in this document or currently available in the field that suits the needs of these special issues. The best solution may be a creative mix of solution methods.

A-3-3 It is important to note that using a verification method is not as simple as inputting a value, executing the method and getting an answer. The results obtained from a verification method are not the only answer to a problem. More often the results obtained from one tool are used as input into another. It cannot be stressed enough that this phase of the PB process is highly iterative and complex.

A-3-4.1 Figure 3-3 shows three categories of input. Examples of each are shown in Figure 3-4.1. It is important to understand that although these figures depict Assumptions, Scenario Data and Design Specifications as being three different categories there is a considerable amount of overlap among the three categories. For example, in Figure 3-4.1, ventilation is listed as falling under the scenario data category. As a piece of scenario data information about ventilation in the area of origin is very important. If the wrong ventilation information is used in a fire scenario then the scenario is inaccurate. However, ventilation information is also a design specification. It is in the design specifications that the designer will find the information regarding the ventilation characteristics and if those design specifications change so does the fire scenario. Many times the code being used (be it prescriptive or performance-based) will specify certain conditions be met. These code regulations can be directly related to ventilation systems (ranging from mechanical systems to doors and windows). Other times the designer must make certain assumptions about the ventilation when developing scenarios (e.g., Is the door open or closed?). Whether it is a code requirement or a project team assumption it becomes a fixed assumption in the project.

Distinguishing whether a design specification or scenario data is a fixed assumption or a variable piece of input primarily is the duty of the project team. The Technical Committee's role in all of this is to understand this complicated relationship and set those code requirements that they feel should remain fixed in a design solution using their document without impinging on the freedom of the project team afforded in performance-based design.

A-3-4.2 When verifying a design it is important to be as accurate as possible. For this reason more than one method should be applied to the design, several times each, to establish a range of results.

A-4-2 The more sophisticated a tool (i.e., computer models) is, the more assumptions and simplifications the tool will be based on. Because of this, misuse of the tool by an inexperienced user is more probable (although all users are susceptible to misuse). Proficiency in using sophisticated tools, like computer models, comes with experience. Other Technical Committees, already considering a PB approach, have decided that the level of experience of the designer is an important factor in the verification process and have required it be documented in the proposed solution to the AHJ.

A-4-3.2 Raymond Friedman wrote an overview of various computer fire and evacuation models and issues to consider when using these tools. (Friedman, Richard. "An International Survey of Computer Models for Fire and Smoke", *Journal of Fire Protection Engineering*, Vol. 4, No. 3, 1992, pp. 81-92.) The article focuses more on fire models than evacuation models but serves as a good reference to better understand the issues surrounding the use of computer models in a fire scenario analysis.

The Fire Protection Handbook, Section 11 Chapters 4 and 5 can also be referenced.

A-4-3.2.2 Typically, field models are expensive to purchase, have a steep learning curve, and may take hours or days to run a single scenario (depending on the complexity of the geometry). They are more likely to explicitly model combustion, but usually still rely on a user specified fire.

A-4-3.2.4 Zone models can predict flows into and out of rooms, heat transfer to enclosure surfaces and convection out of the room, time to ignite a second item, plume flow, gas temperatures under the ceiling, etc. Purpose built models may predict, e.g., only gas temperature, only the time at which a window breaks, or only the upper layer temperature.

A-4-3.6.2 Experiments are typically carried out to explore how varying different aspects of a scenario may affect the outcome of a fire. The key to using experimental data as a verification method for a specific scenario is determining how similar is similar enough.

A-4-3.6.5 The start-up test being the initial operation of a system, immediately after system completion/installation; i.e., an in situ commissioning test.

A-4-4 The following sources contain information on various probabilistic tools. This list is a point of reference and not complete. It should not limit the use of other probabilistic tools:

-*The SFPE Handbook of Fire Protection Engineering, 2nd edition*, NFPA and SFPE, 1995.

- Section 1 / Chapter 11, 12
- Section 3 / Chapter 15
- Section 5 / Chapters 2,3,4,10,11,12

- *The Fire Protection Handbook, 18th edition*, NFPA, 1997.

- Section 11 Chapter 6, 8 11

- *NFPA 101A - Alternative Approaches to Life Safety*, National Fire Protection Association, Quincy, MA, 1998.

A-4-5 A heuristic tool is one that can be easily manipulated to produce misleading results. Although these tools can be applied following scientific methodology they are not mathematically based, therefore, reproducing the results of one designer by another is not likely. Heuristic tools should be used in conjunction with deterministic or probabilistic tools.

A-5-2.2 The NFPA defines the word 'approved' as that which is "Acceptable to the Authority Having Jurisdiction." However, the terms 'acceptable' and 'approved' cannot be used synonymously because in this context they are mutually inclusive. Using sound engineering judgment and by double checking, a performance-based design or step in the process can be deemed acceptable to submit it to the AHJ for approval.

A-5-3.1 As an example, in New Zealand the designer submits a fire design report to the AHJ. Several problems with the fire design reports are identified in Caldwell's paper. They are listed below in Table A-5-3.1.¹² Building off of lessons learned from the performance-based initiative in New Zealand, TC's should pay particular attention to the documentation requirements they implement. Addressing areas seen as inadequate in New Zealand might help to avoid those same problems from reoccurring. Detailed fire design reports will also be invaluable to the AHJ and any reviewer the AHJ may hire. In the performance-based process, documentation requirements provide a simple framework for the AHJ to follow in the review process.¹²

Category	Concerns
Presentation	<ul style="list-style-type: none"> -lack of structure -information hard to locate within report -lacking information and input used to reach conclusions necessary for the design to be reviewed
Scientific Basis	<ul style="list-style-type: none"> -improper assumptions -inconsistency on the use of acceptable references
Design Criteria	<ul style="list-style-type: none"> -unclear or unstated objectives - no explanation of how objectives are satisfied -criteria missing -scenarios not defined or not compatible with scope -criteria unsupported by proper reference
Consistency	<ul style="list-style-type: none"> -inconsistency in interpretation of Acceptable Solutions - no standard framework for submittals -Variance among cities as to who is qualified to submit a design
Responsibility	<ul style="list-style-type: none"> -not clear who is responsible for the fire design (architect, person who did the fire design, or the engineer of record) -person who performed the fire design is not always named in the design report

Table A-5-3.1 Fire Design Report Concerns

A-5-6 Performance-based designs are expected to be more technically complex and require a longer evaluation. An AHJ should be able to meet the requirements of a Fire Inspector Level I (minimum) found in NFPA 1031 - Professional Qualification for Fire Inspector, or equivalent, before being given the authority to approve performance-based design work.

A-6-1 The use of a third party reviewer is one link in making the transition from strictly prescriptive designs to designs created from a combination of prescriptive and performance documents. While making this transition there are obstacles that must be overcome. Often, AHJ's do not have the technical background to approve performance-based designs. The NFPA is in the process of developing a certification program for fire inspectors based on NFPA 1031. It is a step in the right direction to insure that AHJs will be properly qualified to give approval

to designs of both performance and prescriptive origin. However, until that time, there still needs to be a comprehensive check of the work performed by the designer of record.

The practice of bringing in a third party is not new nor is it exclusive to fire protection engineering. However, as it begins to occur more frequently, a much needed framework must be put into place to define the qualifications and responsibilities expected of the third party.

Third party review is not the only way to ensure a proposed solution meets all the requirements and provisions necessary to provide adequate safety. The same level of assurance could be reached by means such as having calculation tools approved for certain applications. This would be similar to the way in which approval laboratories (i.e., UL, FM, etc.) approve the calculation methods used for Halon 1301 systems. Another way would be to require designers to have credentials that show they are qualified to use performance-based methods (e.g., professional engineering license). These and other examples are potential alternatives to the third party review stage, but they are currently only conceptual and will take time to develop.

A-6-2 As a case study, currently in New Zealand there are no guidelines as to who is qualified to act as a third party reviewer. There is concern over this lack of consistency. There are also several questions that have been raised as result of the absence of a standard procedure. For example, does the reviewer just determine if the solution is correct or review the entire process including the solution? There is also no reporting format that the reviewer must follow to show how they conducted the review, what was reviewed, and what sources the reviewer used. Propriety issues regarding new ideas and techniques have also not been addressed.¹² However, despite its remaining challenges it is a system that is working in New Zealand.

These are all issues that the TC needs to be aware of. Third party review is not a perfect system and there are issues yet to be resolved. As the US makes the shift to performance-based design, as New Zealand already has, it is important to keep these issues in mind and try to bring them to some resolution.

Appendix B - Reference Publications

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

1. *NFPA's Future in Performance-Based Codes and Standards*, National Fire Protection Association, Quincy, MA, July, 1995.
2. *Bottom-Up Analysis of National Codes*, Canadian Codes Centre, September 1996.
3. *Webster's Ninth New Collegiate Dictionary*, Merriam- Webster Inc., Springfield, MA, 1991.
4. Friedman, R., *Survey of Computer Models for Fire and Smoke*, 2nd ed., Factory Mutual Research Corporation, Norwood, MA, 1991.
5. *Computer Software Directory*, Society of Fire Protection Engineers, Bethesda, MD, 1994.
6. <http://www.brfl.nist.gov/forum.html> - Forum for International Cooperation in Fire Research - International Survey of Fire Models.
7. Interflam 96 - Seventh International Fire Science and Engineering Conference. St. John's College, Cambridge, England. 26-28 March 1996.
8. First International Symposium- Human Behaviour in Fire. University of Ulster, Ireland. September 1998.
9. Proceedings of the Fifth International Symposium - Fire Safety Science. International Association of Fire Safety Science. Melbourne, Australia. 3-7 March 1997.
10. Fire Engineering Design Guide, A.H. Buchanan editor. University of Canterbury: Christchurch, NZ. 1994. p11
11. Regulations Governing Committee Projects, 3-3.6.1. *1998 NFPA Annual Directory*, National Fire Protection Association, Quincy, MA.
12. Caldwell, Carol A. "Fire Engineering Performance Based Design Guidelines for Design Submittals and Reviews". 1998 Pacific Rim Conference and Second International Conference on Performance-Based Codes and Fire Safety Design Methods, May 3-9, 1998, Maui, Hawaii USA. Proceedings. pp. 339-346.

Performance-Based

Primer #5

Reliability

National Fire Protection Association
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Quincy, MA 02269-9101 USA

Preface

This primer (Primer 5) has been developed by the NFPA Performance-Based Support Team (PB Support Team). The PB Support Team functions under the auspices of the NFPA Standards Council, and reports directly to the Council on an on-going basis. The PB Support Team was created in 1995 to assist NFPA Technical Committees with the transition to performance-based documents.

Primer 5 is the fifth in a series intended to provide NFPA Technical Committees with guidance and information on how to write a performance-based NFPA code, standard, or similar document. This primer is based on the report of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models' entitled *NFPA's Future in Performance-Based Codes and Standards*. This report, released in July 1995 and developed in conjunction with the NFPA Board of Directors, implies the need for the development of further guiding information for NFPA Technical Committees. Primer 5 is one step to fill this need for further guiding information.

It is anticipated that this primer will undergo future changes as they are developed. Any comments on the primer should be sent to:

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Attn.: Standards Council Secretary
1 Batterymarch Park
Quincy, MA 02269-9101

NFPA Technical Committee PB Primer # 5

PERFORMANCE-BASED

RELIABILITY

Draft 2 15 DECEMBER 1999

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NFPA Performance-Based Primer

Performance-Based Reliability

1999 Edition

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

Part I - Information

This section (Part I) provides general information to the Technical Committee regarding the Primers and terms used within the Primers.

Chapter 1 General Information

1-1 *Primer Purpose. The purpose of this primer is to serve as a resource for NFPA Technical Committees during their efforts in developing performance-based provisions and incorporating them into NFPA documents. This primer can be used to develop new stand-alone performance-based documents or to develop performance-based options in existing or future documents. "Document" is used as a collective term for codes, standards, guides, or recommended practices and may refer to any of the four. Additionally, the term "Performance-Based Document" is used throughout this primer, and this phrase includes documents that are either entirely performance-based, or a combination of performance and prescriptive provisions.

1-2 Primer Scope. This primer discusses the issue of reliability, and how it can be incorporated into performance based codes and standards by NFPA Technical Committees. The Technical Committee should focus on the reliability of active and passive systems directly related to the purpose and scope of the committee's document that must be considered by designers and Authorities Having Jurisdiction. This primer is one of six stand-alone primers that serve as resources for NFPA Technical Committees for the development of performance-based provisions.

1-3 Origin. This primer is the direct result of the efforts of the NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models and the report they produced [1]. This primer is based in part on that report and provides an expansion of the concepts contained therein. It is anticipated that the primer will undergo future changes as they are developed.

1-4 Process. As shown in Figure 1-4, there are two distinct, although not exclusive, approaches to developing performance-based provisions. The top-down approach is described in [1] and the bottom-up approach is taken from [2].

1-4.1 A total of six primers are either planned or completed:

Primer #	Title	Status
1	Goals, Objectives & Criteria	Available
2	Characteristics & Assumptions	Available
3	Fire Scenarios	Available
4	Performance-Based Verification Methods	Available
5	Reliability	Available
6	Overview of Performance Approach	In Process

Additional Primers may be developed as needed to address topics, e.g., computer fire modeling, risk management, etc.

1-5 Clarification.

1-5.1. Due to the wide variety of topics covered by NFPA documents, it is difficult to address each topic specifically in this primer. These topics include buildings, systems within buildings, building features, vehicles (including boats and ships), outdoor property, people, and products. Therefore, in this primer “building” will be used to generally indicate the topic of a given NFPA document.

1-5.2. NFPA performance-based codes and standards are intended to be dual track documents, and they will contain both prescriptive and performance-based provisions. However, guides may be entirely performance-based. Because of this, “performance-based document” will be used in a generic sense to refer to any NFPA document containing performance provisions.

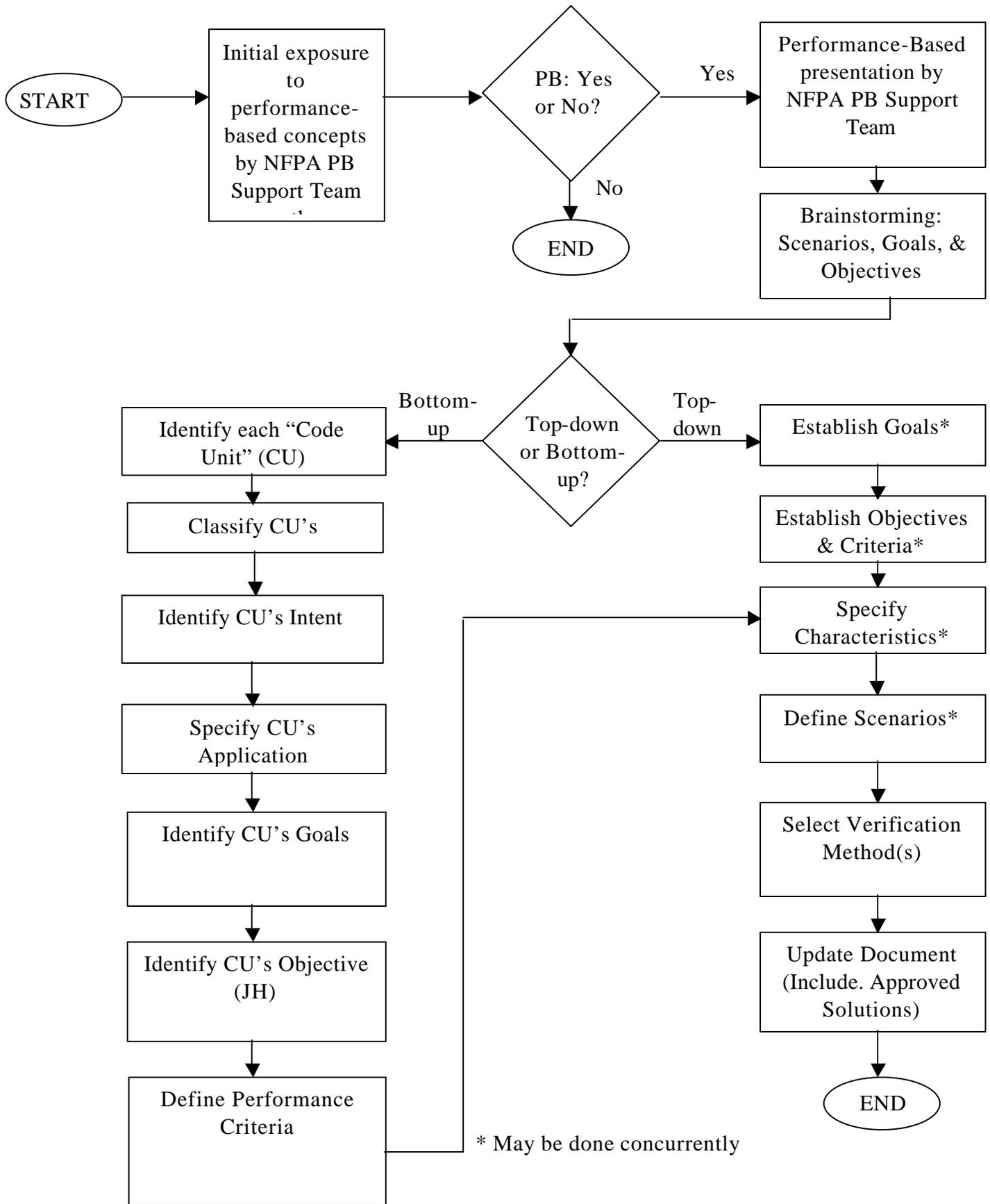


Figure 1-4. Performance-Based Document Development

Chapter 2 Glossary

2-1 General. The following terms are presented to help provide a consistent vocabulary. Definitions of the following terms are taken from [1], unless otherwise noted.

Acceptable. That which has adequately satisfied specified performance criteria. The AHJ holds the final decision on whether or not a design or portion of a design is acceptable.

Approved Method. Authoritative procedure used to develop proposed solutions. A more commonly used example of approved methods are contained within prescriptive documents.

Assumptions. Specifications related to the building, ambient conditions, and surroundings, which do not vary across individual fire scenarios. Examples include ambient pressure and temperature in the building, or fire department response.

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

NOTE: The phrase “authority having jurisdiction” is used in NFPA documents in a broad manner because 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.

Bottom-Up.* One approach used to develop performance-based provisions. Using this approach, the goals, objectives, characteristics, and scenarios of a document that are unstated prior to document revision processing are identified and explicitly stated.² See "Top-down".

Calculation Method.* A description of a system or phenomenon in terms of relationships among elements, permitting study of how some elements vary when other elements are changed. A calculation method normally consists of one or more mathematical relationships, permitting calculation of some elements based on their relationship(s) to other elements. Note that fire science and engineering use "model" as a synonym to calculation method but also for other concepts and elements such as scale models.

Computer Model. A calculation method that is packaged as computer software.

Fire Effects Model. A calculation method that incorporates engineering and scientific principles and applies them in a logical manner to determine

possible consequences and extent of physical effects based on an externally specified fire, expressed as heat release rate as a function of time. (Typically referred to as a "fire model", even though it may not model combustion .)

Evacuation/Egress Model. A calculation method used to describe the behavior and movement of people during a fire situation. May be used in combination with a fire effects and typically incorporating them to determine whether or not occupants may safely escape.

Computer Fire Model. A calculation method that is packaged as computer software and used to predict fire behavior

Characteristics. Qualities of the occupants, building contents, potential fuel packages, process equipment, and facility features and systems. The focus is usually on those characteristics that should be considered when developing a performance-based fire protection design or performance-based provisions for NFPA documents.

Code (Document) Unit. The smallest portion of a code (i.e., a document) that can have an intent and application statement attached to it.² Each code unit is a definable concept having a type, an intent, application (e.g., "application and limitations of the application of the provision such as occupancy, building height, sprinklered/nonsprinklered building, etc.") and one or more objectives.

Design Fire. Component of a fire scenario, consisting of a detailed description of the fire, but excluding any outside conditions or factors regarding the building occupants and other aspects of the design that may impact the fire development and/or severity. This description of the fire should include crucial information such as the fire's size, growth rate, heat release rate, and other related fire properties.

Design Specification.* The aspects of the building design which will impact the fire safety analysis, such as floor area and layout, sprinkler density, building height, ventilation system flow rate, etc. expressed in engineering units.

Design Team. Group of stakeholders including, but not limited to, representatives of the architect, client, and any and all pertinent engineers and other designers. A stakeholder is an individual, or representative of same, having an interest in the successful completion of a project.

Fire Safety Goal. Overall outcome to be achieved with regard to fire. Goals are non-specific and are measured on a qualitative basis. They should be stated in terms of conditions that are intrinsically desirable and do not rely on any assumptions. Goals should be stated in terms that are potentially measurable, even if the precise measurement scale is not specified. Thus, goals may be expressed in terms of impact on people, property, or the

environment, or in terms of mission continuity. A single goal may be applicable to many different NFPA documents.

Fire Scenario. Quantitative description of a fire and any factors affecting or affected by it from ignition to extinguishment; including ignition sources, nature and configuration of the fuel, ventilation, characteristics and locations of occupants, condition of the supporting structure, and conditions and status of operating equipment and fire protection systems. Usually used more narrowly to describe initiating conditions for use with a model, test procedure, or other method used for deriving conditions at later stages. The term "design fire" is used even more narrowly to refer to initiating conditions of the fire, those thus excluding most characteristics of the larger building environment the fire may grow into, occupants, and building systems and features.

Functional (or Performance) Requirement. A statement indicating how the building (system, etc.) must perform in order to achieve the stated objectives and goals; typically, a further refinement of an objective, if needed. For example, to achieve the life safety goal with a smoke control objective, a functional requirement could be "The level of smoke shall remain above the heads of evacuees using either a natural or forced ventilation smoke management system."

Owner. The party who holds financial responsibility for the project and to whom professional services are rendered.

Performance-Based Design Approach. A design process whose fire protection solutions are designed to achieve a specified goal for a specified use or application. This process allows performance-based documents to be implemented and insures that their goals are met.

NOTE: The following describes a performance-based design approach:

- a) Establish fire safety goals.
- b) Evaluate the condition of the occupants, building contents, process equipment, or facility in question with regard to fire protection.
- c) Establish performance objectives and performance criteria.
- d) Identify potential hazards to be protected against.
- e) Define appropriate scenarios.
- f) Select suitable verification methods (e.g., fire models).
- g) Develop trial solutions.
- h) Assess proposed solution.
- i) Document proposed solution along with supplementary information.
- j) Obtain approval of the proposed solution.

Steps a) through f) are also part of the development of a performance-based code or standard. Only steps g) through j) are specific to performance-based design, where the intent is to find a solution for the project. Also, steps c), d), and e) are not necessarily

intended to be sequential; they may in fact be concurrent. While the above is presented in a sequential order, the design approach does not necessarily need to begin with step a) and proceed consecutively through step j). Since different stakeholders (e.g., owner, designer, authorities) must be satisfied, some steps of this approach are iterative. Similarly, for performance-based document development, steps a) through e) may or may not be taken sequentially.

Performance-Based Document. A code, standard, or similar document that specifically states its fire safety goals and references approved methods that can be used to demonstrate compliance with its requirements. The document may be phrased as a method for quantifying equivalencies to an existing prescriptive-based document and/or it may identify one or more prescriptive documents as approved solutions. Furthermore, the document allows the use of all solutions that demonstrate compliance using approved methods.

NOTE: A performance-based document may also include separate prescriptive provisions as a parallel, independent approach to meet the performance-based goals and objectives.

Performance Criteria. Performance objectives for individual products, systems, assemblies, or areas that are further quantified and stated in engineering terms (e.g., temperature, radiant heat flux, level of exposure to combustion products). Performance criteria provide pass/fail threshold values which are treated as data for calculations used to qualify a proposed performance-based solution.

Performance Objective. Requirement for the fire, building, or occupants (or combination thereof) that must be satisfied in order to achieve a fire safety goal. Objectives are stated in more specific terms than goals and tend to be more quantitative than qualitative. Objectives may be thought of as specific goals for individual NFPA documents

Prescriptive-Based Document. A code or standard that prescribes fire protection for a generic use or application. Fire protection is achieved by specifying certain construction characteristics, limiting dimensions, or protection systems without providing a mechanism for how these requirements achieve a desired fire safety goal. Typically these documents do not state their fire safety goals.

NOTE: Many current NFPA codes and standards are not strictly performance-based or prescriptive-based: technically, they can be referred to as prescriptive documents containing some performance provisions. For example, a requirement for a one-hour door sets a measurable performance criterion, going beyond prescription of the door's construction, but does not link the criterion explicitly to a fire safety goal.

Project Team. The design team and the Authority Having Jurisdiction. The AHJ may have no formal or legal responsibility for the design but should be involved at every stage of the project. This ensures the greatest chance for a successful project.

Proposed Solution. A fire protection system design intended to achieve the stated fire safety goals and which is expressed in terms that make it possible to assess whether the fire safety goals and objectives have been achieved. If models are used, then the proposed solution should also specify the models and input data employed.

Safety Factor. Adjustment made to reflect conservatism due to uncertainty in the methods and assumptions employed in measuring performance. A safety factor is not part of the process of setting acceptable levels of safety as a function of allowable risk, as it only reflects the uncertainty regarding the precision of the calculation.

Scenario Data. Specific data, related to each design fire scenario and expressed in engineering terms or conditions, which can be used as input for the design tool or verification method by the designer. The scenario data should be those aspects of the fire scenario relating to the fire itself, including, but not limited to the design fire, fire location, and any other aspects of the fire that need to be input into the verification method being used by the designer.

Top-Down. One approach used to develop performance-based provisions. Using this approach, the goals and objectives are developed during document revision processing without consideration of any current prescriptive requirements: a “clean sheet of paper” approach. See "Bottom-up".

Verification. Confirmation that a proposed solution (i.e., candidate design) meets the established fire safety goals. Verification involves several steps. Verification confirms that the building is built as proposed to a design that will achieve the intended level of safety and that the building's ability to achieve the level of safety has been demonstrated by qualified people using the correct methods applied to the correct data.

Verification Method. A computer model or other tool or method used to demonstrate that a proposed solution meets the fire safety goals for the applicable design fires. The designer can use any type and number of acceptable verification methods to evaluate the effectiveness of the design.

Part II - Background

This section (Part II) discusses the nature of reliability and its relevance to engineered design. NFPA Technical Committees need to address reliability in their document so that AHJ's and designers can have a shared basis for agreeing that a design is sufficiently reliable. How Technical Committees can present this information in their document is discussed in Part III.

Chapter 3 Reliability in Performance Based Design

3-1 Purpose. No design feature is totally reliable. Traditionally, acceptable design reliability has been achieved through a combination of standards and procedures to achieve acceptable reliability for each design system or feature and through redundancy requirements, that is, prescriptive requirements for the inclusion of multiple systems and features that might not all be necessary for safety if one could be sure that all would perform as designed in any fire. The challenge is to address legitimate reliability concerns in a performance-based environment without mandating needlessly expensive inspection, maintenance, or redundancy requirements.

3-2 Definitions. When referring to reliability throughout this document the following definitions will be used:

3-2.1 Basic Engineering Definition. Statistical and engineering references all define "reliability" for engineering purposes as some variation of the following: "the ability of an entity to perform a required function under given conditions for a given time interval." [3]

3-2.2 NFPA Context. In this context "reliability" is used to establish the accuracy of the designer's claim that a proposed solution not only will meet the established fire safety goals, objectives and criteria if the design performs as intended, but that the design will perform as intended -- or close enough -- with sufficiently high probability. It may be useful, in making distinctions, to use the term "operational reliability" to refer to the likelihood that a system or feature will perform at all in response to a need, and the term "performance reliability" to refer to the likelihood that the system or feature will respond effectively and appropriately in response to a need, given that it has performed at all.

In other words, there are two components to reliability, which may be illustrated with fire pumps. First, the fire pump must start when commanded to do so (operational reliability). Second, the pump must provide a specified pressure and flow for a specified period of time or otherwise effectively perform its mission as designed (performance reliability).

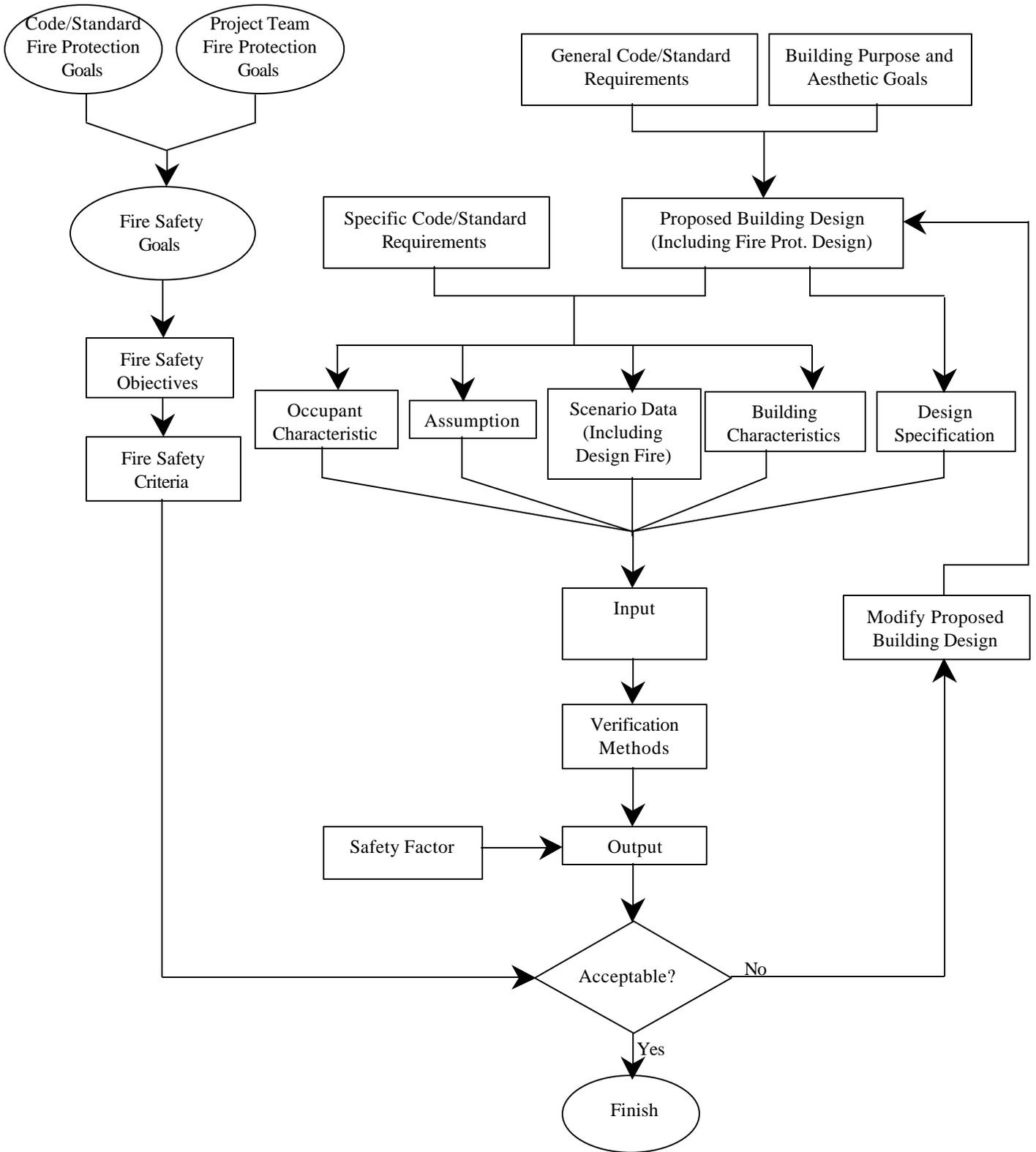
3-2.3 Definition Scope. Reliability is not limited to all-or-nothing failures. Any deviation from designed or intended performance constitutes less than perfect reliability, but it may be overly conservative to evaluate partial failures as if they were complete failures.

3-3 Equipment vs. Human Reliability. Reliability is not entirely, or even primarily, about mechanical or electrical reliability. For most design features and systems, the leading cause for failure to perform as designed during a fire is some human error or oversight that partially or totally defeats the feature or system. Shutting off the main sprinkler valve for maintenance and not remembering to turn it back on is an example related to active suppression systems. Disabling a home smoke alarm because of frustration over nuisance alarms is an example related to active detection/alarm systems. Blocking doors open or poking holes in walls are examples related to passive protection features. Failure of staff to perform their designated roles in containing fires or supporting evacuation is an example related to assigned roles of people in support of the design.

3-4 Active System vs. Other Reliability. Reliability concerns are not limited to active fire protection systems or even to built-in or physical features and systems. Any specification in a design and any assumption regarding manufacturing, construction, installation, maintenance, operation, supporting behavior, or any other aspect or phenomenon whose success is expected to contribute to the achievement of fire safety objectives will have an associated reliability, consisting of the probability that that aspect will perform as designed, intended, or expected in fire.

3-5 Liability Concerns. There will be concerns that explicit acknowledgement of less than perfect reliability is an invitation to liability. It is more likely that failure to acknowledge – and address – less than perfect reliability is an even more sure invitation to liability. From a design standpoint, the reliability issue will not go away just because it has not been explicitly acknowledged. The Technical Committee’s intentions with regard to safety in their area of responsibility will be far clearer and more likely to be accurately and fully implemented if the committee has made its views known on reliability.

3-6. Incorporating Reliability Into a Performance-Based Assessment. Figure 3-6 depicts the elements of a performance-based design. Reliability is not explicitly shown, but it may be addressed at any or all of the calculation points in the assessment shown in Figure 3-6, including but not limited to the proposed building design, the development of adequate fire scenarios and the appropriate scenario data, or the specification of appropriate assumptions.. No matter where it is addressed, reliability can be the basis for deeming a proposed design unacceptable (in the diamond at the bottom), which will require a modification to the design before it is submitted again.



*Figure 3-6 Performance Based Design Process

3-6.1 Addressing Reliability Through Scenarios. Reliability can be addressed in the development and specification of scenarios if specification of the status of design systems, features, and aspects is part of the scenario development exercise, by having some of the selected scenarios specify impaired, or less than perfect, status. Scenarios can be defined to “fail” different systems or features individually, and a series of scenarios can be used to work through all the main systems or features and assess the impact of unreliability for each one. Or, scenarios can be designed to “fail” more than one system or feature at a time, which is a more severe test of overall redundancy. This may be justified if, for example, the failure of one system poses a significant threat of failure to another system or feature, or if external common causes (e.g., earthquake) can cause simultaneous failure of more than one system or feature.

3-6.2 Addressing Reliability Through Objectives. Reliability can be addressed in the objectives by requiring an acceptably high level of reliability as one or more of the objectives. This may require specification of a practical means for measuring or estimating design reliability.

3-6.3 Addressing Reliability Through Assumptions. Reliability can be addressed in the assumptions by assuming a level of reliability, but such assumptions ought to be substantiated by some form of direct evidence. By contrast, a blanket assumption that all design elements are reliable, without any direct evidence, is tantamount to ignoring the reliability issue entirely. Since reliability is a real issue with any design and associated analysis, the reliability issue must be addressed somewhere. If it is not addressed within the code or standard, there should be some formal acknowledgement of where and how it is expected that the issue will be addressed (e.g., in referenced standards for installation and maintenance, or possibly in product standardization requirements falling outside the NFPA system).

3-6.4 Addressing Reliability Through Verification Methods. Some verification methods, notably full fire risk assessments, permit the designer, with approval from the AHJ, to calculate the impact of reliability on the estimated fire safety performance of a design. This is usually a variation of addressing reliability through scenarios, but it includes the use of measured or estimated reliability probabilities to combine design performance in perform-as-designed scenarios with performance in not-perform-as-designed scenarios into an overall measure of design merit. That is, use the verification methods to calculate fire safety performance when the system or feature is reliable (works as designed) and fire safety performance when it is not reliable (does not work at all or does not work as designed), then combine the two using an externally calculated probability of reliability.

3-6.5 Addressing Reliability Through Factors of Safety. Safety factors can sometimes be used mathematically to address reliability, but it is important to understand that that is not the purpose behind safety factors.

For example, suppose a hotel design is being evaluated for its ability to protect guests from a couch fire in the lobby. There is uncertainty involved in measuring the actual burning properties of the couch. There is uncertainty in the characterization of air flow and of other physical characteristics of the room of fire origin. And the calculation method used to estimate the development of fire hazard may introduce modeling uncertainties. All these sources of uncertainty can be studied in an uncertainty or sensitivity analysis and can be offset by safety factors defined as multipliers on fire severity or on the time required to reach certain stages of fire development. But they are not the same concerns as the possibility that the detection/alarm or sprinkler system will be disabled when the fire begins, that doors to the lobby will be blocked open, or that staff will fail to react as they are expected to react.

Using safety factors to address reliability implicitly assumes that the effect of the feature or system unavailability or unreliability takes the same form as a quantitative change in the performance of the feature or system when operational. This is dubious at best. It is not clear that the effect of disabling the detection/alarm or sprinkler system will be the same as the effect of a delay in the time of activation of those systems or a reduction in the speed with which operating sprinklers control fire. It is more reasonable to assume that the effect of blocking open the lobby doors can be reflected in a safety factor on the speed of spread of fire effects.

Generally speaking, though, treating reliability through safety factors is mixing apples and oranges, and should be discouraged, or if not discouraged, carefully scrutinized to see whether the real issues of reliability are captured and addressed. Do not assume that a sufficiently large safety factor will render moot the reliability concerns of all the individual systems and features. If a large safety factor accomplishes that goal, it will be a lucky side effect and not the purpose or intended effect of the safety factor.

Chapter 4 Methods of Addressing Reliability

4-1 Reliability in a Risk Analysis versus Hazard Analysis Framework. A performance-based assessment of a building may be done in either a risk analysis or a hazard analysis framework. In a risk analysis framework, all possible scenarios are considered through analysis of the probability and severity of a representative group of scenarios. In such a framework, reliability concerns become simply one more set of characteristics to consider in defining scenarios, and the impact of reliability on the design's performance is picked up naturally in the analysis. More commonly, however, engineers will use, and performance-based codes and standards will employ, a hazard analysis framework.

4-1.1 Probability Thresholds in a Hazard Analysis Framework. In a hazard analysis framework, probabilities are not considered directly. Safety is assured when it is possible to give a satisfactory answer about the design for any scenario. The answer for most scenarios is: The design achieves the specified fire safety goals, objectives, and criteria for the scenario as demonstrated by application of an appropriate verification method, using appropriate assumptions, to either that scenario or to a similar scenario that is more challenging. The answer for some scenarios is: The design cannot assure achievement of the fire safety goals, objectives and criteria for this scenario but should not be required to because the scenario is so unlikely or has been explicitly declared outside the scope of the requirements, usually because the code- or standard-writers deemed it to be technically infeasible or unacceptably costly to meet the goals, objectives and criteria for that scenario. If low probability is the reason for not incorporating a scenario into the evaluation, then there is an implied minimum threshold of probability that is part of the code's definition of acceptable risk and acceptable safety.

Thresholds also may be embodied in the objectives (e.g., NFPA 101, *Life Safety Code*, 2000 Edition, does not require protection of people intimate with ignition because the reasonable choices available to designers cannot assure such protection). Thresholds also may be embodied in the assumptions (e.g., in NFPA 101, *Life Safety Code* provisions for residences, occupants are assumed to be capable of acting effectively to respond to a fire by evacuating, even though it is known that a fraction of the population living at home lack such capability). Each threshold corresponds to a minimum or maximum condition with an associated implied probability.

4-1.2 Reliability as a Probability Threshold in a Hazard Analysis Framework. If it is reasonable to regard acceptable safety as the assurance that fire safety goals, objectives, and criteria will be met for all fire scenarios likely enough to justify attention, then a system or feature failure, partial or complete, is a rare event that makes an already unlikely fire scenario even more unlikely. To bring the scenario back to the implied minimum probability threshold, some other aspect of the calculation must be made more likely. This is a mathematical argument (based on equivalent risk) for relaxing the scenario, the

assumptions, or the goals, objectives, and criteria when evaluating a design's performance under partial or complete failure of a system or feature.

A less severe initiating fire would qualify as such a relaxation. So would less conservative assumptions about occupants or other relevant conditions not part of the design. And a less ambitious goal, achieved by reducing the scope of potentially affected people or property who must be saved for the design to be successful, could also be handled in this way, even if such a modification does not involve probabilities in as obvious a fashion.

It is also possible to assume that a certain level of reliability, high but less than perfect, is implicit for each system, feature, and aspect in the current prescriptive codes and standards. A performance-based assessment of an alternative design should be evaluated against that baseline, not a baseline of prescriptively required systems, features, and aspects, all with perfect reliability. Each of the elements of performance-based assessment where reliability can be addressed corresponds to a particular practical method of addressing reliability.

4-2 Addressing Reliability Through Scenario Design. A common engineering practice is to test a design, first with all systems and features operating as designed against a specified fire scenario, then successively with each system or feature individually removed from the design, or at least reduced in effectiveness. For a performance-based code or standard, this common engineering practice can be made mandatory by specifying one or more scenarios in which each major fire protection system or feature, in turn, is removed from the design or reduced in effectiveness. This is the approach to reliability adopted by the Committee on Safety to Life in the year 2000 edition of NFPA 101, *Life Safety Code*. In this approach, the initiating fire or other assumptions are made less severe to keep the overall scenario probability comparable to that for other scenarios.

The advantages of this approach are that it seriously treats reliability concerns, that it uses the already established performance-based analysis framework and so does not require any new methods or data sources, and that it provides strong incentives for redundancy.

The disadvantages of this approach include the following: It gives no credit for reliability that is very high but still less than perfect, and so this approach provides no incentive to achieve higher reliability. It tends to encourage consideration of total failure events over partial failure events, no matter how great the difference in probability is between total and partial failure. Some systems or features may be so essential to designs for some facilities that their removal will leave no reasonable way to achieve the goals, objectives, and criteria, if those remain unmodified. Finally, if you follow the logic of this approach to its conclusion, you would have to consider simultaneous failures of multiple systems and features; in such scenarios, even traditional redundancy might not be sufficient.

4-3 Addressing Reliability Through Assumptions. The simplest way to address reliability through assumptions is to assume that all systems and features are reliable. The advantages of this approach are its simplicity and the fact that this assumption is implicit, to a large degree, in many of the prescriptive codes and standards -- all those without provisions for assuring reliability or for significant redundancy. The disadvantages of this approach are that it does not really address reliability in any meaningful sense, and that it creates substantial incentives to reduce redundancy for cost reasons and to accept low reliability in individual systems or features, either inadvertently or to save money on the programs required to assure high reliability.

A more substantive way to address reliability through assumptions is to create a two-track approach. Any design providing evidence or assurances of reliability and redundancy equivalent to those in a design compliant with the prescriptive code or standard will be assumed to have acceptably high reliability and sufficient redundancy. No further analysis or proof of acceptability on reliability grounds will be required. Any design not providing such evidence or assurances is required to address reliability more directly and explicitly, for example, through analysis of designated scenarios.

The advantages of this approach are that it seriously addresses reliability concerns, and that it makes maximum use of established codes and standards and the expertise they embody on acceptable, achievable levels of reliability and the means required to achieve them. The disadvantages of this approach are that it provides no incentive for reliability higher than current implied requirements, and that it may rely on more extensive provisions than are included in the current prescriptive codes and standards. Not every application of every system and feature required in an NFPA code or standard has a complete associated standard to assure acceptable reliability.

Another way to address reliability through assumptions is to assume a lower occupancy load or greater occupant capability. A conservative approach might assume that, with all systems and features operating, the design should be able to protect all occupants in a fully loaded -- even somewhat overloaded -- building, including the most vulnerable and least capable people (e.g., older adults, young children, disabled persons, people impaired by drugs or alcohol). For a reliability analysis with a key system or feature removed or impaired, the design might be evaluated only against a more typical, less conservative occupant set, such as a building occupied to 60% capacity with all occupants consisting of fully capable adults. The advantages and disadvantages of this approach are similar to those of addressing reliability through scenarios.

4-4 Addressing Reliability Through Objectives. As an example, NFPA 101, *Life Safety Code* seeks to protect everyone in the building except people intimate with ignition. It may be, even with a milder, relatively slow initiating fire and more typical, less conservative assumptions as described above, that the design cannot assure protection of all those people in the absence of some key feature or system. But the alternative need not be to treat any

level of performance as acceptable. The goal could be reset to protection of everyone in the room of origin or on the floor of origin or within 100' of the point of fire origin. By considering the combined effect of the systems and features regarded under the prescriptive code or standard as sufficient for redundancy, and analyzing the point in time, the speed, and the manner in which they operate, a Technical Committee can identify a less demanding goal.

Part III - Technical Committee Use

This section (Part III) is included to give general Technical Committee guidance and sources of references for their documents, including a performance-based option.

Chapter 5 Technical Committee

5-1 General. When addressing reliability in their documents, Technical Committees will want to indicate data, assumptions, verification methods, and documentation requirements for designers that will give AHJ's the information they need to evaluate the treatment of reliability in the design analysis.

5-2 Unique Data Issues for Reliability. A unique problem for reliability is that data is very scarce and, where it exists, tends to exist only for highly specialized products (e.g., products built to military specifications for highly demanding environments) or highly unusual applications (e.g., systems with unusually thorough ongoing maintenance, inspection, testing and supervision arrangements) or severely biased data collection regimens (e.g., laboratory tests on time to failure distributions without data on human error reliability).

The detailed limitations of available data bases and the appropriate steps to take in using them to address reliability for a particular design typically will not be the province of the Technical Committee. Referenced engineering guides should provide guidance on these steps and may provide references to data bases. However, it is reasonable for Technical Committees to explicitly recognize the issue, possibly in the form of a documentation requirement for special attention to the match, or mismatch, between the design elements in the designer's proposal and the design elements (and supporting ongoing safety and quality assurance programs) reflected in the design analyst's referenced data bases.

Appendix A

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

A-2.1 Bottom-Up. It is called "bottom-up" because it works "up" from the established prescriptive language to infer the goals, objectives, and other statements that justify the prescriptive language.

A-2.1 Design Specification. The design team should include any design specifications which can be used as input for the design tools, or will impact the assumptions made by the design team. The design specifications listed by the design team should be separated into categories of those that can be readily changed by the fire protection design team, and those that cannot be easily changed by the fire protection design team and would instead require major changes to the overall structural and architectural building design. Included in the first category would be items such as, but not limited to, the ventilation flow rate, sprinkler density, interior finish material (and consequently its flammability), whereas the second category would include items such as, but not limited to, building height, building footprint, floor height, etc.

Figure A-3-6 Performance Based Design Process

Title	Description
Code/Standard Fire Protection Goals	Code/Standard required fire protection outcome presented in a non-specific, qualitative basis.
Project Team Fire Protection Goals	Basic fire protection desires of stakeholders not specifically stated in, or required by, the code or standard.
Fire Safety Goals	Overall outcome to be achieved with regard to fire, measured on a qualitative basis. Discussed in greater detail in <i>Primer 1</i> .
Fire Safety Objectives	Requirement for the fire, building, or occupants that must be satisfied in order to achieve a fire safety goal, stated in a more quantitative manner than fire safety goals. Also discussed in <i>Primer 1</i> .
Fire Safety Criteria	Performance objectives, further quantified and stated in engineering terms, relating to individual products, systems, assemblies or areas. Provides pass/fail threshold values to be compared to design evaluation output. Also discussed in <i>Primer 1</i> .
General Code/Standard Requirements	Provisions from the code or standard relating to the building design and construction, particularly retained prescriptive requirements.
Building Purpose and Aesthetic Goals	Building owner's and stakeholders' overall intentions for the building, ranging from building's intended purpose to desired architectural plan.
Specific Code/Standard Requirements	Provisions from the code or standard directly pertaining to the occupant characteristics, assumptions, scenario data, or building characteristics. These specific requirements combine with characteristics, assumptions and scenario data specified by the design team based upon the proposed building design. These requirements for the characteristics, assumptions, and scenario data cannot be modified by the design team at any time during the evaluation.
Proposed Building Design (Including Fire Protection)	Building design to be evaluated by the fire protection engineer against the previously determined fire safety criteria. Initial proposal should include preliminary architectural and structural design, as well as proposed fire protection system design.

Design)	
Occupant Characteristics	Ability, behavior, and vulnerability of the anticipated distribution of people before and during a specific fire scenario. Important elements include response characteristics such as sensibility and mobility, occupant location, or number of occupants. Characteristics such as number and location of occupants may be dependent on the proposed building design and the fire scenario being investigated, whereas the response characteristics and any code/standard restrained characteristics must remain the same throughout the design. Discussed in greater detail in <i>Primer 2</i> .
Assumptions	Specifications made by the fire protection engineer regarding the building and surrounding area, which are not part of the building design, do not vary across fire scenarios, and will be used as input to evaluate the building. Examples include emergency response or staff assistance. Discussed in greater detail in <i>Primer 2</i> .
Scenario Data (Including Design Fire)	Quantitative description of fire, and any factors affecting or affected by it, in the time from ignition to extinguishment, including ignition sources, ventilation, and configuration of fuel. Factors that do not vary across scenarios may be treated as assumptions. Any specific code/standard requirements for scenario data must be maintained throughout the analysis, regardless of the proposed building design. For example, building systems/features status (doors opened or closed) may be treated as a scenario factor or an assumption. Discussed in greater detail in <i>Primer 3</i> .
Building Characteristics	Features of the building which are not specifically included in overall design, but will have an impact on overall performance, including building contents and anticipated layout. Any specific code/standard requirement for the building characteristics may not be changed at any time in the evaluation. Discussed in greater detail in <i>Primer 2</i> .
Design Specifications	Those aspects of the building design that will have an impact on the fire safety analysis, expressed in engineering terms. Examples include floor area and barrier layout, building height, or sprinkler density.
Input	List of all relevant design information, expressed in engineering terms, to be used in the verification method(s) to evaluate the design. Discussed in greater detail in <i>Primer 4</i> .
Verification Methods	Model, tool, or similar method used to evaluate the proposed design against the level of performance specified by the fire safety criteria. Discussed in greater detail in <i>Primer 4</i> .
Output	Specific results obtained from verification methods and design tools. Expressed in engineering terms, which can be compared directly to fire safety criteria. Discussed in greater detail in <i>Primer 4</i> .
Safety Factors	Adjustment factors applied to compensate for uncertainty in the assumptions, methods, and calculations employed in evaluating engineering designs. Discussed in greater detail in <i>Primer 6</i> .
Acceptable?	Represents comparison of output (obtained from the design evaluation) to fire safety criteria (developed by design team from code/standard and stakeholder goals) to determine if building satisfies performance requirements.
Modify Proposed Building Design	If design output fails to meet all of the fire safety criteria, modifications must be made to the preliminary design. These modifications in the proposed design could lead to changes in the design assumptions, scenario data, building characteristics, and/or design specifications, producing variations in the design input. Only those aspects of the design not specified by the code/standard may be modified, and the Technical Committee should specify which, if any, of the input values cannot be changed by the designer in order to satisfy the performance requirements.
Finish	If the design evaluation satisfies all of the fire safety criteria, then the proposed design becomes a successful trial design. After evaluating each proposed design and determining those that pass all of the fire safety criteria, the design team must select the most desirable for implementation as the final design. This final design, along with all relevant design information and data sources, must be documented in full for submittal to the AHJ for approval. This documentation procedure is discussed in greater detail in <i>Primer 6</i> .

Appendix B - Reference Publications

This Appendix is not part of the recommendations of this NFPA document, but is included for information purposes only.

1. *NFPA's Future in Performance-Based Codes and Standards*, National Fire Protection Association, Quincy, MA, July, 1995.
2. *Bottom-Up Analysis of National Codes*, Canadian Codes Centre, September 1996.
3. *The American Heritage College Dictionary*, 3rd ed., Houghton Mifflin Co., Boston, 1993.
4. *NFPA 101, Life Safety Code*, 2000 Edition, National Fire Protection Association, Quincy, Massachusetts, USA, 1999