Annex E Resources for Protection of Cultural Resource Property Projects

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

E.1 Introduction. A fire protection consultant can be a valuable resource in evaluating the current status of fire safety for a cultural property and in recommending creative solutions to improve fire safety and achieve fire safety goals. To realize the maximum benefit from engaging a fire protection consultant, the consultant's qualifications and the client's needs should be properly matched. The consultant should have qualifications equivalent to member grade in the Society of Fire Protection Engineers (SFPE).

The consultant's experience should be evaluated, both as a company and as individual consultant team members, in providing fire protection consulting services to libraries. Other experience that might also be considered is that for historic buildings or structures and museums.

The consultant's experience should also be compared with the nature of the work to be performed and the size of the project being considered. As a final factor for evaluation of experience, whether the specific team proposed has worked together and the degree to which the experience is team experience should be considered.

Other factors that should be used in evaluating a consultant's qualifications are membership and participation in organizations such as NFPA; the American Institute of Architects (AIA), for registered architects; the National Society of Professional Engineers (NSPE), for registered engineers; and the model building code organizations. Participation on committees of these organizations is a further measure of the consultant's understanding of library fire safety issues.

After information on the fire protection consultant's qualifications has been collected, references should be contacted to determine how the consultant has actually performed on similar projects.

E.2 NFPA. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA publishes this document and related documents on fire protection and will answer inquiries on these documents. The association also conducts educational seminars, studies, and literature searches for a fee.

NFPA maintains a list of fire protection consultants.

E.3 SFPE. Society of Fire Protection Engineers, 9711 Washingtonian Blvd, Suite 380, Gaithersburg, MD 20878.

SFPE is a professional society of fire protection engineers that meets annually, publishes technical information, conducts technical seminars, and supports local chapters. Members are located in all parts of the world. Names and addresses of members in a particular geographic area can be obtained from society headquarters.

E.4 NICET. National Institute for Certification in Engineering Technologies, 1420 King Street, Alexandria, VA 22314.

NICET certifies technicians in the following areas of fire protection:

(1) Automatic sprinkler system layout
(2) Special hazards system layout (i.e., automatic and manual foam–water, halon, carbon dioxide, and dry chemical systems)
(3) Fire detection and alarm systems

People with a NICET certification can also assist in the selection and use of fire protection systems. NICET provides certification for four levels of competence in all three of the listed areas of fire protection.

E.5 UL. UL LLC, 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL has a certification service through which alarm companies can be qualified to issue certificates stating that installed fire warning systems comply with NFPA standards and are properly tested and maintained. A list of alarm service companies authorized to issue UL certificates is available. UL also publishes safety standards and annual directories of labeled and listed products and fire-resistant assemblies.

E.6 AIA. American Institute of Architects, 1735 New York Ave. NW, Washington, DC 20006-5292. www.aia.org

The Historic Resources Committee (HRC), which is one of the AIA Knowledge Communities, has a mission to identify, understand, and preserve architectural heritage, both nationally and internationally. HRC promotes the role of historic architects as leaders in historic preservation activities by offering an array of knowledge delivery in preservation practice, technology, and education. Members monitor and manage the balance between philosophical ideals and business realities, and serve as liaisons to a variety of allied professional preservation organizations, agencies, and programs.

HRC is engaged in promoting within the profession through the development of information and knowledge among members, allied professional organizations, and the public. With sustainability as a buzzword and an increased portion of an architect's work on existing structures, preservation has moved into the mainstream of our community, cultural, and economic interests. The goals of HRC include the following:

(1) To offer expertise in historic architecture to allied and liaison preservation organizations
(2) To teach the value of preservation as design, and to develop case studies in best practices for components and other organizations
(3) To enhance standards of practice for preservation architects

Annex F Examples of Compliance Alternatives

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

Δ **F.1 General.** Direct compliance with prescriptive codes is still the predominant means of ensuring fire safety in historic buildings. Most codes include provisions for equivalent protection by means other than those prescribed in the code. The following examples illustrate ways that preservation goals have been met through carefully designed fire protection that complied with prescriptive code provisions or through equivalency-based solutions that appropriately addressed safety deficiencies in a specific application.

Equivalency provisions allow alternative designs to satisfy regulations if they provide a level of fire safety equivalent to that called for by the regulations. As stated in 3.3.23, an equivalency approach is "an alternative means of providing an equal or greater degree of safety than that afforded by strict conformance to prescribed codes and standards."

There is no single acceptable method of providing appropriate fire safety. Each historic building is unique, requiring that equivalencies be assessed in relation to the particular circumstances of the historic structure and occupancy. What may be appropriate for one building may not be appropriate for another, and it cannot be assumed that the following solutions will apply to every situation. The intent of these examples is to illustrate context-sensitive design for achieving fire safety goals in historic properties.

F.2 Means of Egress. Figure F.2(a) shows a common fire safety problem in historic buildings. The main monumental stairway in this historic building is the primary access and exit route between the main lobby and the upper floors. The open stair is a key architectural feature but could provide a path of fire and smoke migration that would render the route unusable. Figure F.2(b) through Figure F.2(d) illustrate solutions to this problem.

Figure F.2(b) illustrates an egress enclosure solution that involved retrofitting existing historic glazed doors that enclose egress stairs with rated ceramic glass. Part of this process involved evaluating several fire performance tests on the stair door assembly.

Figure F.2(b) illustrates an original door retrofitted with 0.25 in. (7 mm) glass. The glass withstands the fire duration, and because the building is sprinkler protected, the hose stream test was waived for this installation.

The door is normally held open to permit normal occupant movement through the space. This is accomplished by magnetic devices on the floor that release and close the door when the fire alarm activates. The wall panel on the left that covers the retracted door was painted to match the adjoining historic marble.

The example illustrated in Figure F.2(c) involved the need to provide separation where multiple egress paths converged into a single evacuation point that had the potential to become obstructed during a fire. To resolve this situation, accordion-type cross-corridor doors were installed, thereby enabling the preservation of dozens of bronze and glass corridor doors that would have been absorbed into a larger egress path. These doors are normally open out of the visitor's view. However, if a fire is detected, these doors close to create a fire separation. The accordion door tracks, pocket, and cover were painted to match the surrounding veined marble and elaborate coffered ceiling. (Another example of a Won Door application is shown in Figure F.2(d), which illustrates a unit in a partially closed position.)

The accordion door and track in Figure F.2(c) have been carefully concealed and color-matched to minimize visual impact. The wall panel on the left that covers the retracted door was painted to match the adjoining historic marble.

Figure F.2(d) illustrates an accordion door closing to protect a monumental stairway. Under normal conditions, the door is concealed in a wall pocket on the left side of the opening. When a smoke detector identifies a developing fire, a signal is sent to the building fire alarm, which in turn closes the Won Door to prevent fire spread via the stair.

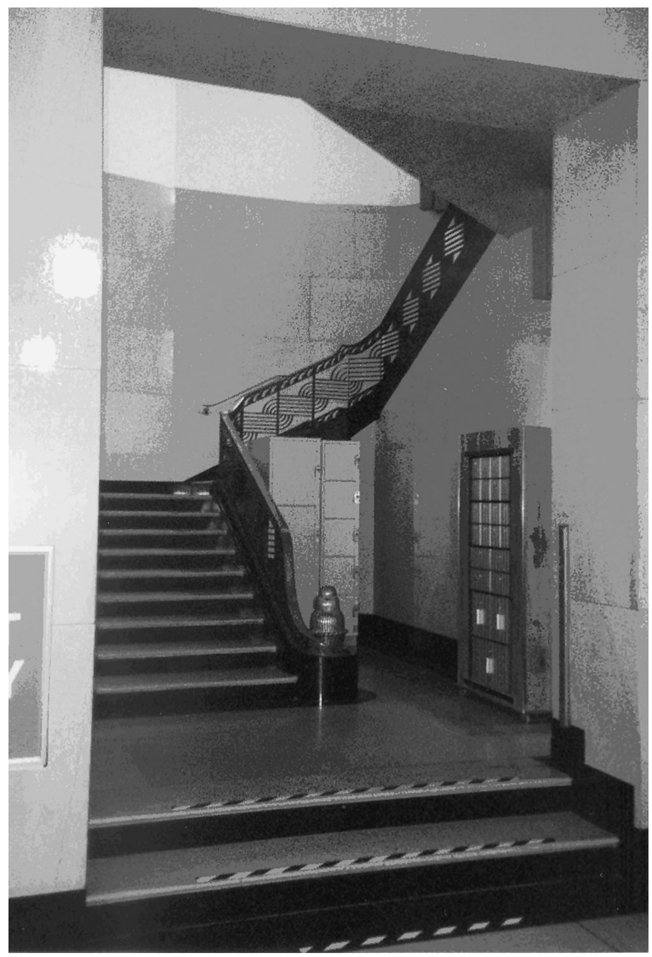


FIGURE F.2(a) Open Monumental Stair.

FIGURE F.2(b) Rated Glass Corridor Doors in Normal Position.

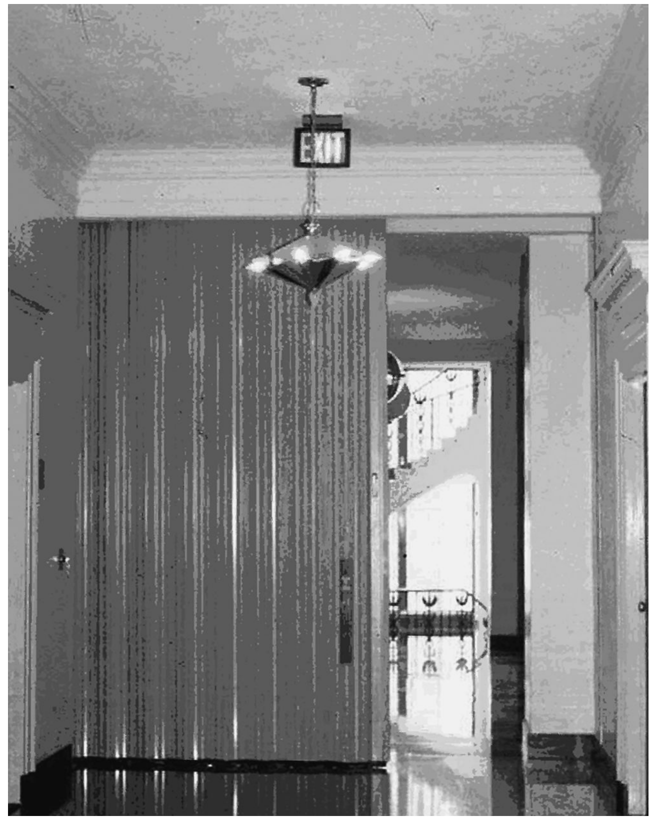


FIGURE F.2(d) Won Door in a Partially Closed Position.

FIGURE F.2(c) Won Door in an Open Position.

F.3 Automatic Fire Suppression Systems. Figure F.3(a) illustrates the use of sprinklers to cool the window assembly during fire exposure. Tests conducted in 1984 by the National Research Council of Canada (NRC) for the atrium of the Toronto, Ontario Hospital for Sick Children (NRC Test CBD-248) demonstrated that when properly wetted by sprinklers, standard glazed windows can provide an effective barrier.

To retain the historic frame and ornamental glazing, the sprinkler in Figure F.3(a) was placed to cool the window assembly during fire exposure.

Figure F.3(b) illustrates automatic fire suppression utilizing water sprays, or mists, to accomplish fire control. Water mist occurs when water is subjected to high pressure ranging from approximately 100 to 1000 psi (6.8 to 68.5 bar) and forced through extremely small orifices. This results in very fine droplets that have a higher heat absorption capability than larger sprinkler drops, enabling fire suppression with approximately 10 percent to 20 percent of the water normally required for sprinklers. Mist may also be an effective radiant heat blocker, which prevents thermal energy from damaging adjacent contents and building features. Currently, water mist nozzles do not offer the same coverage ranges available with sprinklers and are often limited to rooms with a maximum ceiling height of 16 ft (5 m). This results in decreased flexibility in the placement of mist nozzles, but as new nozzle technologies are introduced this difference is expected to diminish.

Figure F.3(b) shows a water mist system in operation during a fire test. Note the fog-like appearance of the sprays, which have millions of fine droplets to overcome the fire's heat.

Figure F.3(a) through Figure F.3(e) illustrate sprinkler piping and heads sensitively placed for minimal visibility and architectural impact. Ideally, all piping should be concealed, but this is not always possible because of the structural, architectural, and financial implications of constructing new enclosures in historic spaces that may contain ornamental ceilings or contoured surfaces.

The sprinkler pipe in the vaulted ceiling shown in Figure F.3(c) was placed along the cornice at the base of the vault. Color-matched sidewall sprinklers were placed to allow proper water spray.

The pipes that serve the sprinkler heads shown in Figure F.3(d) were placed behind the beam, concealing them from the normal line of sight.

Figure F.3(e) shows the sprinkler piping for the fire sprinklers in Figure F.3(d).

In Figure F.3(f) shows the sprinkler head carefully placed in the center of the decorative ceiling rosette to minimize the visual impact.

FIGURE F.3(a) Sprinklers to Maintain Glass Cooling.

FIGURE F.3(b) Water Mist Discharge.

FIGURE F.3(c) Exposed Sprinkler Pipe.

FIGURE F.3(d) Sprinkler Piping Concealed from Normal View.

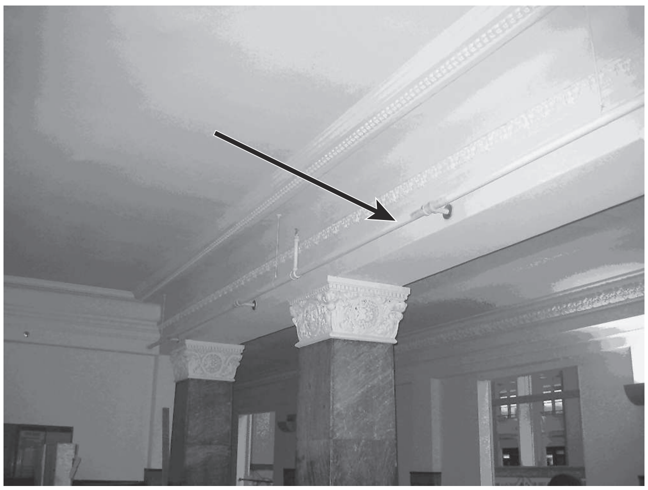


FIGURE F.3(e) Sprinkler Piping Out of Normal Sight.

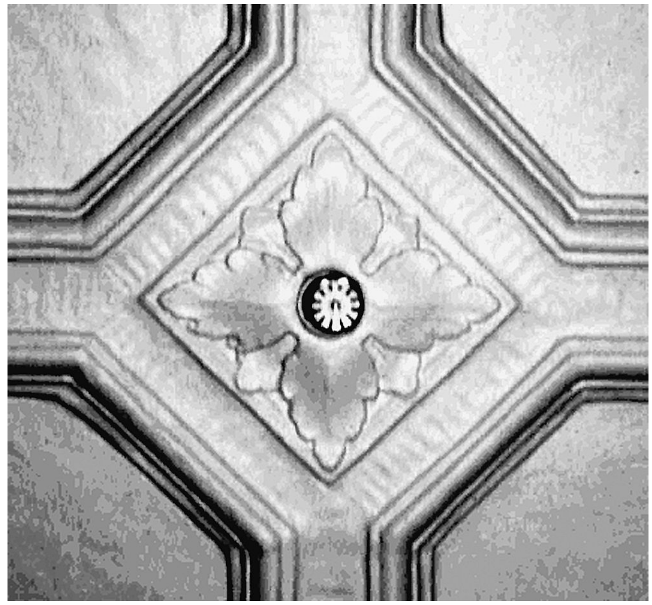


FIGURE F.3(f) Sprinkler in Rosette.

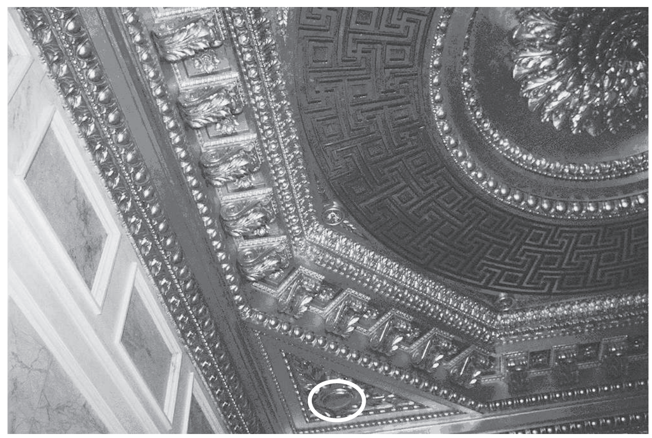


FIGURE F.4(a) Color-Matched Smoke Sensor.

F.4 Fire Detection Systems. Figure F.4(a) through Figure F.4(c) illustrate aesthetically integrated smoke sensors. The selection of a system and its components is dependent on the type and size of building, characteristics of the occupants, anticipated fire growth, and aesthetic and historic fabric issues.

Figure F.4(a) shows a smoke sensor that was color matched to the ornate ceiling. The sensor was disassembled by the manufacturer to permit factory painting of the cover and then reassembled, avoiding damage to the sensing components.

Figure F.4(b) and Figure F.4(c) illustrate projected, or linear, beam-type sensors. These sensors consist of two separate components: a transmitter that projects a narrow light beam and the corresponding optical receiver that monitors the intensity of the light. In certain installations, the transmitter and the receiver are in the same housing with a reflector at the other end of the space. The main advantage of projected beam detection over spot sensors is that it can cover larger areas without placing numerous sensors along the ceiling. Such an arrangement is ideally suited for aesthetically significant open spaces where numerous spot sensors would otherwise be required.

Figure F.4(b) shows a large historic room protected by a set of linear beam smoke detectors. The transmitter and the receiver are placed on opposite walls, avoiding the placement of detectors on the ceiling assembly. A beam detector transmitter and receiver can typically be set up to 300 ft (100 m) apart.

The projected beam smoke detector in Figure F.4(c) transmits a narrow light beam to a similar appearing receiver on the opposite wall.

Figure F.4(d) illustrates how the required manual fire alarm box was mounted on a bollard, avoiding the need to cut into the historic wall materials.

FIGURE F.4(b) Linear Beam Smoke Detector Protected Room.

FIGURE F.4(c) Linear Beam Smoke Detector.

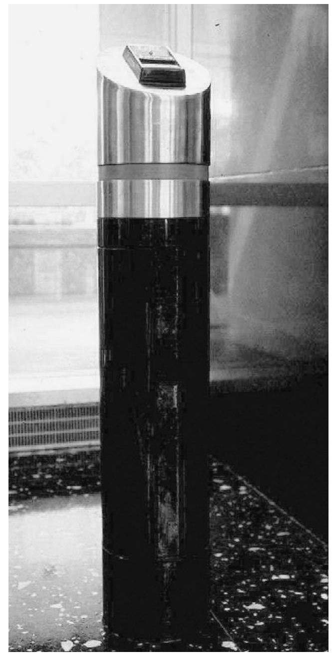


FIGURE F.4(d) Bollard-Mounted Fire Alarm Box.

Annex G Performance-Based Fire Safety Code Compliance.

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

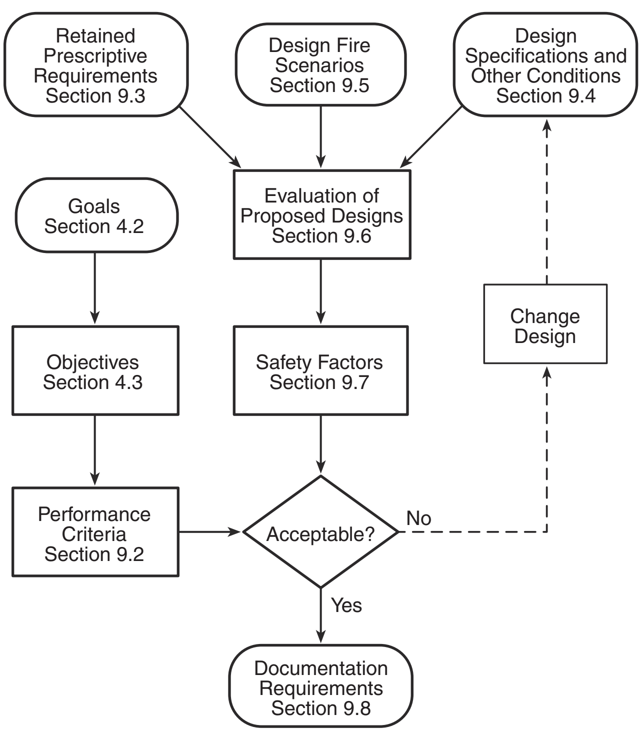
G.1 General. Chapter 9 of this code provides requirements for the evaluation of a performance-based life safety and fire protection design. The evaluation process is summarized in Figure G.1.

G.1.1 Code Criteria. On the left side of Figure G.1 is input from the code. The life safety and historic preservation goals are stated in Section 4.2, and the objectives necessary to achieve those goals are stated in Section 4.3. Section 9.2, Performance Criteria, specifies the measures that are to be used to determine whether the objectives have been met.

G.1.2 Input. At the top of Figure G.1 is the input necessary to evaluate a fire safety design.

G.1.3 Design Specifications. The design specifications need to include certain retained prescriptive requirements as specified in Section 9.3. All assumptions about the life safety design, fire safety design, and the response of the building and its occupants to a fire must be clearly stated, as indicated in Section 9.4. Scenarios are used to assess the adequacy of the design. Eight sets of initiating events are specified for which the ensuing outcomes need to be satisfactory.

G.1.4 Performance Assessment. Appropriate methods for assessing performance are to be used per Section 9.6. Safety factors need to be applied to account for uncertainties in the assessment, as stated in Section 9.7. If the resulting predicted outcome of the scenarios is bound by the performance criteria, then the objectives have been met and the fire safety design, coupled with the goal of maintaining the historic character of the building under evaluation, is considered to be in compliance with this code. Although not part of this code, a design that fails to comply can be changed and reassessed, as indicated on the right side of Figure G.1.



Δ **FIGURE G.1 Performance-Based Fire Safety Code Compliance Process. [*101*:A.5.1.1]**

G.1.5 Documentation. The approval and acceptance of a fire safety design depend on the quality of the documentation of the process. Section 9.8 specifies the minimum set of documentation that needs to accompany a submission.

Δ **G.2** The performance option of this code establishes acceptable levels of risk to occupants of buildings and structures, as addressed in Section 4.2. These risks are also used to evaluate the degree or extent to which the proposed designs will alter or affect the historically significant features of the property. While the performance option of this code does contain goals, objectives, and performance criteria necessary to provide an acceptable level of risk to occupants, it does not describe how to meet the goals, objectives, and performance criteria. Design and engineering are needed to develop solutions that meet the provisions of this chapter. The *SFPE Engineering Guide to Performance-Based Fire Protection* provides a framework for these assessments. Other useful references include the *Australian Fire Engineering Guidelines* and the *British Standard Firesafety Engineering in Buildings.*

Annex H Methods to Determine Untenable Conditions

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

H.1 General. Four methods can be used to avoid exposing occupants to untenable conditions:

(1) Prevent incapacitation by fire effects
(2) Ensure full evacuation prior to untenable conditions
(3) Contain effects of smoke and toxic gas
(4) Contain all fire effects

Δ **H.2 Prevent Incapacitation by Fire Effects.** The design team could set detailed performance criteria that would ensure that occupants are not incapacitated by fire effects. The *SFPE Engineering Guide to Performance-Based Fire Protection* describes a process of establishing tenability limits. That guide references D. A. Purser, who in the *SFPE Handbook of Fire Protection Engineering* describes a fractional effective dose (FED) calculation approach *(see also NFPA 269).* FED addresses carbon monoxide, hydrogen cyanide, carbon dioxide, hydrogen chloride, hydrogen bromide, and anoxia effects. It is possible to use the test data, combined with laboratory experience, to estimate what FED would lead to the survival of virtually all people. That value is approximately 0.8.

There is a relationship between exposures leading to death and those leading to incapacitation. Kaplan found that rodent susceptibility is similar to that of humans, and that for the narcotic gases (carbon monoxide and hydrogen cyanide), human incapacitation occurs at one-third to one-half the lethal exposure. Gann found that carbon monoxide dominates the lethality of fire smoke, since most fire deaths occur remote from the fire room and from fires that have proceeded past flashover. Thus, if the FED value of 0.8 were used for a nonlethal exposure, an FED of 0.3 would be reasonable for a nonincapacitating exposure.

If the AHJ or the design professional is concerned with potential toxic fire effects other than those addressed by the FED procedure as documented, the calculation procedure can be expanded by adding additional terms to the FED equation, where each term has the form of a ratio. The numerator of the ratio is the cumulative exposure to that fire effect, measured as an integral of the product of instantaneous exposure (concentration for toxic products) and time. The denominator of the ratio is the quantity of cumulative exposure for which FED equals the chosen threshold value (e.g., 0.8 or 0.3) based on that fire effect alone.

The American Society for Testing and Materials (ASTM) is actively considering standards that would extend the list of toxic fire effects with standard values.

If the authority having jurisdiction or the design professional is concerned with potential fire effects other than toxicity, the calculation procedure can be modified to include other fire effects, such as thermal effects.

For buildings where an unusually large fraction of the occupants would be especially vulnerable, the calculation procedure should be modified to use FED values lower than those cited above.

H.3 Full Evacuation Prior to Untenable Conditions. For each design fire scenario and the design specifications, conditions, and assumptions, the design team could demonstrate that each room or area would be fully evacuated before the smoke and toxic gas layer in that room descended to a level lower than 6 ft (1.8 m) above the floor. This procedure requires that no occupant would be exposed to fire effects. It requires calculation of the locations, movement, and behavior of occupants, because it keeps fire effects and occupants separate by moving the occupants. A level of 6 ft (1.6 m) is often used in calculations, but with that level, a large fraction of the population would not be able to stand, walk, or run normally and still avoid inhalation of toxic gases. They would have to bend over or otherwise move their heads closer to the floor level.

H.4 Containment of Effects of Smoke and Toxic Gas. For each design fire scenario and the design specifications and assumptions, the design team could demonstrate that the smoke and toxic gas layer will not descend to a level lower than 6 ft (1.8 m) above the floor in any occupied room. The advantage of this procedure is that it conservatively requires that no occupant would be exposed to fire effects, regardless of where occupants were or where they moved. This option removes the need to make any calculations regarding occupants, including their behavior, movement locations, pre-fire characteristics, and reactions to fire effects. This procedure is even more conservative and simpler than the procedure in Section H.2, because it does not allow fire effects in occupied rooms to develop to a point where people could be affected even after there are no people present to be affected.

H.5 Containment of All Fire Effects. For each design fire scenario and the design specifications and assumptions, the design team could demonstrate that no fire effects would reach any occupied room. The advantage of this procedure is that it removes the need to make any calculations regarding occupants, including their behavior, movement, locations, pre-fire characteristics, and reactions to fire effects. A further advantage is that it also removes the need for some of the modeling of fire effects, because it is not necessary to model the filling of rooms, only the spread of fire effects to those rooms. This is even more conservative and simpler than the procedures in H.2 and H.3, because it does not allow any fire effects in occupied rooms.

Annex I Assessment Methods

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

Δ **I.1 General.** The *SFPE Engineering Guide to Performance-Based Fire Protection* outlines a process for evaluating whether trial designs meet the performance criteria during the design fire scenarios.

Procedures described in Sections 9.2 and 9.4 identify required design fire scenarios within which a proposed fire safety design needs to perform and the associated untenable conditions that need to be avoided in order to maintain life safety. Additionally, this same process should be used to establish the level of tolerance that specific contents, building features, or both, can sustain without incurring irreparable damage. This annex discusses methods that form the link from the scenarios and criteria to the goals and objectives.

I.2 Assessment Methods. Assessment methods are used to demonstrate that the proposed design will achieve the stated goals and objectives by providing information indicating that the performance criteria of Section 9.2 can be adequately met. Assessment methods can be either tests or modeling.

I.2.1 Tests. Test results can be directly used to assess a fire safety design when they accurately represent the scenarios developed by using Section 9.4 and when they provide output data matching the performance criteria in Section 9.2. Because the performance criteria for this code are stated in terms of human exposure to lethal fire effects, no test suffices. However, tests are needed to produce data for use in models and other calculation methods. Likewise, there are few specific data regarding the impact of smoke, heat, and flame on dated fabric, materials, and construction materials. When possible, anecdotal information, tests on like materials, or both can be necessary to establish credible damage limits on these materials.

Subsections I.2.1.1 through I.2.1.6 provide further information on types of tests and uses of data.

I.2.1.1 Standardized Tests. Standardized tests are conducted on various systems and components to determine whether they meet some predetermined, typically prescriptive, criteria. Results are given on a pass/fail basis: either the test specimen does or does not meet the pre-established criteria. The actual performance of the test specimen is not usually recorded.

I.2.1.2 Scale. Tests can be either small scale, intermediate scale, 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 is placed in the testing device or apparatus. Intermediate-scale tests can be used to determine the adequacy of system components (e.g., doors and windows, as opposed to entire systems). The difference between small scale and intermediate scale is usually one of definition provided by those conducting the test. Full-scale tests typically are used to test building and structural components or entire systems. The difference between intermediate scale 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).

Full-scale building evacuations can provide information on how the evacuation of a structure is likely to occur for an existing building with a given population but without subjecting occupants to the real physical or psychological effects of a fire.

I.2.1.3 Data Uses. The data obtained from standardized tests have three uses for verification purposes:

(1) The test results can be used instead of a model. This typically is the role of full-scale test results.
(2) 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.
(3) The test results can be used as input to models. This typically is the use of small-scale tests, specifically flammability tests.

I.2.1.4 Start-Up Test. Start-up test results can be used to demonstrate that the fire safety system performs as designed. The system design can be based on modeling. If the start-up test indicates a deficiency, the system needs to be adjusted and retested until it can be demonstrated that the design can meet the performance criteria. Typically, start-up tests apply only to the installation to which they are designed.

I.2.1.5 Experimental Data. Experimental data from nonstandardized tests can be used 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.

I.2.1.6 Human and Organizational Performance Tests. Certain tests determine whether inputs used to determine human performance criteria remain valid during the occupancy of a building. Tests of human and organizational performance might include any of the following:

(1) Measuring evacuation times during fire drills
(2) Querying emergency response team members to determine whether they know required procedures
(3) Conducting field tests to ensure that emergency response team members can execute tasks within predetermined times and accuracy limits (Design proposals should include descriptions of any tests that are needed to determine whether stated goals, objectives, and performance criteria are being met.)

I.2.2 Modeling. Models can be used to predict the performance criteria for a given scenario. Because of the limitations on use of tests alone for this purpose, models are expected to be used in most, if not all, performance-based design assessments.

Fire models do not model fires; they model the effects of a [user-] specified fire (i.e., a heat release rate curve is input). For ease of use, the term *fire model* is used in this discussion instead of the more accurate *fire effects model*.

The effects of fire and its toxic products on the occupants can be modeled, as can the movement and behavior of occupants during the fire incident. The term *evacuation model* is used to describe models that predict the location and movements of occupants, and the term *tenability model* is used to describe models that predict the effects on occupants of specified levels of exposure to fire affects. The term *exposure model* is used to describe models that replicate the movement of smoke and heat and tell how smoke and heat can potentially affect the fabric of the material or content.

Subsections I.2.2.1 through I.2.2.4 provide further information on fire models.

For additional information on selecting, verifying, validating, and documenting the use of fire models, see the *SFPE Guidelines for Substantiating a Fire Model for a Given Application.*

I.2.2.1 Types of Fire Models. Fire models are used to predict fire-related performance criteria. Fire models can be either probabilistic or deterministic. Several types of deterministic models are available: computational fluid dynamics (CFD), or field, models, zone models, purpose-built models, and hand calculations. Probabilistic fire models are also available, but they are less likely to be used for this purpose.

Probabilistic fire models use the probabilities as well as the severity of various events as the basis of evaluation. Some probabilistic models incorporate deterministic models, but this is not a requirement. Probabilistic models attempt to predict the probability and severity associated with an unwanted fire (e.g., likelihood of an expected loss), which can be thought of as the probability-weighted average severity across all possible scenarios. Probabilistic models can be manifested as fault or event trees or to other system models that use frequency or probability data as input. These models tend to be manifested as computer software, but this is not a requirement. Furthermore, the discussion in Section I.3 can also be applied to probabilistic models, although that section concentrates on deterministic models.

CFD models provide the most accurate predictions of all the deterministic models because they divide a given space into thousands of smaller volumes. However, they are still models and as such are not absolute in their depiction of reality. In addition, they are much more expensive to use because they are computationally intensive. Because of their expense, complexity, and intensive computational needs, CFD models require much greater scrutiny than do zone models. It is much more difficult to provide multiple runs of CFD models to check sensitivity to a variety of factors such as design fire cell resolution or ventilation.

Zone models are more widely used than CFD models because they provide reasonably accurate predictions in much less time. It is easier to assess sensitivity of different parameters with zone models, because they generally run much faster and the output is much easier to interpret. Prediction of fire growth and spread has a large number of variables associated with it; consequently, the zone models with their crudeness and speed have advantages over the more complex CFD models.

Purpose-built models (also known as stand-alone 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 specific purpose-built model could predict the conditions of a ceiling jet at a specified location under a ceiling, while a zone model would approximate fire conditions throughout a zone (specified area) of the enclosure.

Purpose-built models might or might not be manifested as computer software. Those that are not manifested as such are referred to as hand calculations. These purpose-built models are, therefore, simple enough that the data management capabilities of a computer are not necessary. Many of these calculations are found in the *SFPE Handbook of Fire Protection Engineering*.

I.2.2.2 Types of Evacuation Models. Three categories of evacuation models can be considered: single-parameter estimation methods, movement models, and behavioral simulation models.

Single-parameter estimations are generally used for simple estimates of movement time. They are usually based on equations derived from observations of movement in nonemergency situations. They can 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 of Fire Protection Engineering* and the NFPA *Fire Protection Handbook*.

Movement models generally handle large numbers of people in a network flow 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 indicates that the design has failed to achieve life safety objectives.

Behavioral 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. However, given the limited availability of data for the development of these models, for their verification by their authors, or for input when using them, their predictive reliability is questionable.

I.2.2.3 Tenability Models. In general, models will be needed here only to automate calculations over time-of-exposure effect equations referenced in A.9.2.2.1.

I.2.2.4 Other Models. Models can be used to describe combustion (as noted, most "fire models" characterize only fire effects), automatic system performance, and other elements of the calculation. Few models are in common use for those purposes, so they are not described further here.

I.3 Sources of Models. Compendia of computer fire models are found in Olenick and Carpenter's "An Updated International Survey of Computer Models for Fire and Smoke." That reference contains models that were developed by the Building Fire Research Laboratory of the National Institute of Standards and Technology and that can be downloaded from the Internet at http://www.bfrl.nist.gov/864/fmabs.html. Evacuation models in all three categories are discussed in the *SFPE Handbook of Fire Protection Engineering* and the NFPA *Fire Protection Handbook*.

I.4 Validation. Models undergo limited validation. Most can be considered demonstrated only for the experimental results they were based on or the limited set of scenarios to which the model developers compared the model's output.

The model user must rely on the available documentation and previous experience for guidance regarding the appropriate use of a given model. For more information on the verification and validation of fire models, see the *SFPE Guidelines for Substantiating a Fire Model for a Given Application*.

The design professional should present the strength of the evidence presented for the validity, accuracy, relevance, and precision of the proposed methods. The authority having jurisdiction, when deciding whether to approve a proposal, should consider those data as well. An element in establishing the strength of scientific evidence is the extent of external review and acceptance of the evidence by peers of the authors of that evidence.

Models have limitations, and most are not user friendly; therefore, experienced users will be able to construct more reasonable models and better interpret output than novices. It is for those reasons that the third-party review and equivalency sections are provided. These statements are not meant to discourage the use of models but rather to indicate that they need to be used with caution and by those well versed in their nuances.

I.5 Input Data. The first step in using a model is to develop the input data.

The heat release rate curve specified by the user is the driving force of a fire effects model. If this curve is incorrectly defined, the subsequent results are not usable. In addition to the smoldering and growth phases that are specified as part of the scenario definition, two additional phases are needed to complete the input heat release rate curve: steady burning and burnout.

Steady burning is characterized by its duration, which is a function of the total amount of fuel available to be burned. In determining the duration of this phase, the designer needs to consider how much fuel is assumed to be consumed in the smoldering and growth phases and how much is assumed to be consumed in the burnout phase that follows. A common assumption is that the burnout phase is the mirror image of the preceding phases, with a reversed heat release rate curve and the same amount of fuel consumed in the burnout phase as in the growth phase. Depending on the assumptions made regarding the amount of fuel consumed during burnout, the time at which this phase starts should be easy to determine.

Bear in mind that the preceding discussion assumes that the burning objects are solid (e.g., table, chairs). If liquid or gaseous fuels are involved, the shape of the curve will be different. For example, smoldering is not relevant for burning liquids or gases, and the growth period is very short, typically measured in seconds. [Peak heat release rate depends primarily on the rate of release, on the leak rate (gases and liquid sprays), or on the extent of spill (pooled liquids).] The steady burning phase is once again dependent on the amount of fuel available to burn. Like the growth phase, the burnout phase is typically short (e.g., closing of a valve), although it is conceivable that longer times can be appropriate, depending on the extinguishment scenario.

Material properties are needed (usually) for all fuel items (initial and secondary), as well as the enclosure surfaces of involved rooms or spaces.

For all fires of consequence, it is reasonable to assume that the fire receives adequate ventilation. If there is insufficient oxygen, the fire will not be sustained and will go out. An overabundance of oxygen is only a concern in special cases (e.g., hermetically sealed spaces), when a fire does not occur due to dilution of the fuel (i.e., a flammable mixture is not produced). Therefore, given that the scenarios of interest can occur in nonhermetically sealed enclosures, it is reasonable to assume that adequate ventilation is available and that if a fire starts it will continue to burn until it either runs out of fuel or is extinguished by other means. The only variable that would need to be assumed is the total vent width.