Chapter 9
RECOMMENDATIONS

9.1 BUILDING STANDARDS AND CODES: WHO IS IN CHARGE?

Codes and standards for the design, construction, operation, and maintenance of buildings are the documents by which a society states its intent to provide public safety and functionality. They incorporate the knowledge, experience, procedures, and practices of the applicable engineering disciplines, the values of the contemporary society, the experiences from prior successes and failures, and knowledge of the commercial products, services, and technologies available for the tasks at hand.

The United States has a unique approach to such codes and standards. In virtually all other developed countries the national government has a primary role in the development of national model codes. In the United States, the private sector develops such codes and standards. Further, with few exceptions, state and local governments are responsible for promulgating and enforcing building and fire safety regulations in the United States. These regulations provide minimum requirements for public welfare and safety. While a single, uniform set of statewide regulations is increasingly being adopted by the states, a similar pattern is developing in major cities and counties. The National Conference of States on Building Codes and Standards (NCSBCS)—a body of the National Governors Association and the Council of State Governments—includes members representing chief building regulatory officials of the states and local code officials from across the nation. While NCSBCS does not develop or implement building codes, it provides a national forum to discuss issues related to codes, standards, and practices that cut across jurisdictional boundaries.

With some exceptions, building and fire safety regulations of state and local jurisdictions are based on national model codes developed by private sector organizations—the International Code Council (ICC) and the National Fire Protection Association (NFPA). At present (June 2005), 45 states plus the District of Columbia use the ICC's *International Building Code*, while 36 states plus the District of Columbia use the ICC's *International Fire Code*. Similarly, NFPA's *National Electrical Code* is used in virtually all jurisdictions. Model codes are developed using committees of experts, generally adapted to reflect local climate and geological conditions by state and local governments, and updated every three years. Proposals to modify the model codes are offered by individuals or organizations. These are discussed in open fora before being accepted or rejected by vote. Localities adopting model codes update their versions periodically as well, to follow roughly the same schedule as the model codes. With the exception of standards for manufactured housing, the federal government's role in determining specific codes is mandatory only for federally owned, leased, regulated, or financed facilities.

The model codes adopt by reference voluntary consensus standards that are developed by a large number of private sector standards development organizations (SDOs). The SDOs include NFPA, ASTM International, the American Society of Civil Engineers (ASCE), the American Institute of Steel Construction (AISC), the American Concrete Institute (ACI), and the American Forest & Paper Association (AF&PA). The processes used by these organizations are accredited by the American

National Standards Institute (ANSI), which administers and coordinates the U.S. voluntary standardization and conformity assessment system.

In addition to standards and codes organizations, there are other key stakeholder groups that either are responsible for or influence the practices used in the design, construction, operation, and maintenance of buildings in the United States. These typically include organizations representing building owners and managers (e.g., Building Owners and Managers Association, Construction Industry Institute), real estate developers (e.g., Real Estate Board of New York), contractors (e.g., Associated General Contractors, Associated Builders and Contractors), architects (e.g., American Institute of Architects), engineers (e.g., National Society of Professional Engineers, Society of Fire Protection Engineers, Structural Engineering Institute, National Council of Structural Engineering Associations), suppliers, and insurers. These groups also provide training, especially as it affects the ability to implement code provisions in practice. Lack of adequate training programs can limit the usefulness or widespread acceptance of improved code provisions. Very few members of the general public and building occupants participate in this process.

The National Institute of Standards and Technology (NIST) is a non-regulatory agency of the U.S. Department of Commerce. NIST does not set building codes or standards, but provides technical support to the private sector and to other government agencies in the development of U.S. building and fire practice, standards and codes. NIST provides this support by: conducting research which helps to form the technical basis for such practice, standards, and codes; disseminating research results to practicing professionals; having its staff participate on technical and standards committees; and, providing technical assistance to the building and fire safety communities. Due to limited participation of the general public and building occupants, NIST has a responsibility to represent the public's interest. As an objective and impartial technical entity, NIST recommendations are given serious consideration by private sector organizations that develop national standards and model codes, which provide minimum requirements for public welfare and safety.

Rigorous enforcement of building codes and standards by state and local agencies, well trained and managed, is critical in order for standards and codes to ensure the expected level of safety. Unless they are complied with, the best codes and standards cannot protect occupants, emergency responders, or buildings.

9.2 NIST'S RECOMMENDATIONS FOR IMPROVING THE SAFETY OF BUILDINGS, OCCUPANTS, AND EMERGENCY RESPONDERS

NIST is conducting its building and fire safety investigation of the WTC disaster of September 11, 2001, under the authority of the National Construction Safety Team Act (15 USC 7301 et seq.). The National Construction Safety Team's final report is required by the Act to include recommendations that address (1) specific improvements to building standards, codes, and practices, (2) changes to, or the establishment of, evacuation and emergency response procedures, and (3) research and other appropriate actions needed to help prevent future building failures.

As part of its WTC Investigation, NIST is issuing draft recommendations for public comment that identify specific improvements in the way buildings are designed, constructed, maintained, and used and in evacuation and emergency response procedures. NIST believes that these recommendations are both realistic and achievable within a reasonable period of time and that their implementation would make buildings safer for occupants and emergency responders in future emergencies. **NIST strongly urges that immediate and serious consideration be given to these recommendations by the building and fire safety communities—especially designers, owners, developers, codes and standards development organizations, regulators, fire safety professionals, and emergency responders. NIST also strongly urges building owners and public officials to (1) evaluate the safety implications of these recommendations to their existing inventory of buildings, and (2) take the steps necessary to mitigate any unwarranted risks without waiting for changes to occur in codes, standards, and practices.** NIST is assigning top priority to work vigorously with these communities to ensure that there is a complete understanding of the recommendations and their technical basis and to provide needed technical assistance. As part of this effort, NIST will develop and maintain a web-based system with information on the status of NIST's recommendations that will be available to the public so that progress in implementing them can be tracked.

In formulating its recommendations from the WTC Investigation, NIST considered:

- Findings related to building performance, evacuation and emergency response, and to procedures and practices used in the design, construction, operation, and maintenance of the buildings;
- Whether these findings relate to the unique circumstances surrounding the terrorist attacks of September 11, 2001, or to normal building and fire safety considerations (including evacuation and emergency response);
- Technical solutions that are needed to address potential risks to buildings, occupants, and emergency responders, considering both identifiable hazards and the consequences of those hazards; and
- Whether the risks apply to all buildings or are limited to certain building types (e.g., buildings that exceed a certain height and floor area or that employ a specific type of structural system), buildings that contain specific design features, iconic/signature buildings, or buildings that house critical functions.

While there were unique aspects to the design of the WTC towers and the terrorist attacks of September 11, 2001, the design, construction, operation, and maintenance of the WTC towers—and the emergency response to the WTC towers—were based on procedures and practices that are commonly used for normal conditions. These include procedures and practices used for construction classification, establishing and determining fire resistance ratings, estimating wind loads, designing structural components and connections, designing egress systems, designing sprinkler systems, evacuation, and emergency response.

As an integral part of its Investigation, NIST reviewed the relevant commonly used procedures and practices and established a baseline performance for the buildings, evacuation, and emergency response. The performance on September 11, 2001 was then compared to the baseline performance. NIST is making several recommendations based on findings from its review of these procedures and practices. NIST is also making recommendations for selected buildings that are at greater risk, e.g., due to their iconic status, critical function, or design.

In its recommendations, NIST does not prescribe specific systems, materials, or technologies; NIST encourages competition among different systems, materials, and technologies that can meet performance requirements. NIST also does not prescribe specific threshold levels; NIST believes that the responsibility for the establishment of threshold levels properly belongs in the public policy setting process, in which the standards and codes development process plays a key role.

Based on its Investigation findings, NIST identified a broad set of issues related to practices, standards, and codes that provided the basis for the recommendations. The 30 draft recommendations resulting from the NIST Investigation were prepared by the Investigation Team with benefit of review by the National Construction Safety Team Advisory Committee. Table 9–1 (which follows the recommendations) shows a crosswalk between the recommendations in each of eight groups and three categories (responsible community, affected building population, and relation to outcome on September 11, 2001). The topics addressed in each group of recommendations are summarized below:

1. Increased structural integrity, including methods for preventing conditions that could result in progressive collapse (when a building or a significant portion of a building collapses due to disproportionate spread of an initial local failure), standardizing the estimation of wind loads that frequently govern the design of tall buildings, and enhancing the stability of tall buildings.
2. Enhanced fire resistance of structures, including the technical basis for determining construction classification and fire resistance ratings, improvements to the technical basis for standard fire resistance testing methods, adoption of the “structural frame” approach to fire resistance ratings, and in-service performance requirements and conformance assessment criteria for spray-applied fire resistive materials.
3. New methods for designing structures to resist fires, including the objective of burnout without collapse, the development of performance-based methods as an alternative to current prescriptive design methods, the development and evaluation of new fire resistive coating materials and technologies, evaluation of the fire performance of conventional and high-performance structural materials, and elimination of technical and standards barriers to the introduction of new materials and technologies.
4. Improved active fire protection, including the design, performance, reliability, and redundancy of sprinklers, standpipes/hoses, fire alarms, and smoke management systems.
5. Improved building evacuation, including system designs that facilitate safe and rapid egress, methods for ensuring clear and timely emergency communications to occupants, better occupant preparedness for evacuation during emergencies, and incorporation of appropriate egress technologies.
6. Improved emergency response, including better access to the buildings and better operations, emergency communications, and command and control in large-scale emergencies.
7. Improved procedures and practices, including encouraging code compliance by nongovernmental and quasi-governmental entities, adoption and application of egress requirements in available code provisions for existing buildings, and retention and availability of building documents over the life of a building.
8. Education and training programs for fire protection engineers, structural engineers, and architects.

These improvements are to be achieved both by complying with existing codes and through provisions that address new requirements. Each recommendation was further noted for the (1) community (stakeholders) responsible for addressing it, (2) the building population affected, and (3) whether the recommendation is related to the outcome on September 11, 2001. These three categories are further divided as follows (also included in Table 9–1):

- Responsible Community:
  - Professional practices
  - Provisions in standards, codes, and regulations
  - Adoption and enforcement of the provisions
  - Research and development or requiring further study
  - Education and training
- Affected Population of Buildings:
  - All tall buildings (buildings over 20 stories in height[16]; building owners and public officials will need to determine appropriate performance requirements for buildings that are at risk due to types of structural, fire safety, or egress systems used, location, use, historic/iconic status, nature of occupancy, etc.)
  - Selected other buildings (buildings less than 20 stories in height that are at risk due to types of systems used, location, use, historic/iconic status, nature of occupancy, etc.).
- Relation to the outcome on September 11, 2001:
  - If in place, could have changed the outcome on September 11, 2001
  - Would not have changed the outcome, yet is an important building and fire safety issue that was identified during the course of the Investigation

The recommendations are listed below in eight groups, with each recommendation assigned a number (1, 2, 3, etc.) for easy reference. The numerical ordering does not reflect any priority.

9.2.1 Group 1. Increased Structural Integrity

The standards for estimating the load effects of potential hazards (e.g., progressive collapse, wind) and the design of structural systems to mitigate the effects of those hazards should be improved to enhance structural integrity.

> **Recommendation 1.** **NIST recommends that: (1) progressive collapse should be prevented in buildings through the development and nationwide adoption of consensus standards and code provisions, along with the tools and guidelines needed for their use in practice; and (2) a**

[16] NIST has found that the physiological impacts on emergency responders of climbing 20 or more stories makes it difficult to conduct effective and timely firefighting and rescue operations in building emergencies without functioning elevators. Better knowledge of the physiological impacts through research could refine the definition of tall buildings used here.

standard methodology should be developed—supported by analytical design tools and practical design guidance—to reliably predict the potential for complex failures in structural systems subjected to multiple hazards.

a. Progressive collapse[17] should be prevented in buildings. The primary structural systems should provide alternate paths for carrying loads in case certain components fail (e.g., transfer girders, columns supporting only gravity loads). This is especially important in buildings where structural components (e.g., columns, girders) support unusually large floor areas.[18] Progressive collapse is addressed only in a very limited way. While the initiating event in design to prevent progressive collapse typically is considered to be the failure of one or two columns at the bottom of the structure, possible initiating events at other locations within the structure, or involving other key components and subsystems, should be analyzed commensurate with the risks considered in the design. The effectiveness of mitigation approaches involving new system and subsystem design concepts should be evaluated with conventional approaches based on indirect design (continuity, strength, and ductility of connections), direct design (local hardening), and redundant (alternate) load paths. The capability to prevent progressive collapse due to abnormal loads should include: (i) comprehensive design rules and practice guides; (ii) evaluation criteria, methodology, and tools for assessing the vulnerability of structures to progressive collapse; (iii) performance-based criteria for abnormal loads and load combinations; (iv) analytical tools to predict potential collapse mechanisms; and (v) computer models and analysis procedures for use in routine design practice. The federal government should coordinate the existing programs that address this need: those in the Department of Defense; the General Services Administration; the Defense Threat Reduction Agency; and NIST. *Affected National Standards*[19]*:* ASCE-7, AISC Specifications, and ACI 318. These standards and other relevant committees should draw on expertise from ASCE-29 for issues concerning progressive collapse under fire conditions. *National Model Building Codes:* The standards should be adopted in national model building codes (i.e., the *International Building Code* and NFPA 5000) by mandatory reference to, or incorporation of, the latest edition of the standard. State and local jurisdictions should adopt and enforce the improved national model building codes and national standards based on all 30 WTC recommendations. The codes and standards may vary from the WTC recommendations, but satisfy their intent.

b. A robust, integrated predictive capability should be developed, validated, and maintained to routinely assess the vulnerability of whole structures to the effects of potential hazards. This capability to evaluate the performance and reserve capacity of structures does not exist and is a significant cause for concern. This capability also would assist in investigations of building failure—as demonstrated by the analyses of the WTC building collapses carried out in this Investigation. The failure analysis capability should include proper identification of the complex failure phenomena to be analyzed under multiple hazards (e.g., bomb blasts, fires, impacts, gas explosions, earthquakes, and hurricane winds), experimentally-validated models that are capable of capturing the essential physical phenomena, and robust tools for routine analysis to predict such failures and their consequences. This capability should be developed via a coordinated effort involving federal, private sector, and academic research organizations in close partnership with practicing engineers.

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[17] *Progressive collapse* (or *disproportionate collapse*) occurs when an initial local failure spreads from structural element to structural element resulting in the collapse of an entire structure or a disproportionately large part of it.

[18] While the WTC towers eventually collapsed, they had the capacity to redistribute loads from impact and fire damaged structural components and subsystems to undamaged components and subsystems. However, the core columns in the WTC towers lacked sufficient redundant (alternate) paths for carrying gravity loads.

[19] A full listing of the affected standards, including the complete names of these standards, is provided in Table 2, which is located following the recommendations.

<u>Recommendation 2.</u> NIST recommends that nationally accepted performance standards be developed for: (1) conducting wind tunnel testing of prototype structures based on sound technical methods that result in repeatable and reproducible results among testing laboratories; and (2) estimating wind loads and their effects on tall buildings for use in design, based on wind tunnel testing data and directional wind speed data. Wind loads specified in current prescriptive codes may not be appropriate for the design of very tall buildings since they do not account for building-specific aerodynamic effects. Further, a review of wind load estimates for the WTC towers indicated differences by as much as 40 percent from wind tunnel studies conducted in 2002 by two independent commercial laboratories. Major sources of differences in estimation methods currently used in practice occur in the selection of design wind speeds and directionality, the nature of hurricane wind profiles, the estimation of "component" wind effects by integrating wind tunnel data with wind speed and direction information, and the estimation of "resultant" wind effects using load combination methods. Wind loads were a major factor in the design of the WTC tower structures and were relevant to evaluating the baseline capacity of the structures to withstand abnormal events such as major fires or impact damage. Yet, there is lack of consensus on how to evaluate and estimate winds and their load effects on buildings.

a. Nationally accepted standards should be developed and implemented for conducting wind tunnel tests, estimating site-specific wind speed and directionality based on available data, and estimating wind loads associated with specified design probabilities from wind tunnel test results and directional wind speed data.

b. Nationally accepted standards should be developed for estimating wind loads in the design of tall buildings. The development of performance standards for estimating wind loads should consider (i) appropriate load combinations and load factors, including performance criteria for static and dynamic behavior, based on both ultimate and serviceability limit states, and (ii) validation of wind load provisions in prescriptive design standards for tall buildings, given the universally acknowledged use of wind-tunnel testing and associated performance criteria. Limitations to the use of prescriptive wind load provisions should be clearly identified in codes and standards.

The standards development work can begin immediately to address many of the above needs. The results of those efforts should be adopted in practice as soon as they become available. The research that will be required to address the remaining needs also should begin immediately and results should be made available for standards development and use in practice. *Affected National Standard:* ASCE-7. *National Model Building Codes:* The standard should be adopted in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

<u>Recommendation 3.</u> NIST recommends that an appropriate criterion should be developed and implemented to enhance the performance of tall buildings by limiting how much they sway under lateral load design conditions (e.g., winds and earthquakes). The stability and safety of tall buildings depend upon, among other factors, the magnitude of building sway or deflection, which tends to increase with building height. Conventional strength-based design methods, such as those used in the design of the WTC towers, do not limit deflections. The deflection limit state criterion, which is proposed here is in addition to the stress limit and serviceability requirement; it should be adopted either to complement the safety provided by conventional strength-based design or independently as an alternate deflection-based approach to the design of tall buildings for life safety. The recommended deflection limit state criterion is independent of the criterion used to ensure occupant comfort, which is met in current practice by limiting accelerations (e.g., in the 15 to 20 milli-g range). Lateral deflections, which already are limited in the design of tall buildings to control damage in earthquake-prone regions, should also be limited in non-seismic areas.[20] *Affected National Standards:* ASCE-7, AISC Specifications, and ACI 318. *National Model Building Codes:* The standards should be adopted in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

9.2.2 Group 2. Enhanced Fire Resistance of Structures

The procedures and practices used to ensure the fire resistance of structures should be enhanced by improving the technical basis for construction classifications and fire resistance ratings, improving the technical basis for standard fire resistance testing methods, use of the "structural frame" approach to fire resistance ratings, and developing in-service performance requirements and conformance criteria for spray-applied fire resistive materials.

<u>Recommendation 4.</u> NIST recommends evaluating, and where needed improving, the technical basis for determining appropriate construction classification and fire rating requirements (especially for tall buildings greater than 20 stories in height)—and making related code changes now as much as possible—by explicitly considering factors including[21]:

- **timely access by emergency responders and full evacuation of occupants, or the time required for burnout without local collapse;**
- **the extent to which redundancy in active fire protection (sprinkler and standpipe, fire alarm, and smoke management) systems should be credited for occupant life safety[22];**
- **the need for redundancy in fire protection systems that are critical to structural integrity[23];**
- **the ability of the structure and local floor systems to withstand a maximum credible fire scenario without collapse, recognizing that sprinklers could be compromised, not operational, or non-existent;**
- **compartmentation requirements (e.g., 12,000 ft^2 [24]) to protect the structure, including fire rated doors and automatic enclosures, and limiting air supply (e.g., thermally resistant window assemblies) to retard fire spread in buildings with large, open floor plans;**
- **the impact of spaces containing unusually large fuel concentrations for the expected occupancy of the building; and**

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[20] Analysis of baseline performance under the original design wind loads indicated that the WTC towers would need to have been between 50 and 90 percent stiffer to achieve a typical drift ratio used in current practice for non-seismic regions, though not required by building codes. Limiting drift would have required increasing exterior column areas in lower stories and/or significant additional damping.

[21] The construction classification and fire rating requirements should be *risk-consistent* with respect to the *design-basis hazards* and the *consequences* of those hazards. The fire rating requirements, which were originally developed based on experience with buildings less than 20 stories in height, have generally decreased over the past 80 years since historical fire data for buildings suggests considerable conservatism in those requirements. For tall buildings, the likely consequences of a given threat to an occupant on the upper floors are more severe than the consequences to an occupant on the first floor or the lower floors. For example, with non-functioning elevators, both the time requirements are much greater for full building evacuation from upper floors and emergency responder access to those floors. It is not clear how the current height and areas tables in building codes consider the technical basis for the progressively increasing risk to an occupant on the upper floors of tall buildings that are much greater than 20 stories in height.

[22] Occupant life safety, prevention of fire spread, and structural integrity are considered separate safety objectives.

[23] The passive fire protection system (includes fireproofing insulation, compartmentation, and firestopping) and the active sprinkler system each provide redundancy for maintaining structural integrity in a building fire, should one of the systems fail to perform its intended function.

[24] Or a more appropriate limit, which represents a reasonable area for active firefighting operations.

- **the extent to which fire control systems, including suppression by automatic or manual means, should be credited as part of the prevention of fire spread.**

Adoption of this recommendation will allow building codes to distinguish the risks associated with different building heights, fuel concentrations, and fire protection systems. Research is needed to develop the data and evaluate alternative proposals for construction classifications and fire ratings. *National Model Building Codes:* The national model building code committees should undertake a comprehensive review of current construction classification and fire rating requirements and establish a uniform set of revised thresholds with a firm technical basis that considers the factors identified above. [25]

Recommendation 5. NIST recommends that the technical basis for the century-old standard for fire resistance testing of components, assemblies, and systems should be improved through a national effort. Necessary guidance also should be developed for extrapolating the results of tested assemblies to prototypical building systems. This effort should address the technical issues listed below[26]:

a. Criteria and test methods for determining:
   - structural limit states, including failure, and means for measurement;
   - effect of scale of test assembly versus prototype application, especially for long-span structures that significantly exceed the size of testing furnaces;
   - effect of end-restraint conditions (restrained and unrestrained) on test results, especially for long-span structures that have greater flexibility;
   - fire resistance of structural connections, especially the fire protection required for a loaded connection to achieve a specified rating[27];
   - effect of the combination of loading and exposure (time-temperature profile) required to adequately represent expected conditions;
   - the repeatability and reproducibility of test results (typically results from a single test are used to determine rating for a component or assembly); and
   - realistic ratings for structural assemblies made with materials that have improved elevated temperature properties (strength, modulus, creep behavior).

b. Improved procedures and guidance to analyze and evaluate existing data from fire resistance tests of building components and assemblies for use in qualifying an untested building element.

c. Relationships between prescriptive ratings and performance of the assembly in real fires.

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[25] The National Fire Protection Association (NFPA) 5000 model code and the International Building Code (IBC) both recognize the risks associated with different building heights and accepted changes in 2001 and 2004, respectively. Both model codes now require that buildings 420 feet and higher have a minimum 4 hour structural fire-resistance rating. The previous requirement was 2 hours. The change provides increased fire resistance for the structural system leading to enhanced tenability of the structure and gives firefighters additional protection while fighting a fire. While NIST supports these changes as an interim step, NIST believes that it is essential to complete a comprehensive review that will establish a firm technical basis for construction classification and fire rating requirements.

[26] The technical issues were identified from the series of four fire resistance tests of the WTC floor system and the review and analysis of relevant documents that were conducted as part of this Investigation.

[27] There is a lack of test data on the fire resistance ratings of loaded connections. The fire resistance of structural connections is not rated in current practice. Also, standards and codes do not provide guidance on fireproofing requirements for structural connections when the connected members have different fire resistance ratings.

Affected National (and International) Standards[28]: ASTM E 119, NFPA 251, UL 263, and ISO 834. *National Model Building Codes:* The standards should be adopted in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

Recommendation 6. NIST recommends the development of criteria, test methods, and standards: (1) for the in-service performance of spray-applied fire resistive materials (SFRM, also commonly referred to as fireproofing or insulation) used to protect structural components; and (2) to ensure that these materials, as-installed, conform to conditions in tests used to establish the fire resistance rating of components, assemblies, and systems. This should include:

- Improved criteria and testing methodology for the performance and durability of SFRM (e.g., adhesion, cohesion, abrasion and impact resistance) under in-service exposure conditions (e.g., temperature, humidity, vibration, impact, with/without primer paint on steel[29]) for use in acceptance and quality control. The current test method to measure the bond strength, for example, does not distinguish the cohesive strength from the tensile and shear adhesive strengths. Nor does it consider the effect of primer paint on the steel surface. Further, no test requirements explicitly consider the effects of abrasion, vibration, shock, and impact under normal service conditions. Also, the effects of elevated temperatures on thermal properties and bond strength are not considered in evaluating the performance and durability of SFRM.

- Inspection procedures, including practical conformance criteria, for SFRM in both the building codes and fire codes for use after installation, renovation, or modification of all mechanical and electrical systems and by fire inspectors over the life of the building. While there are existing standards of practice (AIA MasterSpec and AWCI Standard 12), they are not required by codes nor are they enforced. Further, these standards require improvements to address the issues identified in this recommendation.

- Criteria for determining the effective uniform SFRM thickness—thermally equivalent to the variable thickness of the product as it actually is applied—that can be used to ensure that the product in the field conforms to the near uniform thickness conditions in the tests used to establish the fire resistance rating of the component, assembly, or system. Such criteria are needed to ensure that the as-installed SFRM will provide the intended performance.

- Methods for predicting the effectiveness of SFRM insulation as a function of its properties, the application characteristics, and the duration and intensity of the fire.

- Methods for predicting service life performance of SFRM under in-service conditions.

Affected National Standards: AIA MasterSpec and AWCI Standard 12 for field inspection and conformance criteria; ASTM for SFRM performance criteria and test methods. *National Model Building Codes:* The standards should be adopted in national model building codes by mandatory

[28] While the WTC recommendations are focused mainly on U.S. national standards, each U.S. standard has counterpart international standards. In a recent report (ISO/TMB AGS N 46), the International Organization for Standardization (ISO), through its Advisory Group for Security (AGS), has recommended that since many of the ISO standards for the design of buildings date to the 1980s, they should be reviewed and updated to make use of the studies done by NIST on the World Trade Center disaster, the applicability of new technology for rescue from high buildings, natural disasters, etc. ISO's Technical Advisory Group 8 coordinates standards work for buildings.

[29] NIST tests showed that the adhesive strength of SFRM on steel coated with primer paint was a third to half of the adhesive strength on steel that had not been coated with primer paint. The SFRM products used in the WTC towers were applied to steel components coated with primer paint.

reference to, or incorporation of, the latest edition of the standard. [See Recommendation 10 for more on this issue].

<u>Recommendation 7.</u> **NIST recommends the nationwide adoption and use of the "structural frame" approach to fire resistance ratings.** This approach requires that structural members—such as girders, beams, trusses and spandrels having direct connection to the columns, and bracing members designed to carry gravity loads—be fire protected to the same fire resistance rating as columns. This approach is currently required by the International Building Code (IBC), one of the national model codes, and is under consideration by NFPA 5000, the other national model code. This requirement ensures consistency in the fire protection provided to all of the structural elements that contribute to overall structural stability.[30] *National Model Building Codes:* Both national model building codes should incorporate the structural frame requirement. State and local jurisdictions should adopt and enforce this requirement, which already exists in one of the national model building codes.

9.2.3 Group 3. New Methods for Fire Resistance Design of Structures

The procedures and practices used in the fire resistance design of structures should be enhanced by requiring an objective that uncontrolled fires result in burnout without local or global collapse. Performance-based methods are an alternative to prescriptive design methods. This effort should include the development and evaluation of new fire resistive coating materials and technologies and evaluation of the fire performance of conventional and high-performance structural materials. Technical and standards barriers to the introduction of new materials and technologies should be eliminated.

<u>Recommendation 8.</u> **NIST recommends that the fire resistance of structures should be enhanced by requiring a performance objective that uncontrolled building fires result in burnout without local or global collapse.** Such a provision should apply to all tall buildings, recognizing that sprinklers could be compromised, non-operational, or non-existent. Current methods for determining the fire resistance rating of structural assemblies do not explicitly specify a performance objective. The rating resulting from current test methods indicates that the assembly (component or subsystem) continued to support its superimposed load (simulating a maximum load condition) during the test exposure without collapse. *National Model Building Codes:* This recommendation should be included into the national model codes as an objective and adopted as an integral part of fire resistance design for structures. The issue of non-operational sprinklers could be addressed using the existing concept of Design Scenario 8 of NFPA 5000, where such compromise is assumed and the result is required to be acceptable to the Authority Having Jurisdiction. *Affected National Standards:* ASCE-7, AISC Specifications, ACI 318, and ASCE 29.

<u>Recommendation 9.</u> **NIST recommends the development of: (1) performance-based standards and code provisions, as an alternative to current prescriptive design methods, to enable the design and retrofit of structures to resist real building fire conditions, including their ability to achieve the performance objective of burnout without structural or local floor collapse: and (2) the tools, guidelines, and test methods necessary to evaluate the fire performance of the structure as a whole system.** Standards development organizations, including the American Institute of Steel Construction, have already begun developing performance-based provisions to consider the effects of fire in structural design.

[30] Had this requirement been adopted by the 1968 New York City building code, the WTC floor system, including its connections, would have had the 3 hour rating required for the columns since the floors braced the columns.

This performance-based capability should include, but not be limited to:

a. Standard methodology, supported by performance criteria, analytical design tools, and practical design guidance; related building standards and codes for fire resistance design and retrofit of structures, working through the consensus process for nationwide adoption; comprehensive design rules and guidelines; methodology for evaluating thermostructural performance of structures; and computational models and analysis procedures for use in routine design practice.

b. Standard methodology for specifying multicompartment, multifloor fire scenarios for use in the design and analysis of structures to resist fires, accounting for building-specific conditions such as geometry, compartmentation, fuel load (e.g., building contents and any flammable fuels such as oil and gas), fire spread, and ventilation; and methodology for rating the fire resistance of structural systems and barriers under realistic design-basis fire scenarios.

c. Publicly available computational software to predict the effects of fires in tall buildings—developed, validated, and maintained through a national effort—for use in the design of fire protection systems and the analysis of building response to fires. Improvements should include the fire behavior and contribution of real combustibles; the performance of openings, including door openings and window breakage, that controls the amount of oxygen available to support the growth and spread of fires and whether the fire is fuel-controlled or ventilation-controlled; the floor-to-floor flame spread; the temperature rise in both insulated and uninsulated structural members and fire barriers; and the structural response of components, subsystems, and the total building system due to the fire.

d. New test methods, together with associated conformance assessment criteria, to support the performance-based methods for fire resistance design and retrofit of structures. The performance objective of burnout without collapse will require the development of standard fire exposures that differ from those currently used.

Affected National (and International) Standards: ASCE-7, AISC Specifications, ACI 318, and ASCE-29 for fire resistance design and retrofit of structures; NFPA, SFPE, ASCE, and ISO TC92SC4 for building-specific multicompartment, multifloor design basis fire scenarios; and ASTM, NFPA, UL, and ISO for new test methods. *National Model Building Codes:* The performance standards should be adopted as an alternate method in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

<u>Recommendation 10.</u> NIST recommends the development and evaluation of new fire resistive coating materials, systems, and technologies with significantly enhanced performance and durability to provide protection following major events. This could include, for example, technologies with improved adhesion, double-layered materials, intumescent coatings, and more energy absorbing SFRMs.[31] Consideration should be given to pre-treatment of structural steel members with some type of mill-applied fire protection to minimize the uncertainties associated with field application and in-use damage. If such an approach was feasible, only connections and any fire protection damaged during construction and fit-out would need to be field-treated. *Affected National Standards:* Technical barriers, if any, to the introduction of new structural fire resistance materials, systems, and technologies should be eliminated in the AIA MasterSpec and AWCI Standard 12 for field inspection and conformance criteria and in ASTM standards for SFRM performance criteria and test methods. *National Model Building Codes:* Technical barriers, if any, to the introduction of new

[31] Other possibilities include encapsulation of SFRM by highly elastic energy absorbing membranes or commodity grade carbon fiber or other wraps. The membrane would remain intact under shock, vibration, and impact but may be compromised in a fire, yet allowing the SFRM to perform its thermal insulation function. The carbon wrap would remain intact under shock, vibration, and impact and, possibly, under fire conditions as well.

structural fire resistance materials, systems, and technologies should be eliminated from the national model building codes.

__Recommendation 11.__ **NIST recommends that the performance and suitability of advanced structural steel, reinforced and pre-stressed concrete, and other high-performance material systems should be evaluated for use under conditions expected in building fires.** This evaluation should consider both presently available and new types of steels, concrete, and high-performance materials to establish the properties (e.g., yield and ultimate strength, modulus, creep behavior, failure) that are important for fire resistance, establish needed test protocols and acceptance criteria for such materials and systems, compare the performance of newer systems to conventional systems, and the cost-effectiveness of alternate approaches. Technical and standards barriers to the introduction and use of such advanced steel, concrete, and other high-performance material systems should be identified and eliminated, or at least minimized, if they are found to exist. *Affected National Standards:* AISC Specifications and ACI 318. Technical barriers, if any, to the introduction of these advanced systems should be eliminated in ASTM E 119, NFPA 251, UL 263, ISO 834. *National Model Building Codes:* Technical barriers, if any, to the introduction of these advanced systems should be eliminated from the national model building codes.

9.2.4 Group 4. Improved Active Fire Protection

Active fire protection systems (i.e., sprinklers, standpipes/hoses, fire alarms, and smoke management systems) should be enhanced through improvements to design, performance, reliability, and redundancy of such systems.

__Recommendation 12.__ **NIST recommends that the performance and redundancy of active fire protection systems (sprinklers, standpipes/hoses, fire alarms, and smoke management systems) in buildings should be enhanced to accommodate the greater risks associated with increasing building height and population, increased use of open spaces, available compartmentation, high-risk building activities, fire department response limits, transient fuel loads, and higher threat profile.** The performance attributes should deal realistically with the system design basis, reliability of automatic/manual operations, redundancy, and reduction of vulnerabilities due to single point failures. *Affected National Standards:* NFPA 1, NFPA 13, NFPA 72, NFPA 90A, and NFPA 101. *National Model Building Codes:* The performance standards should be adopted in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

__Recommendation 13.__ **NIST recommends that fire alarm and communications systems in buildings should be developed to provide continuous, reliable, and accurate information on the status of life safety conditions at a level of detail sufficient to manage the evacuation process in building fire emergencies, and that standards for their performance be developed.** This should include means to maintain communications with evacuating occupants that can both reassure them and redirect them if conditions change. While pre-installed fire warden telephone systems in buildings can serve a useful purpose and may be installed in buildings, they should be made available for use by emergency responders. Pre-installed dedicated firefighter telephone systems in buildings are of limited use and effectiveness, and their installation is not encouraged. *Affected National Standards:* NFPA 1, NFPA 72, and NFPA 101. *National Model Building and Fire Codes:* The performance standards should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard.

__Recommendation 14.__ **NIST recommends that control panels at fire/emergency command stations in buildings should be adapted to accept and interpret a larger quantity of more**

reliable information from the active fire protection systems that provide tactical decision aids to fireground commanders, including water flow rates from pressure and flow measurement devices, and that standards for their performance be developed. *Affected National Standards:* NFPA 1, NFPA 72, and NFPA 101. *National Model Building and Fire Codes:* The performance standards should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard.

Recommendation 15. NIST recommends that systems should be developed and implemented for: (1) real-time off-site secure transmission of valuable information from fire alarm and other monitored building systems for use by emergency responders, at any location, to enhance situational awareness and response decisions and maintain safe and efficient operations[32]; and (2) preservation of that information either off-site or in a black box that will survive a fire or other building failure for purposes of subsequent investigations and analysis. Standards for the performance of such systems should be developed, and their use should be required. *Affected National Standards:* NFPA 1, NFPA 72, and NFPA 101. *National Model Building and Fire Codes:* The performance standards should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard.

9.2.5 Group 5. Improved Building Evacuation

Building evacuation should be improved to include system designs that facilitate safe and rapid egress, methods for ensuring clear and timely emergency communications to occupants, better occupant preparedness for evacuation during emergencies, and incorporation of appropriate egress technologies.[33]

Recommendation 16. NIST recommends that public agencies, non-profit organizations concerned with building and fire safety, and building owners and managers should develop and carry out public education campaigns, jointly and on a nationwide scale, to improve building occupants' preparedness for evacuation in case of building emergencies. This effort should include better training and self-preparation of occupants, an effectively implemented system of floor wardens and building safety personnel, and needed improvements to standards. Occupant preparedness should include:

a. Improved training and drills for building occupants to ensure that they know evacuation procedures, are familiar with the egress route, and are sufficiently aware of what is necessary if evacuation is required with minimal notice (e.g., footwear consistent with the distance to be traveled, a flashlight/glow stick for pathway illumination, and dust masks).

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[32] The alarm systems in the WTC towers were only capable of determining and displaying: (a) areas that had at some time reached alarm point conditions; and (b) areas that had not. The quality and reliability of information available to emergency responders at the Fire Command Station was not sufficient to understand the fire conditions. The only information transmitted outside the building was the fact that the building had gone into alarm. Further, the fire alarm system in WTC 7, which was transmitted to a monitoring service, was on "test" on the morning of September 11, 2001 since routine maintenance was being performed. Under test conditions (1) the system is typically disabled for the entire building, not just for the area where work is being performed, and (2) alarm signals typically do not show up on an operator console.

[33] This effort should include standards and guidelines for the development and evaluation of emergency evacuation plans, including best practices for both partial and full evacuation, and the development of contingency plans that account for expected conditions that may require adaptation, including the compromise of all or part of an egress path before or during evacuation, or conditions such as widespread power failure, earthquake, or security threat that restrict egress from the building. Evacuation planning should include the process from initial notification of the need to evacuate to the point the occupants arrive at a place where their safety is ensured. These standards and guidelines should be suitable for assessing the adequacy of evacuation plans submitted for approval and should require occupant training through the conduct of regular drills.

b. Improved training and drills that routinely inform building occupants that roof rescue is not (or is) presently feasible as a standard evacuation option, that they should evacuate down the stairs in any full-building evacuation unless explicitly instructed otherwise by on-site incident commanders, and that elevators can be used if they are still in service and haven't been recalled or stopped.

c. Improved codes, laws, and regulations that do not restrict or impede building occupants during evacuation drills from familiarizing themselves with the detailed layout of alternate egress routes for a full building evacuation[34].

Affected National Standard: NFPA 101. *National Model Building and Fire Codes:* The standard should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard. *Affected National Organizations:* NIBS, NCSBCS, BOMA, and CTBUH.

Recommendation 17. NIST recommends that tall buildings should be designed to accommodate timely full building evacuation of occupants due to building-specific or large-scale emergencies such as widespread power outages, major earthquakes, tornadoes, hurricanes without sufficient advanced warning, fires, accidental explosions, and terrorist attack. Building size, population, function, and iconic status should be taken into account in designing the egress system. Stairwell and exit capacity[35] should be adequate to accommodate counterflow due to emergency access by responders.

a. Improved egress analysis models, design methodology, and supporting data should be developed to achieve a target evacuation performance (e.g., time for full building evacuation[36]) for the design building population by considering the building and egress system designs and human factors such as occupant size, mobility status, stairwell tenability conditions, visibility, and congestion.

b. Mobility challenged occupants should be provided a means for self-evacuation in the event of a building emergency. Current strategies (and law) generally require the mobility challenged to shelter-in-place and await assistance. New procedures, which provide redundancy in the event that the floor warden system or co-worker assistance fails, should consider full building evacuation, and may include use of fire-protected and structurally hardened elevators[37], motorized evacuation technology, and/or dedicated communication technologies for the mobility challenged.

c. If protected/hardened elevators are provided for emergency responders but become unusable during an emergency, due to a malfunction or a conventional threat whose magnitude exceeds the magnitude considered in design, sufficient stairwell capacity should be provided to ensure timely emergency responder access to buildings that are undergoing full evacuation. Such capacity could be provided either via dedicated stairways for fire service use or by building sufficient

[34] New York City Local Law 5 prohibits *requiring* occupants to practice stairwell evacuation during drills.

[35] Egress capacity should be based on an all-hazards approach that considers the number and width of stairs (and doors) as well as the possible use of scissor stairs credited as a single stair.

[36] Use of egress models is required to estimate the egress capacity for a range of different evacuation strategies, including full building evacuation. NIST found that the average surviving occupant in the WTC towers descended stairwells at about half the slowest speed previously measured for non-emergency evacuations.

[37] Elevators should be explicitly designed to provide protection against large, but conventional, building fires. *Fire-protected* elevators also should be *structurally hardened* to withstand the range of foreseeable building-specific or large-scale emergencies. While progress has been made in developing the requirements and technologies for fire-protected elevators, similar criteria and designs for structurally hardened elevators remain to be developed.

stairway capacity (i.e., number and width of stairways and/or use of scissor stairs credited as a single stair) to accommodate the evacuation of building occupants while allowing access to emergency responders with minimal hindrance from occupant counterflow.

d. The egress allowance in assembly use spaces should be limited in state and local laws and regulations to no more than a doubling of the stairway capacity for the provision of a horizontal exit on a floor, as is the case now in the national model codes.[38] The use of a horizontal exit creates an area of refuge with a 2 hour fire rated separation, at least one stair on each side, and sufficient space for the expected occupant load.

Affected National Standard: NFPA 101, ASME A 17. *National Model Building and Fire Codes:* The standards should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard.

Recommendation 18. NIST recommends that egress systems should be designed: (1) to maximize remoteness of egress components (i.e., stairs, elevators, exits) without negatively impacting the average travel distance; (2) to maintain their functional integrity and survivability under foreseeable building-specific or large-scale emergencies; and (3) with consistent layouts, standard signage, and guidance so that systems become intuitive and obvious to building occupants during evacuations.

a. Within a safety-based design hierarchy that should be developed, highest priority should be assigned to maintain the functional integrity, survivability, and remoteness of egress components and active fire protection systems (sprinklers, standpipes, associated water supply, fire alarms, and smoke management systems). The design hierarchy should consider the many systems (e.g., stairs, elevators, active fire protection, mechanical, electrical, plumbing, and structural) and system components, as well as functional integrity, tenant access, emergency responder access, building configuration, security, and structural design.

b. The design, functional integrity, and survivability of the egress and other life safety systems (e.g., stairwell and elevator shafts and active fire protection systems) should be enhanced by considering accidental structural loads such as those induced by overpressures (e.g., gas explosions), impacts, or major hurricanes and earthquakes, in addition to fire separation requirements. In selected buildings, structural loads due to other risks such as those due to terrorism may need to be considered. While NIST does not believe that buildings should be designed for aircraft impact, as the last line of defense for life safety, the stairwells and elevator shafts individually, or the core if these egress components are contained within the core, should have adequate structural integrity to withstand accidental structural loads and anticipated risks.

c. Stairwell remoteness requirements should be met by a physical separation of the stairwells that provide a barrier to both fire and accidental structural loads. Maximizing stairwell remoteness, without negatively impacting the average travel distance, would allow a stairwell to maintain its structural integrity independent of any other stairwell that is subject to accidental loads, even if the stairwells are located within the same structural barrier such as the core. The current "walking path" measurement allows stairwells to be physically next to each other, separated only by a fire barrier. Reducing the clustering of stairways that also contain standpipe water systems provide the fire service with increased options for formulating firefighting strategies. This should not

[38] The New York City Building Code permits a *doubling* of allowed stair capacity when one area of refuge is provided on a floor and a *tripling* of stair capacity for two or more areas of refuge on a floor. In the world of post-September 11, 2001, it is difficult to predict (1) if, and for how long, occupants will be willing to wait in a refuge area before entering an egress stairway, and (2) what the impact would be of such a large group of people moving down the stairs on the orderly evacuation of lower floors.

preclude the use of scissor stairs[39] as a means of increasing stair capacity—provided the scissor stair is only credited as a single stair.

d. Egress systems should have consistent layouts with standard signage and guidance so that the systems become intuitive and obvious to all building occupants, including visitors, during evacuations. Particular consideration should be given to unexpected deviations in the stairwells (e.g., floors with transfer hallways).

Affected National Standard: NFPA 101. *National Model Building and Fire Codes:* The standard should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard.

Recommendation 19. **NIST recommends that building owners, managers, and emergency responders develop a joint plan and take steps to ensure that accurate emergency information is communicated in a timely manner to enhance the situational awareness of building occupants and emergency responders affected by an event. This should be accomplished through better coordination of information among different emergency responder groups, efficient sharing of that information among building occupants and emergency responders, more robust design of emergency public address systems, improved emergency responder communication systems, and use of the Emergency Broadcast System (now known as the Integrated Public Alert and Warning System) and Community Emergency Alert Networks.**

a. Situational awareness of building occupants and emergency responders in the form of information and event knowledge should be improved through better coordination of such information among emergency responder groups (9-1-1 dispatch, fire department or police department dispatch, emergency management dispatch, site security, and appropriate federal agencies), efficient sharing and communication of information between building occupants and emergency responders, and improved emergency responder communication systems (i.e., including effective communication within steel and reinforced concrete buildings, capacity commensurate with the scale of operations, and interoperability among different communication systems).

b. The emergency communications systems in buildings should be designed with sufficient robustness and redundancy to continue providing public address announcements or instructions in foreseeable building-specific or large-scale emergencies, including widespread power outage, major earthquakes, tornadoes, hurricanes, fires, and accidental explosions. Consideration should be given to placement of building announcement speakers in stairways in addition to other standard locations.

c. The Integrated Public Alert and Warning System (IPAWS) should be activated and used, especially during large-scale emergencies, as a means to rapidly and widely communicate information to building occupants and emergency responders to enhance their situational awareness and assist with evacuation.

d. Local jurisdictions (cities and counties or boroughs) should seriously consider establishing a Community Emergency Alert Network (CEAN), within the framework of IPAWS, and make it available to the citizens and emergency responders of their jurisdiction to enhance situational awareness in emergencies[40]. The network should deliver important emergency alerts, information

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[39] Two separate stairways within the same enclosure and separated by a fire rated partition.

[40] Types of emergency communications could include life safety information, severe weather warnings, disaster notifications (including information on terrorist attacks), directions for self-protection, locations of nearest available shelters, precautionary evacuation information, identification of available evacuation routes, and accidents or obstructions associated with roadways and utilities.

and real-time updates to all electronic communications systems or devices registered with the CEAN. These devices may include e-mail accounts, cell phones, text pagers, satellite phones, and wireless PDAs.

Affected National Standard: NFPA 101 and/or a new standard. *National Model Building and Fire Codes:* The standard should be adopted in national model codes by mandatory reference to, or incorporation of, the latest edition of the standard to the extent it is within the scope of building and fire codes.

Recommendation 20. NIST recommends that the full range of current and next generation evacuation technologies should be evaluated for future use, including protected/hardened elevators, exterior escape devices, and stairwell navigation devices, which may allow all occupants an equal opportunity for evacuation and facilitate emergency response access. *Affected National Standard:* NFPA 101, ASME A 17, ASTM E 06. *National Model Building and Fire Codes:* The standards should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard.

9.2.6 Group 6. Improved Emergency Response

Technologies and procedures for emergency response should be improved to enable better access to buildings, response operations, emergency communications, and command and control in large-scale emergencies.

Recommendation 21. NIST recommends the installation of fire-protected and structurally hardened elevators to improve emergency response activities in tall buildings by providing timely emergency access to responders and allowing evacuation of mobility-impaired building occupants. Such elevators should be installed for exclusive use by emergency responders during emergencies. In tall buildings, consideration also should be given to installing such elevators for use by all occupants. The use of elevators for these purposes will require additional operating procedures and protocols.[41]

a. The requirement for remote release of elevator cabs by emergency response personnel should be included in the ASME A 17.1 Safety Code for Elevators and Escalators.

Affected National Standards: ASME A 17, NFPA 70, NFPA 101, NFPA 1221, NFPA 1500, NFPA 1561, NFPA 1620, and NFPA 1710. *National Model Building and Fire Codes:* The standards should be adopted in national model building and fire codes by mandatory reference to, or incorporation of, the latest edition of the standard.

Recommendation 22. NIST recommends the installation, inspection, and testing of emergency communications systems, radio communications, and associated operating protocols to ensure that the systems and protocols: (1) are effective for large-scale emergencies in buildings with challenging radio frequency propagation environments; and (2) can be used to identify, locate, and track emergency responders within indoor building environments and in the field. The

[41] The access time for emergency responders, in tall building emergencies where elevators are not functioning and only stairways can be used, averages between 1 min and 2 min per floor, which, for example, corresponds to between 1 1/2 hour and 2 hours (depending on the amount of gear and equipment carried) to reach the 60th floor of a tall building. Further, the physiological impact on the emergency responders of climbing more than 10 to 12 floors in a tall building makes it difficult for them to immediately begin aggressive firefighting and rescue operations.

federal government should coordinate its efforts that address this need within the framework provided by the SAFECOM program of the Department of Homeland Security.

a. Rigorous procedures, including pre-emergency inspection and testing, should be developed and implemented for ensuring the operation of emergency communications systems and radio communications in tall buildings and other large structures (including tunnels and subways), or at locations where communications are difficult.

b. Performance requirements should be developed for emergency communications systems and radio communications that are used within buildings or in built-up urban environments, including standards for design, testing, certification, maintenance, and inspection of such systems.

c. An interoperable architecture for emergency communications networks—and associated operating protocols—should be developed for unit operations within and across agencies in large-scale emergencies. The overall network architecture should cover local networking at incident sites, dispatching, and area-wide networks, considering: (a) the scale of needed communications in terms of the number of emergency responders using the system in a large-scale emergency and the organizational hierarchy; (b) challenges associated with radio frequency propagation especially in buildings; (c) interoperability with existing legacy emergency communications systems (i.e., between conventional two-way systems and newer wireless network systems); and (d) the need to identify, locate, and track emergency responders at an incident site.

Affected National Standards: FCC, SAFECOM, NFPA Standards on Electronic Safety Equipment, NFPA 70, NFPA 297, and NFPA 1221. *National Model Building Codes:* The standards should be adopted in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

Recommendation 23. NIST recommends the establishment and implementation of detailed procedures and methods for gathering, processing, and delivering critical information through integration of relevant voice, video, graphical, and written data to enhance the situational awareness of all emergency responders. An information intelligence sector[42] should be established to coordinate the effort for each incident. *Affected National Standards:* NIMS, NRP, SAFECOM, FCC, NFPA Standards on Electronic Safety Equipment, NFPA 1500, NFPA 1561, NFPA 1620, NFPA 1710, and NFPA 1221. *National Model Building Codes:* The standards should be adopted in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

Recommendation 24. NIST recommends the establishment and implementation of codes and protocols for ensuring effective and uninterrupted operation of the command and control system for large-scale building emergencies.

a. State, local, and federal jurisdictions should implement the National Incident Management System (NIMS). The jurisdictions should work with the Department of Homeland Security to review, test, evaluate, and implement an effective unified command and control system. The NIMS addresses interagency coordination and establishes a response matrix – assigning lead agency responsibilities for different types of emergencies and functions. At a minimum, each supporting agency should assign an individual to provide coordination with the lead agency at each incident command post.

[42] A group of individuals that is knowledgeable, experienced, and specifically trained in gathering, processing, and delivering information critical for emergency response operations and is ready for activation in large and/or dangerous events.

b. State, local, and federal emergency operations centers (EOCs) should be located, designed, built, and operated with security and operational integrity as a key consideration.

c. Command posts should be established outside the potential collapse footprint of any building which shows evidence of large multifloor fires or has serious structural damage. A continual assessment of building stability and safety should be made in such emergencies to guide ongoing operations and enhance emergency responder safety. The information necessary to make these assessments should be made available to those assigned responsibility (see related Recommendations 15 and 23).

d. An effective command system should be established and operating before a large number of emergency responders and apparatus are dispatched and deployed. Through training and drills, emergency responders and ambulances should be required to await dispatch requests from the incident command system and not to self-dispatch in large-scale emergencies.

e. Actions should be taken via training and drills to ensure a coordinated and effective emergency response at all levels of the incident command chain by requiring all emergency responders that are given an assignment to immediately adopt and execute the assignment objectives.

f. Command post information and incident operations data should be managed and broadcast to command and control centers at remote locations so that information is secure and accessible by all personnel needing the information. Methods should be developed and implemented so that any information that is available at an interior information center is transmitted to a emergency responder vehicle or command post outside the building.

Affected National Standards: NIMS, NRP, SAFECOM, FCC, NFPA Standards on Electronic Safety Equipment, NFPA 1221, NFPA 1500, NFPA 1561, NFPA 1620, and NFPA 1710. *National Model Building Codes:* The standards should be adopted in national model building codes by mandatory reference to, or incorporation of, the latest edition of the standard.

9.2.7 Group 7. Improved Procedures and Practices

The procedures and practices used in the design, construction, maintenance, and operation of buildings should be improved to include encouraging code compliance by nongovernmental and quasi-governmental entities, adoption and application of egress and sprinkler requirements in codes for existing buildings, and retention and availability of building documents over the life of a building.

<u>Recommendation 25.</u> Nongovernmental and quasi-governmental entities that own or lease buildings and are not subject to building and fire safety code requirements of any governmental jurisdiction are nevertheless concerned about the safety of the building occupants and the responding emergency personnel. NIST recommends that such entities should be encouraged to provide a level of safety that equals or exceeds the level of safety that would be provided by strict compliance with the code requirements of an appropriate governmental jurisdiction. To gain broad public confidence in the safety of such buildings, NIST further recommends that it is important that as-designed and as-built safety be certified by a qualified third party, independent of the building owner(s). The process should not use self-approval for code enforcement in areas including interpretation of code provisions, design approval, product

acceptance, certification of the final construction, and post-occupancy inspections over the life of the buildings.[43]

__Recommendation 26.__ NIST recommends that state and local jurisdictions should adopt and aggressively enforce available provisions in building codes to ensure that egress and sprinkler requirements are met by existing buildings[44]. Further, occupancy requirements should be modified where needed (such as when there are assembly use spaces within an office building) to meet the requirements in model building codes. Provisions related to egress and sprinkler requirements in existing buildings are available in such codes as the *International Existing Building Code (IEBC), International Fire Code,* NFPA 1, NFPA 101, and ASME A 17.3. For example, the IEBC defines three levels of building alteration (removal and replacement or covering of existing materials and equipment, reconfiguration of space or system or installation of new equipment, and work area in excess of 50 percent of the aggregate area of the building). At the lowest level there are no upgrade implications for sprinklers and the egress system. At the next level, sprinklers are required in work areas serving greater than 30 persons if certain other conditions related to building height and use such as shared exists also are met. There are numerous requirements for means of egress, including number of exits, specification of doors, dead-end corridors and travel distances, lighting, signage, and handrails. At the highest level, the sprinkler and egress requirements are identical to the second level without the minimum 30 person restriction and the other conditions related to building height and use. The Life Safety Code (NFPA 101) applies retroactively to all buildings, independent of whether any work is currently being done on the building, and ASME 17.3 applies retroactively to all elevators as a minimum set of requirements.

__Recommendation 27.__ NIST recommends that building codes should incorporate a provision that requires building owners to retain documents, including supporting calculations and test data, related to building design, construction, maintenance and modifications over the entire life of the building[45]. Means should be developed for offsite storage and maintenance of the documents. In addition, NIST recommends that relevant building information should be made available in suitably designed hard copy or electronic format for use by emergency responders. Such information should be easily accessible by responders during emergencies. *National Model Building Codes:* Both national model codes should incorporate this recommendation. State and local jurisdictions should adopt and enforce these requirements.

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[43] The long-standing stated policy of The Port Authority of New York and New Jersey (PANYNJ) was to meet and, where appropriate, exceed the requirements of local building and fire codes, and it entered into agreements with the New York City Department of Buildings and The Fire Department of the City of New York in accordance with that policy. Although the PANYNJ sought review and concurrence from New York City in the areas listed in the recommendation, the PANYNJ was not required to yield, and appears not to have yielded, approval authority to New York City. The PANYNJ was created as an interstate entity, a "body corporate and politic," under its charter, pursuant to Article 1, Section 10 of the U.S. Constitution permitting compacts between states. Further, there are many other similar nongovernmental and quasi-governmental entities in the United States. A comprehensive review of documents conducted as part of this Investigation suggests that the WTC towers generally were designed and maintained consistent with the requirements of the 1968 New York City Building Code. Areas of concern included fireproofing of WTC floor system, height of tenant separation walls, and egress requirements for the assembly use space for the Windows of the World in WTC 1 and Top of the World observation deck in WTC 2. These areas of concern did not play a significant role in determining the outcomes related to the events of September 11, 2001.

[44] The WTC towers were unsprinklered when built. It took nearly 28 years after passage of New York City Local Law 5 in 1973, which required either compartmentation or sprinklering, for the buildings to be fully sprinklered (the Port Authority chose not to use the compartmentation option in Local Law 5). This was about 13 years more than the 15-year period for full compliance with Local Law 5 that was set by Local Law 84 of 1979.

[45] The availability of inexpensive electronic storage media and tools for creating large searchable databases make this feasible.

<u>Recommendation 28.</u> NIST recommend that the role of the "Design Professional in Responsible Charge"[46] should be clarified to ensure that: (1) all appropriate design professionals (including, e.g., the fire protection engineer) are part of the design team providing the standard of care when designing buildings employing innovative or unusual fire safety systems[47], and (2) all appropriate design professionals (including, e.g., the structural engineer and the fire protection engineer) are part of the design team providing the standard of care when designing the structure to resist fires, in buildings that employ innovative or unusual structural and fire safety systems. *Affected National Standards:* AIA Practice Guidelines. *National Model Building Codes:* The IBC, which already defines the "Design Professional in Responsible Charge," should be clarified to address this recommendation. The NFPA 5000 should incorporate the "Design Professional in Responsible Charge" concept and address this recommendation.

9.2.8 Group 8. Education and Training

The professional skills of building and fire safety professionals should be upgraded though a national education and training effort for fire protection engineers, structural engineers, and architects.

<u>Recommendation 29.</u> NIST recommends that continuing education curricula should be developed and programs should be implemented for training fire protection engineers and architects in structural engineering principles and design, and training structural engineers, architects, and fire protection engineers in modern fire protection principles and technologies, including fire-resistance design of structures. The outcome would further the integration of the disciplines in effective fire-safe design of buildings. *Affected National Organizations:* AIA, SFPE, ASCE, ASME, AISC, ACI, and state licensing boards. *National Model Building Codes:* Detailed criteria and requirements should be incorporated into the national model building codes under the topic "Design Professional in Responsible Charge."

<u>Recommendation 30.</u> NIST recommends that academic, professional short-course, and web-based training materials in the use of computational fire dynamics and thermostructural analysis tools should be developed and delivered to strengthen the base of available technical capabilities and human resources. *Affected National Organizations:* AIA, SFPE, ASCE, ASME, AISC, and ACI.

9.3 OPPORTUNITY FOR PUBLIC COMMENT

NIST urges organizations responsible for building and fire safety at all levels to carefully consider the draft findings, issues, and recommendations contained in this report. Table 1 shows a crosswalk between the recommendations and the three categories (responsible community, application, and relation to outcome on September 11, 2001). NIST welcomes comments from technical experts and the public on this draft report—including specific improvements to the language in the recommendations to ease their speedy adoption—as soon as possible but no later than **August 4, 2005**. Comments can be sent by e-mail

[46] In projects involving a design team, the "Design Professional in Responsible Charge"—usually the lead architect—ensures that the team members use consistent design data and assumptions, coordinates overlapping specifications, and serves as the liaison to the enforcement and reviewing officials and to the owner. The term is defined in the International Building Code and in the ICC Performance Code for Buildings and Facilities (where it is the Principal Design Professional).

[47] If the fire safety concepts in tall buildings had been sufficiently mature in the 1960s, it is possible that the risks associated with jet-fuel ignited multifloor fires might have been recognized and taken into account when the impact of a Boeing 707 aircraft was considered by the structural engineer during the design of the WTC towers.

to wtc@nist.gov, facsimile to 301-975-6122, or regular mail to WTC Technical Information Repository, Stop 8610, 100 Bureau Drive, Gaithersburg, MD 20899-8610.

9.4 BEGINNING THE IMPLEMENTATION PROCESS

In its final report, which is expected to be released by September 2005, NIST will finalize these draft recommendations for specific and appropriate improvements to the way buildings are designed, constructed, maintained, and used. It will be important for these recommendations to be thoroughly and promptly considered by the many organizations responsible for building and fire safety. For example, several of the recommendations (e.g., 7, 10, 21, 25, 26, 27, and 28) can be considered immediately.

After issuance of the final report, the National Construction Safety Team Act requires NIST to:

- Conduct, or enable or encourage the conduct of, appropriate research recommended by the Team;
- Promote (consistent with existing procedures for the establishment of building standards, codes, and practices) the appropriate adoption by the Federal Government, and encourage the appropriate adoption by other agencies and organizations, of the recommendations of the Team with respect to—
    - Technical aspects of evacuation and emergency response procedures;
    - Specific improvements to building standards, codes, and practices; and
    - Other actions needed to help present future building failures.

As a part of NIST’s overall WTC response plan, the Institute has begun to reach out to the organizations responsible for building and fire safety (especially those listed in Table 9–2) to pave the way for a timely, expedited consideration of recommendations stemming from this Investigation.

NIST will develop a web-based system that will be available to the public so that progress in implementing the recommendations can be tracked. The Web site will list each of the recommendations, the specific organization or organizations (e.g., standards and codes developers, professional groups, state and local authorities) responsible for its implementation, the status of its implementation by organization, and the plans or work in progress to implement the recommendation.

In addition, NIST will hold a conference September 13–15, 2005, to reinforce the importance of its findings and recommendations from the Investigation and encourage their implementation. NIST already has expanded its research in areas of high-priority need.

Table 9–1. Crosswalk of Recommendations to Categories.

Recommendation Area	Recommendation Group	Recommendation Number	Responsible Community					Application		Relation to 9/11 Outcome	
			Practices	Standards, Codes, Regulations	Adoption & Enforcement	R&D/Further Study	Education & Training	All Tall Buildings	Selected Other Buildings	Related	Unrelated
Increased Structural Integrity	1	1	✓	✓	✓	✓	✓	✓	✓	✓	
		2	✓	✓		✓		✓	✓		✓
		3	✓	✓		✓		✓			✓
Enhanced Fire Resistance of Structures	2	4	✓	✓		✓		✓			✓
		5		✓		✓		✓			✓
		6	✓	✓	✓	✓		✓			✓
		7		✓	✓		✓	✓	✓		✓
New Methods for Fire Resistance Design of Structures	3	8	✓	✓	✓	✓	✓	✓	✓	✓	
		9	✓	✓		✓	✓	✓	✓		✓
		10	✓	✓		✓		✓	✓	✓	
		11	✓			✓		✓	✓		✓
Improved Active Fire Protection	4	12	✓	✓		✓		✓	✓	✓	
		13		✓		✓		✓		✓	
		14		✓		✓		✓	✓	✓	
		15	✓	✓		✓		✓	✓	✓	✓
Improved Building Evacuation	5	16	✓	✓		✓	✓	✓		✓	✓
		17	✓	✓		✓	✓	✓	✓	✓	✓
		18	✓	✓				✓		✓	
		19	✓	✓			✓	✓	✓	✓	
		20	✓	✓		✓		✓	✓	✓	

Recommendation Area	Recommendation Group	Recommendation Number	Responsible Community					Application		Relation to 9/11 Outcome	
			Practices	Standards, Codes, Regulations	Adoption & Enforcement	R&D/Further Study	Education & Training	All Tall Buildings	Selected Other Buildings	Related	Unrelated
Improved Emergency Response	6	21	✓	✓		✓		✓		✓	
		22	✓	✓	✓	✓	✓	✓		✓	
		23	✓	✓	✓	✓	✓	✓	✓	✓	
		24	✓	✓	✓	✓	✓	✓		✓	
Improved Procedures and Practices	7	25	✓	✓	✓			✓	✓		✓
		26	✓		✓			✓	✓		✓
		27	✓	✓	✓			✓	✓	✓	
		28	✓	✓			✓	✓	✓	✓	
Continuing Education and Training	8	29	✓	✓			✓	✓	✓	✓	
		30	✓				✓	✓	✓		✓

Table 9–2a. Standards Affected by the Recommendations.

Affected Standard	Group Number	Recommendation
American Concrete Institute, ACI 318 - Building Code Requirements for Structural Concrete	1. Increased Structural Integrity 3. New Methods for Fire Resistance Design of Structures	1, 3, 8, 9, 11
American Institute of Architects, AIA MASTERSPEC – Master Specification System for Design Professionals and the Building/Construction Industry	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	6, 10
American Institute of Architects Practice Guidelines	7. Improved Procedures and Practices	28
American Institute of Steel Construction Specification for Structural Steel Buildings	1. Increased Structural Integrity 3. New Methods for Fire Resistance Design of Structures	1, 3, 8, 9, 11
American Society of Civil Engineers, ASCE 7 – Minimum Design Loads for Buildings and Other Structures	1. Increased Structural Integrity 3. New Methods for Fire Resistance Design of Structures	1, 2, 3, 8, 9
American Society of Civil Engineers, ASCE 29 – Standard Calculation Methods for Structural Fire Protection	1. Increased Structural Integrity 3. New Methods for Fire Resistance Design of Structures	1, 8, 9
American Society of Mechanical Engineers, ASME A 17 – Elevators and Escalators, and A 17.1 – Safety Code for Elevators and Escalators	5. Improved Building Evacuation 6. Improved Emergency Response	17, 20, 21
American Society of Mechanical Engineers, ASME A 17.3 – Safety Code for Existing Elevators and Escalators	7. Improved Procedures and Practices	26
Association of the Wall and Ceiling Industry AWCI 12 – Design Selection Utilizing Spray-Applied Fire-Resistive Materials AWCI 12-A – Standard Practice for the Testing and Inspection of Field Applied Fire-Resistive Materials AWCI 12-B – Standard Practice for the Testing and Inspection of Field Applied Itumescent Fire-Resistive Materials	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	6, 10
ASTM International Committee E 06, Performance of Buildings; Subcommittee E 06.77, High-Rise Building External Evacuation Devices	5. Improved Building Evacuation	20
ASTM International, ASTM E 119 – Standard Test Methods for Fire Tests of Building Construction and Materials	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	5, 11
Department of Homeland Security, National Incident Management System (NIMS)	6. Improved Emergency Response	23, 24

Affected Standard	Group Number	Recommendation
Department of Homeland Security, National Response Plan (NRP)	6. Improved Emergency Response	23, 24
Department of Homeland Security, SAFECOM	6. Improved Emergency Response	22, 23, 24
Federal Communications Commission, Emergency Responder Radio Communications Regulations	6. Improved Emergency Response	22, 23, 24
International Organization for Standardization, ISO 834 – Fire Resistance Tests	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	5, 11
National Fire Protection Association, NFPA 1 – Fire Prevention Code	4. Enhanced Active Fire Protection 7. Improved Procedures and Practices	12, 13, 14, 15, 26
National Fire Protection Association, NFPA 13 – Installation of Sprinkler Systems	4. Enhanced Active Fire Protection	12
National Fire Protection Association, NFPA 70 – National Electrical Code	6. Improved Emergency Response	21, 22
National Fire Protection Association, NFPA 72 – National Fire Alarm Code	4. Enhanced Active Fire Protection	12, 13, 14, 15
National Fire Protection Association, NFPA 90A – Standard for Installation of Air-Conditioning and Ventilating Systems	4. Enhanced Active Fire Protection	12
National Fire Protection Association, NFPA 101 – Life Safety Code	4. Enhanced Active Fire Protection 5. Improved Building Evacuation 7. Improved Procedures and Practices	12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 26
National Fire Protection Association, NFPA 251 – Standard Methods of Tests of Fire Endurance of Building Construction and Materials	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	5, 11
National Fire Protection Association, NFPA 297 – Guide on Principles and Practices for Communications Systems	6. Improved Emergency Response	22
National Fire Protection Association, NFPA 1221 – Standard for the Installation, Maintenance, and Use of Emergency Service Communications Systems	6. Improved Emergency Response	21, 22, 23, 24
National Fire Protection Association, NFPA 1500 – Standard on Fire Department Occupational Safety and Health	6. Improved Emergency Response	21, 23, 24
National Fire Protection Association, NFPA 1561 – Standard on Emergency Services Incident Management System	6. Improved Emergency Response	21, 23, 24
National Fire Protection Association, NFPA 1620 – Recommended Practice for Pre-Incident Planning	6. Improved Emergency Response	21, 23, 24

Affected Standard	Group Number	Recommendation
National Fire Protection Association, NFPA 1710 – Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments	6. Improved Emergency Response	21, 23, 24
Underwriters Laboratories, UL 263 – Fire Tests of Building Construction and Materials	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	5, 9, 11

Table 9–2b. Model Codes Affected by the Recommendations.

Affected Model Code	Group	Recommendation
International Building Code	2. Enhanced Fire Resistance of Structures 7. Improved Procedures and Practices	1–24, 26–29
International Existing Building Code	7. Improved Procedures and Practices	26
International Fire Code	7. Improved Procedures and Practices	26
National Fire Protection Association, NFPA 5000 – Building Construction and Safety Code	2. Enhanced Fire Resistance of Structures 7. Improved Procedures and Practices	1–24, 26–29

Table 9–2c. Organizations Affected by the Recommendations.

Affected Organization	Group	Recommendation
American Concrete Institute	8. Education and Training	29, 30
American Institute of Architects	8. Education and Training	29, 30
American Institute of Steel Construction	8. Education and Training	29, 30
American Society of Civil Engineers	3. New Methods for Fire Resistance Design of Structures 8. Education and Training	9, 29, 30
American Society of Mechanical Engineers	8. Education and Training	29, 30
ASTM International	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	6, 9, 10
Building Owners & Managers Association	5. Improved Building Evacuation	16
Council on Tall Buildings and Urban Habitat	5. Improved Building Evacuation	16
International Code Council	2. Enhanced Fire Resistance of Structures	4
International Organization for Standardization, Technical Committee TC92SC4 – Fire Safety Engineering	3. New Methods for Fire Resistance Design of Structures	9
National Conference of States on Building Codes & Standards, Inc.	5. Improved Building Evacuation	16

Affected Organization	Group	Recommendation
National Fire Protection Association	2. Enhanced Fire Resistance of Structures 3. New Methods for Fire Resistance Design of Structures	4, 9
National Fire Protection Association Technical Committee on Electronic Safety Equipment	6. Improved Emergency Response	22, 23, 24
National Institute of Building Sciences	5. Improved Building Evacuation	16
Society of Fire Protection Engineers	3. New Methods for Fire Resistance Design of Structures 8. Education and Training	9, 29, 30
State licensing boards	8. Education and Training	29