NFPA 909

Code for the Protection of Cultural Resource Properties — Museums, Libraries, and Places of Worship

2005 Edition



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

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NFPA 909

Code for the

Protection of Cultural Resource Properties — Museums, Libraries, and Places of Worship

2005 Edition

This edition of NFPA 909, *Code for the Protection of Cultural Resource Properties — Museums, Libraries, and Places of Worship*, was prepared by the Technical Committee on Cultural Resources and acted on by NFPA at its November Association Technical Meeting held November 13–17, 2004, in Miami Beach, FL. It was issued by the Standards Council on January 14, 2005, with an effective date of February 7, 2005, and supersedes all previous editions.

This edition of NFPA 909 was approved as an American National Standard on February 7, 2005.

Origin and Development of NFPA 909

Since the first NFPA document was issued on this subject in 1948 *(Protecting Our Heritage)*, the Technical Committee on Cultural Resources has developed a series of recommended practices to govern these specialized buildings and sites. Five separate documents governing libraries, museums, places of worship, historic structures, and historic sites existed in 1996.

In each case, the documents were written as recommended practices or guides. There were a number of reasons why the documents were developed and maintained as such. One reason had to do with the delicate nature of the facilities and sites. Unlike commercial buildings, "new" historic structures are not constructed. In other words, all of the historic structures are existing, making retrofit of many common fire protection systems impractical to install in some cases. In addition, retrofit of fire alarm systems or sprinkler systems can be cost prohibitive for a smaller, historically significant structure. Unfortunately, many of the readily available solutions to correct fire protection problems in other types of existing facilities might not be practical in the case of older, historic buildings.

A number of philosophical issues centered on the methods used to protect cultural resource facilities. One main item dealt with a structured fire prevention program that is carried out by the facility operator. The span of these protection schemes must account for structures ranging from single-family dwellings to public libraries to public museums.

In 1997, work on a comprehensive project to merge the five separate documents was completed. A new standard, NFPA 909, *Standard for the Protection of Cultural Resources, Including Museums, Libraries, Places of Worship, and Historic Properties*, consolidated the fire protection requirements for libraries, museums, and places of worship into one document. This milestone recognized that many traditional fire protection solutions do not work unless significant resources are applied to a given problem or situation. This same philosophy was carried over to the 2001 edition of NFPA 909. A continued focus of the 2001 edition was the need to have a structured fire prevention program that would be carried out by the facility operator.

The status of the 2001 edition was also upgraded to a code, in lieu of a standard, in recognition of the wide range of requirements that exist in NFPA 909. Specifically, sections of NFPA 909 stipulate when and where certain requirements are mandatory. In addition to these changes, the chapter on historic structures and buildings was completely revised. That chapter now defers to the 2001 edition of NFPA 914, *Code for Fire Protection of Historic Structures*, which underwent a complete revision.

The 2005 edition of NFPA 909 has undergone a major reorganization in accordance with the *Manual of Style for NFPA Technical Committee Documents*. Technical changes include the deletion of a previous annex on fire risk assessment in heritage premises in favor of reference to more current approaches on the subject. Other changes include the type of automatic sprinklers to be used in cultural resource properties and the activation of fire dampers. In addition, emergency action checklists and inspection forms have been added for places of worship.

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Committee Scope: This Committee shall have primary responsibility for documents on fire safety for libraries, museums, places of worship, and historic structures and their contents, but shall not overlap the provisions of NFPA *101®, Life Safety Code®*.

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

Chapter 1 Administration

1.1 Scope.

1.1.1 This code describes principles and practices of fire safety for cultural resource properties (museums, libraries, and places of worship) and for those who operate, use, or visit them.

1.1.2 This code covers ongoing operations and rehabilitation and acknowledges the need to preserve culturally significant and character-defining building features and sensitive, often irreplaceable, collections and to provide continuity of operations.

1.2 Purpose.

1.2.1 This code shall prescribe minimum requirements for the protection of cultural resource properties and their contents from fire through a comprehensive fire protection program.

1.2.2 Because of the special nature of cultural resource properties, this code shall supplement existing codes and standards to apply specifically to buildings or portions of buildings devoted to such use.

1.3* Application. This code shall apply to culturally significant structures, spaces within other buildings used for culturally significant purposes, and their contents.

1.3.1 New Cultural Resource Property Occupancies. The requirements of this code shall apply to the following:

(1) New buildings or portions thereof used as a cultural resource property occupancy
(2) Additions made to a cultural resource property
(3) Alterations, modernizations, or renovations to existing properties
(4) Existing buildings or portions thereof upon change of occupancy to a cultural resource property occupancy

1.3.2 Existing Cultural Resource Property Occupancies.

1.3.2.1 An existing building in which a cultural resource property occupancy is housed that was established prior to the effective date of this code shall be permitted to be approved for continued use if it conforms to or is made to conform to the provisions of this code to the extent that, in the opinion of the authority having jurisdiction, reasonable life safety against the hazards of fire and explosion is provided and maintained.

1.3.2.2 Libraries, museums, and places of worship housed in historic structures shall also comply with the requirements of NFPA 914, *Code for Fire Protection of Historic Structures.*

1.4 Equivalency.

1.4.1 Nothing in this code is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, or effectiveness, provided that the following conditions are met:

(1) Technical documentation is submitted to the authority having jurisdiction to demonstrate equivalency or superiority.
(2) The system, method, or device is acceptable to the authority having jurisdiction.

1.4.2 Cultural resource properties or portions of such structures that do not strictly comply with this code shall be considered to be in compliance if it is shown that equivalent protection is provided or that no specific hazard is created or continued through noncompliance.

1.4.3 A designer capable of applying more complete and rigorous analysis to evaluate and address special or unusual problems shall have latitude in the development of the applicable design.

1.4.3.1 In such cases, the designer shall be responsible for demonstrating the validity of the approach.

1.4.3.2 This code shall not eliminate the need for competent engineering judgment.

1.4.3.3 This code shall not be intended to be used as a design handbook.

1.5 Compliance Options.

1.5.1 General. Building design and fire protection features and programs meeting the life safety, collection preservation, building preservation, and continuity of operations goals and objectives of Chapter 4 shall be provided in accordance with either of the following:

(1) Prescriptive-based provisions of 1.5.2
(2) Performance-based provisions of 1.5.3

1.5.2 Prescriptive-Based Options. A prescriptive-based design shall be in accordance with Chapters 1 through 8 and Chapters 11 through 17 of this code.

1.5.3 Performance-Based Options. A performance-based design shall be in accordance with Chapters 1 through 7 and Chapters 9, 11, 13, and 14 of this code.

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1.5.4 Management Operational Systems. Management operational systems complying with Chapter 10 of this code shall be permitted as an element of a prescriptive- or performance-based solution.

1.6 Enforcement. This code shall be administered and enforced by the authority having jurisdiction designated by the governing authority. *(See Annex F for sample wording for enabling legislation.)*

1.6.1 Organization. The governing body shall designate a fire safety manager who shall administer and enforce this code.

1.6.2 Approvals by Other Authorities Having Jurisdiction. The fire safety manager shall require that the laws, rules, and regulations of all other regulatory agencies having jurisdiction shall be met when not in conflict with this code.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this code and shall be considered part of the requirements of this document.

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

NFPA 1, *Uniform Fire Code™,* 2003 edition.

NFPA 10, *Standard for Portable Fire Extinguishers,* 2002 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems,* 2002 edition.

NFPA 14, *Standard for the Installation of Standpipe and Hose Systems,* 2003 edition.

NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems,* 2002 edition.

NFPA 30, *Flammable and Combustible Liquids Code,* 2003 edition.

NFPA 33, *Standard for Spray Application Using Flammable or Combustible Materials,* 2003 edition.

NFPA 40, *Standard for the Storage and Handling of Cellulose Nitrate Film,* 2001 edition.

NFPA 42, *Code for the Storage of Pyroxylin Plastic,* 2002 edition.

NFPA 45, *Standard on Fire Protection for Laboratories Using Chemicals,* 2004 edition.

NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work,* 2003 edition.

NFPA 70, *National Electrical Code®,* 2005 edition.

NFPA 72®, National Fire Alarm Code®, 2002 edition.

NFPA 75, *Standard for the Protection of Information Technology Equipment,* 2003 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems,* 2002 edition.

NFPA 90B, *Standard for the Installation of Warm Air Heating and Air-Conditioning Systems,* 2002 edition.

NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations,* 2004 edition.

NFPA *101®, Life Safety Code®,* 2003 edition.

NFPA 110, *Standard for Emergency and Standby Power Systems,* 2002 edition.

NFPA 211, *Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances,* 2003 edition.

NFPA 232, *Standard for the Protection of Records,* 2000 edition.

NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations,* 2004 edition.

NFPA 703, *Standard for Fire Retardant Impregnated Wood and Fire Retardant Coatings for Building Materials,* 2000 edition.

NFPA 780, *Standard for the Installation of Lightning Protection Systems,* 2004 edition.

NFPA 914, *Code for Fire Protection of Historic Structures,* 2001 edition.

NFPA 1123, *Code for Fireworks Display,* 2000 edition.

NFPA 1144, *Standard for Protection of Life and Property from Wildfire,* 2002 edition.

NFPA 5000®, Building Construction and Safety Code®, 2003 edition.

2.3 Other Publications.

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

ASTM E 1591, *Standard Guide for Obtaining Data for Deterministic Fire Models,* 2000 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this code. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary,* 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

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

3.2.3* Code. A standard that is an extensive compilation of provisions covering broad subject matter or that is suitable for adoption into law independently of other codes and standards.

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

3.2.5 Shall. Indicates a mandatory requirement.

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

3.2.7 Standard. A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix or annex, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

3.3 General Definitions.

3.3.1 Addition. An extension or increase in the building area, aggregate floor area, height, or number of stories of a structure.

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3.3.2 Alternative Calculation Procedure. A calculation procedure that differs from the procedure originally employed by the design team but that provides predictions for the same variables of interest. [***101***, 2003]

3.3.3 Analysis.

3.3.3.1 ***Sensitivity Analysis.*** An analysis performed to determine the degree to which a predicted output will vary given a specified change in an input parameter, usually in relation to models. [***101***, 2003]

3.3.3.2 ***Uncertainty Analysis.*** An analysis performed to determine the degree to which a predicted value will vary. [***5000***, 2003]

3.3.4 Arson. The crime of maliciously and intentionally, or recklessly, starting a fire or causing an explosion. [**921**, 2004]

3.3.5 Barrier.

3.3.5.1 ***Fire Barrier.*** A continuous vertical or horizontal assembly, such as a wall or floor, that is designed and constructed with a specified fire resistance rating to limit the spread of fire and that also will restrict the movement of smoke. Such barriers might have protected openings.

3.3.5.2 ***Smoke Barrier.*** A continuous assembly, or an assembly with discontinuities created by protected openings, where such assembly is designed and constructed to resist the movement of smoke.

3.3.6 Book Stack. Area dedicated to the storage of library media.

3.3.6.1* ***Multitier Book Stack.*** A system of back-to-back metal (steel or wrought iron) bracket shelving stacked by being bolted together into multiple levels or tiers at approximately 7 ft (2.1 m) intervals to form a book stack with walkways for each tier suspended from the posts or columns supporting the bracket shelving sections in each range.

3.3.6.2 ***Single-Tier Book Stack.*** Freestanding bracket, cantilever, or case shelving enclosed on one level by a fire compartment.

3.3.7* Building. Any structure used or intended for supporting or sheltering any use or occupancy. [***101***, 2003]

3.3.8 Character-Defining Feature. A prominent or distinctive aspect, quality, or characteristic of a cultural property that contributes significantly to its physical character.

3.3.9 Collections. Prehistoric and historic objects, works of art, scientific specimens, religious objects, archival documents, archaeological artifacts, library media, and cultural materials assembled according to a rational scheme and maintained for the purpose of preservation, research, study, exhibition, publication, or interpretation.

3.3.10 Collections Storage Room. An enclosure providing a safe and secure environment for collections, including vaults and book stacks.

3.3.11* Compact Storage Module. An assembly of shelving sections mounted on carriages with the arrangement of carriages on tracks so as to provide one moving aisle serving multiple carriages between fixed end ranges.

3.3.12* Compact Storage System. A storage installation composed of multiple compact storage modules.

3.3.13 Compartment. See 3.3.24, Fire Compartment.

3.3.14 Compliance. Adherence or conformance to laws and standards. [**914**, 2005]

3.3.15 Conservation. The professional practice of examination, documentation, treatment, and preventative care devoted to the preservation of cultural property.

3.3.16* Cultural Resource Properties. Buildings, structures, sites, or portions thereof that are culturally significant or that house culturally significant collections for museums, libraries, and places of worship.

3.3.17 Damage Limitation Plan. Written procedures that outline and prioritize the actions to take following a disaster to minimize property damage and loss.

3.3.18 Data Conversion. The process of developing the input data set for the assessment method of choice. [***101***, 2003]

3.3.19 Design Specifications. Building characteristics and other conditions that are under the control of the design team. [**914,** 2001]

3.3.20 Design Team. A group of stakeholders including, but not limited to, representatives of the architect, client, and any pertinent engineers and other designers. [***101***, 2003]

3.3.21 Exposure Fire. A fire that starts at a location that is remote from the area being protected and grows to expose that which is being protected. [***101***, 2003]

3.3.22 Fire Alarm System. A system or portion of a combination system that consists of components and circuits arranged to monitor and annunciate the status of fire alarm or supervisory signal-initiating devices and to initiate the appropriate response to those signals. [***72***, 2002]

3.3.23 Fireblock. A material, barrier, device, or construction installed in concealed spaces to prevent the extension of fire for an unspecified period of time. [***5000***, 2003]

3.3.24 Fire Compartment. A space within a building that is enclosed by fire barriers on all sides, including the top and bottom. [***101***, 2003]

3.3.25 Fire Hazard. Any situation, process, material, or condition that, on the basis of applicable data, can cause a fire or explosion, or provide a ready fuel supply to augment the spread or intensity of a fire or explosion, all of which pose a threat to life or property. [**914**, 2005]

3.3.26 Fire Model. Mathematical prediction of fire growth, environmental conditions, and potential effects on structures, systems, or components based on the conservation equations or empirical data. [**805**, 2001]

3.3.27 Fire Protection System. Any fire alarm device or system or fire extinguishing device or system, or their combination, that is designed and installed for detecting, controlling, or extinguishing a fire or otherwise alerting occupants, or the fire department, or both, that a fire has occurred. [**1141,** 2003]

3.3.28 Fire Resistance Rating. The time, in minutes or hours, that materials or assemblies have withstood a fire exposure as established in accordance with the test procedures of NFPA 251, *Standard Methods of Tests of Fire Endurance of Building Construction and Materials*. [**220**, 1999]

3.3.29 Fire Resistive. Properties or designs to resist the effects of any fire to which a material or structure can be expected to be subjected.

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3.3.30 Fire Retardant. A liquid, solid, or gas that tends to inhibit combustion when applied on, mixed in, or combined with combustible materials. [**1**, 2003]

3.3.31* Fire Safety Manager. The person designated by the governing body or responsible party of a cultural resource property with the duties and responsibilities of providing and ensuring reliability of fire protection for that facility or institution.

3.3.32 Firestop. A specific system, device, or construction consisting of the materials that fill the openings around penetrating items such as cables, cable trays, conduits, ducts, pipes, and their means of support through the wall or floor openings to prevent the spread of fire. [***5000***, 2003]

3.3.33 Fuel Load. The total quantity of combustible contents of a building, space, or fire area, including interior finish and trim, expressed in heat units or the equivalent weight in wood. [**921**, 2004]

3.3.34 Goal. A nonspecific overall outcome to be achieved that is measured on a qualitative basis. [***101***, 2003]

3.3.35 Governing Body. The board of directors, trustees, or other body charged with governance and fiduciary responsibility of a cultural resource property.

3.3.36* Hazardous Area. An area of a structure or building that poses a degree of hazard greater than that normal to the general occupancy of the building or structure. [***5000***, 2003]

3.3.37 Historic Fabric. Original or added building or construction materials, features, and finishes that existed during the period that is deemed to be most architecturally or historically significant, or both.

3.3.38 Historic Site. A place, often with associated structures, that has historic significance.

3.3.39* Historic Structure. A building, bridge, lighthouse, monument, pier, vessel, or other construction that is designated or that is deemed eligible for such designation by a local, regional, or national jurisdiction as having historical, architectural, or cultural significance. [**914**, 2005]

3.3.40 Hot Work. Work involving burning, welding, or a similar operation that is capable of initiating fires or explosions. [**51B**, 2003]

3.3.41* Impairment. A shutdown of a system or portion thereof. [**25**, 2002]

3.3.42 Incapacitation. A condition under which humans do not function adequately and become unable to escape untenable conditions. [***101***, 2003]

3.3.43 Initiating Device. A system component that originates transmission of a change-of-state condition, such as in a smoke detector, manual fire alarm box, or supervisory switch. [***72***, 2002]

3.3.44 Input Data Specification. Information required by the verification method. [***101***, 2003]

3.3.45* Library. Any building or place in which books and other media are kept for reading, reference, research, or lending.

3.3.45.1* *Secondary Storage Facility.* Warehouse facilities established to house books and other collections.

3.3.46 Means of Egress. A continuous and unobstructed way of travel from any point in a building or structure to a public way consisting of three separate and distinct parts: (1) the exit access, (2) the exit, and (3) the exit discharge. [***101***, 2003]

3.3.47* Museum. An institution that acquires, conserves, researches, communicates, and exhibits material evidence of people and their environment for purposes of study, education, and enjoyment.

3.3.48 Noncombustible. Not capable of supporting combustion.

3.3.49 Notification Appliance. A fire alarm system component such as a bell, horn, speaker, light, or text display that provides audible, tactile, or visible outputs, or any combination thereof. [***72***, 2002]

3.3.50 Objective. A goal that is achieved through the attainment of a skill, knowledge, or both, and that can be observed or measured. [**472**, 2002]

3.3.51 Occupancy. The purpose for which a building or other structure, or part thereof, is used or intended to be used. [***5000***, 2003]

3.3.52 Occupant Characteristics. The abilities or behaviors of people before and during a fire. [***101***, 2003]

3.3.53 Occupant Load. The total number of persons that might occupy a building or portion thereof at any one time. [***5000***, 2003]

3.3.54 Performance-Based Design Approach. A design process where fire safety solutions are designed to achieve a specified goal for a specified use or application. [**914**, 2001]

3.3.55 Performance Criteria. Threshold values on measurement scales that are based on quantified performance objectives. [***101***, 2003]

3.3.56 Place of Worship. Any building that functions primarily as a group meeting place for the practice of religion, including, but not limited to, churches, synagogues, cathedrals, temples, mosques, and meeting halls.

3.3.57 Plenum. A compartment or chamber to which one or more air ducts are connected and that forms part of the air distribution system. [**90A**, 2002]

3.3.58 Prescriptive-Based Document. A code or standard that prescribes fire safety for a generic use or application. [**914**, 2001]

3.3.59 Preservation. The act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic building or structure.

3.3.60 Private. Intended for or limited to the use of some particular person(s) or group.

3.3.61 Process Team. A group of stakeholders including, but not limited to, representatives from architects, clients, engineers and designers, authorities having jurisdiction, and preservation specialists. [**914**, 2001]

3.3.62 Proposed Design. A design developed by a design team and submitted to the authority having jurisdiction for approval. [***101***, 2003]

3.3.63 Protected Premises. The physical location protected by a fire alarm system, fire suppression system, or both.

3.3.64 Protection. Measures and actions taken to prevent or minimize loss from fire, arson, vandalism, theft, and similar hazards to persons and property.

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3.3.65 Protective Systems, Equipment, or Apparatus. Automatic sprinklers, standpipes, carbon dioxide systems, clean agent systems, automatic covers, and other devices used for extinguishing fires.

3.3.66 Public. Of, pertaining to, or affecting a population or a community as a whole; open to all persons.

3.3.67 Rehabilitation. The act or process of returning a structure to a state of utility through repair or alteration that makes possible an efficient contemporary use, including the preservation of those portions or features of the structure that are significant to its historical, architectural, or cultural value.

3.3.68 Restoration. The act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by means of the removal of features from other periods of its history, reconstruction of missing features, and repair of damaged or altered features from the restoration period. [**914**, 2001]

3.3.69 Safe Location. A location remote or separated from the effects of a fire so that such effects no longer pose a threat. [***101***, 2003]

3.3.70 Safety Factor. A factor applied to a predicted value to ensure that a sufficient safety margin is maintained. [***101***, 2003]

3.3.71 Safety Margin. The difference between a predicted value and the actual value where a fault condition is expected. [***101***, 2003]

3.3.72 Scenario.

3.3.72.1 ***Design Fire Scenario.*** A fire scenario used for evaluation of a proposed design. [**914**, 2001]

3.3.72.2* ***Fire Scenario.*** A set of conditions that defines the development of fire, the spread of combustion products throughout a building or portion of a building, the reactions of people to fire, and the effects of combustion products. [***101***, 2003]

3.3.73 Smoke Detector. A device that detects visible or invisible particles of combustion. [***72***, 2002]

3.3.74* Special Event. Any activity outside the normal daily operations.

3.3.75 Sprinkler System. For fire protection purposes, an integrated system of underground and overhead piping designed in accordance with fire protection engineering standards. The installation includes one or more automatic water supplies. The portion of the sprinkler system above ground is a network of specially sized or hydraulically designed piping installed in a building, structure, or area, generally overhead, and to which sprinklers are attached in a systematic pattern. The valve controlling each system riser is located in the system riser or its supply piping. Each sprinkler system riser includes a device for actuating an alarm when the system is in operation. The system is usually activated by heat from a fire and discharges water over the fire area. [**13**, 2002]

3.3.76 Stakeholder. An individual, or representative of same, having an interest in the successful completion of a project. [***101***, 2003]

3.3.77* Utilities. Building service control and distribution systems and their associated equipment, pipes, ducts, wires, and cables.

3.3.78 Verification Method. A procedure or process used to demonstrate or confirm that the proposed design meets the specified criteria. [***101***, 2003]

3.3.79 Vertical Opening. An opening through a floor or roof. [***101***, 2003]

Chapter 4 Goals and Objectives

4.1 General. Fire safety goals and objectives shall be adopted that reflect the level of loss and interruption of service to the client community that those responsible for the cultural resource property are willing to accept as a result of a fire.

4.2 Goals.

4.2.1 Life Safety. The life safety goal of this code shall be to provide an environment in which its occupants are reasonably protected from death or injury resulting from fire and similar perils as follows:

(1) Protection of occupants not intimate with the initial fire development
(2) Improvement of the survivability of occupants intimate with the initial fire development

4.2.2 Property Protection.

4.2.2.1 Collection Preservation. The collection preservation goal of this code shall be to provide a reasonable level of protection against damage or loss to collections from fire, products of combustion, and fire suppression agents and activities.

4.2.2.2 Building Preservation. The building preservation goal of this code shall be to provide a reasonable level of protection against damage or loss to the buildings, their unique characteristics, and their contents from fire, products of combustion, and fire suppression agents and activities.

4.2.3 Continuity of Operations. The continuity of operations goal of this code shall be to provide a reasonable level of protection against disruption of facility operations consistent with the organization's fire safety goals.

4.3 Objectives.

4.3.1 Life Safety.

4.3.1.1 An egress system shall be designed, implemented, and maintained to protect the occupants not intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place.

4.3.1.2 Structural integrity during a fire shall be maintained to protect the occupants not intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place.

4.3.1.3 Building construction and operations necessary to achieve the goals of this code shall be effective, maintained, and operational in perpetuity.

4.3.2 Collection Preservation. Fire safety and fire protection features shall be designed, approved, implemented, and maintained to preserve the original qualities of the collection.

4.3.3 Building Preservation.

4.3.3.1 Fire safety and fire protection features shall be designed, approved, installed, and maintained to preserve the

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original qualities or character of a building, structure, site, or environment.

4.3.3.2 Removal or alteration of any distinctive architectural features for the purpose of improving fire protection or life safety shall be minimized.

4.3.4 Continuity of Operations. Fire safety and fire protection features shall be designed, approved, implemented, and maintained to minimize disruption of operations consistent with the organization's fire safety goals.

Chapter 5 Fire Safety Management

5.1 General.

5.1.1 Responsibility.

5.1.1.1 Governing Body.

5.1.1.1.1 The facility's governing body or those responsible for the institution shall establish and maintain plans and programs to protect against the effects of fire.

5.1.1.1.2* As part of developing the fire safety management plan, a fire risk assessment shall be conducted.

5.1.1.2* Fire Safety Manager.

5.1.1.2.1 The facility's governing body or those responsible for the institution shall appoint a fire safety manager who is responsible for the protection of the site from fire.

5.1.1.2.2 The fire safety manager's duties shall include but are not limited to oversight of the following:

(1) Life safety systems
(2) Fire prevention
(3) Fire inspections
(4) Periodic property surveys
(5) Operation, maintenance, and testing of fire protection equipment such as fire detection and fire suppression equipment
(6) Management operational systems *(see Chapter 10)*

5.1.1.2.3 Fire safety review and approval by the fire safety manager shall be a requirement for all displays or exhibits, plans for new construction, and renovations, restorations, or reconfigurations of space.

5.2 Fire Safety Log.

5.2.1* The fire safety manager shall be responsible for maintaining a current file of the cultural resource property's fire protection program.

5.2.2 As a minimum, records of the following shall be kept:

(1) Training of staff and volunteers, including fire evacuation drills and use of portable fire extinguishers
(2) Testing, inspection, and maintenance reports for all fire safety equipment and systems, including records of actions taken to correct deficiencies
(3) "As-built" plans, specifications, wiring and layout diagrams, and acceptance test reports for all fire protection systems (e.g., fire detection and alarm systems, automatic fire suppression systems)
(4) The facility's fire safety management plan
(5) Inspection reports by local code enforcement officials, the authority having jurisdiction, local fire service officials, and insurance loss control representatives, including records of actions taken to correct deficiencies identified during each inspection
(6) Fire protection system's actuation and alarm reports complete with the cause of the alarm or activation, response, and corrective action(s) taken
(7) Full reports, including cause, extent of damage, response, and recovery, of all fire incidents

5.3 Planning for Fire Protection.

5.3.1 Fire Safety Goals. Fire safety goals shall comply with Section 4.2.

5.3.2 Fire Hazard Analysis.

5.3.2.1 A survey shall be made to determine existing and potential fire hazards.

5.3.2.2* Fire hazards shall be evaluated and classified based on their severity and the difficulty and cost of abating them.

5.3.2.3 The survey shall include the following:

(1) Identification of the cultural resource properties and their special hazards and the creation of an action plan to minimize, eliminate, or protect against each of those hazards
(2) Identification of those fire risks and means of egress problems that can be created by special events and the creation of an internal process and action plan to minimize or eliminate those potential threats for each event
(3) Assessments of expected increases in public visitation during special events, celebrations, and special exhibitions and the creation of provisions for identifying and taking immediate action to prevent numbers of visitors from exceeding building and means of egress capabilities
(4) Identification of temporary or special exhibitions that can create special fire protection risks and means of egress problems or that can compromise existing fire protection systems and the creation of an action plan for preventing such problems and implementing immediate corrective actions if problems arise later

5.4* Fire Safety Management Plan.

5.4.1 A fire safety management plan shall be developed for systematic achievement of fire safety goals and shall be updated annually.

5.4.2 The fire safety management plan shall include a yearly comprehensive facility inspection procedure with a documentation and corrective action process to ensure that all problems and hazards identified during the inspection are recorded and corrected as soon as possible. *(See Annexes J and K for additional information.)*

5.4.3* Emergency Management Plan. The fire safety management plan shall include an emergency management plan.

5.4.3.1 An annual exercise shall ensure that management and staff can implement and work with the plan and incorporate lessons learned from the exercise into an updated plan.

5.4.3.2 The plan shall include provisions for notifying the fire department of the type and location of the emergency and directing first responders to the site once they arrive.

5.4.3.3 Emergency telephone numbers shall be posted on or be adjacent to all telephones.

5.4.4 Emergency Evacuation Plan.

5.4.4.1 The fire safety management plan shall include an emergency evacuation plan prepared in cooperation with the local fire department and other applicable authorities.

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5.4.4.2 The emergency evacuation plan shall be updated annually and shall include the following:

(1) Fire safety precautions for special events and celebrations in which conditions vary substantially from normal operating conditions
(2) Fire safety precautions incorporating necessary adjustments for temporary and special exhibits
(3) Modification of staff training and drills to adjust for altered circumstances and larger visitation that can be created by special events and exhibits
(4) Provisions to notify the local fire service of special events that involve increased hazards or that are expected to require adjustments to the emergency evacuation plan

5.4.5 Fire Exit Drills. Fire exit drills shall be conducted at intervals identified in the approved fire safety management plan but not less than annually.

5.4.6 Damage Limitation Plan.

5.4.6.1 The fire safety management plan shall include a damage limitation plan prepared in cooperation with the fire department, applicable occupants, police, specialist contractors, and insurance representatives.

5.4.6.2 The damage limitation plan shall be updated annually and shall include the following:

(1) Procedures to identify and prioritize collections and other valuable materials in accordance with the facility's policy
(2) A list of salvage equipment suppliers (e.g., pumps, generators, freezing equipment, storage facilities, and other similar suppliers) and tradespeople
(3) A current list of disaster recovery specialists for damaged fine art, collections, and archives, such as conservators from museums, archives, and other cultural resource properties willing to lend mutual aid assistance
(4) A list of people assigned to assist with salvage operations, including staff to deal with the press, fire authorities, police, and authorities that can restrict entry following a fire of suspicious origin
(5)*Measures to maintain up-to-date copies of important documents in a secure, off-site location
(6) Procedures to identify and handle hazardous materials, such as asbestos, solvents, or PCBs, that can cause a health hazard or contaminate the structure or contents after a fire
(7) Procedures to impound fire-fighting water where it poses a hazard to the environment
(8) Stockpiles of resources and equipment for emergency on-site conservation

5.4.7 Property Conservation Plan. The fire safety management plan shall include a plan to conserve the building and contents after a fire.

5.4.7.1 Employees and others with a role in the property conservation plan shall receive additional training in the activities necessary to fulfill their designated role.

5.4.7.2 Training shall be reinforced by annual drills.

5.5 Training.

5.5.1 Requirements.

5.5.1.1 The facility's governing board and its fire safety manager shall ensure that all staff, including volunteers and interns, receive initial and annual training pertinent to their assigned emergency responsibilities at the facility, which can include the following:

(1) Fire protection plan
(2) Emergency evacuation plan
(3) Property conservation plan
(4) Fire protection and detection systems, including the use of portable fire extinguishers

5.5.1.2 Training shall be reinforced by annual drills.

5.5.2 Training shall include emergency evacuation of mobility-impaired individuals and others (e.g., children) who need special assistance.

5.5.3 A record shall be maintained of all fire and damage limitation training.

Chapter 6 Security

6.1* General.

6.1.1 Arson. Arson prevention shall be included in the cultural resource property's fire safety goals required in Chapter 4.

6.1.2 Fire Hazard Analysis.

6.1.2.1 The fire hazard analysis required in Chapter 5 shall include an evaluation of conditions that increase the risk of arson.

6.1.2.2* A fire hazard analysis that includes evaluation of conditions that increase the threat of arson shall be completed prior to commencement of construction, alteration, or renovation projects.

6.1.3* Fire Protection Plan.

6.1.3.1 Security practices, procedures, operations, and systems to reduce the threat of arson shall be integrated into the cultural resource property's fire protection plan.

6.1.3.2 The fire protection plan shall include screening all personnel, including part-time employees and volunteers, against records of known fire setters.

6.1.4* Book Returns. Book returns shall be constructed to prevent the spread of fire and smoke from the return into the rest of the building, or the book return shall be located in an outside receiving bin away from the exterior walls of the building.

6.2 Locking Devices.

6.2.1 Where permitted by the authority having jurisdiction, delayed egress locking devices shall comply with the provisions of 11.2.1.6 of *NFPA 5000, Building Construction and Safety Code*.

6.2.2 Delayed egress locking devices shall be tested regularly, but not less than quarterly, and a written record of the test and the results shall be kept.

6.3* Construction Areas.

6.3.1 Access to construction areas shall be restricted to personnel authorized by the owner or the contractor.

6.3.2* Security officers assigned to construction areas shall receive daily updates on the status of fire protection equipment; special hazards, including hot work; modified access routes; and emergency procedures.

6.4 Access Control. Procedures shall be implemented to screen and identify official visitors, contractors, and other persons who have access to nonpublic areas of the cultural resource property.

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Chapter 7 Process

7.1* General. The process by which this code shall be applied is shown in Figure 7.1.

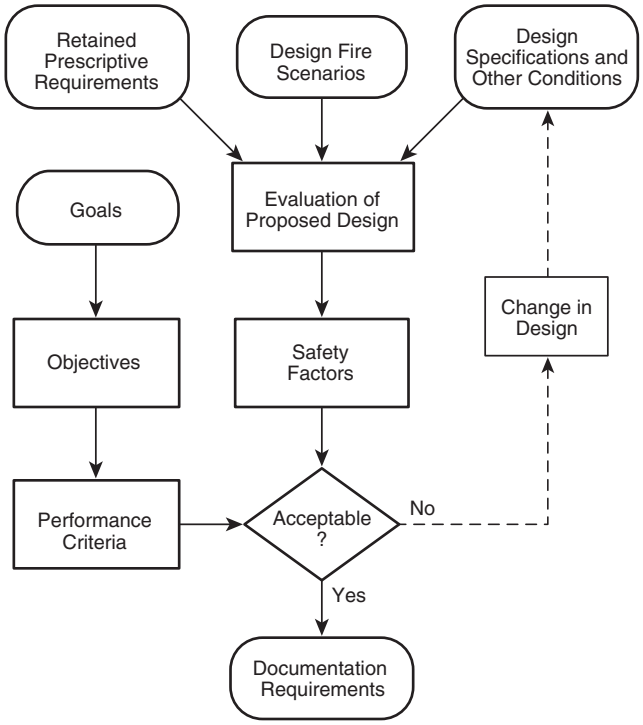

FIGURE 7.1 Process Flow Chart. (See Sections 4.2, 4.3, and 9.2 through 9.8.)

7.2* Process Team.

7.2.1 The governing body shall identify a process team to oversee application of the code to the cultural resource property.

7.2.2 The team shall include persons with expertise in cultural resource property preservation and fire protection.

7.3* Assessment. A detailed assessment or survey of the facility's fire safety features, the culturally significant features of the structure and collection, and the parameters of the facility's operation shall be completed.

7.3.1 Identification of Culturally Significant Elements, Features, and Collections.

7.3.1.1 Documentation.

7.3.1.1.1 The governing body and the fire safety manager shall have a demonstrated knowledge and understanding of the culturally significant elements of the structure and its contents.

7.3.1.1.2* All persons involved with the design of the building, exhibits, and other aspects of the project shall have a demonstrated knowledge of the cultural significance of the structure, the collection, or both.

7.3.1.1.3* All persons involved with the construction process shall be thoroughly briefed on the significance and importance of the structure, spaces, character-defining features, and collections prior to the beginning of the work.

7.3.1.2 Structure.

7.3.1.2.1* Exterior. The building survey shall identify those character-defining features and finishes that make the exterior of the building significant.

7.3.1.2.2* Interior. The building survey shall identify all significant interior spaces, floor plan organization, and character-defining features and finishes in the building.

7.3.1.3* Construction. The building survey shall determine primary and secondary significance of all character-defining features and facades.

7.3.1.4 Collections. The building survey shall identify all significant collections, archives, and other contents of cultural significance, their location, and any unique vulnerability to damage or loss.

7.3.1.5 Operations. The building survey shall identify the facility's client community and the effect of a disruption of operations on the delivery of service to that community.

7.3.2 Prioritization of Significant Elements, Collections, and Operations.

7.3.2.1 The building survey shall determine primary and secondary significance of all culturally significant elements, collections, or both, and the primary and secondary operational priorities for the facility.

7.3.2.2 Modifications or additions shall be completed in a manner to minimize the impact to culturally significant elements, collections, and the operation.

7.3.3 Identification of Fire Safety Issues.

7.3.3.1 Code, Standard, and Regulation Compliance.

7.3.3.1.1 The building survey of existing conditions shall include a review of all fire safety–related requirements to determine if and where the cultural resource property is deficient with respect to applicable codes.

7.3.3.1.2 Alternative methods that offer equivalent or greater protection while preserving the character-defining spaces, features, finishes, and collections of the cultural resource property shall be permitted.

7.3.3.2 Fire Hazards and Safety Deficiencies. The building survey shall identify known conditions that could contribute to the start or spread of a fire or to the endangerment of people, collections, or property by fire.

7.3.3.3 Fire Spread. The building shall be evaluated to determine potential paths of fire spread, both internal and external, that are inherent to its design.

7.3.3.4 Means of Egress.

7.3.3.4.1 Life safety aspects of the building shall be evaluated in accordance with the requirements of NFPA *101, Life Safety Code*.

7.3.3.4.2 The building survey shall identify egress systems and any deficiencies.

7.3.3.4.3 An evaluation of the means of egress shall be completed that includes a review of life safety–related items, including, but not limited to, numbers of exits, exit capacity, exit fire resistance, smoke control, dead-end corridors, travel distances, and unenclosed stairs.

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7.4 Options.

7.4.1 Structures that are found to satisfy the objectives of both life safety and cultural resource property preservation of this code shall be subject to the compliance audit required by Section 7.9.

7.4.2 Where structures are found to have life safety deficiencies, preservation needs, or both, a plan of correction shall be developed that satisfies one of the following:

(1) Prescriptive compliance, including equivalencies, alternatives, and modifications
(2) Risk-indexing compliance *(see 8.1.3)*
(3) Performance-based compliance
(4) Any combination of items 7.4.2(1) through 7.4.2(3)

7.5 Option Appraisal and Selection.

7.5.1* Selection Criteria.

7.5.1.1 An appraisal of the available options shall be made by the process team, and a method of application of the code shall be selected.

7.5.1.2 The method of application shall be from the prescriptive-based approach, the performance-based approach, or a combination of both.

7.5.2 Prescriptive-Based Option. Prescriptive solutions shall meet the requirements of Chapters 1 through 8 and Chapters 10 through 17, including any exceptions contained within the referenced prescriptive codes and standards.

7.5.3 Performance-Based Option. Performance-based solutions shall be developed in accordance with Chapters 1 through 7 and Chapters 9, 11, 13, and 14.

7.6 Design Review. The process team shall review and approve the preferred design approach for achieving compliance.

7.7 Initial Compliance Audit. On completion of the implementation phase, an initial compliance audit shall be performed by the process team to ensure compliance with the selected design approach.

7.8 Approval. The authority having jurisdiction shall make the final determination as to whether compliance has been achieved.

7.9 Compliance Audit.

7.9.1 A compliance audit shall be conducted by the authority having jurisdiction or its designee at intervals identified in the approved fire safety management plan but not less than annually.

7.9.2 Additional compliance audits shall be conducted prior to special events *(see Chapter 15)*.

7.9.3 Exit Interview.

7.9.3.1 The authority having jurisdiction or its designee shall conduct an exit interview with the fire safety manager and the owner or governing body of the cultural resource property upon completion of the periodic compliance audit.

7.9.3.2 The exit interview shall identify all areas of noncompliance with the approved fire safety management plan.

7.9.3.3 Following the periodic compliance audit, any deficiencies shall be addressed, with corrective action taken and documented in the fire safety log.

Chapter 8 Prescriptive-Based Option

8.1 General.

8.1.1* Application.

8.1.1.1 Prescriptive requirements of the applicable codes shall be applied with the intent of achieving the goals and objectives of Chapter 4.

8.1.1.2 Application of prescriptive requirements shall include alternatives, equivalencies, modifications, or any combination thereof.

8.1.2* Alternatives. Prescribed alternative methods of compliance with the applicable code shall be identified.

8.1.3* Equivalency.

8.1.3.1 The authority having jurisdiction shall approve other fire safety approaches, systems, methods, or devices that are equivalent or superior to those prescribed by this code, provided adequate documentation is submitted to demonstrate equivalency.

8.1.3.2* Approaches, systems, methods, or devices approved as equivalent by the authority having jurisdiction shall be recognized as being in compliance with this code.

8.1.4* Modification of Requirements.

8.1.4.1 The requirements of the applicable codes shall be permitted to be modified if their application clearly would be impractical in the judgment of the authority having jurisdiction, but only where it is also clearly evident that a reasonable degree of safety is provided.

8.1.4.2 The modifications allowed, and any additional requirements imposed as a result, shall be documented in the fire safety management plan.

8.2* Compensatory Features. Where equivalencies or modifications to existing requirements are proposed, the following fire safety features shall be considered as compensatory:

(1) Noncombustible or limited-combustible construction materials
(2) Noncombustible or fire retardant–treated interior finish materials
(3) Noncombustible or fire retardant–treated materials for furnishings and contents
(4) Rated walls and doors that prevent the horizontal spread of fire and smoke, to subdivide building areas or to segregate specific hazards, such as boilers, furnaces, or storage areas, from the remainder of the building
(5) Enclosure of stairways, ventilation shafts, and other vertical openings with rated construction to prevent the vertical spread of fire and smoke
(6)*Firestops and fireblocks to prevent the spread of fire within walls, between rafters and joists, and through horizontal and vertical fire barriers
(7)*Fire-resistive construction using fire-resistive materials
(8)*Fire detection and alarm systems that sound an alarm within the structure and that transmit an alarm signal to an alarm-monitoring location or to a local fire department
(9) Automatic suppression systems, manual suppression systems, or a combination of both
(10) Management and operational controls that meet the requirements of Chapter 8

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(11) Installation of arc-fault circuit-interrupters (AFCIs)
(12) Height of ceilings, with recognition that a large volume of space above head height provides occupants at floor level additional time to safely exit the room or building

Chapter 9 Performance-Based Option

9.1* General.

9.1.1 Application. The requirements of this chapter shall apply to fire protection systems and life safety systems designed using the performance-based option permitted by 7.5.3.

9.1.2 Goals and Objectives. The performance-based design shall meet the goals and objectives of this code identified in Sections 4.2 and 4.3.

9.1.3* Approved Qualifications. The performance-based design shall be prepared by a person with qualifications acceptable to the authority having jurisdiction. *(See also 9.8.12.)*

9.1.4* Independent Review. The authority having jurisdiction shall be permitted to require review and evaluation of the proposed design by an approved, independent third party.

9.1.5 Sources of Data.

9.1.5.1 The source for each input data requirement that must be met using a data source other than a design fire scenario, an assumption, or a building design specification shall be identified and documented.

9.1.5.2 Such data shall be characterized with regard to the degree of conservatism reflected, and a justification for the source shall be provided.

9.1.6 Final Determination. The authority having jurisdiction shall make the final determination concerning whether the performance objectives have been met.

9.1.7* Maintenance of Design Features.

9.1.7.1 Design features and management programs required for the building to continue to meet the performance goals and objectives of this code shall be maintained for the life of the building.

9.1.7.2 This management program shall include compliance with all documented assumptions and design specifications.

9.1.7.3 Any variations to the management program shall require the approval of the authority having jurisdiction prior to the actual change. *(See also 7.9.1.)*

9.1.8 Special Definitions. The following is a list of special terms used in this chapter:

(1) Alternative calculation procedure *(See 3.3.2.)*
(2) Data conversion *(See 3.3.18.)*
(3) Design fire scenario *(See 3.3.72.1.)*
(4) Design team *(See 3.3.20.)*
(5) Exposure fire *(See 3.3.21.)*
(6) Fire model *(See 3.3.26.)*
(7) Fire scenario *(See 3.3.72.2.)*
(8) Fuel load *(See 3.3.33.)*
(9) Incapacitation *(See 3.3.42.)*
(10) Input data specification *(See 3.3.44.)*
(11) Occupant characteristics *(See 3.3.52.)*
(12) Performance criteria *(See 3.3.55.)*
(13) Proposed design *(See 3.3.62.)*
(14) Safe location *(See 3.3.69.)*
(15) Safety factor *(See 3.3.70.)*
(16) Safety margin *(See 3.3.71.)*
(17) Sensitivity analysis *(See 3.3.3.1.)*
(18) Stakeholder *(See 3.3.76.)*
(19) Uncertainty analysis *(See 3.3.3.2.)*
(20) Verification method *(See 3.3.78.)*

9.2 Performance Criteria.

9.2.1 General.

9.2.1.1 A cultural resource property shall meet the performance criteria for life safety, cultural resource property and collection conservation, and continuity of operations.

9.2.1.2 Each design shall meet the objectives specified in Section 4.3 if, for each design fire scenario, assumption, and design specification, the performance criteria in 9.2.2 are met.

9.2.2 Performance Criteria.

9.2.2.1* Life Safety Performance Criteria. No occupants other than those intimate with ignition shall be exposed to instantaneous or cumulative untenable conditions.

9.2.2.2* Cultural Resource Property and Collections Preservation Criteria. Culturally significant features, rooms, spaces, or contents shall not be exposed to instantaneous or cumulative fire effects that would cause irreversible damage.

9.2.2.3 Continuity of Operations Criteria. The cultural institution shall not experience a disruption of routine operations greater than that deemed acceptable in the facility's fire safety management plan required by Chapter 5 and the goals established in Chapter 4.

9.3 Retained Prescriptive Requirements.

9.3.1* Systems and Features. All fire protection systems and features of the building shall comply with the applicable sections of *NFPA 5000, Building Construction and Safety Code*, for those systems and features.

9.3.2 Means of Egress. Features of the means of egress not specifically addressed in the performance criteria shall comply with NFPA *101, Life Safety Code*.

9.4 Design Specifications and Other Conditions.

9.4.1* Clear Statement. Design specifications and other conditions used in the performance-based design shall be demonstrated to the authority having jurisdiction to be realistic and sustainable.

9.4.2 Assumptions and Design Specifications Data.

9.4.2.1 Each assumption and design specification used in the design shall be accurately translated into input data specifications, as appropriate for the calculation method or model.

9.4.2.2 Any assumptions and design specifications that the design analyses do not explicitly address or incorporate and that are therefore omitted from input data specifications shall be identified, and a sensitivity analysis of the consequences of that omission shall be performed.

9.4.2.3 Any assumptions and design specifications modified in input data specifications because of limitations in test methods or other data generation procedures shall be identified, and a sensitivity analysis of the consequences of the modification shall be performed.

9.4.3* Building Characteristics. Characteristics of the building or its contents, equipment, or operations not inherent in the

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design specifications but that affect occupant behavior or the rate of hazard development shall be explicitly identified.

9.4.4* Operational Status and Effectiveness of Building Features and Systems. The performance of fire protection systems and building features shall reflect the documented performance of the components of those systems or features unless design specifications are incorporated to modify the expected performance.

9.4.5 Occupant Characteristics.

9.4.5.1* General. The selection of occupant characteristics to be used in the design calculations shall be approved by the authority having jurisdiction and shall provide an accurate reflection of the expected population of building users.

9.4.5.1.1 Occupant characteristics shall represent the normal occupant profile unless design specifications are used to modify the expected occupant features.

9.4.5.1.2 Occupant characteristics shall not vary across fire scenarios except as authorized by the authority having jurisdiction.

9.4.5.2* Response Characteristics. Each of the following basic performance characteristics shall be considered:

(1) Sensibility
(2) Reactivity
(3) Mobility
(4) Susceptibility

9.4.5.2.1 Estimations of these characteristics shall reflect the expected distribution in a population appropriate to the use of the building.

9.4.5.2.2 The source of data for these characteristics shall be documented.

9.4.5.3 Location. The assumption shall be made that in every normally occupied room or area at least one person will be located at the most remote point from the exits.

9.4.5.4* Number.

9.4.5.4.1 The design shall be based on the maximum number of people that every occupied room or area is expected to contain.

9.4.5.4.2 Where success or failure of the design is contingent on a maximum number of occupants, operational controls shall be used.

9.4.5.5* Staff Assistance. The ability of trained employees to be included as part of the fire safety system shall be identified, and the necessary training and capabilities documented.

9.4.6 Emergency Response Personnel. Design characteristics or other conditions related to the availability, speed of response, effectiveness, roles, and other characteristics of emergency response personnel shall be specified, estimated, or characterized sufficiently for evaluation of the design.

9.4.7* Post-Construction Conditions. Design characteristics or other conditions related to activities during the life of the building that affect the ability of the building to meet the stated goals and objectives shall be specified, estimated, or characterized sufficiently for evaluation of the design.

9.4.8 Off-Site Conditions. Design characteristics or other conditions related to resources or conditions outside the property being designated that affect the ability of the building to meet the stated goals and objectives shall be specified, estimated, or characterized sufficiently for evaluation of the design.

9.4.9* Consistency of Assumptions. The design shall not include mutually inconsistent assumptions, specifications, or statements of conditions.

9.4.10* Special Provisions. Additional provisions that are not covered by Section 9.4 but are required for the design to comply with the performance objectives shall be documented.

9.5 Design Fire Scenarios.

9.5.1* General.

9.5.1.1 The authority having jurisdiction shall approve the parameters used in design fire scenarios.

9.5.1.2 The proposed design shall be regarded as meeting the goals and objectives if it achieves the performance criteria for each required design fire scenario. *(See 9.5.3.)*

9.5.2* Evaluation.

9.5.2.1 Design fire scenarios shall be evaluated using a method acceptable to the authority having jurisdiction and appropriate for the conditions.

9.5.2.2 Each scenario shall be challenging, but realistic, with respect to at least one of the following scenario specifications:

(1) Initial fire location
(2) Early rate of growth in fire severity
(3) Smoke generation

9.5.3* Required Design Fire Scenarios.

9.5.3.1 Design fire scenarios shall include but not be limited to those specified in 9.5.3.2 through 9.5.3.9.

9.5.3.1.1 Each scenario shall include a life safety aspect (Part A) and a building protection aspect (Part B) when applicable.

9.5.3.1.2 Scenarios demonstrated by the design team to the satisfaction of the authority having jurisdiction as inappropriate for the building use and conditions shall not be required.

9.5.3.2* Design Fire Scenario 1. Design Fire Scenario 1 shall be an occupancy-specific design fire scenario representative of a typical fire for the occupancy.

9.5.3.2.1 This scenario shall explicitly account for the following:

(1) Occupant activities, number, and location
(2) Room size
(3) Nature and significance of furnishings and contents
(4) Fuel properties and ignition sources
(5) Ventilation conditions

9.5.3.2.2 The first item ignited and its location shall be explicitly defined.

9.5.3.3* Design Fire Scenario 2. Design Fire Scenario 2 shall be an ultrafast-developing fire in the primary means of egress with interior doors open at the start of the fire.

9.5.3.3.1 Part A. This design fire scenario shall address reducing the number of available means of egress.

9.5.3.3.2 Part B. This design fire scenario shall address reducing the effects of a rapidly spreading fire on interior finish and structural components.

9.5.3.4* Design Fire Scenario 3. Design Fire Scenario 3 shall be a fire that starts in a normally unoccupied room and that

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potentially endangers a large number of occupants in a large room or other area.

9.5.3.4.1 Part A. This design fire scenario shall address a fire that starts in a normally unoccupied room and migrates into the space that can hold the greatest number of occupants in the building.

9.5.3.4.2 Part B. This design fire scenario shall address a fire that starts in an unoccupied space and that potentially can grow and endanger the area of greatest cultural value or the most significant elements of the collections.

9.5.3.5* Design Fire Scenario 4. Design Fire Scenario 4 shall be a fire that originates in a concealed wall or ceiling space adjacent to a large number of occupants in a large room.

9.5.3.5.1 Part A. This design fire scenario shall address a fire that originates in a concealed space that does not have either a detection system or a suppression system and that spreads into the room within the building that potentially can hold the greatest number of occupants.

9.5.3.5.2 Part B. This design fire scenario shall address a fire that originates in a concealed space with neither a detection system or a suppression system and that potentially can grow and endanger the area of greatest cultural value or the most significant elements of the collection.

9.5.3.6* Design Fire Scenario 5. Design Fire Scenario 5 shall be a slow-developing fire that is shielded from fire protection systems and is in close proximity to a high-occupancy area.

9.5.3.6.1 Part A. This scenario shall address a relatively small ignition source that causes a significant fire.

9.5.3.6.2 Part B. This scenario shall address a relatively small ignition source that causes a significant fire that potentially endangers the area of greatest cultural value or the most significant elements of the collection as the result of the delayed suppression of the fire.

9.5.3.7* Design Fire Scenario 6.

9.5.3.7.1 Design Fire Scenario 6 shall be the most severe fire that results from the largest possible fuel load characteristic of the normal operation of the building.

9.5.3.7.2 This scenario shall address the concern of a rapidly developing fire with occupants present.

9.5.3.8* Design Fire Scenario 7.

9.5.3.8.1 Design Fire Scenario 7 shall be an outside exposure fire.

9.5.3.8.2 This scenario shall address a fire that starts remotely from the area of concern and either spreads into the area, blocks escape from the area, or develops untenable conditions within the area.

9.5.3.9* Design Fire Scenario 8. Design Fire Scenario 8 shall be a fire that originates in ordinary combustibles in a room or area with each passive or active fire protection system rendered unavailable one by one.

9.5.3.9.1 This design fire scenario shall address each fire protection system or fire protection feature, considered individually, as being unreliable or unavailable.

9.5.3.9.2* Design Fire Scenario 8 shall not be required for fire protection systems where the level of reliability in conjunction with the design performance in the absence of the system is acceptable to the authority having jurisdiction.

9.5.4 Design Fire Scenario Data.

9.5.4.1 Each design fire scenario used in the performance-based design proposal shall be translated into input data specifications, as appropriate for the calculation method or model.

9.5.4.2 Any design fire scenario specifications that the design analyses do not explicitly address or incorporate and that are therefore omitted from input data specifications shall be identified, and a sensitivity analysis of the consequences of that omission shall be performed.

9.5.4.3 Any design fire scenario specifications modified in input data specifications because of limitations in test methods or other data generation procedures shall be identified, and a sensitivity analysis of the consequences of the modification shall be performed.

9.6 Evaluation of Proposed Design.

9.6.1 General.

9.6.1.1 A proposed design's performance shall be assessed relative to each performance objective in Section 4.3 and each applicable scenario in Section 9.5, with the assessment conducted through the use of appropriate calculation methods.

9.6.1.2 The authority having jurisdiction shall approve the choice of assessment methods.

9.6.2 Use. The design professional shall use the assessment methods to demonstrate that the proposed design will achieve the goals and objectives as measured by the performance criteria in light of the safety margins and uncertainty analysis for each scenario given the assumptions.

9.6.3 Input Data.

9.6.3.1 Data.

9.6.3.1.1 Input data for computer fire models shall be obtained in accordance with ASTM E 1591, *Standard Guide for Obtaining Data for Deterministic Fire Models*.

9.6.3.1.2 Data for use in analytical models that are not computer-based fire models shall be obtained using appropriate measurement, recording, and storage techniques to ensure the applicability of the data to the analytical method being used.

9.6.3.2 Data Requirements. A complete listing of input data requirements for all models, engineering methods, and other calculation or verification methods required or proposed as part of the performance-based design shall be provided.

9.6.3.3* Uncertainty and Conservatism of Data. Uncertainty in input data shall be analyzed and, as determined appropriate by the authority having jurisdiction, addressed through the use of conservative values.

9.6.4* Output Data. The assessment methods used shall accurately and appropriately produce the required output data from input data based on the design specifications, assumptions, and scenarios.

9.6.5 Validity. Evidence shall be provided that confirms the validity and appropriateness of assessment methods used for the proposed building, use, and conditions.

9.7* Safety Factors. Approved safety factors shall be included in the design methods and calculations to reflect uncertainty in the assumptions, data, and other factors associated with the performance-based design.

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9.8 Documentation Requirements.

9.8.1* General.

9.8.1.1 All aspects of the design, including those described in 9.8.2 through 9.8.13, shall be documented.

9.8.1.2 The format and content of the documentation shall be acceptable to the authority having jurisdiction.

9.8.2* Technical References and Resources.

9.8.2.1 The authority having jurisdiction shall be provided with documentation to support the validity, accuracy, relevance, and precision of the proposed methods.

9.8.2.2 The engineering standards, calculation methods, and other forms of scientific information provided shall be appropriate for the particular application and methodologies used.

9.8.3 Building Design Specifications. All details of the proposed building design that affect the ability of the building to meet the stated goals and objectives shall be documented.

9.8.4 Performance Criteria. Performance criteria, with sources, shall be documented.

9.8.5 Occupant Characteristics. Assumptions regarding occupant characteristics shall be documented.

9.8.6 Design Fire Scenarios. Descriptions of design fire scenarios shall be documented.

9.8.7 Input Data. Input data to models and assessment methods, including sensitivity analysis, shall be documented.

9.8.8 Output Data. Output data from models and assessment methods, including sensitivity analysis, shall be documented.

9.8.9 Safety Factors. Safety factors utilized shall be documented.

9.8.10 Prescriptive Requirements. Retained prescriptive requirements shall be documented.

9.8.11* Modeling Features.

9.8.11.1 Assumptions made by the model user and descriptions of models used, including known limitations, shall be documented.

9.8.11.2 Documentation shall be provided that indicates the validity and appropriateness of the assessment methods used to address the design specifications, assumptions, and scenarios.

9.8.12 Evidence of Modeler Capability. The design team's relevant experience with the models, test methods, databases, and other assessment methods used in the performance-based design proposal shall be documented.

9.8.13 Use of Performance-Based Design Option. Design proposals shall include documentation that provides anyone involved in ownership or management of the building with notification of the following:

(1) That the building was approved as a performance-based design with certain specified design criteria and assumptions
(2) That any remodeling, modification, renovation, change in use, or change in the established assumptions shall require re-evaluation and re-approval
(3) That all special events shall be reviewed and approved based on the designs developed under this chapter

9.9 Records. Records required in Section 9.8 shall be maintained for the life of the current performance-based design.

Chapter 10 Management Operational Systems

10.1 General.

10.1.1 This chapter shall establish criteria for management operational systems that are acceptable as elements of a prescriptive solution or performance-based approach as provided in Section 1.5.

10.1.2 Other operational control features shall be permitted subject to the approval of the authority having jurisdiction.

10.2 Responsibility/Authority.

10.2.1 The owner, governing board, or other body having custody over the building shall designate a fire safety manager.

10.2.2 The fire safety manager shall have the authority to implement all elements of the fire safety management plan, including, but not limited to, the following:

(1) Directing the actions of building staff and occupants with regard to fire safety
(2) Entering into legally binding contractual agreements with the authority having jurisdiction
(3) Ordering required fire safety drills and exercises
(4) Halting contractor and maintenance operations that might threaten the fabric or contents of the building

10.2.3 The fire safety manager shall be responsible for implementing all elements of the approved fire safety management plan.

10.2.4 Reporting Fires.

10.2.4.1 All fires, however small, shall be reported to the local fire department and the fire safety manager.

10.2.4.2 When a fire is deemed suspicious, the fire safety manager shall take steps to ensure that the fire scene is secured pending investigation.

10.3 Management Plan.

10.3.1 The fire safety management plan shall consist of required elements as set forth in Chapter 5 and optional elements as agreed to by the fire safety manager and the authority having jurisdiction.

10.3.2 The fire safety management plan shall become effective on approval of the authority having jurisdiction and the fire safety manager.

10.4 Operational Requirements.

10.4.1 Operational controls or a plan of operations shall include special provisions that are granted as part of a performance-based or prescriptive-based approach in evaluating the building as defined by the process team and as approved by the authority having jurisdiction.

10.4.2 Operational controls shall include the special provisions pertaining to the management, operations, and stewardship of the cultural resource property.

10.4.3 Operational controls shall be defined as part of the fire safety management plan.

10.4.4 Procedures for Opening and Closing. The fire safety management plan shall include checklists that identify specific activities required in conjunction with opening and closing the building on a daily basis and for any special events that are held on the property.

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10.5 Fire Emergency Response Planning. The fire safety manager and the governing body shall develop and implement an emergency management plan as required in 5.4.3.

10.6 Training.

10.6.1 The fire safety manager, building staff, and volunteers shall be trained as agreed on with the authority having jurisdiction.

10.6.2 At a minimum, training shall include the emergency management plan, emergency evacuation plan, use of fire protection equipment, and other elements of the approved fire safety management plan.

10.6.3 Drills.

10.6.3.1 Drills shall be conducted to reinforce training and to evaluate staff and volunteer preparedness at intervals agreed on by the fire safety manager and the authority having jurisdiction but not less than annually.

10.6.3.2 Where required, the authority having jurisdiction shall be notified in advance of all drills.

10.6.4 Additional training shall be obtained when any of the following conditions occur:

(1) The use, occupancy, structure, or internal layout of the building changes.
(2) Drills indicate that staff or volunteers are not sufficiently familiar with the facility's fire safety management plan and fire protection equipment to respond properly under emergency conditions.
(3) Special events that have unusual occupancies or conditions are scheduled.
(4) Portable fire extinguishers constitute a part of the fire safety management plan.
(5) New materials, substances, or products are introduced into the building.

10.7 Record Keeping.

10.7.1 The fire safety manager shall be responsible for maintaining a current fire safety log *(see Section 5.2)*.

10.7.2 All records shall be made available to the authority having jurisdiction on request.

10.8 Compliance Audits. Compliance audits shall be conducted in accordance with the requirements of Section 7.9.

10.9 Enforcement. Where a compliance audit reveals noncompliance with the approved fire safety management plan or changes in the use or arrangement of the building, the authority having jurisdiction shall be notified.

10.10 Modification of the Plan. Proposed modifications to the fire safety management plan shall be approved by the authority having jurisdiction.

Chapter 11 Fire Prevention

11.1* General. This chapter shall outline the minimum protection criteria necessary for protection of cultural resource properties.

11.2 Decorations.

11.2.1 Decorative materials used for special events, occasions, and holidays shall be noncombustible or shall be treated with an approved fire-retardant coating.

11.2.2 Decorations shall be kept a minimum of 0.9 m (36 in.) from ignition sources, such as light fixtures, radiators, electric heaters, and other heat-generating devices.

11.2.3 The use of Christmas trees shall be in accordance with Section 10.15 of NFPA 1, *Uniform Fire Code*.

11.3* Fire Spread Control.

11.3.1 Interior doors shall be kept closed when the building is not occupied except as permitted in 11.3.2.

11.3.2 Where doors are required to remain open for interior ventilation, and air movement concerns are critical to the conservation of historic building fabric, collections, or both, or where the interior doors are themselves part of the historic fabric, careful and professional analysis of the open doors' impact shall be performed, and documented alternative methods to control fire spread shall be implemented.

11.4* Housekeeping.

11.4.1 Stairwells, corridors, doorways, and any other portions of the means of egress for a building shall be maintained free of combustibles, trash containers, and other materials.

11.4.2 Attics.

11.4.2.1 Attic spaces shall be kept free of combustibles and locked.

11.4.2.2 Combustible materials shall be permitted to be stored in attics protected by automatic suppression systems designed to allow such storage.

11.4.3* Electrical rooms, mechanical rooms, and telephone closets shall be kept free of combustibles and locked.

11.4.4 Stacks, exhaust ducts, and filters shall be cleaned as frequently as necessary to prevent the buildup of combustible dusts and fibers.

11.4.5 Air plenums and void spaces shall be kept clean and free of combustibles.

11.4.6 Rags, clothing, and waste material contaminated with oils, such as animal or vegetable oils, paints, thinners, wax, furniture polish, and other liquids or compounds that could cause spontaneous heating, shall be isolated from other combustibles and kept in metal containers with tight-fitting metal lids.

11.4.7 Ventilated metal lockers shall be provided for storage of highly combustible supplies and workers' clothing contaminated with combustible or flammable liquids.

11.4.8 Packing Materials.

11.4.8.1 Combustible packing materials, such as shredded paper, Styrofoam™ packing material ("peanuts"), plastic, and excelsior, shall be stored in metal containers with self-closing covers.

11.4.8.2 Where packing materials cannot be protected using metal containers with self-closing covers, dedicated crating and packing areas shall be enclosed in 1-hour fire-resistive construction or shall be equipped with sprinklers.

11.4.9 Trash shall be collected and disposed of at the end of each workday and more often if necessary.

11.4.10 Dumpsters used for bulk collection of trash or recyclable paper shall be constructed of metal with metal covers.

11.4.11 Dumpsters and other large trash containers inside buildings shall be stored in one of the following ways:

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(1) In trash rooms that have both automatic sprinklers and a 1-hour fire resistance rating
(2) In loading dock areas that are separated from the rest of the building with a 2-hour fire resistance rating or 1-hour fire resistance rating and protected with automatic sprinklers

11.4.12 Trash containers, dumpsters, and other central waste-disposal units located outside shall be a minimum distance of 4.6 m (15 ft) from all parts of a building exterior, including but not limited to windows, doors, roof eaves, and utility controls.

11.5 Smoking.

11.5.1 Smoking shall be prohibited inside buildings except in designated areas that meet the following requirements:

(1) Smoking areas shall be clearly and publicly identified.
(2) Smoking areas shall be provided with suitable ashtrays and other receptacles for the disposal of smoking materials.
(3) Smoking areas shall be physically separated from the rest of the building with a minimum 1-hour fire resistance rating for walls, ceilings, and floors.
(4) A rated, fully charged, and operable portable fire extinguisher complying with NFPA 10, *Standard for Portable Fire Extinguishers*, shall be located in each designated area.

11.5.2* Smoking shall be permitted only in designated areas.

11.6 Hot Work. Hot work shall not be permitted in or near the premises unless there is no viable alternative.

11.6.1 Hot Work Permit. A hot work permit, issued by the fire safety manager or designee, shall be required to authorize work with any open-flame devices used in soldering, brazing, cutting, welding, or paint removal.

11.6.2 Permit Requirements.

11.6.2.1 The hot work permit shall prescribe measures to protect the collections and ensure life safety.

11.6.2.2 The hot work permit shall include the following requirements as a minimum:

(1) A person trained in the use of fire extinguishers shall be stationed in the vicinity of the hot work operation for the duration of the work and for 60 minutes thereafter with frequent monitoring during the following 3 hours. Approved fire extinguishers shall be provided adjacent to the work area.
(2) All combustibles within 11 m (35 ft) of the work site shall be relocated or be covered with noncombustible or fire retardant–coated tarpaulins or otherwise shielded with metal or noncombustible guards or curtains.
(3) A statement of the work to be performed and the way it is to be carried out shall be required to be provided before the hot work permit is issued.

11.7 Open Flames.

11.7.1 Approval. Use of open flames and flame-producing devices, such as candles, oil lamps, fireplaces, forges, kilns, glassblowers, cook stoves, and so forth, shall be approved by the authority having jurisdiction.

11.7.2 Precautions. The following precautions shall be taken to control open flame and flame-producing devices:

(1) All employees working around open flame or flame-producing devices shall be trained in the use and operation of the device and in emergency response procedures.
(2) Open flames and flame-producing devices shall be monitored constantly by a trained person.
(3) A fire extinguisher, listed for the purpose, shall be located within 9 m (30 ft) of the area where open flames or flame-producing devices are in use.
(4) Candles shall be kept a minimum of 1.25 m (4 ft) from combustible window treatments and wall or ceiling hangings.
(5) Fireplaces shall be covered with a fire screen when not used for cooking or similar demonstrations.
(6) Open flames within 31 m (100 ft) of the building shall not be left unattended.
(7) Open flames either inside or outside the building shall be extinguished prior to shutdown of the facility.

11.7.3 Chimneys.

11.7.3.1 Chimneys that serve active fireplaces or stoves shall comply with the requirements of NFPA 211, *Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances*.

11.7.3.2 Chimneys that serve active fireplaces or stoves shall be lined, provided with a spark arrester, and maintained in good working order.

11.7.3.3 Chimneys that serve active fireplaces or stoves shall be inspected and cleaned annually by a competent person.

11.8 Electrical Hazards.

11.8.1 Portable electrical appliances shall be connected to a building electrical circuit that is protected with an arc-fault circuit interrupter (AFCI) except as permitted in 11.8.2.

11.8.2 Portable electrical appliances that are provided with thermal and electrical limit controls that will cause the appliances to fail in a safe condition if they malfunction shall be permitted.

11.8.3 Temporary wiring, including extension cords, shall comply with the requirements of NFPA 70, *National Electrical Code*.

11.8.4 Cabling.

11.8.4.1 Communication cabling, such as telecommunications, network, and protective systems cabling, shall comply with the requirements of NFPA 70.

11.8.4.2 When any such cabling passes through fire barriers or fire walls, such penetrations shall be protected in accordance with Chapter 8 of *NFPA 5000, Building Construction and Safety Code*.

Chapter 12 New Construction, Additions, Alterations, and Renovations

12.1* General. New construction, additions, alterations, and renovations shall comply with Chapters 14 and 15 of *NFPA 5000, Building Construction and Safety Code*, as well as the requirements of this chapter.

12.2* Construction Oversight.

12.2.1* Contractor Selection. Contractors selected to work on the project shall have a demonstrated knowledge and experience in working with cultural resource properties.

12.2.2* Initial Meeting/Indoctrination of Contractors.

12.2.2.1 Prior to beginning work on the project, an introductory meeting shall be held with the contractors, subcontractors, and representatives of the institution.

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12.2.2.2 All persons involved with the construction process shall be thoroughly briefed on the significance and importance of the structure, spaces, character-defining features, and collections prior to beginning work.

12.2.2.3 The initial meeting shall cover the project fire safety program, including special protection for existing facilities and contents, emergency precautions, notification of both emergency services and curatorial staff, and security issues pertinent to the project.

12.2.3 Supervision During Construction. Management of the cultural institution shall designate their own representative with the authority to specify additional protection requirements for the construction project necessary to safeguard the existing facility, its contents, and fabric.

12.2.3.1 The management representative shall have the authority to enforce the institution's protection requirements and to stop work or other activities when they jeopardize the safety or security of the facility or its contents.

12.2.3.2 This supervision shall include the following:

(1) Site security and monitoring of contractors and visitors
(2) Isolation of construction from the existing building and collections
(3) Location and handling of flammable liquids and gases
(4) Removal of rubbish and combustibles
(5) Hot work and other sources of ignition
(6)*Handling of sprinklers and other fire protection system components
(7) Location and type of portable extinguishers to be used in the proximity of collections or historic fabric

12.2.3.3* Following suspension of work each day, the representative or designee shall conduct a walk-through of the work area and surroundings to ensure that the site is secured and that hazards are properly addressed.

12.3 Fire Spread Control.

12.3.1 New openings in fire-rated assemblies, such as doorways and pipe and duct penetrations, shall have self-closing or automatic fire doors and automatic fire dampers that have fire resistance ratings in accordance with Chapter 8 of *NFPA 5000, Building Construction and Safety Code*.

12.3.2 Actuation of any automatic fire protection system in a fire area shall close all automatic fire dampers in the fire area served by the system.

12.3.3 Penetrations in fire-rated assemblies around wiring, pipes, ducts, and so forth, shall be sealed with approved materials to maintain the integrity of the fire-rated assembly *(see Chapter 8 of NFPA 5000, Building Construction and Safety Code)*.

12.3.4 New elevator shafts, dumbwaiters, stairways, and other vertical openings through the structure shall be constructed in a manner that prevents the spread of fire, smoke, and heat from one level to another.

12.3.5 New doors in fire-rated assemblies that are required to remain in the open position for any reason shall be equipped with approved door-holding devices controlled by a listed smoke detector.

12.4* Fire Protection Systems.

12.4.1 General.

12.4.1.1 Existing Fire Protection Systems. The design and layout of existing fire detection and suppression systems shall be evaluated by the project design team to ensure that system operation is not compromised.

12.4.1.2 New Construction. Fire protection systems shall be incorporated in all new construction in accordance with the institution's fire protection program and plan.

12.4.2* Design. Automatic fire sprinkler systems or alternative fire suppression systems shall be provided for all new construction.

12.4.3* Fire Detection and Alarm Systems. Fire detection and alarm systems shall comply with the requirements of *NFPA 72, National Fire Alarm Code*.

12.4.3.1 Smoke detectors shall be installed in every area and space where ambient conditions permit.

12.4.3.2 Where ambient conditions would adversely affect the performance, reliability, and normal operation of smoke detectors, other forms of detection technology, such as heat detection, shall be used.

12.4.3.3 Alarm Monitoring.

12.4.3.3.1 Fire detection and alarm systems and automatic fire suppression systems shall transmit alarm condition signals to an approved monitoring facility.

12.4.3.3.2 The monitoring facility and the communications method used for alarm signal transmission shall comply with the requirements of *NFPA 72, National Fire Alarm Code*.

12.4.4 Automatic Fire Sprinkler Systems.

12.4.4.1 Automatic fire sprinkler systems shall comply with the requirements of NFPA 13, *Standard for the Installation of Sprinkler Systems*.

12.4.4.2* Standard-response sprinklers shall be permitted for use in light-hazard areas.

12.4.5 Alternative Fire Suppression Systems. Where other types of fire suppression systems are provided, they shall comply with the requirements of 55.5.1 of *NFPA 5000, Building Construction and Safety Code*.

12.4.6* Standpipe and Hose Systems. Standpipe and hose systems, where required, shall comply with the requirements of NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*.

12.4.7* Portable Fire Extinguishers. Portable fire extinguishers shall be selected, installed, and maintained in compliance with the provisions of NFPA 10, *Standard for Portable Fire Extinguishers*.

12.5 Roof Coverings.

12.5.1 Unlisted combustible roof coverings shall be treated with an approved fire-retardant coating.

12.5.2 The facility shall maintain a record of this treatment, including certificates of approval of retardant, application method, and retreatment schedule.

12.5.3 Fire retardant–coated roof coverings shall be retreated in accordance with the manufacturer's specifications.

12.6 Emergency Power.

12.6.1* Emergency generators, where required, shall comply with the requirements of NFPA 110, *Standard for Emergency and Standby Power Systems*.

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12.6.2 Emergency generators shall have sufficient capacity to support critical fire safety functions and fire suppression systems, where required.

12.6.3* Emergency generators that support other functions considered essential shall have sufficient capacity to support all functions with no degradation of fire safety system support.

12.7* Hazardous Areas. Hazardous areas shall be separated from other areas by a fire separation with a minimum 1-hour fire resistance rating.

12.8 Interior Finishes.

12.8.1 Interior finishes that prevent flames from spreading rapidly or generating dangerous amounts of smoke and toxic products of combustion shall be selected.

12.8.2 Interior finish materials shall comply with the requirements of Chapter 10 of *NFPA 5000, Building Construction and Safety Code*.

12.9 Lightning Protection. A lightning protection system, where required, shall be designed, installed, and maintained in accordance with NFPA 780, *Standard for the Installation of Lightning Protection Systems*.

12.10 Location. A cultural resource property located within or attached to a building or structure classified as industrial or storage or as containing high hazard contents, as defined in Chapter 6 of *NFPA 5000, Building Construction and Safety Code*, shall be separated by walls or partitions and floor or floor-ceiling assemblies having a fire resistance rating in accordance with Table 6.2.4.1 of *NFPA 5000*.

12.11* Protection Against Exposure Fires. An exposed wall shall prevent heat, flames, and smoke from a nearby fire from being transmitted through it.

12.12 Protection from Wildland Fires.

12.12.1 The governing body or party responsible for cultural resource properties located in areas that are wooded or surrounded by fire-prone vegetation or heavy brush shall incorporate the requirements of NFPA 1144, *Standard for Protection of Life and Property from Wildfire*, into the facility's or institution's fire protection program and plan.

12.12.2 Reduction of fuel loading in the landscape surrounding and owned by the cultural resource property shall be implemented in accordance with the requirements of NFPA 1144, *Standard for Protection of Life and Property from Wildfire*.

12.12.3 Where the landscape is historic and either a contributing element to the property's historic designation or designated itself, the governing body or responsible party shall obtain the evaluation and recommendation of a professional historic landscape architect for reducing fire loading that could threaten either the cultural resource property or the historic landscape.

12.12.4 The evaluation shall include an analysis with respect to the requirements of NFPA 1144, *Standard for Protection of Life and Property from Wildfire*.

12.12.5 The resulting recommendations of the evaluation shall be included in the fire protection program and plan.

12.12.6 Access roads shall be maintained and kept fully accessible at all times to accommodate fire service vehicles.

12.13 Water Control. Provisions shall be made for removal of accumulated water from manual and automatic fire-fighting operations.

Chapter 13 Fire Precautions During Alterations, Additions, and Renovations

13.1 Fire Protection Systems.

13.1.1 Alterations, additions, or renovations of fire protection systems shall comply with the provisions of Chapter 55 of *NFPA 5000, Building Construction and Safety Code*, and shall be approved by the authority having jurisdiction.

13.1.2 Impairments. The provisions of 14.3.1.1 shall apply when fire protection systems or equipment is taken out of service.

13.2 Precautions.

13.2.1* Contracts. All construction, alteration, or renovation contracts shall specify methods and responsibility for controlling fire hazards.

13.2.2 Supervision.

13.2.2.1 Responsibility for enforcement of the terms of the contract relating to fire hazards shall be assigned, and authority shall be given to stop work pending correction of hazards.

13.2.2.2 The responsible local authorities, such as fire and building code enforcement departments, shall be consulted.

13.2.3 Separation of Construction Areas. Each construction area shall be isolated by partitions that resist the spread of fire to other parts of the building.

13.2.3.1 Tarpaulins or plastic sheeting, if used, shall be noncombustible or of a fire-retardant variety.

13.2.3.2 Required exits and normal guard routes shall be maintained or supplementary routes provided.

13.2.3.3 Where construction blocks an exit route, adjoining spaces shall also be closed, as necessary, to avoid excessive crowding in common paths of travel or dead ends.

13.2.3.4 Fire extinguishers, listed for the purpose, shall be accessible and protected from accidental damage.

13.2.4 Ignition Sources.

13.2.4.1 Hot work operations shall comply with Section 11.6.

13.2.4.2 Portable heating appliances shall comply with 13.4.2.

13.2.4.3 On-site recharging of gas cylinders shall be prohibited.

13.2.4.4 Temporary lighting and wiring shall comply with the requirements of Section 14.4 of *NFPA 5000, Building Construction and Safety Code*.

13.2.4.5 Smoking shall be prohibited or restricted to designated areas. *(See 13.4.8.)*

13.2.4.6 Gasoline-powered engines, such as those used in compressors and hoists, shall not be permitted inside the building.

13.2.5 Housekeeping. Housekeeping shall comply with 13.4.9.

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13.2.6 Flammable and Combustible Liquids. No more than a 1-day supply of paint thinners, solvents, and other flammable and combustible liquids used in the project shall be kept in the building.

13.2.6.1 Flammable liquids shall be stored in approved safety cabinets and containers.

13.2.6.2 Quantities of flammable and combustible liquids in excess of those necessary to complete a day's work shall be stored at least 15 m (50 ft) away from the main construction project.

13.2.7 Fire Protection Systems.

13.2.7.1 Fire Detection Systems. Handling of impairments to fire detection systems shall be in accordance with Section 14.3.

13.2.7.2 Fire Suppression Systems.

13.2.7.2.1 Automatic fire suppression systems shall be kept in working order during the project to the extent consistent with the nature of the construction.

13.2.7.2.2 Disconnected or shutoff standpipes or fire suppression systems shall be restored to service as soon as it is practical.

13.2.7.2.3 Inspections of standpipe and sprinkler valves shall be conducted and recorded in accordance with the provisions of NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems.*

13.2.7.2.4 Fire hydrants, sprinklers, standpipes and sprinkler fire department connections, and hose outlet valves shall not be obstructed by building materials, debris, or shrubbery and shall be maintained in accordance with NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems.*

13.2.8 Electrical Systems. Installations and modifications to electrical systems shall be made by licensed or registered electricians.

13.3 Temporary Construction and Equipment.

13.3.1 Construction Offices, Trailers, and Sheds.

13.3.1.1 Construction offices, trailers, sheds, and other temporary facilities of combustible construction shall comply with Section 4.1 of NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations.*

13.3.1.2 Heating devices used in construction offices, trailers, and sheds shall be listed for the purpose.

13.3.1.3* A minimum clearance of 1 m (39 in.) shall be maintained around stoves and heaters and a minimum clearance of 152 mm (6 in.) shall be maintained around all chimney and vent connectors to prevent ignition of adjacent combustible materials.

13.3.1.4 Structures, equipment, and materials shall not impede egress of occupants or workers from the building or hinder access by fire apparatus to the building and hydrants.

13.3.1.5 The areas beneath all temporary offices and other facilities shall not be used for the storage of construction materials, equipment, or supplies, and measures shall be put in place to ensure that no combustible waste matter is allowed to accumulate in these areas.

13.3.2 Construction Equipment and Materials.

13.3.2.1 Equipment.

13.3.2.1.1 Internal combustion engine–powered air equipment, such as compressors, hoists, derricks, and pumps, shall be placed so the exhaust discharges away from combustible materials and air intakes for the building heating, ventilation, and air-conditioning (HVAC) system.

13.3.2.1.2 A minimum clearance of 150 mm (6 in.) shall be maintained between equipment exhaust piping and combustible materials.

13.3.2.1.3 Service areas, fuel storage, and flammable gas storage for construction equipment shall not be located inside the building.

13.3.2.2* Materials.

13.3.2.2.1* Flammable and combustible liquids shall comply with 13.2.6.

13.3.2.2.2 Combustible construction materials stored inside the building shall be strictly limited to those necessary for that day's work.

13.3.2.2.3 Where steel construction is present, combustible storage shall not be placed in areas where specified fire-resistive coatings have not been applied to structural members.

13.3.2.2.4 Storage of highly combustible materials such as foam, plastic, and rubber products shall not be permitted inside the building.

13.3.2.2.5 Storage of construction materials shall not impede egress from buildings or access of fire apparatus to hydrants or to the building.

13.4 Construction Processes and Hazards.

13.4.1 Cutting and Welding Operations. Cutting and welding operations shall comply with the requirements of NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work.*

13.4.1.1 The person designated to be in charge of fire protection shall issue a hot work permit each day that cutting, welding, and other hot work operations are being conducted, as required by Section 11.6.

13.4.1.2* At the close of the work day, the person responsible for fire protection on the site shall inspect areas where welding, cutting, or other hot work operations have been conducted for hot metal or smoldering combustible materials.

13.4.1.3 Flammable gas cylinders used in the welding or cutting process shall be protected from vehicle damage and high temperatures.

13.4.2 Temporary Heating Equipment.

13.4.2.1 Temporary heating equipment shall be listed for the purpose and used and installed in accordance with the listing.

13.4.2.2 Temporary heating equipment shall comply with Chapters 50 and 53 of *NFPA 5000, Building Construction and Safety Code.*

13.4.2.3 Temporary heating equipment shall be used only on a stable surface in a protected location where the equipment will not be overturned.

13.4.2.4 Portable equipment using oil or liquefied petroleum gas as fuel shall be moved to a well-ventilated area away from combustible material and allowed to cool prior to refueling.

13.4.2.5* A portable fire extinguisher, listed for the purpose, shall be located within 9 m (30 ft) of all portable heating devices.

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13.4.2.6 Chimney or vent connectors from direct-fired heaters, where required, shall be maintained at least 457 mm (18 in.) from combustible materials.

13.4.2.7 Temporary heating equipment shall be attended and maintained by trained personnel.

13.4.3 Flammable and Combustible Liquids. The use and storage of flammable and combustible liquids shall be controlled and monitored. *(See 13.2.6.)*

13.4.4 Roofing.

13.4.4.1 Tar Kettles.

13.4.4.1.1 Tar kettles used in roofing shall comply with Section 16.7 of NFPA 1, *Uniform Fire Code*.

13.4.4.1.2* Fire extinguishers, listed for the purpose, shall be located as required in 16.7.1.6 of NFPA 1, *Uniform Fire Code*.

13.4.4.2 Liquefied Petroleum Gas (LPG).

13.4.4.2.1 Cylinders or containers used for fueling tar kettles shall be protected against tampering and vandalism.

13.4.4.2.2 Containers shall be kept 6 m (20 ft) from combustible materials or spare containers.

13.4.4.2.3 When possible, cylinders and containers shall be placed in a secure area for protection against tampering.

13.4.4.2.4 Cylinders or containers that cannot be secured in a protected area shall have the dome covers locked and secured or the valve handle shall be removed or secured in the off position.

13.4.4.2.5 Storage of LPG cylinders on rooftops shall not be permitted.

13.4.4.3 Used roofing mops shall not be stored inside the building.

13.4.5 Plumbing.

13.4.5.1 Plumbing work involving open flames shall be conducted only under the supervision of the person in charge of fire protection and shall require a hot work permit reissued each day.

13.4.5.2 The provisions of 13.4.1 shall apply for cutting and welding operations.

13.4.6 Demolition Work.

13.4.6.1 Gas supplies shall be shut off at a point outside the affected area and shall be capped.

13.4.6.2 Electrical service shall be reduced or eliminated in the affected area.

13.4.6.3 Hot work shall not be permitted in combustible buildings except as outlined in Section 11.6.

13.4.6.4 Fire walls, fire doors, cutoffs, and other fire separation assemblies shall be maintained intact where possible.

13.4.7 Other Hazardous Operations. The fire safety manager shall conduct a hazard assessment of operations that introduce fire hazards to determine whether the risk is consistent with the facility's fire safety objectives.

13.4.7.1 Paint-stripping operations that involve heat-producing devices shall not be permitted.

13.4.7.2 Floor sander dust accumulation bags shall be emptied into closed metal containers outside the building before the close of the day.

13.4.8 Smoking.

13.4.8.1 Smoking shall be prohibited inside any building or building space under construction, renovation, or repair.

13.4.8.2 Where smoking is allowed, the governing body or responsible party for the institution or property shall designate a smoking area outside the work area where contractors and workers are permitted to smoke.

13.4.8.2.1 The designated smoking area shall be clearly and publicly identified and shall be located a sufficient distance away from all combustible and flammable materials or liquids to prevent a fire from starting.

13.4.8.2.1.1 Receptacles for spent smoking materials shall be provided in the designated smoking area.

13.4.8.2.1.2 A portable fire extinguisher, in compliance with the provisions of NFPA 10, *Standard for Portable Fire Extinguishers*, shall be located at each designated smoking area.

13.4.8.2.2 If located inside the cultural resource property, the smoking area shall fully comply with all the requirements of Section 11.5.

13.4.9 Housekeeping.

13.4.9.1 The accumulation of debris or rubbish shall not be permitted inside construction areas or close to a source of ignition.

13.4.9.2 Debris and rubbish shall be removed daily from the site and shall not be burned in the vicinity.

13.4.9.3 Contractors shall provide receptacles for rubbish, papers, and other debris.

13.4.9.4 A chute employed for the removal of debris shall be erected on the outside of the building.

13.4.9.5 Burning waste materials on the premises shall not be permitted.

13.4.10 Electrical.

13.4.10.1 Electrical wiring and equipment shall comply with the requirements of NFPA 70, *National Electrical Code*.

13.4.10.2 Temporary lighting, bulbs, and fixtures shall be installed such that they do not come in contact with combustible materials.

13.4.10.3 Circuit breakers for circuits that are not in use shall be shut off.

13.4.10.4 Temporary wiring shall be removed immediately upon elimination of the need for which the wiring was installed.

13.4.11 Environmental Conditions. Openings in structures susceptible to damage from high winds that could cause skewing and misalignment of the structure, disruption of water supplies, or delivery systems for fire protection shall have secure coverings.

13.5 Fire Protection.

13.5.1 Fire Barriers.

13.5.1.1 Fire walls and exit enclosures required for the completed building shall be given priority during construction.

13.5.1.2 Fire doors with approved closing devices and hardware shall be installed as soon as practical and before combustible materials are introduced.

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13.5.1.3 Fire doors shall not be obstructed from closing.

13.5.2 Fire Detection Systems.

13.5.2.1 Existing fire detection and alarm systems shall be maintained in working order during the project to the extent consistent with the nature of the construction.

13.5.2.2 Smoke detectors in the construction area shall be removed or shall be protected from dust, dirt, and extreme temperatures during construction.

13.5.2.3 Smoke detectors in temporary detection systems inside the construction area that are covered to keep out dust and dirt while work is in progress shall be uncovered at the end of each work day.

13.5.2.4 After final construction cleanup by all trades, all smoke detectors shall be cleaned or replaced.

13.5.2.5 Reacceptance testing in compliance with *NFPA 72, National Fire Alarm Code* shall be performed after any adjustment, modification, or repair to any system wiring or component.

13.6 Fire Suppression.

13.6.1* Access.

13.6.1.1 Control Area.

13.6.1.1.1 A suitable location at the site shall be designated as a control area and shall be equipped with floor plans, utility control plans, emergency contact telephone numbers, labeled keys, and appropriate material safety data sheets.

13.6.1.1.2 Where security is of concern, this area shall be locked.

13.6.1.2 Access for heavy fire-fighting equipment to the immediate job site shall be provided at the start of construction and maintained until all construction has been completed.

13.6.1.3 Free access from the street to fire hydrants and to outside connections for standpipes, sprinklers, or other fire-extinguishing equipment, whether permanent or temporary, shall be provided and maintained at all times.

13.6.1.4 Protective pedestrian walkways shall be constructed such that they do not impede access to hydrants, fire department connections, or fire-extinguishing equipment.

13.6.1.5 During construction operations, free access to permanent, temporary, or portable fire-extinguishing equipment and systems shall be maintained.

13.6.1.6 At least one stairway in usable condition shall be provided at all times in multistory buildings.

13.6.2* Water Supply. Water for fire suppression shall be available throughout all phases of construction.

13.6.3 Standpipes.

13.6.3.1 New standpipes that are required or existing standpipes in buildings being altered shall be maintained in accordance with the progress of building activity so that the standpipes are always ready for fire department use.

13.6.3.2 Class I manual dry standpipes shall be permitted where approved by the authority having jurisdiction.

13.6.3.3 Where required by the responding fire department, hose and nozzles shall be provided and maintained ready for use as soon as either a temporary or permanent water supply is available.

13.6.4 Automatic Fire Suppression Systems.

13.6.4.1 Where automatic fire suppression systems are provided, the installation shall be placed in service and monitored as soon as it is practical.

13.6.4.2 Where fire suppression systems existed prior to the rehabilitation project, the system shall be kept in service as long as possible during the rehabilitation work.

13.6.4.3 Where fire suppression systems must be taken out of service for modification, the local fire department shall be notified and the system shall be returned to service as soon as possible.

13.6.5 Portable Fire Extinguishers.

13.6.5.1 Portable fire extinguishers, listed for the purpose, shall be located, mounted, and maintained in compliance with NFPA 10, *Standard for Portable Fire Extinguishers.*

13.6.5.2* At least one portable fire extinguisher, listed for the purpose, shall be accessible on each floor near each usable stairway.

13.7 Emergency Communications.

13.7.1 Prior to beginning any renovations or alterations, workers shall be instructed on emergency communications procedures.

13.7.2 A fixed telephone or equivalent method of summoning the fire service shall be provided and readily available.

13.7.3 The telephone number of the fire service shall be prominently posted on or immediately adjacent to each fixed telephone.

13.7.4 Written instructions shall be posted on how to notify the local fire service of a fire and on actions for security officers or other staff to take after the fire service has been notified.

13.7.5 On activation of a fire alarm or other notification device or identification of an actual fire, personnel shall evacuate the building.

Chapter 14 Inspections, Testing, and Maintenance

14.1* General. This chapter shall establish requirements for critical and regular inspection, testing, and maintenance of fire protection systems and other equipment in cultural resource properties.

14.2 Fire Protection Systems.

14.2.1 All fire protection systems shall be inspected, tested, and maintained in full compliance with the manufacturer's recommendations and the requirements of the following:

(1) NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, for water-based fire protection systems
(2) Chapter 55 of *NFPA 5000, Building Construction and Safety Code*
(3) *NFPA 72, National Fire Alarm Code*

14.2.2 Responsibility.

14.2.2.1 The responsibility for maintenance of fire protection systems shall be that of the governing body or responsible party of the cultural resource property.

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14.2.2.2 Inspection, testing, and maintenance shall be implemented in accordance with procedures meeting or exceeding those established in the standard for that type of fire protection system and in accordance with the manufacturer's instructions.

14.2.2.3 Personnel who have developed competence through training and experience shall perform inspection, testing, and maintenance of fire protection systems.

14.2.3* Inspection. Inspection and testing frequencies, responsibilities, test routines, and reporting procedures shall comply with NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*; Chapter 55 of *NFPA 5000, Building Construction and Safety Code*; and *NFPA 72, National Fire Alarm Code*.

14.2.4 Testing. All fire protection systems shall be tested to verify that they function as intended.

14.2.4.1 Test results shall be compared with those of the original acceptance test (if available) and with the most recent test results.

14.2.4.2 Records shall be retained for the next test and for 1 year thereafter.

14.2.5 Maintenance.

14.2.5.1 Maintenance shall be performed to keep all fire protection systems operable, and necessary repairs shall be made.

14.2.5.2 As-built system installation drawings, original acceptance test records, and device or equipment manufacturer's maintenance bulletins shall be retained by the fire safety manager to assist in developing and maintaining the inspection, testing, and maintenance standards for all fire protection equipment, systems, and components.

14.3 Impairments to Fire Protection Systems.

14.3.1 General. When an emergency or preplanned activity takes any fire protection system out of operational service, measures shall be taken during the impairment to ensure that increased risks are minimized and the extent and duration of the impairment is limited.

14.3.1.1 Where fire protection systems such as sprinkler systems, fire pumps, and fire detection and alarm systems are out of service for 4 hours or more, the fire safety manager shall notify the fire department and post a fire watch.

14.3.1.2 The fire watch shall be provided with an approved means to notify the fire department.

14.3.2 Preplanned Impairments.

14.3.2.1 The fire safety manager shall authorize all preplanned impairments in advance of work.

14.3.2.2 The fire safety manager shall be responsible for verifying that written procedures for impairments are followed before authorizing a system impairment. *(See 14.3.3.)*

14.3.3 Procedure.

14.3.3.1 A written procedure shall be established and implemented by the fire safety manager to control any emergency or preplanned impairment.

14.3.3.2 This procedure shall include, as a minimum, the following:

(1) Identification and tagging of all impaired equipment and systems
(2) Inspection and risk evaluation
(3) Identification of extent or expected duration of impairment
(4) Notification of the fire department
(5)*Notification of other personnel or organizations as appropriate
(6)*Statement of additional measures deemed necessary for the duration of the impairment of the systems
(7)*Actions and notifications to be taken when all impaired equipment and systems are restored to operational service
(8) Prior to a preplanned impairment, assembly of all necessary parts, tools, materials, and labor at the impairment site before the system or equipment is removed from service
(9) Expedition of all repair work

14.3.4 Restoring Systems to Service. When all impaired systems are restored to operational service, the impairment coordinator shall verify that the following items have been completed:

(1) All necessary inspections and tests required by the appropriate section of Chapter 55 of *NFPA 5000, Building Construction and Safety Code*, for the fire protection system or equipment involved have been conducted to verify that affected systems and equipment are operational.
(2) Those individuals notified in accordance with 14.3.3.2(5) have been advised that protection has been restored.
(3) Impairment tags have been removed.

14.4 Heating, Air-Conditioning, and Cooking Equipment.

14.4.1 Heating, air-conditioning systems, and cooking appliances shall be maintained in accordance with the manufacturer's specifications and shall comply with NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*; NFPA 90B, *Standard for the Installation of Warm Air Heating and Air-Conditioning Systems*; and NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*.

14.4.2 Heaters and ductwork, including hoods and ducts for ranges, shall be kept free of flammable and combustible deposits.

14.5 Chimneys. Chimneys for active stoves or fireplaces shall be inspected and cleaned annually in compliance with the requirements of NFPA 211, *Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances*.

14.6* Electrical Systems. Electrical systems shall be maintained in compliance with NFPA 70, *National Electrical Code*, and the manufacturer's instructions.

14.7 Fire Barriers. The integrity of fire barriers shall comply with Chapter 8 of *NFPA 5000, Building Construction and Safety Code*.

14.8 Fire Retardant–Treated Materials. Applied coatings and treatments shall be maintained in accordance with NFPA 703, *Standard for Fire Retardant Impregnated Wood and Fire Retardant Coatings for Building Materials*.

14.9 Fire Extinguishers. Portable fire extinguishers shall be maintained in compliance with NFPA 10, *Standard for Portable Fire Extinguishers*.

Chapter 15 Special Events

15.1 General. Plans for special events shall be reviewed and approved by the fire safety manager.

15.2 Occupant Loading.

15.2.1 The event coordinator shall ensure that the number of occupants admitted to the building is monitored and controlled

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so that the occupant load does not exceed the capacity of the means of egress or the number of exits required by NFPA *101*, *Life Safety Code*.

15.2.2 Orderly circulation of guests shall be maintained when special events are planned for large groups.

15.3 Egress.

15.3.1 Exits, access to exits, and all other evacuation capabilities shall be maintained.

15.3.2 Tables, plants, stages, or other temporary fixtures shall not visually or physically obstruct an exit, exit sign, or exit access or reduce the width of an exit passage.

15.3.3 Prior to a performance or event, staff (especially temporary or part-time staff), contractor personnel, attendees, and participants shall be notified of the following:

(1) How fire alarms are annunciated (i.e., audibly, visually, by voice communication, or a combination of these methods)
(2) Locations of exit routes, exits, and assembly points
(3) How to safely evacuate the area

15.3.4 Key staff, including event coordinators, volunteers, and security, shall be familiar with exit routes and shall ensure that exits are obvious, operable, and not blocked or restricted in any way.

15.3.5 On activation of the fire alarm, occupants shall be evacuated from the building according to the egress plan.

15.4 Cooking Equipment.

15.4.1 Cooking and food warming shall be undertaken only in facilities built for the purpose, and only electric food-warming equipment shall be used in other areas.

15.4.2 All cooking and food warming shall be closely supervised at all times.

15.4.3 A portable fire extinguisher, listed for the purpose, shall be located within 3 m (10 ft) of any cooking, warming, or related operation and shall be identified clearly.

15.5 Smoking. Smoking shall be prohibited except as permitted in Section 11.5.

15.6 Fireworks. Demonstrations of fireworks shall be held outside the building or structure and shall conform to NFPA 1123, *Code for Fireworks Display*.

15.7 Combustibles.

15.7.1 Tents and canopies shall be noncombustible or certified as having been treated with an approved fire-retardant coating.

15.7.2 Draperies, bunting textiles, wood, and miscellaneous support and decorative materials used inside the building shall be noncombustible, impregnated with an approved fire retardant, or treated with an approved fire-retardant coating.

15.8 Electrical Equipment.

15.8.1 Electrical appliances and equipment, including temporary installations, shall be listed, and wiring shall comply with NFPA 70, *National Electrical Code*.

15.8.2 Exposed electrical wiring and extension cords shall not be placed across travel or exit routes.

15.8.3 A licensed or registered electrician shall verify that electrical circuits do not exceed their rated capacity.

Chapter 16 Museums, Libraries, and Their Collections

16.1 General.

16.1.1 The requirements of Chapters 1 through 15 shall apply to all museums and libraries.

16.1.2 This chapter shall apply to buildings, rooms, or spaces within buildings that store or display museum collections, buildings or spaces within buildings that provide storage for library collections available to the general public or community served by the library, and historic buildings exhibited or used as museums or that have library collections and reading rooms serving the public.

16.1.3 Privately owned library and museum collections not open to the public shall not be required to meet the requirements of this document.

16.1.4* This chapter shall supplement existing codes and standards to apply specifically to buildings or portions of buildings devoted to museum or library use.

16.2* Planning. The governing body of the museum or library and its director or chief executive officer shall be responsible for developing and implementing a fire safety management plan in accordance with Chapter 5.

16.3 Public Areas.

16.3.1 Drapes, Curtains, and Props. Drapes, curtains, props, and similar decorations shall be noncombustible or shall be treated with a listed, approved fire retardant in accordance with the manufacturer's recommendations.

16.3.1.1 Fire-Retardant Treatments.

16.3.1.1.1 The fire safety manager shall maintain records of all chemical fire-retardant treatments.

16.3.1.1.2 Records of fire-retardant treatments shall include the certificate of approval for each fire-retardant coating used, application method, and retreatment schedule.

16.3.2 Decorative materials used for special occasions and holidays shall be used in accordance with Section 11.2.

16.3.3 Carpeting on vertical surfaces shall have a Class A rating and shall comply with the requirements of Chapter 10 of *NFPA 5000, Building Construction and Safety Code*.

16.3.4 Tiered auditorium space structures and other elevated platforms on which people are permitted to sit shall be of noncombustible construction.

16.4* Collection Storage Rooms.

16.4.1 Application. This section shall apply to building areas used for collection storage rooms.

16.4.2 Life Safety.

16.4.2.1 Emergency lighting shall be provided for egress and shall comply with the requirements of NFPA *101*, *Life Safety Code*.

16.4.2.2 Fire alarm notification appliances and manual fire alarm boxes shall be provided in every collection storage room.

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16.4.3* Fire Prevention.

16.4.3.1 Smoking shall be prohibited in all collection storage rooms.

16.4.3.2 Electrical distribution power panels shall not be installed in collection storage rooms.

16.4.3.3 Utilities other than those supporting fire suppression, fire detection, and security systems or that directly serve the space shall not pass through collection storage rooms.

16.4.3.4 Controls for utilities that serve the collection storage room shall be located outside the space so that access to the controls does not require entry into the collection storage room.

16.4.3.5 Controls for utilities that serve collection storage rooms shall be designed to allow isolation of collection storage room utilities in an emergency.

16.4.3.6* Fixed space heaters installed in collection storage rooms shall be listed, and the installation shall be approved by the authority having jurisdiction.

16.4.3.7 Portable space heaters shall not be permitted.

16.4.3.8 Housekeeping. Housekeeping shall be maintained as required by Section 11.4.

16.4.4* Fire Protection.

16.4.4.1 Collection storage rooms shall be enclosed by fire barriers having a minimum 1-hour fire resistance rating.

16.4.4.2 Collection storage rooms adjoining incinerator rooms, furnace and boiler rooms, paint shops, and other spaces having a significant fire hazard shall be separated from such spaces by a fire barrier having a 2-hour fire resistance rating.

16.4.4.3 Automatic smoke detection shall be provided in every storage room.

16.4.4.4* An approved automatic fire suppression system shall be provided in collection storage rooms greater than 46.5 m^2 (500 ft^2) unless the space contains only noncombustible collections including packing or crating materials, cabinets, and shelves or where all collections are stored inside approved noncombustible cabinets.

16.4.5* Smoke Control. Approved systems shall be provided to prevent smoke and soot from entering collection storage rooms.

16.4.6 Hazardous Materials.

16.4.6.1* Cellulose Nitrate Film. Storage and handling of cellulose nitrate film shall comply with the requirements of NFPA 40, *Standard for the Storage and Handling of Cellulose Nitrate Film.*

16.4.6.2 Pyroxylin Plastic. Storage of materials or media containing pyroxylin plastic shall comply NFPA 42, *Code for the Storage of Pyroxylin Plastic.*

16.4.6.3 Wet Collections.

16.4.6.3.1* Storage of collections preserved in combustible or flammable petrochemical solutions shall comply with the requirements of NFPA 30, *Flammable and Combustible Liquids Code.*

16.4.6.3.2 Containers used for storing specimens in combustible, flammable, or toxic liquids shall have tight-sealing lids that minimize evaporation loss or spillage of contents should the container tip over.

16.4.6.3.3 Only approved containers shall be used in dispensing and topping off operations.

16.4.6.3.4 Carts used to transport storage containers shall be sturdy and designed to carry their loads close to the ground.

16.4.6.3.5 Shelving. Shelving units used to hold wet collections shall meet the following requirements:

(1) Designed to support the loads placed on them
(2) Tied together or anchored securely to prevent an earthquake or other event from toppling one or more shelves
(3) Constructed with raised lips and barriers across all open shelves to prevent containers from falling off the shelves
(4) Anchored and braced in storage areas that are subject to earthquakes
(5) *Designed so that anchors and bracing provide shelving with strength equal to or greater than the building structure

16.4.7* Storage of Records. Collection accession and other vital records and archival materials shall be stored and protected in accordance with NFPA 232, *Standard for the Protection of Records.*

16.4.8* Compact Storage.

16.4.8.1 Fire Suppression System.

16.4.8.1.1 An automatic fire suppression system shall be required for compact storage of collections.

16.4.8.1.2 Where the compact storage system consists entirely of enclosed noncombustible cabinets and no collections or other combustibles are stored outside the enclosed cabinets, automatic fire suppression shall be permitted to be omitted subject to the approval of the authority having jurisdiction.

16.4.8.1.3* The design shall recognize the nature of the hazard from a fire that originates in a compact mobile storage unit, where fuel loads are invariably large and fire growth is significantly different from that in other kinds of storage.

16.4.8.1.4 System Design.

16.4.8.1.4.1* The automatic fire suppression system, the compact storage system, and the storage compartmentalization features shall be designed to limit fire damage in accordance with the facility's fire safety objectives.

16.4.8.1.4.2 Design calculations shall include the number and size of the storage modules, the separation provided between the modules end-to-end and back-to-back, and the type of materials being stored.

16.4.8.1.4.3 Where the automatic suppression is provided by automatic fire sprinkler systems, the systems shall be wet pipe, single interlock pre-action, or single noninterlock pre-action systems.

16.4.8.1.4.4 Dry pipe or double-interlock pre-action systems shall not be installed in compact storage areas.

16.4.8.2 Where compact storage is installed in an existing storage area, the existing automatic fire detection and fire suppression systems shall be modified as required to accommodate the increased fire loading.

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16.4.9 Electronic Media.

16.4.9.1 Concealed spaces, combustible electric cable insulation, and storage of paper and records associated with electronic data processing equipment shall comply with the requirements of NFPA 75, *Standard for the Protection of Information Technology Equipment*.

16.4.9.2 Storage of Video, Audiotape, and Computer Media. Bulk storage of video, audio, and computer tapes greater than 500 standard VHS tapes or the equivalent shall meet the following requirements:

(1) Tapes shall be stored in metal storage cabinets in rooms with a minimum 1-hour fire resistance rating.
(2) Automatic smoke detection shall be provided in the storage room.

16.4.10* Book Stacks.

16.4.10.1 Utilities Serving Book Stack Spaces. Utilities other than those supporting fire suppression, detection, and security systems or that directly serve book stack spaces shall not pass through book stack spaces.

16.4.10.1.1 Electrical distribution power panels shall not be installed in book stacks.

16.4.10.1.2 Controls for utilities serving book stack spaces shall be located outside the spaces so that access to the controls does not require entry into the book stack.

16.4.10.1.3 Controls for utilities serving book stack spaces shall be designed to allow isolation of book stack utilities in an emergency.

16.4.10.2 Single-Tier Book Stacks.

16.4.10.2.1 An automatic fire detection system designed and installed in compliance with *NFPA 72, National Fire Alarm Code*, shall be installed in single-tier book stacks.

16.4.10.2.2 Where specified to achieve fire safety goals by the fire protection plan required by Chapter 5, an automatic fire suppression system designed and installed in compliance with NFPA 13, *Standard for the Installation of Sprinkler Systems*, or Section 55.5 of *NFPA 5000, Building Construction and Safety Code*, shall be installed in the book stacks.

16.4.10.3* Multitier Book Stacks.

16.4.10.3.1 An automatic fire detection system designed and installed in compliance with *NFPA 72, National Fire Alarm Code*, shall be installed in the book stacks.

16.4.10.3.2 An automatic fire suppression system designed and installed in compliance with NFPA 13, *Standard for the Installation of Sprinkler Systems*, or Section 55.5 of *NFPA 5000, Building Construction and Safety Code*, shall be installed in the book stacks.

16.4.10.3.3 Smoke barriers shall be installed in all vertical openings between tiers or decks.

16.4.10.3.4 The fire load in a fire compartment containing a multitier book stack shall be determined by combining the fuel loading of all levels or tiers in the multitier book stack enclosed by the fire compartment.

16.4.10.3.5 Storage on floor-to-ceiling shelving in multitier book stacks shall be permitted where a sprinkler system, designed in accordance with the requirements for this occupancy in NFPA 13, *Standard for the Installation of Sprinkler Systems*, is installed.

16.4.11 Secondary Storage Facilities.

16.4.11.1 Rack Shelving. Rack storage shelving in excess of 4 m (12 ft) in height shall be protected in compliance with NFPA 13, *Standard for the Installation of Sprinkler Systems*.

16.4.11.2 Vertical Fire Barriers.

16.4.11.2.1 Vertical fire barriers shall be installed in the shelf system at intervals not exceeding 15 m (50 ft).

16.4.11.2.2 Other spacing of the vertical fire barriers shall be permitted when acceptable to the authority having jurisdiction.

16.4.11.3 Battery Chargers.

16.4.11.3.1 Battery chargers used by forklift trucks, electrically powered vehicles, and pallet lifters shall be separated from the rack storage area in a fire compartment with a 1-hour fire resistance rating.

16.4.11.3.2 A portable fire extinguisher for use on live electrical equipment in compliance with NFPA 10, *Standard for Portable Fire Extinguishers*, shall be located inside the compartment.

16.4.11.3.3 Charging leads and plugs shall be designed to resist hard wear and shall be inspected weekly by a competent person.

16.4.11.3.4 Ventilation.

16.4.11.3.4.1 The ventilation system in the battery-charging area shall be designed to limit the concentration of hydrogen in the compartment to 1 percent or less by volume.

16.4.11.3.4.2 Where the concentration of hydrogen exceeds 1 percent by volume, the compartment shall be equipped with explosionproof electrical fixtures in compliance with NFPA 70, *National Electrical Code*.

16.5 Ignition Control.

16.5.1* Smoking. Smoking shall be prohibited except as permitted by Section 11.5.

16.5.2 Space Heaters.

16.5.2.1 Portable space heaters are not permitted except as specified in 16.5.2.2.

16.5.2.2 Portable space heaters approved for the purpose by the authority having jurisdiction shall be permitted to be used where the building contents have been removed and the building turned over to the contractor for a construction or renovation project.

16.5.2.3 Listed fixed space heaters shall be permitted.

16.5.2.4 Listed fixed space heaters shall be approved by the authority having jurisdiction and shall be installed in accordance with the listing.

16.5.3 Hot Work and Open Flames.

16.5.3.1 All work with open flame devices used in soldering, brazing, paint removal, cutting, and welding shall be used only as permitted by Section 11.6.

16.5.3.2 Open flame demonstrations shall be in accordance with Section 11.7.

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16.6* Housekeeping. Housekeeping shall be maintained as required by Section 11.4.

16.6.1 Shipping and receiving areas shall be kept clear of accumulated combustible packing and crating materials.

16.6.2 Discarded packing materials shall be disposed of daily in accordance with 11.4.8 and 11.4.9.

16.6.3* Safety precautions shall be in place to minimize and control fire hazards.

16.7 New Construction.

16.7.1 Support Areas. Support areas shall comply with Chapter 12.

16.7.2 Collection Storage Rooms. Collection storage rooms shall be in compliance with Section 16.4.

16.8 Alterations and Renovations. Alterations, additions, and renovations shall comply with Chapters 12 and 13.

16.9* Exhibit Design and Construction.

16.9.1 The fire safety manager shall thoroughly review exhibit installation plans to ensure compliance with the fire protection plan and to further ensure that the proposed exhibit will not in any way compromise or adversely affect the following:

(1) Life safety systems, equipment, and measures in the exhibit, the exhibition area, and the building
(2) Means of egress from the exhibit, the exhibition area, and the building
(3) Fire protection systems, including detection, alarms, and automatic suppression, in the exhibit, the exhibition area, and the building
(4) Fire safety in the exhibit, the exhibition area, and the building
(5) Emergency lighting systems in the exhibit, the exhibition area, and the building

16.9.2 Special lighting effects in the exhibit and exhibition area shall not reduce illumination below the minimum level specified in NFPA *101*, *Life Safety Code*, for egress or create any fire hazard.

16.9.3 The fire safety manager shall be kept fully informed and involved at every stage, including preliminary planning, design, fabrication, and installation, for each and every exhibit mounted or installed.

16.9.4 Exhibit Materials.

16.9.4.1* Exhibits shall be fabricated and constructed using materials that are either noncombustible or fire retardant treated.

16.9.4.2 Exhibit construction or backing materials placed in direct physical contact with or immediate proximity to collection objects shall not be fire retardant treated if such treatment will harm the collection object(s) involved.

16.9.4.3 The provisions of 16.9.4.2 shall apply only on an object-by-object-type basis and shall not be used as a total exemption from the use of fire-resistant or noncombustible materials in an exhibit.

16.9.4.4 Exhibit construction or backing materials treated with a chemical fire retardant shall be retreated with an approved fire retardant in accordance with the manufacturer's specifications.

16.9.4.5 Record of Treatment.

16.9.4.5.1 The fire safety manager shall maintain records of all chemical fire-retardant treatments.

16.9.4.5.2 Records shall include the certificate of approval for each fire-retardant coating used, application method, and retreatment schedule.

16.9.4.6 Combustible materials that cannot be made fire retardant shall be located so as to minimize potential hazards.

16.9.5 Portable extinguishers appropriate for the hazard shall be located in compliance with NFPA 10, *Standard for Portable Fire Extinguishers*.

16.9.6 Electrical Requirements.

16.9.6.1 All electrical wiring and work installed for an exhibit shall comply with the provisions of NFPA 70, *National Electrical Code*.

16.9.6.2* Arc-fault circuit interrupters (AFCIs) shall be required in all new exhibit construction.

16.9.7 Temporary walls and exhibit components, such as cases and dioramas, shall not interfere with the operation of any fire protection system.

16.9.8 Automatic fire suppression systems shall be redesigned or modified to account for increased fuel loads.

16.9.9 When special exhibits are expected to draw large crowds, controls shall be established to ensure that lines and assembly or waiting areas, whether inside or outside the facility, do not impair evacuation capabilities or emergency access and to limit the number of visitors in each area within the facility to the posted maximum occupancy.

16.10 Hazardous Areas.

16.10.1 Hazardous areas shall be separated from other areas by a minimum of 1-hour fire-rated construction and shall have an automatic fire suppression system.

16.10.2* Paint spraying and spray booths shall comply with NFPA 33, *Standard for Spray Application Using Flammable or Combustible Materials*.

16.10.3 Flammable and combustible liquids, such as paints, pesticides, and solvents, used in conservation areas shall be stored in accordance with NFPA 30, *Flammable and Combustible Liquids Code*.

16.10.4 Fumigation. Flammable or combustible pesticides used to rid collection objects of insect or mold infestations shall be stored, handled, and used in accordance with the provisions of NFPA 30, *Flammable and Combustible Liquids Code*.

16.10.5* Cellulose Nitrate Film. Cellulose nitrate film shall be projected, stored, handled, or processed for conversion to safety film in compliance with NFPA 40, *Standard for the Storage and Handling of Cellulose Nitrate Film*.

16.10.6 Pyroxylin Plastic. Storage of materials or media containing pyroxylin plastic shall comply with NFPA 42, *Code for the Storage of Pyroxylin Plastic*.

16.10.7 Print Shops and Binderies. Low–flash point inks, blanket wash solutions, and adhesives shall be used and stored in compliance with NFPA 30, *Flammable and Combustible Liquids Code*.

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16.10.8* Laboratories. Laboratories shall comply with NFPA 45, *Standard on Fire Protection for Laboratories Using Chemicals*.

16.10.8.1 Laboratories shall be protected by an automatic fire suppression system.

16.10.8.2 Flammable or combustible liquids shall be stored and used in compliance with NFPA 30, *Flammable and Combustible Liquids Code*.

16.10.8.2.1 Cabinets or rooms for the storage or dispensing of flammable liquids shall comply with the requirements of NFPA 30, *Flammable and Combustible Liquids Code*.

16.10.8.2.2 Listed safety containers shall be provided for the storage and use of flammable and combustible liquids.

16.10.8.2.3 No more than a 1-day supply of flammable or combustible liquids shall be kept in the building except in an approved storage cabinet or room.

16.10.8.3 Where required, explosionproof or intrinsically safe–type lighting fixtures, motors, and switches shall be installed in compliance with NFPA 70, *National Electrical Code*.

16.10.8.4 Appliances. Hot plates and other heat-producing appliances shall be listed for their application.

16.10.8.4.1 Hot plates and other heat-producing appliances shall be maintained in accordance with the manufacturers' instructions.

16.10.8.4.2 Pilot lights at wall switches or on the appliances shall be provided to visually indicate whether the appliance is energized.

16.10.8.5 Waste receptacles shall be self-closing metal containers.

Chapter 17 Places of Worship

17.1* General.

17.1.1 The requirements of Chapters 1 through 15 apply to buildings used as places of worship.

17.1.2* This chapter shall apply specifically to buildings, parts of buildings, or enclosed structures that function as a place of worship.

17.1.3 Protection of areas within or associated with a place of worship that function as a museum to display or store artifacts and areas functioning as libraries, book storage, or document storage shall conform to Chapter 16.

17.2 Planning.

17.2.1 Responsibility. The governing body and leadership of the place of worship shall be responsible for the development and implementation of a fire safety program in accordance with Chapter 5.

17.2.2 Emergency Plan. Following the risk assessment, an emergency plan shall be developed for the worship facility, including provision for emergency evacuation, fire department notification, and protection of critical records and valuable artifacts in accordance with Section 5.3.

17.2.2.1 An emergency evacuation plan shall be developed and filed with the fire department for all assembly areas and shall specifically address evacuation of occupancies such as Sunday schools, nurseries, and senior citizens' meeting areas where the number of trained staff with respect to the number of individuals needing special assistance is low.

17.2.2.2 The plan shall include provisions for notifying the fire department and directing first responders to the location of the fire once they arrive at the site.

17.2.2.3 Emergency telephone numbers shall be posted on or adjacent to all telephones.

17.2.2.4 The plan shall identify historical records such as marriage, birth, and baptismal certificates, valuable artifacts, and relics of special significance and shall provide for their removal, salvage, or both.

17.2.3 Training.

17.2.3.1 All staff and employees of the place of worship, as well as nursery attendants, instructors, and other key volunteers, shall be trained in the provisions of the emergency evacuation plan and fire department notification.

17.2.3.2 This training shall include emergency evacuation of mobility-impaired individuals and children.

17.3 Fire Prevention.

17.3.1 Draperies and Decorations.

17.3.1.1 All combustible draperies and decorations shall be treated with a fire-retardant compound.

17.3.1.2 Fire-retardant treatment of religious and historically significant fabrics shall not be required where such treatment will cause damage to the fabric.

17.3.1.3 Decorations and draperies shall be kept a minimum of 1.2 m (4 ft) from ignition sources, including candles, censers, light fixtures, radiators, and electric heaters.

17.3.1.4 Decorative materials used for special occasions and holidays shall be noncombustible or shall be treated with a listed and approved fire retardant.

17.3.2* Housekeeping. Housekeeping practices in accordance with Section 11.4 shall be maintained.

17.3.2.1 Concealed spaces in the attic, basement, organ pipe runs, steeples, and beneath stairs and raised altar areas shall be kept free from accumulations of combustible materials.

17.3.2.2 Flammable liquids such as paints, varnishes, cleaning solvents, and floor polishes shall be stored inside an approved flammable liquids storage cabinet.

17.3.2.3 Quantities of flammable liquids stored inside the building shall be stored and used in compliance with NFPA 30, *Flammable and Combustible Liquids Code*.

17.3.2.4 Approved, self-closing trash containers shall be used to house oily rags.

17.3.2.5 Trash disposal shall be performed regularly.

17.3.2.6 Power lawn mowers, snow blowers, and other gas-powered implements shall not be stored within the structure.

17.4 Fire Protection Systems. Fire suppression and detection systems shall be incorporated in all existing construction in accordance with the institution's fire protection program and plan.

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17.5 Candles and Censers. The use of all open-flame devices shall comply with 13.7.2 of NFPA *101*, *Life Safety Code*, and 20.1.4.2 of NFPA 1, *Uniform Fire Code*.

17.5.1 All lit candles shall be maintained a minimum of 1.2 m (4 ft) from combustible draperies and hangings.

17.5.2 All fixed candles shall be supported to prevent them from tipping over.

17.5.3 Following the extinguishment of all candles and incense fires, an individual shall remain on the premises for 30 minutes to guard against potential reignition.

17.5.4 Incense fires in censers shall be extinguished after use and before the censers are stored.

17.6 Historical Records and Artifacts. Valuable record storage shall be protected in accordance with NFPA 232, *Standard for the Protection of Records*.

17.7 Special Facilities.

17.7.1 Kitchens.

17.7.1.1 Kitchen Maintenance.

17.7.1.1.1 Kitchens shall be maintained in a clean and orderly manner.

17.7.1.1.2 Surfaces and equipment shall be kept free of grease, and food wastes shall be disposed of promptly.

17.7.1.1.3 Means of egress from kitchens shall be maintained free of trash containers and other materials.

17.7.1.2 Household Appliances.

17.7.1.2.1 Listed household/consumer appliances shall be permitted in kitchens and shall be installed and maintained in accordance with their listings.

17.7.1.2.2 Household/consumer cooking appliances shall be provided with a listed household/consumer hood.

17.7.1.3 Commercial Cooking Appliances. Listed commercial cooking appliances shall be provided with a hood and exhaust system, grease-removal devices, auxiliary equipment, and fire-extinguishing equipment in compliance with NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*.

17.7.1.4 Use and Maintenance.

17.7.1.4.1 Equipment shall be used, inspected, and maintained in compliance with NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*.

17.7.1.4.2 Only nonflammable cleaners shall be used.

17.7.2 Schools.

17.7.2.1 Preschool or nursery school facilities located in a place of worship shall comply with NFPA *101*, *Life Safety Code*.

17.7.2.2 The governing body of the place of worship shall consult the local authority having jurisdiction prior to starting a school in their building.

17.7.3 Homeless Shelters.

17.7.3.1 If a place of worship contains sleeping rooms for the homeless, this occupancy shall comply with the requirements of NFPA *101*, *Life Safety Code*.

17.7.3.2 The governing body shall consult the local authority having jurisdiction prior to the addition of sleeping facilities to a place of worship.

17.7.4* Sanctuaries, Auditoriums, and Gymnasiums. Sanctuaries, auditoriums, and gymnasiums shall comply with NFPA *101*, *Life Safety Code*.

17.7.5 Libraries. Libraries shall be protected in accordance with Chapter 16.

17.7.6 Artifacts and Museum/Exhibit Areas. Museum areas, including artifact and exhibit areas, shall be protected in accordance with Chapter 16.

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Annex A Explanatory Material

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

A.1.3 Such structures include, but are not limited to, buildings that store or display museum or library collections, historic structures, and places of worship. These structures also include spaces within other buildings used for such culturally significant purposes.

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

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

A.3.2.3 Code. The decision to designate a standard as a "code" is based on such factors as the size and scope of the document, its intended use and form of adoption, and whether it contains substantial enforcement and administrative provisions.

A.3.2.4 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.6.1 Multitier Book Stack. The system is usually erected inside a structural shell housing the book stack. Typically, a vertical opening (space gap or "deck slit") is present between the walkway and the ranges at each tier from the bottom tier to the top tier. *[See Figure A.16.4.10.3(a) and Figure A.16.4.10.3(b).]*

A.3.3.7 Building. The term *building* is construed as if followed by the words *or portions thereof*. A historic building is one designated by a local, regional, or national jurisdiction as having historical, architectural, or cultural significance. Designation could be in an official existing or future national, regional, or local historic register, listing, or inventory. Properties that meet the criteria for eligibility should be treated as eligible. This also includes buildings in a historic district that are not architecturally distinguished but whose scale, proportions, materials, and details are consistent with the character of the district.

A.3.3.11 Compact Storage Module. See Figure I.1 and Figure I.3.

A.3.3.12 Compact Storage System. See Figure I.4.

A.3.3.16 Cultural Resource Properties. Such properties include, but are not limited to, museums, libraries, historic structures, and places of worship.

A.3.3.31 Fire Safety Manager. In smaller organizations this role can be combined with that of another position or appointment. In larger institutions, the person's responsibilities should be permitted to include supervision of other fire protection staff. The authorized person should be an employee of the cultural resource facility or institution who has certification, education, training, and/or experience with generally accepted fire protection practices. Alternatively, cultural resource facilities or institutions should be permitted to designate appropriate outside persons such as consulting fire protection engineers, fire service personnel, insurance company loss control representatives, local code officials, or other individuals with similar fire protection credentials.

A.3.3.36 Hazardous Area. Examples include the following:

(1) Storage or use of combustibles or flammables
(2) Storage or use of toxic, noxious, or corrosive materials
(3) Use of heat-producing appliances

A.3.3.39 Historic Structure. Examples of historic structures can be found in *National Register Bulletin 15, How to Apply the National Register Criteria for Evaluation*, "How to Define Categories of Historic Properties."

A.3.3.41 Impairment. Impairments can be classified as either of the following types:

(1) *Emergency*, in which a fire protection system, equipment, or a portion thereof is out of order due to an unexpected occurrence, such as a ruptured sprinkler pipe or device or component failure
(2) *Preplanned*, in which a fire protection system, equipment, or a portion thereof is out of service due to work that has been planned in advance, such as modifications to the water supply or sprinkler system piping

A.3.3.45 Library. The term *library* covers an extremely wide range of situations: A library can be a small special or valuable collection in a private home or other building, or it can be a separate section in a building used for many purposes. It also can be a multimillion-dollar complex of buildings, the purpose of which is to provide not only storage for books, but also study and reading areas, catalog rooms, workrooms, binderies, art collections, shops, and places of public assembly. However, all libraries have one characteristic in common: ample fuel in the form of books and other library materials, which can include compact discs, microforms, magnetic tapes, phonograph records, and motion picture films (cellulose nitrate as well as "safety" film), which can burn and contribute to a serious fire.

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A.3.3.45.1 Secondary Storage Facility. This facility utilizes warehouse rack storage methods exceeding 4 m (12 ft) in height.

A.3.3.47 Museum. The American Association of Museums defines a museum as an organized and permanent nonprofit institution, essentially educational or aesthetic in purpose, with professional staff, which owns and uses tangible objects, cares for them, and exhibits them to the public on some regular schedule.

A.3.3.72.2 Fire Scenario. A fire scenario defines the conditions under which a proposed design is expected to meet the fire safety goals. Factors typically include fuel characteristics, ignition sources, ventilation, building characteristics, and occupant locations and characteristics. Fire scenarios include more than the characteristics of the fire itself but exclude design specifications and any characteristics that do not vary from one fire to another; the latter are called assumptions. The term *fire scenario* is used here to mean only those specifications required to calculate the fire's development and effects, but in other contexts, the term can be used to mean both the initial specifications and the subsequent development and effects (i.e., a complete description of fire from conditions prior to ignition to conditions following extinguishment).

A.3.3.74 Special Event. Special events include receptions, dinners, private viewings, and similar activities held at the cultural resource property for specific groups (e.g., members, boards, outside organizations).

A.3.3.77 Utilities. Utilities can include lighting and electrical power services; telecommunication and security services; electrical control circuits; HVAC distribution control circuits and duct systems; water, steam, wastewater, and drain pipes and services; fire suppression systems, including water based and non–water based; oil, gas, hydraulic, and pneumatic systems; and any other electrical or mechanical building services.

A.5.1.1.1.2 Techniques for preparing a fire risk assessment are presented in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*; NFPA's *Fire Protection Handbook*, Chapters 3.7, 3.8, and 3.11; and the *SFPE Handbook of Fire Protection Engineering*, Section 5. NFPA 551, *Guide for the Evaluation of Fire Risk Assessments*, provides guidance on how to evaluate fire risk assessments.

A.5.1.1.2 The fire safety manager can be an employee of the institution who has certification, education, training, and/or experience with generally accepted fire protection practices. Institutions can also use appropriate outside resources, such as consulting engineers, fire department personnel, insurance company loss control representatives, code officials, or other individuals with similar credentials.

A.5.2.1 Some records should be kept longer than others. The fire safety management plan should specify the retention period for each type of record.

A.5.3.2.2 Competent application of systems analysis is a powerful tool in identifying cost-effective alternatives to achieve fire safety goals. For assistance, see NFPA 550, *Guide to the Fire Safety Concepts Tree*.

A.5.4 The fire safety management plan should address the following topics, as appropriate to the circumstances of a particular building:

(1) Compartmentation
(2) Structural analysis
(3) Alarm and communications
(4) Means of egress
(5) Smoke control
(6) Fire suppression
(7) Water supply
(8) Ignition prevention
(9) Fire department/public protection response
(10) Fuel control

A.5.4.3 The development of an emergency plan should be in accordance with NFPA 1600, *Standard on Disaster/Emergency Management and Business Continuity Programs*, which provides guidance on managing the emergency condition to minimize loss of life, collections, and property and on planning for recovery from the emergency situation.

A.5.4.6.2(5) Examples of such records include, but are not limited to, the following:

(1) Collections inventories (e.g., accession, catalog, conservation, and loan documents along with copies of donation and gift forms)
(2) Historical records, including baptismal and wedding records
(3) Essential business and insurance records
(4) Building plans and systems documentation (e.g., drawings, specifications, operating manuals, photographs, photographic surveys, and other visual materials)

A.6.1 It is important to control the threat of arson. Precautions can minimize the likelihood of a serious fire. The most common fire setters are vandals, disgruntled patrons, and employees. They might break in at night or gain legitimate access during normal operating hours. *(See Table B.2 and Table B.4.1.)* Experience indicates that if an unsuccessful arson fire has occurred, a repeat attempt is likely unless the fire setter is brought to justice. The cultural resource property then becomes a specific target, and extra precautions are warranted. The following special precautions are suggested as recommendations for high-risk properties:

(1) The strongest deterrent to fire setters is good security. Suggested elements of a sound security plan are as follows:
   (a) Reasonable surveillance, including use of electronic equipment, of all areas accessible to the public, with spot checks at regular intervals. All nonpublic areas should have controlled access.
   (b) A background investigation for stability and character should be conducted, to the extent legal restrictions allow, on potential employees, security personnel, and others having free access to the entire facility.
   (c) All accessible openings, including doors, windows, vents, and roof access hatches, should be properly secured. Fire exits should be arranged to prevent outside entry. Doors, windows, and hatches should be checked to make sure locks are in good repair.
   (d) Exterior lighting is an effective and often underrated security measure against arsonists and other miscreants. Where not provided by public utilities, lighting should be added at all concealed approaches to the facility.
   (e) A rigid closing procedure, including supervisory follow-up responsibility, should be established to ensure that all unauthorized people have left the building, that openings are secured, and that fire hazards, including ashtrays and trash receptacles, are checked.

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(f) Many fires have been set in book returns. Book returns should be constructed to prevent the spread of fire and smoke from the return into the rest of the library. A better alternative could be to eliminate the inside book return and provide an outside receiving bin away from the exterior walls of the library building.

(2) High-risk locations require a higher level of precautions if any of the following conditions exist:
   (a) Properties in high–crime rate areas
   (b) Cultural resource properties associated with or connected to social or political causes
   (c) Locations having previously incurred an arson fire or threat
   (d) Facilities where seriously strained relations between employees and management exist

(3) For facilities in high-risk locations, the following precautions should be employed:
   (a) Security/guard service during idle periods or intrusion alarms connected to a reliable, constantly attended location
   (b) Cooperative liaison with police and fire departments
   (c) Closed-circuit television and monitors for remote areas with public access, because the cameras provide a formidable psychological deterrent to arsonists, vandals, and other wrongdoers
   (d) Supplementary outside lighting with a 2 m (7 ft) wire fence in concealed access areas of the building
   (e) Cutting back of bushes, shrubs, and other plant materials that could provide cover for an intruder

A.6.1.2.2 The analysis should take into consideration the ways fire can spread and the location and position of the following features:

(1) Air intakes
(2) Dumpsters and rubbish bins
(3) Blind areas adjacent to fire escape doors
(4) Contractor accommodation and storage areas

A.6.1.3 To minimize the probability and impact of deliberately set fires, consideration should be given to the need for security measures designed to reduce the threat of arson. Such measures include the following:

(1) Access control systems
(2) Closed-circuit television and surveillance systems
(3) Intruder detection and alarm systems
(4) Security lighting
(5) Upgraded security features for doors and windows
(6) Perimeter protection, such as fences
(7) Enhanced patrols

A.6.1.4 The nature of libraries—their access by the public, with many areas obscured from view of attendants—results in their being an opportune target for arsonists as well as others bent on other forms of malicious damage. The most common fire setters are vandals, disgruntled patrons, and employees. They can break in at night or gain legitimate access during normal operating hours. A frequent method of external attack has been to place burning materials into the book return.

A.6.3 Deliberate and malicious setting of fires is the most common cause of fire incidents in the construction phase of building rehabilitation. Control of access to the property is essential in preventing arson. The practice of good housekeeping will minimize the amount of combustible material readily available to facilitate an arson fire. If a location has experienced labor management difficulties or has previously sustained a set fire or vandalism, it is established as a target for arson, and additional security should be provided. Arsonists have set fires in museums, libraries, places of worship, and historic buildings with motives ranging from mindless vandalism to attempts to cover crimes such as burglary. Arsonists are usually from the outside but not always (possibly employees or volunteers with a grudge or imagined grievance).

A.6.3.2 A qualified person should be assigned overall responsibility for site security during the project. Welding operations on the work site can result in a fire long after work has stopped for the day. Therefore, if security officers are assigned to the work site, officers on duty should be informed of all locations where welding operations were performed. They should be instructed to thoroughly and carefully check each of these locations during their regular patrols of the work site and to look for evidence of smoldering.

A.7.1 This code gives both prescriptive-based and performance-based approaches to achieving its fundamental objectives. Equivalency is also included as an integral concept to achieve compliance. The code, therefore, provides a specific process chapter to guide the user in its application and to reduce possible confusion in the reading and implementation of the code.

A.7.2 A process team should be interdisciplinary in nature, representing both safety and preservation concerns. Early consultation and coordination at each step of the process is highly desirable and strongly recommended. While every effort should be made to create an interdisciplinary team of players, the code recognizes that there will be times when such a diversity of members is not possible. The code, therefore, suggests but does not require any particular membership of the team. Participants on the team can include the following:

(1) Design professionals
(2) Fire protection consultant
(3) Authorities having jurisdiction, including the following:
   (a) Preservation officer or review agency
   (b) Fire code official
   (c) Building code official or permitting authority
   (d) Insurance company representative/broker
(4) Representative contractor
(5) Building manager
(6) Fire safety manager
(7) Building occupants
(8) Building owner

A.7.3 The assessment is intended to evaluate the relevant culturally significant elements, spaces, contents, and features and the relevant fire safety issues associated with the structure. The extent and depth of the assessment might vary, depending on the cultural significance of the building and its component elements, the size and complexity of the building, changes of occupancy classification, and other factors as appropriate.

A.7.3.1.1.2 Demonstrated knowledge might be evidenced by experience with similar properties or submission of designs and solutions that exhibit an understanding of and sensitivity to the impact of their systems on cultural resource properties. Methods of identifying or ensuring that contractors and personnel have a true understanding of the special needs and concerns of cultural resource properties include interviews and predesign conferences and verified referrals or recommendations from other cultural institutions.

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A.7.3.1.1.3 Prequalification of contractors and referrals can be used to find contractors experienced in dealing with culturally significant properties. Project specifications should spell out the special precautions needed for the construction activity. Job site meetings should be used to familiarize laborers as well as craftsmen with these special concerns. Curators and key staff members should take part in these meetings.

A.7.3.1.2.1 Character-defining features include, but are not limited to, sheathing or facade materials, roofing materials, chimneys, skylights, cornices, windows and doors, and porches and railings.

A.7.3.1.2.2 Character-defining features and finishes include, but are not limited to, distinctive architectural details, wainscoting, parquet flooring, picture molding, mantels, ceiling medallions, built-in bookshelves and cabinets, crown molding, and arches, as well as simpler, more utilitarian features, such as plain windows and doors and associated trim. The building survey should establish important characteristics of the building type, style, period, or historic function. The building survey should review significant spaces to establish rooms or other interior locations that are typical of the building type or style or are associated with specific persons or events.

A.7.3.1.3 Required exterior modifications or additions should be located on the less visible and least significant exterior elevations in order to keep the impact on culturally significant structures to a minimum.

A.7.5.1 The selection of the method of application of the code could result from a consideration of the following:

(1) Extent of deviation of the building from the prescriptive code
(2) Difficulty in providing remedies in accordance with the prescriptive code
(3) Cultural significance of features that would be compromised by meeting the prescriptive code

The relative cost of performance-based and prescriptive-based approaches should also be considered, because this information might affect the financial means of the building owner to provide code compliance in the building.

The option appraisal and selection portion of the code can function as a tool to assist in selection of a prescriptive-based or performance-based application. A building need not meet both sets of requirements.

A.8.1.1 The three approaches to compliance with prescriptive requirements—alternatives, equivalencies, and modifications—are presented in order of their legal certitude. Therefore, they should be considered in that order to minimize the need for lengthy negotiations or variance hearings. However, early conversations among interested parties can establish an acceptable level of compliance for a particular case.

A.8.1.2 Alternatives refer to options that are explicitly stated in the requirements of the prevailing code. They are often incorporated in exceptions to specific provisions. A careful reading of the prevailing code could revel more acceptable options to the standard compliance requirements. Particular attention to alternatives should be given where jurisdictions have adopted model codes but have made exceptions for existing or historic buildings.

A.8.1.3 Equivalency refers to alternative fire safety measures that can be established to provide a level of safety equivalent to the prevailing code. For example, the installation of fire detection and suppression that is not legally required in place of structurally altering the interior of a building can result in an equivalent level of protection. Less common is the compensation for a code deficiency by operational features, for example, compensating for a dead-end corridor with occupant training.

Equivalency is a common code clause that allows other means of compliance if they can be demonstrated and documented. There are many ways to address the issue of documenting equivalency, such as, in order of complexity, precedents, ad hoc equivalency, risk indexing, and component performance evaluation.

Precedents are continually established in the regulation of fire safety for cultural resource properties and historic buildings. They represent acceptable alternatives that have not been formally incorporated into a regulatory document. The annexes of this document are a unique source of identifying many of these precedents. Others might be available locally.

Ad hoc equivalency can be established by employing subjective logic. One qualitative approach used to evaluate alternative arrangements for equivalent safety is NFPA 550, *Guide to the Fire Safety Concepts Tree*. The tree is a logic diagram that represents all possible means of meeting fire safety objectives. Increasing fire safety measures on one branch of the tree can offset a lack of required measures on another branch, thus establishing an arrangement of equivalent fire protection.

Fire risk indexing is a method that should be permitted to be used to establish conformance to a prevailing code. This process consists of a multi-attribute decision analysis approach to quantitatively balance variables of risk, hazard, and safety to achieve an acceptable level of fire safety. Fire risk indexing is a systematic approach to equivalency that considers the building in its entirety and produces a calculated value to identify the degree of compliance with the intent of a prescriptive code.

The following documents have an established record of meeting code objectives through an indexing approach:

(1) NFPA 101A, *Guide on Alternative Approaches to Life Safety*, Chapters 4 through 9
(2) *Wisconsin Historic Building Code*, Subchapter IV, Building Evaluation Method, Chapter ILHR 70

Performance-based fire safety can also be approached on a component basis rather than a systemic basis. Some fire safety components already have a form of performance criteria such as fire resistance. Component performance can also be evaluated on a more ad hoc basis through the use of equivalency clauses in building codes. Codifying more component performance criteria can provide solutions for many problems. For example, establishing measurable fire safety objectives for doors, stairs, fire escapes, dead ends, exit signs, and similar features is particularly useful for dealing with these issues in existing cultural resource properties, particularly in historic buildings.

A.8.1.3.2 Any departure from the prescriptive code should be shown through adequate documentation to provide an equivalent level of protection. The extent of documentation/analysis required to demonstrate equivalency should be commensurate with the complexity of the issue.

Equivalent solutions rely on the prescriptive code or standard as a departure point from strict compliance. Identification is made of the areas where the building deviates from the prescriptive requirement, and an equivalent solution is considered for any nonconforming issue. Equivalent solutions

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continue to work within the framework of the prescriptive code and justify departures from the prescriptive requirements, either individually or collectively, with an alternative acceptable to the authorities having jurisdiction. The code provides extensive annex material in an effort to provide a stronger framework of information to authorities having jurisdiction as they form decisions on proposed equivalent alternatives. The code also encourages the identification of still more resources to continue to support authorities having jurisdiction in their role of judging proposed alternatives. Maximum flexibility within the confines of equivalent safety is encouraged at all times.

The intent of the code is that liberal use be made of the annex material and references as a basis for establishing equivalency. These and other materials, commonly consulted to provide documentation for performance-based design approaches, also provide strong guidance and support for equivalency solutions. Other materials and information to be considered can include the identification of precedents and research findings.

Materials located in the annex sections of this code, as well as the referenced documents found in various portions of this code, can be used as sources of information to evaluate design alternatives. The application of specific information from these or other sources must be demonstrated as sound through the performance-based approach requirements described in Chapter 9 of the code. The annex and referenced sources of information are not intended to be exclusive sources of information. Any source of information that can be demonstrated to be credible and valuable to the evaluation of the proposed design can be used in conjunction with this code.

A.8.1.4 In existing cultural resource properties, it is not always practical to strictly apply the provisions of the prevailing code. Physical limitations can require disproportionate effort or expense with little increase in life safety. In such cases, the authority having jurisdiction should be satisfied that reasonable life safety is ensured.

In existing cultural resource properties, especially those classified as historic, it is intended that any condition that represents a serious threat to life be mitigated by application of appropriate safeguards. It is not intended to require modifications for conditions that do not represent a significant threat to life, even though such conditions are not literally in compliance with the prevailing code. Among the means of reasonably modifying prescriptive requirements are tolerances and waivers.

Tolerances allow for flexibility by relaxing the many "magic numbers" in code requirements, for example, 50 people, 813 mm (32 in.) wide, 1-hour fire resistance, and so forth. Reasonable dimensional tolerances should be permitted in applying prescriptive requirements to historic buildings. A 10 percent to 20 percent tolerance in prescriptive criteria might be reasonable if it allows historic preservation objectives to be achieved. In legal jargon, such tolerances are referred to as *de minimis*; that is, they are considered insignificant with respect to the overall safety of the building. Tolerance in strict application of installation standards can also be appropriate, for example, allowing a particularly sensitive room to remain unprotected in an otherwise fully sprinklered building.

Waivers can be another form of *de minimis* code application. Waivers can be appropriate where applying a code requirement in an existing cultural resource property is not reasonable. For example, a requirement that all exit doors need to swing outward could be unreasonable for some situations in historic buildings.

A.8.2 The subjects discussed in Section 8.2 are intended to be a partial listing of system features or beneficial attributes of a structure that could help compensate or offset one or more prescriptive code deficiencies. These provisions are not mandatory, but should be identified when an argument is made for alternative approaches, equivalencies, or modifications to the prescriptive code requirements.

A.8.2(6) Filling concealed spaces with inert materials, such as mineral wool insulation or other similar fire-resistive materials, can further retard the spread of fire. Care should be taken to ensure that the introduction of fire barriers or fire stopping does not inadvertently result in a disturbance of the building's microclimate by impeding airflow, which might result in the growth of mold or fungus.

A.8.2(7) The U.S. Department of Housing and Urban Development has developed the "Guideline on Fire Ratings of Archaic Materials and Assemblies" to identify approximate fire resistance qualities of older construction methods.

A.8.2(8) Fire detection systems that can discriminate or identify any number of characteristics of fire (e.g., presence of smoke, critical temperature rise, or infrared/ultraviolet radiation) are also considered to be a compensatory feature. The detection device that offers the fastest response with respect to the type of occupancy should be a primary consideration.

A.9.1 Chapter 9 of this code provides requirements for the evaluation of a performance-based life safety and fire protection design. The evaluation process is summarized in Figure A.9.1.

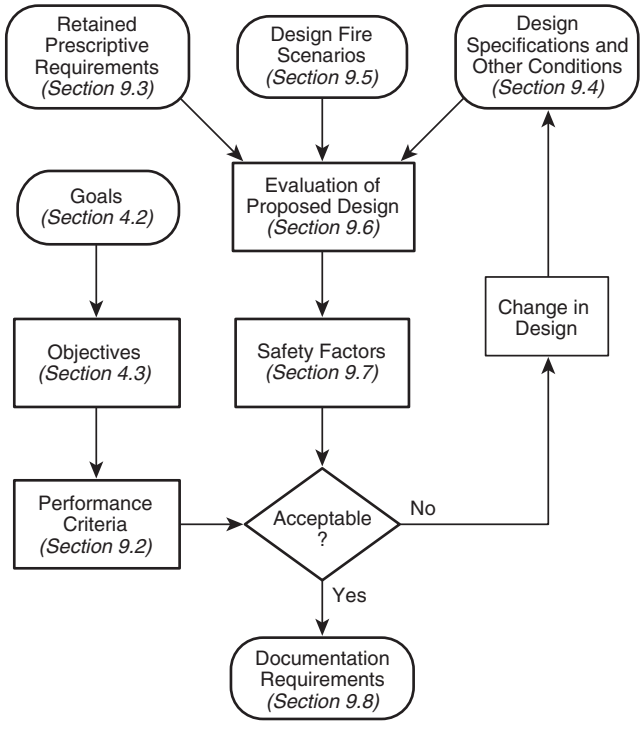

FIGURE A.9.1 Performance-Based Fire Safety Code Compliance Process.

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On the left side of Figure A.9.1 is input from the code. The life safety and cultural resource property preservation goals are stated in Section 4.2. The objectives necessary to achieve those goals are stated in Section 4.3. Section 9.2, Performance Criteria, specifies the measures that are to be used to determine whether the objectives have been met.

At the top of Figure A.9.1 is the input necessary to evaluate a fire-safe design. The design specifications need to include certain retained prescriptive requirements as specified in Section 9.3. All assumptions about the life safety design, fire safety design, and the response of the building and its occupants to a fire must be clearly stated as indicated in Section 9.4. Scenarios are used to assess the adequacy of the design as specified in Section 9.5. Eight sets of initiating events are specified for which the ensuing outcomes need to be satisfactory.

Appropriate methods for assessing performance are to be used per Section 9.6. Safety factors need to be applied to account for uncertainties in the assessment as stated in Section 9.7. If the resulting predicted outcomes of the scenarios are bounded by the performance criteria, the objectives have been met and the fire safety design, coupled with the goals of maintaining the culturally significant features of the building under evaluation, is considered to be in compliance with this code. A design that fails to comply can be changed and reassessed as indicated on the right side of Figure A.9.1.

The approval and acceptance of a fire safety design depend on the quality of the documentation of the process. Section 9.6 specifies the minimum set of documentation that needs to accompany a submission.

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

A.9.1.3 Qualifications should include experience, education, and credentials that demonstrate knowledgeable and responsible use of applicable models and methods.

A.9.1.4 A third-party reviewer is a person or group of persons chosen by the authority having jurisdiction to review proposed performance-based designs.

A.9.1.7 Continued compliance with the goals and objectives of the code involves many things. The building construction—including openings, interior finish, and fire- and smoke-resistive construction—and the building and fire protection systems need to retain at least the same level of performance as provided for the original design parameters. Performance designs that include features that are related to management operational systems need to include specific instructions related to these features. The use and occupancy should not be allowed to change to the degree that assumptions made about the occupant characteristics, combustibility of furnishings, and existence of trained personnel are no longer valid. In addition, action provided by other personnel, such as event staff or emergency responders, should not be allowed to diminish below the documented assumed levels. Also, actions needed to maintain reliability of systems at the anticipated level need to meet the initial design criteria. If such changes occur, the approach will need to be modified and the plan and design documentation amended to reflect those changes.

A.9.2.2.1 One of the following methods can be used to avoid exposing occupants to untenable conditions:

(1) The design team could set detailed performance criteria that would ensure that occupants are not incapacitated by fire effects. The *SFPE Engineering Guide to Performance-Based Analysis and Design of Buildings* describes a process for establishing tenability limits.
(2) The *SFPE Engineering Guide to Performance-Based Analysis and Design of Buildings* references D. A. Puser in the *SFPE Handbook of Fire Protection Engineering*, which describes a fractional effective dose (FED) calculation approach also contained in the 1996 edition of NFPA 269, *Standard Test Method for Developing Toxic Potency Data for Use in Fire Hazard Modeling*. FED addresses carbon monoxide, hydrogen cyanide, carbon dioxide, hydrogen chloride, hydrogen bromide, and anoxia effects. It is possible to use the test data, combined with laboratory experience, to estimate what FED would lead to the survival of virtually all occupants. This value is approximately 0.8.
(3) There is a relationship between exposures leading to death and those leading to incapacitation. Kaplan found that rodent susceptibility is similar to that of humans and that for the narcotic gases (CO and HCN), human incapacitation occurs at one-third to one-half the lethal exposure. Gann found that carbon monoxide dominates the lethality of fire smoke, since most fire deaths occur remote from the fire room from fires that have proceeded past flashover. Thus, if the FED value of 0.8 were used for nonlethal exposure, an FED of 0.3 would be reasonable for a nonincapacitating exposure.
(4) If the authority having jurisdiction or the design professional is concerned with potential toxic fire effects other than those addressed by the FED procedure as documented, the calculation procedure can be expanded by adding additional terms to the FED equation, where each term has the form of a ratio. The numerator of the ratio is the cumulative exposure to that fire effect, measured as an integral of the product of instantaneous exposure (concentration for toxic products) and time. The denominator of the ratio is the quantity of cumulative exposure for which FED equals the chosen threshold value (e.g., 0.8 or 0.3) based on that fire effect alone.
(5) ASTM is actively considering standards that would extend the list of toxic fire effects with standard values.
(6) If the authority having jurisdiction or the design professional is concerned with potential fire effects other than toxicity, the calculation procedure can be modified to include other fire effects, such as thermal effects.
(7) For buildings where an unusually large fraction of the occupants would be especially vulnerable, the calculation procedure should be modified to use FED values lower than those cited in A.9.2.2.1(3) and A.9.2.2.1(4).
(8) For each design fire scenario and the design specifications, conditions, and assumptions, the design team could demonstrate that each room or area would be fully evacuated before the smoke and toxic gas layer in that

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room descended to a level lower than 1.8 m (6 ft) above the floor. This procedure would require that no occupant be exposed to fire effects. It requires calculation of the locations, movement, and behavior of occupants, because it keeps fire effects and occupants separate by moving the occupants. A level of 1.8 m (6 ft) is often used in calculations, but with that level, a large fraction of the population would not be able to stand, walk, or run normally and still avoid inhalation of toxic gases. They would have to bend over or otherwise move their heads closer to the floor level.

(9) For each design fire scenario and the design specifications and assumptions, the design team could demonstrate that the smoke and toxic gas layer would not descend to a level lower than 1.8 m (6 ft) above the floor of any occupied room. The advantage of this procedure is that it conservatively requires that no occupant need be exposed to fire effects, regardless of where occupants are or where they move. This option removes the need to make any calculations regarding occupants, including their behavior, movement locations, pre-fire characteristics, and reactions to fire effects. This procedure is even more conservative and simpler than the procedure in A.9.2.2.1(2), because it does not allow fire effects in occupied rooms to develop to a point where people could be affected even after there are no people present to be affected.

(10) For each design fire scenario and the design specifications and assumptions, the design team could demonstrate that no fire effects would reach any occupied room. The advantage of this procedure is that it removes the need to make any calculations regarding occupants, including their behavior, movement, locations, pre-fire characteristics, and reactions to fire effects. A further advantage is that it also removes the need for some of the modeling of fire effects, because it is not necessary to model the filling of rooms, only the spread of fire effects to those rooms. This method is even more conservative and simple than the procedures in A.9.2.2.1(2) and A.9.2.2.1(3), because it does not allow any fire effects in occupied rooms.

A.9.2.2.2 This evaluation should consider the use of multiple or redundant systems, features, and techniques. Prioritizing what, if any, objects or building features are deemed acceptable to be lost to a fire needs to be evaluated and determined. The following procedures could be potential areas of evaluation for the design team:

(1) Set detailed performance criteria that will ensure that selected rooms or spaces are protected from flame, heat, or smoke. The *SFPE Engineering Guide to Performance-Based Analysis and Design of Buildings* describes a process of establishing damage limits. The *SFPE Handbook of Fire Protection Engineering* also contains relevant information on thermal damage to various building materials and information on corrosivity of smoke.

(2) Demonstrate for each design fire scenario and the design specifications, conditions, and assumptions that each room or area will be fully isolated from the fire before the smoke and thermal layer in that room descends to a level where irreversible damage can occur.

(3) Demonstrate for each design fire scenario and the design specifications, conditions, and assumptions that the smoke and thermal layer will not descend to a level where irreversible damage can occur in any room. The advantage of this procedure is that it conservatively requires that no culturally significant item need be exposed to fire effects, regardless of where that room or space is located.

(4) Demonstrate for each design fire scenario and the design specifications, conditions, and assumptions that no fire effects will reach any room or space beyond the room of origin. An advantage of this method is that it also removes the need for some of the modeling of fire effects, because it is not necessary to model the filling of rooms, only the spread of fire effects to those rooms. This method is even more conservative and simple than the procedures in A.9.2.2.2(2) and A.9.2.2.2(3), because it does not allow any fire effects into any rooms with culturally significant features.

A.9.3.1 This requirement applies both to systems and features, including management operational systems required by the code, that reference applicable standards and to any additional systems or features included in the design at the discretion of the design team. The referenced standards are hereby expected to provide positive assurance of an acceptable level of reliability. The referenced standards themselves can be prescriptive or performance based.

A.9.4.1 The design specifications and other conditions form the input to evaluation of proposed design (*see Section 9.6*). Where a specification or condition is not known, a reasonable estimation can be made. However, the design team needs to take steps to ensure that the estimation is valid during the life of the building. Estimations need to be documented. *(See Section 9.8.)*

A.9.4.3 These characteristics should extend beyond the normal analysis of building construction features. Elements such as the type of construction, the construction technique, the use of special materials, as well as any unusual design features in the building, should also be explicitly identified.

A.9.4.4 Systems addressed by this requirement include automatic fire suppression systems and fire alarm systems. Performance issues that need to be documented might include response time indexes, discharge densities, and distribution patterns. Calculations should not include an unlimited supply of extinguishing agent if only a limited supply is provided in the actual structure or building.

A.9.4.5.1 Examples of design features that might be incorporated to modify expected occupant characteristics include training, use of staff to assist with notification and movement, or type of notification appliance used.

A.9.4.5.2 The four basic characteristics — sensibility, reactivity, mobility, and susceptibility — comprise a minimum, exhaustive set of mutually exclusive performance characteristics of people in buildings that can affect a fire safety system's ability to meet life safety objectives. The characteristics are briefly described as follows:

(1) Sensibility to physical cues is the ability to sense the sounding of an alarm. It can also include discernment and discrimination of visual and olfactory cues in addition to auditory emanations from the fire itself.

(2) Reactivity is the ability to interpret cues correctly and to take appropriate action. Reactivity can be a function of cognitive capacity, speed of instinctive reaction, or group dynamics. Occupants might need to consider the reliability of a decision or the likelihood of a wrong decision, as in the influence of familiarity with the premises on finding one's way.

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(3) Mobility (speed of movement) is determined by individual capabilities as well as by crowding phenomena such as that which results from arching at doorways.
(4) Susceptibility to products of combustion can affect survivability in a fire environment. Metabolism, lung capacity, pulmonary disease, allergies, or other physical limitations influence the extent to which one is susceptible to products of combustion.

In application, as with the use of computer evacuation models, assumptions can address a larger number of factors that are components of the basic performance characteristics described in Table A.9.4.5.2.

Table A.9.4.5.2 Performance Characteristics

Characteristics	Description
Alertness	Awake/asleep; can depend on time of day
Responsiveness	Ability to sense cues and react
Commitment	Degree to which occupant is committed to an activity underway before the alarm
Focal point	Point at which an occupant's attention is focused (e.g., to front of the classroom, stage, or computer)
Physical and mental capabilities	Can affect ability to sense, respond, and react to cues; can be related to age or disability
Role	Can determine whether occupants will lead or follow others
Familiarity	Can depend on time spent in building or participating in emergency training
Social affiliation	Extent to which an occupant acts/reacts as an individual or as a member of a group
Condition	Over the course of the fire, the effects—both physiological and psychological—of the fire and its combustion products on each occupant

A.9.4.5.4 The number of people expected to be in a room or area should be based on the occupant load factor specified in NFPA *101*, *Life Safety Code*, or other approved source.

A.9.4.5.5 For example, in museums and libraries, staff characteristics such as number, location, quality, and frequency of training should be considered.

A.9.4.7 Design proposals need to state explicitly any design specifications or estimations regarding building fire safety plans, inspection programs, or other ongoing programs whose performance is necessary for the building, when occupied and operational or when closed after hours, to meet the stated goals and objectives.

A.9.4.9 This requirement includes assumptions about the interrelations between the performance of building elements and systems, occupant behavior, or emergency response actions that conflict with each other. For each fire scenario, care needs to be taken to ensure that conflicts in actions do not occur. Typical conflicts could include the following and similar assumptions:

(1) A fire door will remain closed during the fire event to contain smoke, while occupants use this same door during egress from the area.
(2) A room door to a culturally significant space is closed at all times, yet the door is normally open for public viewing.
(3) Fire apparatus will arrive immediately from a distant location to charge fire department connections to provide water.

For example, an assumption that compartmentation blocking the passage of fire and smoke will be maintained at the door from a culturally significant space or to a stairwell cannot be paired with an assumption that evacuation through that door will extend over many minutes.

A.9.4.10 This requirement includes provisions that are in excess of basic requirements covered by referenced codes and standards, typical design requirements, and operating procedures. It includes provisions such as more frequent periodic testing and maintenance to increase the reliability of fire protection systems, redundant systems to increase reliability, onsite staff assistance to enhance detection of fires and aid in fire response procedures, staff training, availability and performance of emergency response personnel, and other factors.

A.9.5.1 Design fire scenarios define the challenge a building is expected to withstand. They also need to define the threat to the culturally significant features or attributes of the building. Design fire scenarios capture and limit value judgments on the type and severity of the fire challenge to which a proposed fire safety system needs to respond. The system includes any or all of the following aspects of the proposed design that are intended to mitigate the effects of a fire:

(1) Egress system
(2) Automatic detection and suppression
(3) Barriers
(4) Staff training
(5) Placement of manual extinguishers

Design fire scenarios come from two sources — those that are specified in 9.5.3.2 through 9.5.3.9 and those that are developed by the design team based on the unique characteristics of the building as required by 9.5.2. In most, if not all, cases more than one design fire scenario should be developed to meet the requirements of 9.5.2.

Once the set of design fire scenarios is established — both those specified by 9.5.3.2 through 9.5.3.9 and those that are developed as required by 9.5.2 — they must be quantified into a format that can be used for the evaluation of proposed designs. The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* outlines a process and identifies the tools and references that can be used at each step of this process.

A.9.5.2 The protection systems and features used to meet the challenge of the design fire scenario should be typical of and consistent with those used for other similar areas of the building. They should not be designed to be more effective in the building area addressed than in similar areas not included and that are, therefore, not explicitly evaluated.

A.9.5.3 It is desirable to run a wide variety of fire scenarios to evaluate the complete fire protection and life safety capabilities of the building or structure. Fire scenarios should not be limited to one or two worst-case fire scenarios.

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The descriptive terms used to indicate the rate of fire growth for the scenarios are intended to be generic. Use of *t*-squared fires is not required for any scenarios.

A.9.5.3.2 An example of such a scenario for a cultural resource property would involve a public museum or library. A large concentration of occupants could be present. A significant element or feature could be immediately threatened by fire. This is a cursory example in that much of the explicitly required information indicated in 9.5.3.1 can be determined from the information provided in the example. Note that it is usually necessary to consider more than one scenario to capture the features and conditions typical of an occupancy.

A.9.5.3.3 Examples of such scenarios are a fire involving ignition of gasoline as an accelerant in a means of egress or renovation materials or other fuel configurations that can cause an ultrafast fire. The means of egress chosen is the doorway with the largest egress capacity among doorways normally used in the ordinary operation of the building. The baseline occupant characteristics for the property are assumed. Such spaces can also contain building materials or features that are culturally significant. At ignition, doors are assumed to be open throughout the building.

A.9.5.3.4 An example of such a scenario is a fire in a storage or collections room adjacent to the largest occupiable room in the building or adjacent to the room or space with the most cultural significance. The contents of the room of fire origin are specified to provide the largest fuel load and the most rapid growth in fire severity consistent with the normal use of the room. The adjacent occupiable room is assumed to be filled to capacity with occupants. Occupants are assumed to be somewhat impaired in whatever form is most consistent with the intended use of the building. The room contains contents that are vulnerable to minor quantities of heat or smoke. At ignition, doors from both rooms are assumed to be open. Depending on the design, doorways might connect the two rooms, or they might connect via a common hallway or corridor.

For purposes of this scenario, an occupiable room is one that could contain people (i.e., a location within a building where people are typically found).

A.9.5.3.5 An example of such a scenario is a fire originating in a concealed wall or ceiling space adjacent to a large occupied function room or a room or space containing a special collection, furniture, or work of art. Ignition involves concealed combustibles, including wire or cable insulation and thermal or acoustical insulation. The adjacent function room is assumed to be occupied to capacity. The baseline occupant and building characteristics for the property are assumed. At ignition, doors are assumed to be open throughout the building.

A.9.5.3.6 An example of such a scenario is a cigarette fire in a trashcan. The trashcan is close enough to room contents to ignite more substantial fuel sources but is not close enough to any occupant to create an intimate-with-ignition situation or close enough to immediately endanger any of the culturally significant spaces or objects. If the intended use of the property involves the potential for some occupants to be incapable of movement at any time, the room of origin is chosen as the type of room likely to have such occupants, and it is filled to capacity with occupants in that condition. If the intended use of the property does not involve the potential for some occupants to be incapable of movement, the room of origin is chosen to be an assembly or function area characteristic of the use of the property, and the trashcan is placed so that it is shielded from suppression systems. At ignition, doors are assumed to be open throughout the building.

A.9.5.3.7 An example of such a scenario is a fire originating in the largest fuel load of combustibles possible in normal operation in a function or assembly room or a process/manufacturing area characteristic of the normal operation of the property. The configuration, type, and geometry of the combustibles are chosen so as to produce the most rapid and severe fire growth or smoke generation consistent with the normal operation of the property. The baseline occupant characteristics of the property are assumed. At ignition, doors are assumed to be closed throughout the building.

This category includes everything from a couch fire in a small dwelling to a rack fire in combustible liquids stock in a home improvement or wholesale retail store.

A.9.5.3.8 An example of such a scenario is an exposure fire. The initiating fire is the closest and most severe fire possible, consistent with the placement and type of adjacent properties and the placement of plants and combustible adornments on the property. The baseline occupant characteristics for the property are assumed.

This category includes wildland/urban interface fires, exposure from fires originating in adjacent structures, and exterior wood shingle problems, where applicable.

A.9.5.3.9 This scenario addresses a set of conditions with a typical fire originating in the building with any one passive or active fire protection system or feature being ineffective. Examples of this category include unprotected openings between floors or between fire walls or fire barrier walls, rated fire doors that fail to close automatically or are blocked open, sprinkler system water supply shut off, nonoperative fire alarm system, smoke management system not operational, or automatic smoke dampers blocked open. This scenario should represent a reasonable challenge to the other building features provided by the design and presumed to be available.

The concept of a fire originating in ordinary combustibles is intentionally selected for this event. This fire, although it presents a realistic challenge to the building and the associated building systems, does not represent the worst-case scenario of the most challenging fire event for the building.

Examples of fires that originate in ordinary combustibles include the following:

(1) *Corridor of a historic museum.* Staff is assumed not to close any exhibition space or room doors upon detection of fire. The baseline occupant characteristics for the property are assumed, and the areas or viewing rooms off the corridor are assumed to be filled to capacity with visitors. At ignition, all such doors in the area are not equipped with self-closing devices and are assumed to be open throughout the smoke or fire compartment.
(2) *Large assembly room or area in the interior of the building.* The automatic suppression systems are assumed to be out of operation. The baseline occupant characteristics for the property are assumed, and the room of origin is assumed to be filled to capacity. At ignition, doors are assumed to be closed throughout the building. A specific or rare collection piece is located in the room of origin.
(3) *Unoccupied small function room adjacent to a large assembly room or area in the interior of the building.* The automatic detection systems are assumed to be out of operation. The

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baseline occupant characteristics for the property are assumed, the room of origin is assumed to be unoccupied, and the assembly room is assumed to be filled to capacity. At ignition, doors are assumed to be closed throughout the building. The room is of particular cultural significance and is vulnerable to potential damage from an undetected fire.

A.9.5.3.9.2 This paragraph applies to each active or passive fire protection system individually and requires two different types of information to be developed by analysis and approved by the authority having jurisdiction. System reliability is to be analyzed and accepted. Design performance in the absence of the system is also to be analyzed and accepted, but acceptable performance need not mean fully meeting the stated goals and objectives. It could be possible to meet fully the goals and objectives with a key system unavailable, and yet no system is totally reliable. The authority having jurisdiction will determine what level of performance, possibly short of the stated goals and objectives, is acceptable, given the very low probability (i.e., the system's unreliability probability) that this situation will occur.

A.9.6.3.3 Procedures used to develop required input data need to preserve the intended conservatism of all scenarios and assumptions. Conservatism is only one means to address the uncertainty inherent in calculations and does not remove the need to consider safety factors, sensitivity analysis, and other methods of dealing with uncertainty. The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* outlines a process for identifying and treating uncertainty.

A.9.6.4 An assessment method translates input data, which can be test specifications, parameters or variables for modeling, or other data, into output data that are measured against the performance criteria. Computer fire models should be evaluated for their predictive capability in accordance with ASTM E 1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*.

A.9.7 The assessment of precision required in 9.5.4.3 requires sensitivity and uncertainty analysis, which can be translated into safety factors.

The first run a model user makes should be labeled as the base case, using the nominal values of the various input parameters. However, the model user should not rely on a single run to use as the basis for any performance-based fire safety system design. Ideally, each variable of parameter that the model user made to develop the nominal input data should have multiple runs associated with it, as should combinations of key variables and parameters. Thus, a sensitivity analysis should be conducted that provides the model user with data that indicate how the effects of a real fire can vary and how the response of the proposed fire safety design can also vary. The interpretation of a model's predictions can be a difficult exercise if the model user does not have knowledge of fire dynamics or human behavior.

The first thing the model user should try to determine is whether the predictions actually make sense (i.e., they do not contradict intuition or preconceived expectations). Most likely, if the results do not pass this test, an input error has been committed.

Some factors to consider in the interpretation of a model's results are as follows:

(1) Sometimes the predictions appear to be reasonable but are, in fact, incorrect. For example, a model can predict higher temperatures farther from the fire than closer to it. The values themselves can be reasonable (e.g., not hotter than the fire), but they do not "flow" down the energy as expected.
(2) A margin of safety can be developed using the results of the sensitivity analysis, which provides the possible range of when a condition is estimated to occur, in conjunction with the performance criteria.
(3) Safety factors and margin of safety are two concepts used to quantify the amount of uncertainty in engineering analyses. Safety factors are used to provide a margin of safety and to represent or address the gap in knowledge between the theoretically perfect model (i.e., reality) and the engineering models that can only partially represent reality.
(4) Safety factors can be applied to either the predicted level of a physical condition or the time that the condition is predicted to occur. Thus, a physical and/or a temporal safety factor can be applied to any predicted condition. A predicted condition (i.e., a parameter's value) and the time it occurs are best represented as distributions. Ideally, a computer fire model predicts the expected or nominal value of the distribution. Safety factors are intended to represent the spread of those distributions.
(5) Given the uncertainty associated with data acquisition and reduction and the limitations of computer modeling, any condition predicted by a computer model can be thought of as an expected or nominal value within a broader range. For example, an upper-layer temperature of 600°C is predicted at a given time. If the modeled scenario is then tested (i.e., in a full-scale experiment based on the computer model's input data), the actual temperature at that given time could be 640°C or 585°C. Therefore, the temperature should be reported as 600°C (+40°C/–15°C) or as a range of 585°C to 640°C.
(6) Ideally, predictions are reported as nominal values, with some percentage, or as absolute values. As an example, an upper-layer temperature prediction could be reported as 600°C, ±30°C or as 600°C, ±5 percent. In this case, the physical safety factor is 0.05 (i.e., the amount by which the nominal value should be degraded and enhanced). Given the state of the art of computer fire modeling, this safety factor is very low. Physical safety factors tend to be on the order of tens of percent; 60 percent is not unheard of.
(7) Part of the problem with this approach is that it is difficult to state what percentage or range is appropriate. These values can be obtained when the computer model predictions are compared to test data. However, using computer fire models in design mode does not facilitate determination of the range of values, since the room being analyzed has not been built yet, and test scenarios do not necessarily depict the intended design.
(8) Perform a sensitivity analysis on the assumptions that affect the condition of interest. Develop a base case that uses all nominal values for input parameters. Vary the input parameters over reasonable ranges and note the variation in predicted output. The output variation can then become the basis for physical safety factors.
(9) The temporal safety factor addresses the issue of when a condition is predicted and is a function of the rate at which processes are expected to occur. If a condition is predicted to occur 2 minutes after the start of the fire, this time frame can be used as a nominal value. A similar process of that described for physical safety factors can

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also be employed to develop temporal safety factors. In this case, however, the rates (e.g., of heat release or toxic product generation) will be varied instead of absolute values (e.g., material properties).

(10) The margin of safety can be thought of as a reflection of societal values and can be imposed by the authority having jurisdiction to that purpose. Because authorities having jurisdiction most likely will focus on the predicted time for a condition (e.g., the model predicts occupants will have 5 minutes to safely evacuate), the margin of safety will be characterized by temporal aspects and tacitly applied to the physical margin of safety.

(11) Because escaping the harmful effects of fire (or mitigating them) is, effectively, a race, time is the parameter of choice when assessing fire safety system designs based on computer model predictions. When an authority having jurisdiction is faced with the predicted time of untenability, a decision needs to be made regarding whether sufficient time is available to ensure the safety of building occupants. The authority having jurisdiction, in assessing the margin of safety, needs to determine whether time is sufficient to get everyone out safely. If the authority having jurisdiction feels that the predicted egress time is too close to the time of untenability, the authority having jurisdiction can impose an additional time that the designer needs to incorporate into the system design. In this way, the authority having jurisdiction can impose a greater margin of safety than that originally proposed by the designer.

A.9.8.1 The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* describes the documentation that should be provided for a performance-based design.

Proper documentation of a performance-based design is critical to the design acceptance and construction. Proper documentation also ensures that all parties involved understand what is necessary for the design implementation, maintenance, and continuity of the fire protection design. If attention to detail is maintained throughout the documentation, there should be little dispute during approval, construction, startup, and use.

Poor documentation can result in rejection of an otherwise good design, poor implementation of the design, or inadequate system maintenance and reliability, and it provides an incomplete record for future changes or if the design is forensically tested.

A.9.8.2 The sources, methodologies, and data used in performance-based designs should be based on technical references that are widely accepted and used by the appropriate professions and professional groups. Such acceptance is often based on documents that are developed, reviewed, and validated under one of the following processes:

(1) Standards developed under an open consensus process conducted by recognized professional societies, codes or standards organizations, or governmental bodies

(2) Technical references that are subject to a peer review process and are published in widely recognized peer-reviewed journals, conference reports, or other publications

(3) Resource publications, such as the *SFPE Handbook of Fire Protection Engineering,* that are widely recognized technical sources of information

The following factors are helpful in determining the acceptability of a method or source:

(1) Extent of general acceptance in the relevant professional community. Indications of acceptance include peer-reviewed publications, widespread citations in the technical literature, and adoption by or within a consensus document.

(2) Extent of documentation of the method, including the analytical method itself, assumptions, scope, limitations, data sources, and data reduction methods.

(3) Extent of validation and analysis of uncertainties. This includes comparisons of the overall method with experimental data to estimate error rates as well as analysis of the uncertainties of input data, uncertainties and limitations in the analytical method, and uncertainties in the associated performance criteria.

(4) Extent to which the method is based on sound scientific principles.

(5) Extent to which the proposed application is within the stated scope and limitations of the supporting information, including the range of applicability for which there is documented validation. Factors such as spatial dimensions, occupant characteristics, ambient conditions, and so forth, can limit valid applications.

In many cases, a method will be built from and include numerous component analyses. These component analyses should be evaluated using the same factors as are applied to the overall method.

A method to address a specific fire safety issue, within documented limitations or validation regimes, might not exist. In such a case, sources and calculation methods can be used outside their limitations, provided the design team recognizes the limitations and addresses the resulting implications.

The technical references and methodologies to be used in a performance-based design should be closely evaluated by the design team, the authority having jurisdiction, and possibly a third-party reviewer. The strength of the technical justification should be judged using criteria presented in A.9.8.2. This justification can be strengthened by the presence of data obtained from fire testing.

A.9.8.11 Documentation for modeling should conform to ASTM E 1472, *Standard Guide for Documenting Computer Software for Fire Models*, although most, if not all, models were originally developed before this standard was promulgated.

A.11.1 Understanding, practicing, and enforcing the basic concepts and principles of fire prevention are some of the most important actions any cultural resource facility or institution can undertake. This chapter presents some of the basic precautions applicable to all types of cultural resources. Subsequent chapters devoted to museums and libraries (Chapter 16) and places of worship (Chapter 17) contribute additional material specific to each type of resource. Historic buildings are specifically addressed by NFPA 914, *Code for Fire Protection of Historic Structures. (See NFPA 1, Uniform Fire Code, for comprehensive fire prevention information.)*

A.11.3 In a fire, the prevention of interior spread of flames and smoke is critical to stopping a fire from rapidly growing. The simple act of ensuring that interior doors are kept closed when a building is not occupied is a major positive fire prevention activity. Part of the facility's comprehensive fire protection program and plan should include evaluation and incorporation of procedures for ensuring that interior doors are

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closed wherever possible. The governing body or party responsible for the facility and the authority having jurisdiction must understand the potentially dangerous conflict in allowing interior doors to remain open to facilitate interior ventilation and air movement, thereby significantly enhancing the threat of the unimpeded spread of fire and smoke through the facility.

A.11.4 A high standard of housekeeping is one of the most important factors in the prevention of fire. Maintaining this high standard of housekeeping is every employee's responsibility; however, it is the facility director who assumes the final responsibility for this critical activity.

A.11.4.3 Expendable materials (i.e., filters, light bulbs, and refrigerant) that are directly associated with the proper operation or maintenance of equipment found in any of these rooms can be permitted. The supply of these materials should be kept to a minimum. Depending on the quantity of materials and degree of hazard either associated with the equipment or inherent in the materials themselves, the storage of these materials might be further restricted to specialized storage containers (e.g., metal cabinets or other suitable means). Coat closets or other spaces being used for telephone or computer equipment along with general storage need to be evaluated for fire integrity. Enhancement of the fire compartmentation and/or the installation of fire sprinklers might be required.

A.11.5.2 Designated smoking areas should not include any of the following areas:

(1) Exhibition areas or galleries
(2) Collections or any other types of storage areas
(3) Any type of workshop
(4) Laboratories
(5) Library reading rooms
(6) Library book stacks
(7) Assembly areas such as classrooms, auditoriums, theaters, chapels, or large sanctuaries
(8) Restrooms
(9) Mechanical rooms
(10) Receiving areas or stockrooms
(11) Projection rooms
(12) Electronic equipment and telecommunications rooms

A.12.1 The more important general principles for fire-safe construction are set forth in the following paragraphs. Detailed recommendations for good practice are also contained in various NFPA publications. In most localities, building codes and ordinances govern the type of construction to be used.

Codes frequently provide for the safety of persons in the building but not for the protection of the collections or the preservation of the historic fabric of the building or the collections. Therefore, it is critical at the conception of the project to specify the level of fire safety to be achieved in the construction. It is recommended that a professional fire protection engineer be retained to participate in the development of the fire protection specifications and to verify that the specifications are fulfilled satisfactorily.

Design of the automatic fire protection and detection systems and building construction are interrelated. In addition to protecting combustible contents and providing improved safety to life, automatic fire suppression systems can in some cases enable the use of less expensive construction than would be permissible without them.

The following features of building design and engineering should be considered during construction:

(1) Selection of materials and types of construction that are either noncombustible or fire resistant
(2) Compartmentation of a building so that fire or smoke can be confined
(3) Consideration of an engineered smoke management system
(4) Selection of interior finishes and furnishings

It is desirable to select materials and types of construction that are either noncombustible or fire resistive. Fire-resistive construction is desirable and for multistory structures is essential. Fire-resistive construction is described in NFPA 220, *Standard on Types of Building Construction*, and requires structural members, including walls, partitions, columns, floor, and roof construction, to be of noncombustible materials and have fire resistance ratings from 2 to 4 hours, depending on the structural members.

The contents of a cultural resource facility are valuable, sometimes of very high value or even irreplaceable, and almost always combustible. Therefore, every effort should be made to construct the building to resist the spread of fire. This means that during a fire the walls, roof, floor, columns, and partitions should prevent the passage of flame, smoke, or excessive heat and continue to support their loads. "Fire resistive" is not the same as "noncombustible." Some materials that will not burn lose their strength when exposed to intense heat, which might cause walls or floors to collapse. Iron or steel multitier book stacks are an example of this type of structure. Many types of construction using various building materials have been tested and rated according to the length of time they will resist fire. The duration of resistance needed by a library depends on the amount of combustible material in the contents of each room as well as in the structure itself. Different structural assemblies have fire resistance ranging from less than 1 hour to more than 4 hours.

NOTE: NFPA 220, *Standard on Types of Building Construction*, classifies and defines various kinds of building construction. Testing laboratories list information on structural assemblies that have been tested in accordance with NFPA 251, *Standard Methods of Tests of Fire Endurance of Building Construction and Materials*.

It is unwise to construct buildings that house cultural resource institutions of materials that will contribute fuel to a fire and that, by the nature of the construction, create combustible concealed spaces. Voids between a ceiling and the floor above are good examples of concealed spaces through which fire can spread rapidly and where access for fire fighting is difficult.

The term *compartmentation* in fire protection is used to mean subdivision of a building into relatively small areas so that fire or smoke can be confined to the room or section in which it originates. This principle can be applied to libraries and museums without restricting the flexibility of arrangement of library collections or the flow of visitors. Compartmentation requires fire-resistive wall and floor construction, with openings provided with self-closing or automatic fire doors having fire resistance ratings in accordance with the fire resistance ratings of the wall or ceiling/floor assemblies they are to protect.

In a similar way, properly enclosed stairways equipped with fire doors will prevent the spread of fire, smoke, and heat from one level to another. Elevator shafts, dumbwaiters, and all

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other vertical openings through the structure should be similarly safeguarded. Air-handling systems (ventilation, heating, and cooling) should be constructed and equipped to prevent the passage of smoke, heat, and fire from one area to another or from one level to another as provided in NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*.

An engineered smoke management system should be considered as one of the means to achieve the fire safety objectives established for the cultural resource institution. Depending on building construction, interior finish, and furnishings and other contents, a substantial level of smoke damage can be sustained from even a relatively small, well-controlled fire. A smoke management system generally should be considered a complement to the protection provided by automatic sprinklers or other fire suppression systems and the barriers that define the fire zones. The smoke management system can assist in limiting smoke from spreading beyond the initial fire zone. See NFPA 92A, *Recommended Practice for Smoke-Control Systems*; NFPA 92B, *Standard for Smoke Management Systems in Malls, Atria, and Large Spaces*; and NFPA 204, *Standard for Smoke and Heat Venting*.

An important consideration is the proper selection of interior finishes and furnishings. Highly flammable wall and ceiling finishes should be avoided. NFPA *101*, *Life Safety Code*, and most building codes specify minimum requirements for interior finish materials. Combustible draperies should be avoided. Extra care should be used in regard to the burning characteristics of upholstered furniture, insulating materials, and acoustical materials. Careful selection of interior finishes is always important, especially in the absence of automatic fire suppression or protection.

A.12.2 The cultural resource property is most vulnerable during periods of renovation, alteration, and new construction. Additional hazards, such as smoking by contractors, sources of ignition such as welding and cutting, temporary electrical wiring, and heating, are introduced. Coupled with those hazards are the security risks associated with allowing access to contractors, inspectors, and other outsiders. Incidents of vandalism, arson, and theft increase exponentially during periods of construction. Additionally, construction activities in cultural resource properties require a higher level of supervision and oversight than standard projects because of their potential impact on the existing building, collections, and other culturally significant objects.

A.12.2.1 Knowledge and experience in working with cultural resource properties are critical to ensure that the contractors are sensitive to the value and damageability of the building and its collections. Criteria that can be used in determining whether a contractor is qualified to work on this type of project include the following:

(1) Education and training in a cultural field
(2) Experience with similar types of projects of similar size and complexity
(3) Satisfaction of management at other institutions with the contractor's sensitivity and suitability of result
(4) Demonstrated success in meeting time, quality, cost, and protection requirements
(5) References from similar institutions or cultural resource properties
(6) Proposals that demonstrate sensitivity to the special needs of the institution and its collections

A.12.2.2 It is important that time be spent at the beginning of the project to make sure that all contractors and subcontractors understand the nature of the project, special building features or collections that require special protection during construction, and other curatorial concerns. A meeting also provides an opportunity for contractors and other workers to ask questions or review alternative approaches that might have an impact on other contractors or better address curatorial concerns. Participants should include all contractors, subcontractors, workers, security staff, and curatorial staff, depending on the size of the institution and the project. Based on items discussed in this meeting, a contract can be drawn up detailing security and protection requirements for the project; as an added measure, each contractor or worker on the project might be asked to sign the contract.

A.12.2.3.2(6) Proper care and handling of sprinklers and other system components are critical in preventing damage or weakening, which can result in accidental discharge after installation. This is especially true for the more fragile quick response sprinklers and those incorporating glass bulbs. The following precautions should be taken when handling sprinklers:

(1) Store sprinklers in a cool, dry place.
(2) Protect sprinklers during storage, transportation, and handling and after installation.
(3) Do not place sprinklers loose in boxes, bins, or buckets.
(4) Leave protective caps, where provided, attached to sprinklers until after installation.
(5) Use the designated wrench provided by the manufacturer and specifically designed for installation of each specific type of sprinkler head.
(6) Do not use a sprinkler deflector to thread sprinklers onto fittings or to torque sprinklers into place.
(7) Replace sprinklers that become coated with paint, drywall, or other material rather than attempting to clean them.

A.12.2.3.3 Most fires involving construction projects are slow-smoldering fires, which can be detected in their early stages by conducting a walk-through of the facility after operations have ceased for the day. Ideally, these rounds should be conducted every half hour for the first 2 hours, with guard service making rounds on an hourly basis thereafter.

A.12.4 Without automatic fire protection systems, fire-resistive or noncombustible construction can survive, but combustible contents in the fire compartment will not. Fire protection systems should provide for both detection and extinguishment. While these functions are separate, they can and often should be consolidated into one continuous fire protection system that detects a fire, sounds the alarm, alerts the fire service, and initiates automatic extinguishing devices. Smoke detection systems provide an opportunity for occupant action with portable fire extinguishers before fire development activates the automatic sprinkler or other fire suppression system. Careful planning permits the installation of the necessary equipment with a minimal effect on the appearance or use of the public spaces in the cultural resource facility.

Additional descriptions, applications, and limitations of the protective systems mentioned in this chapter are contained in Section D.3, Glossary of Fire Protection Systems.

Planning for the fire protection equipment must also include providing and maintaining an adequate water supply to support standpipe and hose systems for fire service use as well as for automatic sprinkler systems.

A vast selection of makes, models, and styles of fire protection equipment is available today to meet practically any need

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a cultural resource institution might have. Choosing a reputable supplier and installer is a crucial decision that a fire protection consultant can assist a library in making. In lieu of a consultant, other valuable information can usually be obtained from the insurer, other businesses in the area, and the local fire department. The cultural resource institution should seek to procure a system for which parts and service are readily available now and will be in the future. In addition, the fire protection equipment and system should be listed or approved.

Many states and jurisdictions require designers and installers of fire protection systems to be licensed and certified by national boards. Prospective installers should be asked to show proof of their qualifications, as well as their experience in installing similar systems, preferably in similar occupancies. Check to see how satisfied these other businesses were with the installation and final product. Libraries generally have special concerns and needs, especially in book-stack areas, which must be discussed in detail with the contractor prior to beginning work. A detailed construction schedule is helpful and should be worked out in advance. The staff should also be made aware of the improvements to take place and how the fire protection systems work.

Once a fire protection system is installed, it is imperative that the system be thoroughly inspected, tested, and maintained to ensure that it functions properly.

A.12.4.2 See NFPA 550, *Guide to the Fire Safety Concepts Tree*, for a method to determine fire protection objectives.

A.12.4.3 Various devices with controlled sensitivity can detect a fire condition from smoke, a critical temperature, or the rate of temperature rise. These detectors can provide the warning needed to get people safely out of the building and start fire-extinguishing action promptly. Fire protection specialists should be consulted to determine what kinds of detectors best fit the conditions in different parts of the building. *(See Section D.3, Glossary of Fire Protection Systems.)*

The fire detection system sounds an alarm to alert the occupants. Detection systems should also transmit signals to a listed or approved central station or a fire department that is staffed or attended 24 hours a day, especially in the case of an unoccupied building. Maintenance and testing of the detection system are important, particularly in any building where it is the only automatic protection system. A number of fires have shown this to be true. Failures of fire detection systems have been due to bad design, poor maintenance, and lack of testing. *(See NFPA 72, National Fire Alarm Code, and NFPA 1221, Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems, for further information on fire detection and alarm systems.)*

Operation of any of fire detection or suppression systems or signals from their supervisory systems should cause actuation of an alarm at a constantly attended location. It could also cause actuation of the building alarm system as described in NFPA *101*, *Life Safety Code*. The alarm can be bells, horns, a live voice, a prerecorded message, flashing lights, or other suitable means. All alarm systems should be installed and maintained in accordance with the applicable NFPA standards. *(See NFPA 72, National Fire Alarm Code, Chapter 3, Emergency Voice/Alarm Communication Systems, for further information on alarms.)*

A.12.4.4.2 Standard-response sprinklers employ more robust operating elements than quick-response sprinklers and can be more appropriate for use in areas where concern for inadvertent water discharge outweighs the advantages of thermal sensitivity.

A.12.4.6 Where standpipes and hose lines are required or installed to provide reliable and effective fire streams in the shortest possible time, they shall be installed in accordance with NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*, and maintained in accordance with NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*. Training and skill in the use of hose streams are essential to avoid personal injury and unnecessary property damage. Occupants should not attempt to use a fire hose unless they are part of an organized fire brigade that has received training in compliance with OSHA regulations. It must be emphasized that the use of standpipe hose lines, as with the use of fire extinguishers, should not be allowed to delay the transmission of alarms to the fire department.

A.12.4.7 Portable extinguishers are important items of fire protection equipment and should be installed in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*. They permit the use of a limited quantity of extinguishing agent on a small fire at the moment someone discovers it. Therefore, they should be present in adequate numbers. The extinguisher should be of a kind intended for the class of fire anticipated. Multiclass portable extinguishers are available that remove any doubt whether the correct extinguisher is being used. Extinguishers should be properly located and inspected regularly so they will be in working order when needed. Personnel should know the locations of and be instructed in the proper use of fire extinguishers. It must be emphasized that the use of fire extinguishers should not be allowed to delay the transmission of alarms to the fire department.

A.12.6.1 Emergency generators provide enhanced levels of protection and should be incorporated in all heritage buildings unless the reason for their omission is valid.

A.12.6.3 Examples are temperature and humidity control to a particular storage vault, essential data processing equipment, or critical research projects.

A.12.7 Wet-specimen storage rooms, workshops, display shops, conservation laboratories, paint rooms, kitchens, and rooms containing central heating equipment such as boilers and furnaces are considered hazardous areas.

A.12.11 Exposure protection for walls can include fire windows with wired glass, fire doors, exterior automatic sprinklers, water curtains, automatic fire shutters, or a combination of these. *(See NFPA 80, Standard for Fire Doors and Fire Windows.)*

A.13.2.1 See NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations.*

A.13.3.1.3 See NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations.*

A.13.3.2.2 Construction materials stored inside the building or structure should be kept to a minimum. Materials not immediately needed should be stored away from the structure to minimize fuel loading and to reduce the likelihood that excess materials will block egress routes. Where possible, equipment and materials should be stored in secured areas with a functional fire suppression system, or materials should be subdivided and stored in secured noncombustible structures. Equipment too large to be stored in such areas should be stored in secured fenced yard areas.

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A.13.3.2.2.1 Storage for excess quantities of flammable and combustible liquids should be located downgrade from the project when possible. The storage site should also be a sufficient distance away from heavy traffic areas to minimize the exposure to personnel and others.

A.13.4.1.2 If security officers are not assigned to the work site, all welding or cutting operations should stop a minimum of 3 hours before the end of the normal work day to allow sufficient time for any fire conditions to be found in areas where hot work was performed.

A.13.4.2.5 See NFPA 10, *Standard for Portable Fire Extinguishers*.

A.13.4.4.1.2 See NFPA 10, *Standard for Portable Fire Extinguishers*.

A.13.6.1 Pre-fire plans should be updated periodically with the local fire service. For large projects, a fire safety coordinator for the site should be appointed who should ensure that all procedures, precautionary measures, and safety standards are clearly defined in writing and are understood and complied with by all personnel on the construction site.

A.13.6.2 The local fire service should verify by on-site testing whether the water supply is capable of sustaining adequate pressure and flow rates for fire-fighting operations as anticipated in their pre-fire plan for the building. Where underground water mains are to be provided, they should be installed, tested, and placed in service prior to other construction work.

A.13.6.5.2 The code official or site manager might require additional portable fire extinguishers, based on specific hazards.

A.14.1 History has shown that the performance reliability of fire protection systems and equipment increases where comprehensive inspection, testing, and maintenance procedures are enforced. Diligence during inspections is important.

A.14.2.3 Inspection and testing determine what, if any, maintenance actions are required to maintain the operability of fire protection systems.

A.14.3.3.2(5) The authority having jurisdiction, the insurance carrier, the central station or alarm company monitoring impaired systems, and supervisory staff in areas of the facility affected by the impairment should be notified.

A.14.3.3.2(6) It might be necessary to post a fire watch.

A.14.3.3.2(7) Notify the same personnel and organizations as in A.14.3.3.2(5).

A.14.6 Electrical systems should be maintained in accordance with NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*.

A.16.1.4 While this chapter prescribes minimum requirements for the protection of museums, libraries, and their collections from fire, additional guidance in fire prevention, fire protection, and fire loss contingency planning is provided in this annex for trustees, chief librarians, museum directors, and other staff officers who are responsible for the fire safety of the building(s) and the collections therein and for the life safety of those persons who visit or work in the buildings. It emphasizes the responsibility of all such officials to protect against fire hazards in their properties by using qualified personnel and consultants to present an analysis of the fire risk embodied in the collections, building(s), and operations. This analysis should also include an assessment of the impact of the loss or interruption that fire would impose on the facility's service to the community.

A.16.2 The hazard analysis required by 5.3.2 must include those special hazards often created by museum and library operations. Such hazards include but are not limited to the following:

(1) Conservation laboratories and areas where collections are treated using a variety of combustible and flammable materials
(2) Special types or classes of collections as follows:
  (a) Scientific specimens stored in alcohol
  (b) Cellulose nitrate negatives and motion picture film
  (c) Military weaponry, arms, or artifacts that must be checked to ensure that they are not "live"
  (d) Rare objects or specimens composed of unstable and combustible material(s)
  (e) Objects that the demonstration or use of which can create a potential fire hazard, such as historic electrical equipment, steam engines, forging machinery, and fireplaces
(3) Special historic, artistic, and/or scientific processes that can be demonstrated to the public or used to recreate objects, such as the following:
  (a) Cooking demonstrations
  (b) Silver, gold, and pewter casting
  (c) Blacksmithing and similar craft demonstrations
  (d) Artillery and weaponry demonstrations
  (e) Historic manufacturing processes of all types
  (f) Art demonstrations and/or classes that use flammable solvents or materials
  (g) Glass blowing and glass molding
(4) Concentrations of combustible collections on exhibit, in book stacks, or in storage, which by their very concentration can create a fire hazard through increased fire loading, as follows:
  (a) Historic building fragments and representative parts often retained by historic properties as documentary collections. These collections, while important, can create heavy fire loading if they are not stored selectively and carefully.
  (b) Scientific specimens stored in alcohol or other flammable liquids.
  (c) Large quantities of combustible objects, for example, historic wooden molds and patterns used to cast metal machine parts or components of an iron building (like a greenhouse). Numbering in the thousands, these items are sometimes stored in bulk containers rather than individually, creating an increase in hazard. *(Source: Burklin and Purington, Fire Terms: A Guide to Their Meaning and Use)*
(5) Exhibit fabrication and construction areas and workshops in which combustible and flammable materials, paints, and solvents are frequently present
(6) Maintenance workshops, combustible supply storage areas, boiler and mechanical equipment rooms, and other support areas

The facility's governing board and its fire safety manager must understand that the specific fire hazards within their institution might differ considerably from the examples given. These are offered only as examples of the types of hazards often found in museums and libraries.

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A.16.4 Cultural resource institutions are using more plastic-based storage containers than ever before. Plastic is used for film storage, magazine dividers, storage boxes and bins, clothing bags, and various covers. Staff members need to realize that the presence of plastic-based materials can increase the risk of direct and indirect damage to the building, contents, and collections of a cultural resource institution. Most plastic, when burned, produces thick, acrid, black products of combustion (smoke). As plastic burns, it degrades to its original petrochemical form, resulting in fire conditions similar to combustible liquid spill fires with a very high rate of heat release. Smoke from burning plastic can be very damaging, both in the area of fire origin and throughout a facility. Past experience has demonstrated that plastic covers and bags have a tendency to attract smoke particles to clothing and other fabrics.

Staff should also consider the impact that plastic will have on the design of the fire protection systems protecting an area in a facility. Significant quantities of plastic usually require higher levels of fire protection than do similar quantities of ordinary combustibles (e.g., paper, wood, cardboard, textiles). Thorough fire protection planning and design require that consideration be given to how smoke from a fire will be removed from the facility. Depending on the design, size, and compartmentalization of a facility, smoke removal can often be easily accomplished by the local fire department using portable fans. Larger facilities with few openings or windows to the outside should consider ventilation system designs that will enable manually operated exhaust systems to ventilate smoke from the areas without relying on direct openings to the outside. In these types of facilities, fire departments might not be able to properly evacuate smoke in a timely fashion with the equipment typically available.

A.16.4.3 The primary goal of this subsection is to separate the fuel from ignition sources and other sources of risk. Padding, dust covers, humidity buffering materials, and other materials having a high surface-to-mass ratio should be noncombustible or treated with an approved fire-retardant coating.

A.16.4.3.6 All sources of ignition should be excluded from the book stacks. Fixed space heaters should be permitted only under rigidly controlled conditions, as approved by the authority having jurisdiction.

A.16.4.4 Proper clearance should be maintained between fire protection system nozzles and stored material.

A.16.4.4.4 Such collections include bronze sculptures, ceramics, and minerals.

A.16.4.5 Smoke control systems should comply with the requirements of NFPA 92A, *Recommended Practice for Smoke-Control Systems*; NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*; and NFPA 204, *Standard for Smoke and Heat Venting*.

A.16.4.6.1 The current editions of NFPA 40, *Standard for the Storage and Handling of Cellulose Nitrate Film*, and NFPA 42, *Code for the Storage of Pyroxylin Plastic*, do not specify requirements for cellulose nitrate film negatives.

A.16.4.6.3.1 The Society for the Preservation of Natural History Collections (SPNHC) in a publication titled *Storage of Natural History Collections: A Preventative Conservation Approach,* and the Distilled Spirits Council of the United States have fire protection guidelines that deal strictly with alcohol and provide additional information on the use of glass containers in excess of 1 gallon (3.8 L). Many specimens can fit only in containers much larger than 1 gallon (3.8 L) in size.

A.16.4.6.3.5(5) Seismic protection design typically includes a combination of the following:

(1) Rack design: shelving constructed to meet seismic strength requirements.
(2) Bottom bracing: shelving secured to the floor with fasteners of adequate strength to resist the anticipated shear and tension forces.
(3) Top bracing: sway bracing at the top of the racks to provide horizontal strength adequate to resist the expected seismic forces. In most cases, bracing is tied to structural members of the building to provide a path for the horizontal forces.

A.16.4.7 Consideration should be given to storing valuable or sensitive records and collections closer to (but not on) the floor, as fire and its by-products are more likely to damage collections closer to the ceiling, even those remote from the fire. Items subject to water damage should not be stored directly on the floor, but should be skidded or raised to reduce their exposure to damage from water or flooding. NFPA 232, *Standard for the Protection of Records*, provides additional information on the storage and protection of archival material. In addition, consideration should be given to creating duplicate records and storing them at an off-site location.

A.16.4.8 Compact storage systems present a severe fire challenge that requires engineering solutions specifically designed for each installation.

A.16.4.8.1.3 The automatic fire suppression system, the compact storage system, and the storage compartmentation features should be designed to limit fire damage in accordance with the facility's fire safety objectives (e.g., confine fire growth to the compact storage module of origin). Significant factors to consider include the number and size of the storage modules, the separation provided between the modules (end-to-end and back-to-back), and the type of materials being stored. In general, double-interlock pre-action systems and dry pipe systems are inappropriate for compact storage, because of the additional delay they introduce, coupled with the delays in activation resulting from the compact storage units themselves.

Other protection features, which should be considered to limit the extent of potential fire damage, include the following:

(1) Very high density sprinkler systems
(2) Quick-response sprinklers
(3) Early-warning smoke detection
(4) Spacers between carriages or, for automated systems, automatic park mode to increase flue spaces between carriages upon activation of a fire alarm or during idle periods
(5) Metal vertical barriers in the middle of the shelf
(6) Open-top shelving

A.16.4.8.1.4.1 The system should be designed to confine fire growth to the compact storage module of origin or the shelving range of origin.

A.16.4.10 With potential fire durations of more than 8 hours, fuel loads in book stacks can range from numbers more comparable to warehouse occupancies than to business occupancies.

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An emergency plan should be developed that designates routes to access book stacks, means of venting smoke, and plans to reach and fight a fire at its source. The plan should be developed in cooperation with the local fire service.

A.16.4.10.3 In many libraries, the part of the building used to house books is only a shell within which the exposed (i.e., unprotected) metal book stacks are self-supporting and rise continuously through several floor levels of the building. The book stack walkways are suspended from the book stack structure with 2.12 m (7 ft) between levels or tiers. *[See Figure A.16.4.10.3(a).]* This results in openings between the stacks and the walkways that provide flue-like channels for the uninterrupted upward flow of air through the books from the base of the structure to the top. *[See "deck slit" in Figure A.16.4.10.3(b).]* Because fire barriers are not between levels or tiers, the entire shell enclosing the multitier book stack structure must be regarded as one fire compartment, and everything it contains will be at risk to any fire that develops within or spreads to that compartment. Cast-iron or steel structural members lose strength at the high temperatures encountered in fires. Under fire conditions, the cast-iron or steel multitier book stacks might collapse. For this reason, the fire service could be unable to enter the multitier book stack structure for manual fire fighting.

Fire growth in multitier book stacks is rapid. In the unsprinklered phase of the fire tests conducted by Factory Mutual Engineering in 1959, fire spread vertically through the open deck slits in a vase-shaped pattern (e.g., spreading horizontally at each tier as it advanced vertically), reaching the fourth tier of a four-tier book stack test assembly in 9.5 minutes *(see Annex M).*

The requirement to install smoke barriers in all vertical openings between tiers or decks not only will restrict the spread of smoke but will also help contain the smoke and heat to facilitate detection and sprinkler operation in the immediate area of the fire. Without these barriers, detectors and sprinklers could operate in areas remote from the fire before operation of these systems in the fire area. *(See description of the 1986 Los Angeles Central Library Fire in B.3.2.1.12.)*

In new libraries or in major renovations of existing structures, this type of book stack should be avoided. Floor assemblies should be of conventional building construction with appropriate fire-resistive ratings and the book stack ranges supported by the floor assembly on which they are placed.

A.16.5.1 Smoking in museums and libraries presents not only a fire hazard but also a threat to the collections. For these reasons, smoking should be either completely prohibited within the building(s) or strictly controlled in accordance with the provisions of Section 11.5.

A.16.6 In museum and library settings where many operational activities occur simultaneously that can create fire hazards, housekeeping, maintenance, and waste and rubbish removal are all important, interconnected fire prevention–related activities. The facility's governing board and its fire safety manager should ensure a high standard of housekeeping and maintenance throughout the building(s). At a minimum, the following should be included:

(1) Collections shipping and receiving areas should be kept clear of accumulated combustible packing and crating materials. Discarded packing materials should be properly disposed of in accordance with Section 11.4.

(2) In exhibit construction and fabrication areas, the following precautions should be taken:
   (a) Fire safety and prevention practices must be an integral part of daily operations in these areas.
   (b) Sawdust and combustible scrap generated during work should be collected and properly disposed of at the end of every work day.
   (c) Combustible supplies should not be permitted to accumulate in such quantities as to create a high fuel load.
   (d) Exhibit cases and components no longer in use should be disassembled and recycled whenever possible. Storage of unused exhibit cases and components in the building(s) should be strictly limited. Such storage contributes to fire loading in the facility.
   (e) Only containers approved for the disposal of solvent waste rags and materials should be used, and these should be emptied and properly disposed of at the end of each work day.

(3) In conservation laboratories and studios, and collections restoration, cleaning, and treatment areas, the following precautions should be taken:
   (a) Fire safety and prevention practices must be an integral part of daily operations in these areas.
   (b) Only containers approved for the disposal of solvent waste rags and materials should be used, and these should be emptied and properly disposed of at the end of each work day.
   (c) Sawdust and combustible scrap generated during work should be collected and properly disposed of at the end of every work day.
   (d) Combustible supplies should not be permitted to accumulate in such quantities as to create a high fuel load.

(4) Maintenance work and support areas such as repair shops, boiler and mechanical rooms, utility closets, plumbing chases, supply rooms, and janitorial closets are often high fire risk areas, particularly if improperly used for the storage of combustible or flammable materials. The following precautions should be taken:
   (a) Boiler and mechanical rooms should never be used for the storage of any combustible or flammable materials or liquids.
   (b) Plumbing and utility closets, access points, and chases should never be used for the storage of any combustible or flammable materials or liquids.
   (c) In maintenance work and repair rooms, the following precautions should be taken:
      i. Fire safety and prevention practices must be an integral part of daily operations in these areas.
      ii. Sawdust and combustible scrap generated during work should be collected and properly disposed of at the end of every work day.
      iii. Combustible supplies should not be permitted to accumulate in such quantities as to create a high fuel load.
      iv. Only containers approved for the disposal of solvent waste rags and materials should be used, and these should be emptied and properly disposed of at the end of each work day.

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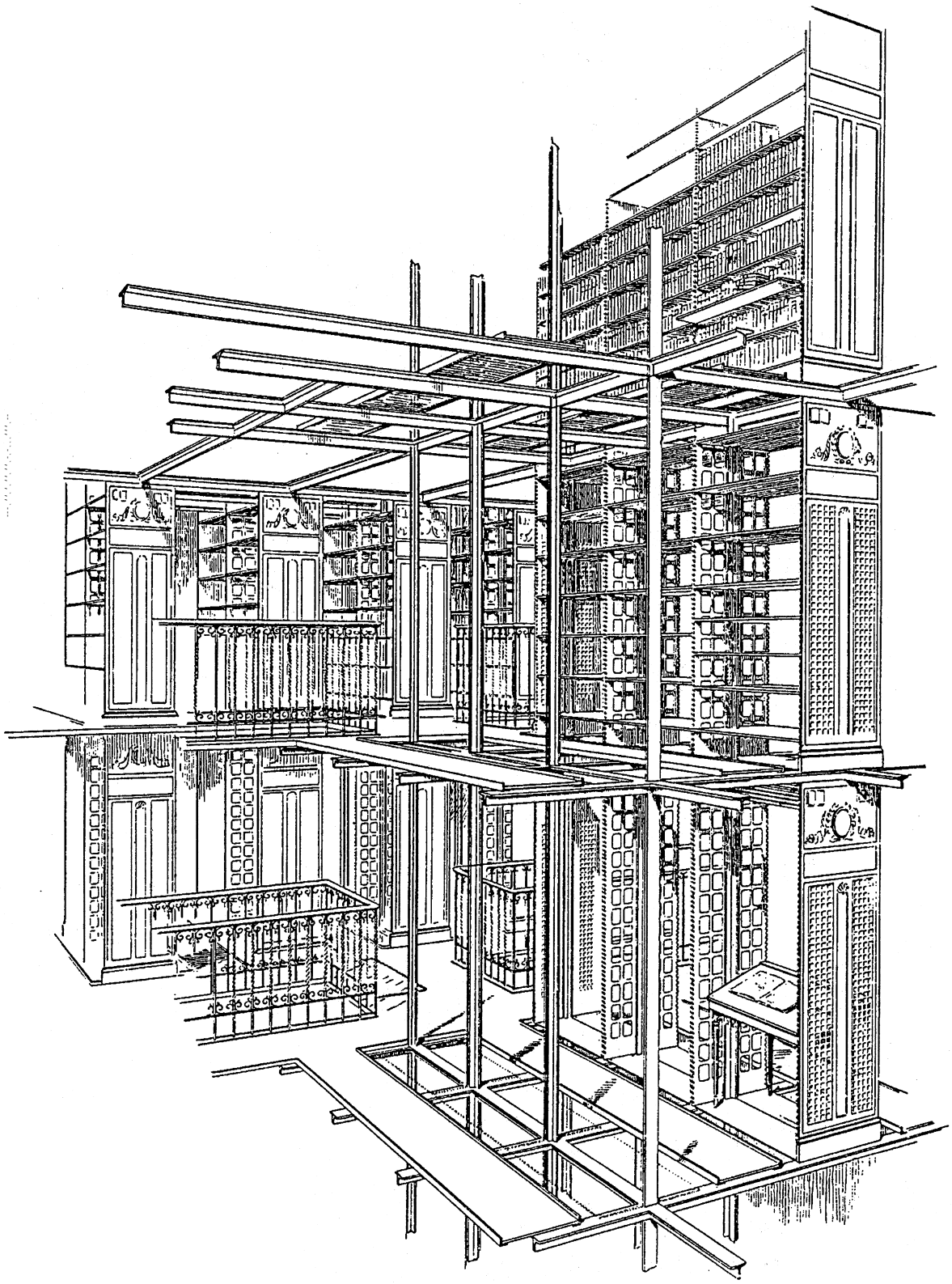

FIGURE A.16.4.10.3(a) Perspective View of Multitier Book Stack.

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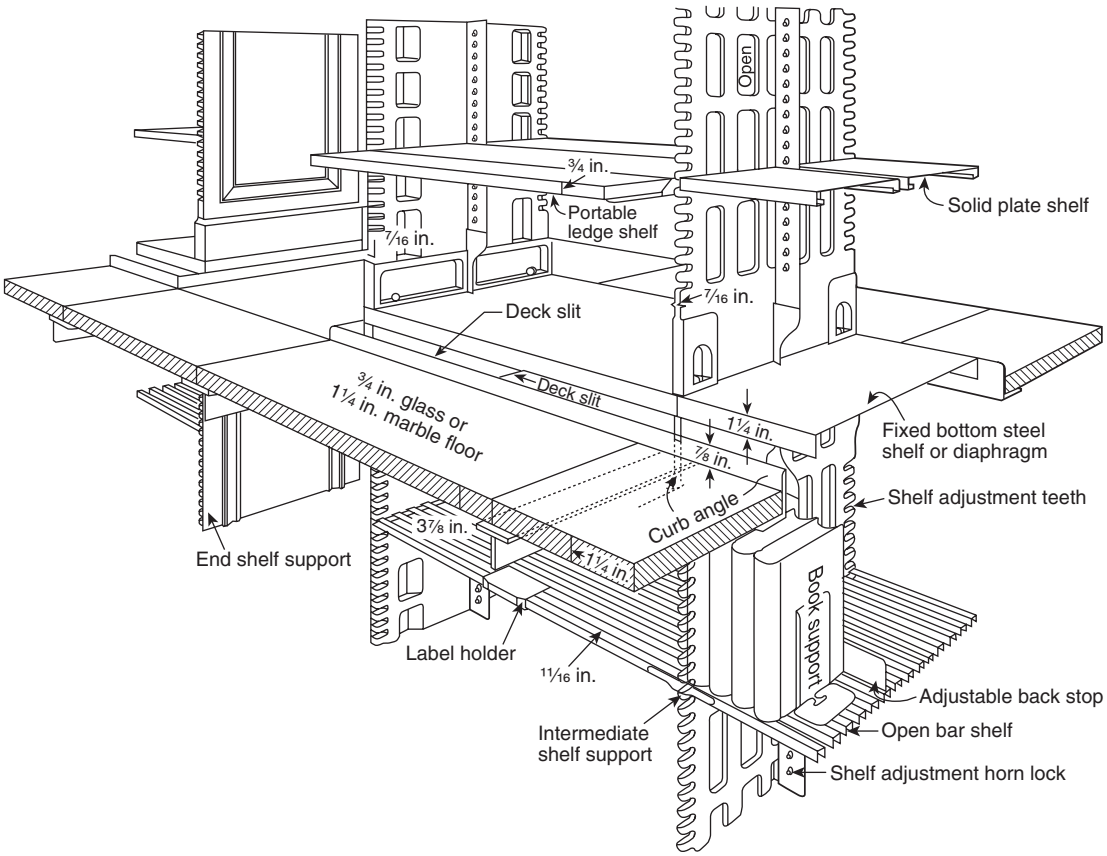

FIGURE A.16.4.10.3(b) Perspective Detail of Multitier Book Stack Showing Section Through Deck Flooring, Fixed Bottom Shelf, and Adjustable Shelves. (Note: For SI units, 1 in. = 25.4 mm.)

(5) Staff offices and support areas often contain fire risks. All office and support spaces should be kept clean and the following enforced:
   (a) Personal electrical appliances such as coffee pots, hot plates, microwaves, and similar devices should be subject to inspection by the museum, the fire safety manager, and the authority having jurisdiction. Faulty appliances should be removed from the museum.
   (b) Electric equipment such as coffee pots, copy machines, and other office equipment not intended or needed for continuous operation should be turned off at the end of each work day.
   (c) Electrical outlets should not be overloaded.
      i. Extension cords should not be used in place of electrical outlets; where additional power is required for more than temporary, very occasional use, a properly installed electrical outlet should be provided.
      ii. Extension or power cords should never be run under carpeting, cabinets, boxes, papers, or files, or across thresholds, over doorways, or in aisle ways and egress routes.
   (d) Office papers, files, boxes, and other combustible materials should not be permitted to accumulate on HVAC vents, ducts, fan coil units, or radiators.
      i. Paper and other combustible materials should not be permitted to accumulate, thereby creating additional fire loading, in the museum.
      ii. All materials retained as institutional and staff records should be properly stored in closed filing cabinets.
   (e) Office supply closets and rooms should be kept clean and organized. Combustible materials should not be permitted to accumulate to such an extent that they create additional fire loading or become a fire risk.

A.16.6.3 Conservation laboratories and studios, restoration, cleaning, and treatment areas, and exhibit construction and fabrication areas are high fire risk areas.

A.16.9 Many museums and libraries accomplish their interpretive and educational goals through permanent, temporary, and special exhibits installed in the museum building. Exhibits are changed frequently. As a result, spatial configurations, means of egress, life safety, fire protection systems, occupancy loads, exits, and fire risks can all change and potentially cause adverse effects. The facility's governing board and its fire safety manager should include review procedures for all exhibits, existing and proposed, in the facility's fire protection plan and procedures.

A.16.9.4.1 Treated foam board, fire-retardant-treated wood, textiles, and similar materials decrease fuel load created by exhibit construction.

A.16.9.6.2 Consideration should be given to retrofitting existing exhibit electrical systems with AFCIs.

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A.16.10.2 Where feasible, paint spraying should be in a separate building.

A.16.10.5 Currently, NFPA 40, *Standard for the Storage and Handling of Cellulose Nitrate Film*, and NFPA 42, *Code for the Storage of Pyroxylin Plastic*, do not specify requirements for cellulose nitrate film negatives. Cellulose nitrate film becomes less stable as it deteriorates with age or is exposed to elevated temperatures. It can ignite spontaneously, deflagrate when it ignites, and burn without atmospheric oxygen, and the smoke causes a potentially fatal chemical pneumonia in persons exposed to it without respiratory protection. Because motion picture film is wound on a reel, one layer directly against the next, the heat of decomposition accelerates the rate of deterioration between the layers of film. Storing each specimen in a paper sleeve or envelope retards the deterioration of still cellulose nitrate film negatives. Each specimen should be inspected at least annually to monitor deterioration.

A.16.10.8 Many libraries and museums have laboratories for the preservation and restoration of books, documents, and other objects of art or artifacts. Invariably, there are quantities of flammable solvents such as alcohol, waxes, and other materials that ignite readily or evolve explosive or poisonous fumes that require special attention to provide adequate general room ventilation, if not local exhaust fume hoods.

A.17.1 To assist in assessing the overall risk associated with places of worship, Figure A.17.1(a) provides a useful emergency action plan checklist.

Chapter 17 provides information to those individuals or groups of individuals who are charged with the construction, alteration, maintenance, and operation of buildings that are used as places of assembly for religious services and related activities. The self-inspection form shown in Figure A.17.1(b) can help to implement some of the fire safety practices recommended in this document. This form also can enable those same individuals or groups to evaluate the state of their preparedness for a fire emergency and might reveal deficiencies that require remedial action.

The self-inspection form is intended for in-house use at regular intervals. However, such an inspection should not take the place of two other vital safety measures: (1) a thorough, objective, periodic inspection by municipal fire officials or fire safety specialists and (2) regularly scheduled testing of installed fire detection and extinguishing systems by specialists skilled in their maintenance.

Places of worship vary widely in character. Not all items listed on the form will be applicable. By eliminating such inapplicable items, the form can be appropriately modified to meet the specific needs of users.

These self-inspections should do more than disclose conditions of negligence that could be the source of fire or that might result in greater damage and, possibly, loss of life in case of fire. The primary purpose is to ensure the correction of these conditions. Therefore, it is imperative that all questions answered "no" be considered as indicators of fire safety deficiencies.

A.17.1.2 This chapter prescribes minimum requirements for the protection of places of worship and their contents from fire. Because of the special nature of places of worship, this chapter modifies and supplements existing codes and standards to apply specifically to buildings or portions of buildings with this function.

A.17.3.2 Storage areas often present a serious fire hazard.

A.17.7.4 Special precautions should be taken to minimize risks associated with combustible stage props, temporary lighting, and other special hazards introduced in conjunction with plays, festivals, tournaments, and similar productions.

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EMERGENCY ACTION PLAN CHECKLIST

	Yes	No
1. Has an emergency action plan been established with assigned responsibilities?	❑	❑
2. Has a clear-cut emergency organization been established, preferably following existing lines of authority?	❑	❑
3. Are organization members designated by position and not just by name?	❑	❑
4. Do organization members know their own responsibilities, as well as who has decision-making authority in any given situation?	❑	❑
5. Has a central command center location been established?	❑	❑
6. Are communications at the command center adequate?	❑	❑
7. Do emergency organization members know under what circumstances they are to report to the command center?	❑	❑
8. Are emergency telephone numbers posted in the command center and throughout the building?	❑	❑
9. Do organization members know what medical resources are available and how to access them?	❑	❑
10. Are evacuation procedures established and familiar to all employees?	❑	❑
11. Have special procedures been established for evacuation of the handicapped?	❑	❑
12. Are fire-reported procedures established and familiar to all employees?	❑	❑
13. Have firefighting plans been developed that coordinate internal and external resources?	❑	❑
14. Have emergency shutdown procedures been developed?	❑	❑
15. Have plans been made for capture and control of elevators?	❑	❑
16. Have arrangements been made for emergency repair or restoration of service?	❑	❑
17. Have drills and training been adequate to ensure a workable emergency plan?	❑	❑
18. Are floor plans showing location of all exits, fire-protection equipment, shutoff valves, etc., readily available for use by the fire service and other emergency personnel?	❑	❑
19. Has a positive method been established to notify the fire service?	❑	❑
20. Has responsibility been established to ensure a timely evacuation?	❑	❑
21. Does the emergency action plan call for the entire area to be inspected to make certain that total evacuation has been achieved?	❑	❑
22. If a fire is discovered, have plans been made to ensure that the fire alarm has been activated?	❑	❑
23. Have plans been made to direct occupants to a safe outside area?	❑	❑
24. Have plans been made to direct and assist the fire service upon its arrival?	❑	❑
25. Has a fire brigade been established to monitor a fire pending arrival of the fire service?	❑	❑
26. Has a plan been established to begin salvage operations as soon as dictated by safety personnel?	❑	❑
27. Has the salvage plan been reviewed with the fire service?	❑	❑
28. Has the entire emergency action plan been reviewed with the local fire service?	❑	❑

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FIGURE A.17.1(a) Checklist for an Emergency Action Plan.

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FIRE SAFETY SELF-INSPECTION FORM FOR PLACES OF WORSHIP

General Conditions

1. Construction

❑ Fire resistive ❑ Noncombustible ❑ Combustible

(See NFPA 220, Standard on Types of Building Construction.)

2. Size

Floor area _____

Number of floors _____

Number of connecting buildings or wings _____

Number of entrances _____

Number of emergency exits _____

Number of exit width units available _____

Number of employees _____

Number of visitors per day _____

Average _____

Maximum _____

Number of exit width units required by NFPA *101, Life Safety Code* _____

3. Exposures	**Serious**	**Moderate**	**Light**	**None**
North	❑	❑	❑	❑
East	❑	❑	❑	❑
South	❑	❑	❑	❑
West	❑	❑	❑	❑

(See NFPA 80A, Recommended Practice for Protection of Buildings from Exterior Fire Exposures.)

4. Water Supply

❑ Municipal system ❑ Reservoir/pond ❑ Storage tanks

Capacity _____

Size of water mains _____

Distance from hydrants _____

5. Fire Service

❑ Municipal fire department ❑ Facility brigade ❑ Both

Time required for fire service to reach building _____

6. Fire Protection	**Yes**	**No**	**Partial**
Standpipe system	❑	❑	❑
Sprinkler system	❑	❑	❑
Inert gas extinguishing system	❑	❑	❑
Automatic fire detection system	❑	❑	❑
Local fire alarm system	❑	❑	❑
Direct alarm to fire service or central station	❑	❑	❑
Monitored night guard service	❑	❑	❑
Fire walls and self-closing fire doors protecting horizontal openings between building units*	❑	❑	❑
Furnace room separated from rest of building by fire walls and self-closing fire doors*	❑	❑	❑

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FIGURE A.17.1(b) Self-Inspection Form for Fire Safety Practices Recommended in NFPA 909 for Places of Worship.

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	Yes	No	Partial
Fire-resistive enclosures protecting stairways and other vertical openings*	❑	❑	❑
Exit doors opening outward*	❑	❑	❑
Locked exit doors equipped with panic hardware*	❑	❑	❑

*See NFPA *101, Life Safety Code.*

Changes in character of buildings, occupancy, water supply or hydrants, accessibility, or other general conditions affecting fire safety since the previous inspection:

_____

_____

_____

General Inspection

1. Roof	Yes	No	N/A	Comments
Is roof covering noncombustible?	❑	❑	❑	
Are scuppers and drains unobstructed?	❑	❑	❑	
Are lightning arresters in good condition?	❑	❑	❑	
Are skylights protected by screens?	❑	❑	❑	
Is access to fire escapes unobstructed?	❑	❑	❑	
Do fire escape stairs appear to be in good condition?	❑	❑	❑	
Are fire escape stairs unobstructed?	❑	❑	❑	
Are standpipe and sprinkler roof tanks and supports in good condition?	❑	❑	❑	
Are standpipe and sprinkler control valves secured in proper position?	❑	❑	❑	
2. All Floors (inspect from top floor to basement)				
Are all aisles and exitways of sufficient width to comply with NFPA *101, Life Safety Code*?	❑	❑	❑	
Are self-closing fire doors unobstructed and properly equipped with a closing device?	❑	❑	❑	
Are fire exits and directional signs properly illuminated?	❑	❑	❑	
Are sprinklers unobstructed?	❑	❑	❑	
Are standpipe hose outlets properly marked and unobstructed?	❑	❑	❑	
Are recorded weekly inspections made of all sprinkler control valves to make certain they are open?	❑	❑	❑	
Are dry-pipe valves (for sprinklers in areas exposed to freezing) in service, with air pressure normal?	❑	❑	❑	
Are all fire detection and fire suppression systems in service and tested regularly?	❑	❑	❑	
Are sufficient fire extinguishers present?				
Are extinguishers of the proper type? *(See NFPA 10, Standard for Portable Fire Extinguishers.)*	❑	❑	❑	
Are extinguishers properly mounted and labeled?	❑	❑	❑	
Are extinguishers properly charged and tagged with inspection tags?	❑	❑	❑	
Is housekeeping properly maintained?	❑	❑	❑	

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FIGURE A.17.1(b) ***Continued***

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	Yes	No	N/A	Comments
Are cleaning supplies safely stored?	❑	❑	❑	
Are all trash receptacles emptied at least daily?	❑	❑	❑	
Are supply closets and slop sink areas clean and orderly?	❑	❑	❑	
Are electric hot plates and coffee makers prohibited or limited to those with an appropriate automatic shutoff bearing the label of a testing laboratory?	❑	❑	❑	
Are space heaters prohibited?	❑	❑	❑	
Are extension cords prohibited?	❑	❑	❑	
3. Ground Floor				
Do entrance and exit doors provide unobstructed egress?	❑	❑	❑	
Is safe egress uncompromised by security measures?	❑	❑	❑	
4. Basement				
Is rubbish removed from the building daily?	❑	❑	❑	
Is rubbish removed from the premises on a regular schedule?	❑	❑	❑	
Are stocks of flammable liquids stored away from the building?	❑	❑	❑	
Are sprinklers unobstructed and at least 18 in. (457 mm) above top of storage?	❑	❑	❑	
5. Sanctuaries, Auditoriums, and Classrooms				
Is safe capacity posted?	❑	❑	❑	
Is occupancy restricted to the capacity posted as safe?	❑	❑	❑	
Are standing and sitting in aisles prohibited?	❑	❑	❑	
Do furnishings and wall coverings comply with fire safety standards?	❑	❑	❑	
Are exits unobstructed, unlocked, and properly illuminated?	❑	❑	❑	
Are aisles unobstructed?	❑	❑	❑	
Does projection room meet local codes?	❑	❑	❑	
Are smoking regulations enforced?	❑	❑	❑	
6. Kitchen and Dining Area				
Is capacity posted?	❑	❑	❑	
Is occupancy limited to the safe seating capacity?	❑	❑	❑	
Are aisles of sufficient width to comply with NFPA *101, Life Safety Code*?	❑	❑	❑	
Are exit routes unobstructed and properly illuminated?	❑	❑	❑	
Are ranges, hoods, and exhaust ducts cleaned regularly? (Note date when they were last cleaned.)	❑	❑	❑	
Do exhaust ducts terminate in a safe area?	❑	❑	❑	
Are grease ducts and deep fryers equipped with automatic suppression systems?	❑	❑	❑	
If below ground level, is area sprinklered?	❑	❑	❑	

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FIGURE A.17.1(b) ***Continued***

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Exterior Inspection

1. Evacuation	Yes	No	N/A	Comments
Do all exits, emergency exits, and fire escapes have unobstructed passage to safe areas?	❑	❑	❑	
2. Environment				
Are grounds clear of accumulations of flammable material?	❑	❑	❑	
Have neighboring occupancies minimized exterior fire hazards?	❑	❑	❑	
Is fire service access clear?	❑	❑	❑	
Are standpipe systems and sprinkler system fire department connections unobstructed and operable?	❑	❑	❑	
Are hydrants unobstructed?	❑	❑	❑	
Are fire department connections compatible with fire department equipment?	❑	❑	❑	
3. Training				
Do all staff members know how to transit a fire alarm?	❑	❑	❑	
Do all staff members know their assigned duties in evacuating the building?	❑	❑	❑	
Do all staff members know how and when to use portable fire extinguishers?	❑	❑	❑	
Do all staff members know their responsibilities in fire prevention?	❑	❑	❑	
4. Organization				
Is there a fire protection manager or a designated alternate on duty whenever the building is occupied?	❑	❑	❑	
Does the fire protection manager conduct an adequate training program for himself/herself and the entire staff?	❑	❑	❑	
Is the written fire emergency plan up-to-date and properly distributed?	❑	❑	❑	
Has someone been assigned to handle emergency operations (e.g., salvage, reports to authorities and news media)?	❑	❑	❑	

Date of latest fire drill: _____

Special Comments

Inspection made by: _____ Date: _____

Title: _____

Report reviewed by: _____ Date: _____

Title: _____

Corrective Action: Item	Referred to:

Corrective actions completed: _____ Date: _____

Fire protection manager: _____

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FIGURE A.17.1(b) ***Continued***

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Annex B Fire Experience in Cultural Resource Properties

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

B.1 Fire Experience. Cultural resource properties are vulnerable to a wide variety of common occurrences responsible for most fires. Careless smoking, malfunction of heating equipment, faulty wiring, improper use of a cutting torch, and incendiarism are some causes of fires in cultural resource properties. Fires have occurred in buildings with fire-resistive construction, in structures made largely of wood, in large fully staffed institutions, and in small institutions with limited resources. Fires have broken out in cultural resource properties during the day when they were open and filled with people and at night when they were closed.

B.2 Museums. Between 1980 and 1998 an average of 86 museum fires occurred per year, resulting in an annual average loss of $1.9 million in property damage, reported to U.S. fire departments. (This statistic refers to a whole building classified as a museum, including art galleries, aquariums, and planetariums, not individual museum rooms.) Table B.2 shows the major causes of these fires. Experience shows that the risk of fire is increased when a facility is being renovated or when a new exhibit is being installed.

Table B.2 shows the causes of structure fires in museums or art galleries. These are fires reported to U.S. municipal fire departments and so exclude fires reported only to federal or state agencies or industrial fire brigades. Fires, civilian deaths, and civilian injuries are expressed to the nearest 1, and property damage is rounded to the nearest hundred dollars. Sums may not equal totals due to rounding. Property damage figures have not been adjusted for inflation. The 12 major cause categories are based on a hierarchy developed by the U.S. Fire Administration. Fires in which the cause was unknown were allocated proportionally among fires of known cause.

B.2.1 Why Museum Fires Spread. The museum fires briefly described in B.2.2 illustrate one or more of the conditions under which a fire will spread beyond its area of origin and why resultant damage can be extensive. First and foremost is the absence of sprinklers or other means of automatic protection. Second, and almost equally important, is the lack of adequate compartmentation (or subdivision of areas) where there is a continuity of combustibles. A third condition is the delay in discovering and reporting the fire. The first moments following ignition can be critical, because it frequently takes only a few minutes for a small fire to grow. In the absence of automatic fire detection or protection, discovery of a fire might be left to chance, possibly by a passerby or neighbor. At that point, a fire could be so well established that loss to the museum will inevitably be substantial.

B.2.2 Illustrative Fires. The following descriptions of fires illustrate some of the more common sources of ignition, factors contributing to the prompt extinguishment or spread of the fire, and the enormity of the losses suffered when protection is not provided. It is important to note that every museum cited was located in close proximity to a highly trained fire department that responded promptly upon notification of the fire.

B.2.2.1 National Museum of Natural History (Smithsonian Institution), Washington, DC, January 22, 1989. A scientist mistakenly turned on a hotplate as he left his laboratory. A smoke detector alarm was later received in the museum's control room, and a security officer was immediately dispatched to the room. In the two minutes it took for him to arrive at the lab, a single sprinkler had been actuated and extinguished the fire. Total loss was under $1000.

Table B.2 Major Causes of Structural Fires in U.S. Museums and Art Galleries, 1980–1998 (Annual Averages)

	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage	
Major Cause	No. of Fires	Percent	No. of Deaths	Percent	No. of Injuries	Percent	Loss	Percent
Electrical distribution	21	24.6	0	NA	0	22.3	$ 532,300	27.2
Incendiary or suspicious	16	18.3	0	NA	0	0.0	$ 502,200	25.7
Other equipment	9	10.9	0	NA	0	6.1	$ 263,600	13.5
Open flame, ember, or torch	8	9.1	0	NA	0	14.3	$ 38,400	2.0
Heating equipment	7	8.0	0	NA	0	19.9	$ 500,800	25.6
Smoking materials	6	7.5	0	NA	0	0.0	$ 12,700	0.6
Cooking equipment	6	7.1	0	NA	0	0.0	$ 24,800	1.3
Exposure (to other hostile fire)	4	4.3	0	NA	0	0.0	$ 51,600	2.6
Natural causes	4	4.1	0	NA	0	0.0	$ 21,800	1.1
Appliance, tool, or air conditioning	3	3.5	0	NA	0	30.8	$ 1,900	0.1
Other heat source	1	1.7	0	NA	0	6.5	$ 4,600	0.2
Child playing	1	0.7	0	NA	0	0.0	$ 0	0.0
Total	86	100.0	0	NA	1	100	$1,954,800	100

Source: National estimates based on NFIRS and NFPA surveys.

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B.2.2.2 Fort Hill–John C. Calhoun Shrine, Clemson, SC, May 30, 1988. Criminals used gasoline to set fire to this 185-year-old home (museum) to create a diversion while they burglarized a jewelry store. The museum had been equipped with a sprinkler system in 1968. Three sprinklers operated (one outside and two inside) to extinguish the fire before the fire department arrived. Less than 1 percent of the museum and its contents were damaged by fire or water.

B.2.2.3 Louisiana State Museum (The Cabildo), New Orleans, LA, May 11, 1988. During exterior renovation work on one of this country's most historic buildings, it is believed a torch being used to solder a copper downspout ignited the combustible felt paper or wood in the roof. The fire apparently entered the attic and burned unnoticed for some time before being detected by smoke detectors on the floor below. Notification to the fire department was not automatic and was finally made by a passerby on the street who noticed smoke. Despite heroic efforts by the fire department, the attic, third floor (which was used for collection storage), and the roof were lost to fire, and there was significant smoke and water damage to the floors below. An estimated 500,000 gallons of water were used to control this fire. The fire chief in charge stated that if the museum had been protected by a sprinkler system only two sprinklers would probably have been necessary to control or extinguish this fire. Loss was $5 million.

B.2.2.4 Huntington Gallery, San Marino, CA, October 17, 1985. While this art gallery was protected by both smoke and heat detectors, none was installed in the elevator shaft where a fire of electrical origin is thought to have burned for some time before bursting out onto the first floor. As the outside air hit the fire source, a fireball was created that traveled 60 to 70 feet down the corridor, totally destroying a painting done in 1777. Loss was $1.5 million.

B.2.2.5 Byer Museum of Art, Evanston, IL, December 31, 1984. A fire of electrical origin is believed to have originated between the walls on the first floor of this three-story building. The fire apparently burned within the walls for some time before bursting through into the museum. For an unknown reason, the smoke detection system did not operate. The fire totally destroyed the upper two floors and roof and caused extensive water damage to the first floor. Loss was $3 million.

B.2.2.6 Museum of Modern Art, Rio de Janeiro, Brazil, July 8, 1978. Watchmen discovered a fire in this concrete and glass building about 4 a.m. The museum had no automatic fire detection or suppression systems and no interior fire barriers. It also had no emergency plan. The fire probably started from a cigarette or defective wiring in an improvised room used for a show a few hours earlier. Spreading through flammable ceilings and partitions, within 30 minutes it destroyed 90 percent of the museum's permanent collection (about 1000 works of art) and the paintings borrowed for special exhibition. It would appear that the delay in alarm, the large amount of combustibles, and the lack of an automatic fire suppression system contributed to the large loss.

B.2.2.7 San Diego Aerospace Museum, San Diego, CA, February 22, 1978. The museum and the International Aerospace Hall of Fame occupied an old wood and stucco exposition building without automatic fire detection or suppression systems. Workers in a neighboring structure reported a fire at 8:13 p.m., apparently set by two arsonists seen running away. The fire department dispatched 14 units comprising 83 of its personnel. The first unit arrived at 8:17 p.m. but was unable to save the building or its contents. Only a specimen of moon rock survived, having been stored overnight in a fire-resistive safe. Loss to the building was $15 million. Loss to the museum was 40 planes, many historic specimens and irreplaceable documents, and an aviation library valued at $1 million; loss to the Hall of Fame included all its portraits and memorabilia.

B.2.2.8 National Museum of American History (Smithsonian Institution), Washington, DC, September 30, 1970. A fire reported at 5:05 a.m. destroyed a combustible computer exhibit and damaged the Hall of Numismatics. None of the historic collections of coins and stamps was damaged. The fire walls worked well, but the museum had no automatic fire suppression systems. Water used in fighting the fire caused some damage to the exhibit floor below. Smoke damaged offices and storerooms on two floors above. The cause was probably an electrical short circuit in the exhibit. Loss was over $1 million.

B.2.2.9 Henry Ford Museum, Dearborn, MI, August 9, 1970. A fire started in a dressing room, possibly from an overheated hair-curling iron. Flames quickly spread through several historic shops reconstructed of wood and a section of agricultural and crafts displays. Excessive combustible storage behind the exhibits aided fire spread in the unsprinklered, undivided, one-story, fire-resistive main exhibit hall, of which about 22,296 m^2 (240,000 ft^2) burned. Fire doors that employees kept wet with twenty-five 9.5 L (2½ gal) water extinguishers prevented the fire from reaching the small museum theater. Loss was over $2 million.

B.2.2.10 Museum of Modern Art, New York City, April 15, 1958. Workers repainting the second-floor galleries and enlarging the air-conditioning system failed to observe fire safety precautions. They smoked on the job while using nonflameproofed drop cloths, went to lunch leaving paint cans open, and tied stairway doors open for convenience in moving equipment. During the noon hour, a worker saw a small fire in a drop cloth and called for help. A museum guard brought a hand extinguisher, and they tried to put out the blaze before turning in an alarm. The fire quickly spread to the cans of paint, untreated wood scaffolding, and combustible gallery partitions. Thick smoke poured into the clustered stairwells. Finally, someone pulled the building alarm and the separate alarm with direct connections to the fire and police departments. More than 500 people in the museum had considerable difficulty escaping. The smoke-filled stairways and elevator shaft delayed fire fighters in locating the fire. The fire was brought under control two hours after the alarm was given but not before one person was killed, 33 were injured, two major paintings were destroyed (including a Monet masterpiece), and seven were severely damaged. Property loss was $700,000.

B.3 Library Fires. While libraries generally have a good record of fire prevention, they house high fuel loads that can result in severe, even catastrophic losses when ignition occurs and adequate fire protection is not provided. Fires occur in libraries worldwide with considerable frequency and serious results. From 1980 through 1997, an average of 198 library fires per year, resulting in an annual average loss of $4.7 million in property damage, were reported to U.S. fire departments. *[See Table B.3.1(a) and Table B.5.]*

B.3.1 Why Library Fires Spread. Fires have occurred in libraries of many different types and from a wide variety of causes. *[See Table B.3.1(b).]* Serious damage has occurred in buildings of fire-resistive as well as combustible construction. Fires occur in libraries worldwide with considerable frequency and serious results.

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Table B.3.1(a) Structural Fires in U.S. Libraries by Year, 1980–1997

Year	No. of Fires	No. of Civilian Injuries	No. of Civilian Deaths	Direct Property Damage
1980	386	0	0	$ 2,170,700
1981	266	0	0	$ 215,000
1982	276	0	0	$13,864,000
1983	194	0	0	$ 3,557,000
1984	238	0	3	$ 225,000
1985	279	0	0	$ 1,424,000
1986	206	0	5	$42,859,000
1987	197	0	0	$15,163,000
1988	150	0	0	$ 482,000
1989	151	0	0	$ 1,916,000
1990	171	0	2	$ 679,000
1991	175	0	0	$ 118,000
1992	158	0	1	$ 1,940,000
1993	124	0	0	$ 2,264,000
1994	144	0	0	$ 170,000
1995	131	0	0	$ 927,000
1996	182	0	2	$ 1,187,000
1997	140	0	0	$ 341,000
Annual Average	198	0	1	$ 4,972,000

Source: National estimates based on NFIRS and NFPA surveys.

Table B.3.1(b) Major Causes of Structural Fires in U.S. Libraries, 1980–1998 (Annual Averages)

	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage	
Major Cause	No. of Fires	Percent	No. of Deaths	Percent	No. of Injuries	Percent	Loss	Percent
Incendiary or suspicious	78	40.0	0	NA	0	24.5	$4,018,200	84.5
Electrical distribution	38	19.6	0	NA	0	10.0	$ 281,400	5.9
Other equipment	16	8.3	0	NA	0	0.0	$ 16,700	0.4
Open flame, ember, or torch	12	6.2	0	NA	0	10.3	$ 17,800	0.4
Smoking materials	11	5.9	0	NA	0	11.4	$ 65,300	1.4
Heating equipment	11	5.7	0	NA	0	32.5	$ 143,200	3.0
Cooking equipment	8	4.0	0	NA	0	0.0	$ 14,900	0.3
Appliance, tool, or air conditioning	7	3.8	0	NA	0	11.4	$ 31,200	0.7
Child playing	5	2.3	0	NA	0	0.0	$ 56,600	1.2
Natural causes	4	2.0	0	NA	0	0.0	$ 30,900	0.6
Exposure (to other hostile fire)	3	1.3	0	NA	0	0.0	$ 78,100	1.6
Other heat source	2	0.9	0	NA	0	0.0	$ 300	0.0
Total	195	100.0	0	NA	1	100.0	$4,754,400	100.0

Source: National estimates based on NFIRS and NFPA surveys.

Table B.3.1(a) and Table B.3.1(b) show the causes of structure fires in libraries. These are fires reported to U.S. municipal fire departments and so exclude fires reported only to federal or state agencies or industrial fire brigades. Fires, civilian deaths, and civilian injuries are expressed to the nearest 1, and property damage is rounded to the nearest hundred dollars. Sums might not equal totals due to rounding. Property damage figures have not been adjusted for inflation. The 12 major cause categories in Table B.3.1(b) are based on a hierarchy developed by the U.S. Fire Administration. Fires in which the cause was unknown were allocated proportionally among fires of known cause.

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B.3.2 Illustrative Fires. The following examples were chosen to illustrate the many ways in which library fires have started and spread and the great destruction they have caused. In these fires alone, tens of millions of valuable books, recordings, and other media have been needlessly lost to fire. Damage has been directly proportional to the promptness of discovery, the transmission of an alarm, the availability of automatic fire suppression, and the amount of combustibles in the fire area. The total situation can be such that even the most proficient fire-fighting service will be unable to cope with it, as evidenced by the great losses in the Jewish Theological Seminary Library fire, the Temple University Law Library fire, and the Los Angeles Central Public Library fires. In contrast, the examples of fires in protected facilities demonstrate the benefits of providing suitable fire protection systems.

B.3.2.1 Libraries Without Automatic Fire Protection Systems. Factors common to the most destructive library fires are arson, delayed discovery, delayed reporting, and the absence of any automatic suppression or detection capability. Some typical fires involving one or more of these factors are listed, including three disasters that tested the resources of three of our largest cities (Los Angeles, New York City, and San Diego).

B.3.2.1.1 Linkoping City Library, Linkoping, Sweden, September 20, 1996. This important city library was largely destroyed by a fire that appeared to have been set deliberately at 11:00 p.m. in the immigrants' information office, which was located in the same building. Six hundred people attending a conference escaped safely. Within 20 minutes, the building was fully involved. The fire services were sparing in their use of water in order to prevent water from entering the basement storage areas where the manuscript collections were located. Most of those collections were saved, although about 70,000 books were lost.

B.3.2.1.2 Virginia Library, Hampton, VA, July 1996. At about 10:00 p.m., an occupant of a dormitory in an adjacent structure notified the fire department of a fire on the roof of a structure containing a library and a linen exchange. The one-story building of ordinary construction covered an area of 25,602 ft^2. Walls were block, the floor framing was concrete, the roof framing and deck were wood, and the roof was covered by built-up tar and gravel. The building had two ceilings. The property was closed for the night.

Arriving fire fighters found smoke coming from the structure's roof. An investigation revealed that an unknown person had intentionally ignited ordinary combustibles in a rear storage room. Holes in the lower ceiling allowed the fire to spread to the area between the roof and the original ceiling. A brisk wind fanned the fire throughout the building. It is believed that the fire burned for approximately 10 minutes before it was detected. Automatic heat detectors were present in the library and the linen exchange office but not in the room where the fire started. They were not actuated. No suppression system was present. The structure and contents were destroyed. Two vehicles parked nearby were also damaged by radiant heat. Total direct property damage was estimated at $4,500,000. No injuries were reported.

B.3.2.1.3 Carrington City Library, Carrington City, ND, November 5, 1994. An arson fire destroyed the building and its contents, valued at more than $200,000. Only half of that amount was covered by insurance. The library's entire collection of nearly 13,500 books had to be discarded, with the exception of about 300 books that were in circulation at the time of the fire.

B.3.2.1.4 Norwich Central Library, Norwich, England, August 1, 1994. Fire destroyed more than 350,000 books, with many priceless manuscripts, some dating to the 11th century, suffering water damage from fire fighter hose streams. The fire is believed to have started as a result of faulty wiring in a bookcase. The collections contain more than two million documents, including cathedral records dating back to 1090. The London *Daily Telegraph* reported, "Norwich refurbished its 31-year-old library earlier this year [1994] but decided not to install a sprinkler system, fearing it would cause too much damage if there was a fire." Even though the library was located adjacent to the city's main fire station, the fire was out of control by the time the fire department arrived.

B.3.2.1.5 Grand Canyon Community Library, Grand Canyon Village, AZ, March 18, 1994. A 9 a.m. fire destroyed around 14,000 books in a building that had been listed on the National Register of Historic Places. Only 500 books that were in circulation at the time of the fire were not destroyed. Cause of the fire was not reported. Loss was estimated at over $1 million.

B.3.2.1.6 Dakota County Library Branch, Hastings, MN, June 4, 1993. An arson fire involving a juvenile destroyed the entire library collection of 73,500 books and caused $300,000 damage to the building. Damage to books and library furnishings were estimated at more than $1 million. A passing motorist reported the fire at 4:30 a.m. The building had no automatic fire detection or suppression systems because it was considered "up to code" when it was constructed in 1964.

B.3.2.1.7 Rio Vista Library, Rio Vista, CA, January 16, 1993. A fire caused by combustible materials left near a radiator heater when staff departed at 5 p.m destroyed the library's total collection of 32,000 books and the historic building that housed them. Persons attending a meeting in a second-floor room discovered the fire at 10:15 p.m. Losses were estimated at $1.3 million.

B.3.2.1.8 Calgary Public Library, Thornhill Branch, Calgary, Alberta, Canada, April 1, 1990. Fire fighters were called to an arson fire in a building that housed the library and a Calgary social and health services office at 4:30 a.m. Initial estimates of $1 million in losses were subsequently reduced by more than half when it was determined that of 60,000 books damaged in the fire, more than 80 percent could be salvaged. These were mostly smoke-damaged books that could be cleaned.

B.3.2.1.9 Nellie McClung Public Library, Victoria, British Columbia, Canada, December 4, 1989. Fire was discovered shortly after midnight by a passing police patrol and was first suspected to be arson because of the explosive pace of fire development. Arson was subsequently ruled out because no trace of forced entry or use of flammable liquid accelerants was found. The 13-year-old building was gutted, and 34,000 books were destroyed. It took the fire fighters 45 minutes to control the fire and five hours to fully extinguish it. The fire caused damage in the range of $1 million to $2 million to the library and its collections. It was reported that the library only had automatic sprinkler protection in the boiler room.

B.3.2.1.10 Joliet Public Library, Joliet, IL, April 19, 1989. About 9:45 p.m., two flaming Molotov cocktails were hurled from the alley through a window in the children's wing. Two arson incidents in Joliet school libraries — one earlier in the week and one a month and a half earlier — preceded this incident. The fire resulted in smoke and water damage throughout the building but caused only minor damage to the

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structure. All the children's collections were lost, and damage to the library reached an estimated $1.3 million.

B.3.2.1.11 Library of USSR Academy of Science, Leningrad, Russia, February 14, 1988. A fire that started as a result of an electrical defect in a newspaper collection storage room of this great library burned for 2 hours unnoticed because the detection system failed. Forty brigades then pumped water into the flames for the next 19 hours. Soviet journalists described the fire as paralleling the Chernobyl nuclear catastrophe. Destroyed by fire were 400,000 volumes of rare or unique works; another 3.6 million books were water soaked. As *Pravda* reported, "The disaster could well have been prevented."

B.3.2.1.12 Los Angeles Central Public Library, Los Angeles, CA.

B.3.2.1.12.1 April 29, 1986. An arsonist set a fire on tier 5 in the multitier book stacks at 10:40 a.m., when there were 400 persons in the library. A detection system gave immediate notice of the fire to a security officer, and the fire department was called. The security officer responded to tier 6 as indicated by the smoke detection annunciator panel but found no fire there at that time. The "deck slits" had not been sealed with smoke barriers *(see 16.4.10.3.3)* when the smoke detection system was installed, because they were still needed for book stack ventilation. As a result, the opportunity was lost for occupant extinguishment while the fire was small. Time available for occupant action was probably very short because, typical of fires in multitier book stacks without automatic sprinkler protection, vertical fire spread through the open deck slits would have been very rapid — possibly less than 10 minutes from tier 5 to the top tier in the book stack (tier 8). The fire department response was prompt, but the fire proved one of the most difficult Los Angeles had ever seen, and it was not until 7½ hours later that it was declared under control. More than 400,000 items were destroyed, and 700,000 wet books were placed in freezer warehouses to await eventual restoration. Damage to the reinforced concrete building structure and its historic fabric was extensive and significant. The senior fire service officer, Chief Donald Manning, said, "If it had been sprinklered, we might have had a few hundred books damaged; we might have had a few thousand dollars damage." *(See Isner, "Investigation Report," in NFPA Fire Journal, March/April 1987.)*

B.3.2.1.12.2 September 3, 1986. A second incendiary fire, started in a stack of papers, struck the Central Library, causing $2 million damage to music collections. The public had been excluded from the building since the April 1986 fire, and only staff members and security people were there.

B.3.2.1.12.3 October 11, 1988. A third fire resulted when hot metal from welding operations on the third floor dropped down a chute into scrap lumber in the basement. Damage was limited to smudging of the elegant murals that had been cleaned after the 1986 fires at a cost of $500,000. The fire fighters put down the flames in 30 minutes. Plans for the expansion and remodeling of the library include complete automatic sprinkler protection.

B.3.2.1.13 Hollywood Regional Library, Hollywood, CA, May 2, 1982. Vandals broke into the library during the night and set it on fire. There were neither sprinklers nor automatic detection equipment. The destruction was almost total, and the loss amounted to more than $5 million. A new building replacing this library was dedicated in June 1986 with the design incorporating modern protection systems (i.e., automatic suppression and detection).

B.3.2.1.14 San Diego Aerospace Museum and Library, San Diego, CA, February 22, 1978. A fire of incendiary origin destroyed the museum and library. The loss, estimated at $16.3 million, included artifacts, works of art, photographs, and the Prudden Collection of 10,000 volumes. At the time of the fire, the 62-year-old structure was undergoing reconstruction, which involved replacement of exterior cement plaster. During this operation the underlying plywood used in the construction was exposed, and the fire was set in the plywood. The building had neither sprinklers nor automatic fire detection systems.

B.3.2.1.15 Ceres Public Library, Ceres, CA, August 14, 1977. The Gondring Library and several adjacent offices were destroyed in a fire that developed when two youths dropped a paper match into a book return slot. The library loss was approximately $230,000. There were neither sprinklers nor automatic fire detection equipment.

B.3.2.1.16 University of Toronto Engineering Library, Toronto, Ontario, February 1977. A fire of undetermined origin in the Sir Sandford Fleming Building caused severe damage to the Engineering Library collections and to the building. The building loss was estimated at $5.85 million and the cost of repairs or replacement of books at $700,000. There were no sprinklers in the building. A detection system sent signals, but because alarm circuits were being tested during the night, the signals were confused, and a delayed response resulted.

B.3.2.1.17 Smith College Library, Northampton, MA, October 21, 1975. A fire of electrical origin damaged the reference room of the Neilson Library. Damage to the interior finish and furnishings and the loss of a considerable number of books was estimated at $342,000. Some areas of the library were equipped with automatic sprinklers and smoke detection systems, but the reference room was unprotected.

B.3.2.1.18 Temple University Charles Klein Law Library, Pennsylvania, PA, July 1972. A fire originating in an office area gutted the Charles Klein Law Library and caused extensive damage to the collections. There were neither sprinklers nor automatic detection equipment, and a passerby reported the fire at 1:45 p.m. The fire department attacked the fire and subdued it in 90 minutes, pouring water into the building at the rate of 41,635 L/min (11,000 gpm) at one point. Salvage of wet books held the damage to collections at $1.72 million, while the total loss was estimated at $5 million. *(See Willey, "Investigation Report," in NFPA Fire Journal, November 1972.)*

B.3.2.1.19 Jewish Theological Seminary Library, New York City, April 1966. Employees fought an incendiary fire on the 10th floor of a 12-story tower for 20 minutes before calling the fire department. There were no automatic systems for detection or suppression of fire. The loss was estimated at $8.18 million and included irreplaceable books and manuscripts.

B.3.2.1.20 Michigan State Library and Office Building, Lansing, MI, February 8–13, 1951. An incendiary fire burned for five days, resulting in a loss of $2.85 million and two floors of the building that could not be salvaged.

B.3.2.1.21 University of Michigan, Department of Government Library, Ann Arbor, MI, June 6, 1950. A daytime fire set by a faculty member resulted in a $637,000 loss.

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B.3.2.2 Representative Fires in Libraries with Automatic Fire Protection Systems.

B.3.2.2.1 Broward County Main Library, Fort Lauderdale, FL, March 23, 1993. The automatic sprinkler system contained a fire in a first-floor trash room at about 9:57 p.m. on a Sunday. Investigators believe a carelessly discarded cigarette caused the fire. Excess trash from a weekend special event in the library contributed to the severity of the fire. Portions of the first floor were damaged, including security and delivery offices and storage rooms. Some library materials in those areas were also damaged.

B.3.2.2.2 South Bend Public Library, South Bend, IN, October 28, 1992. A fire that started in an elevator shaft during the unoccupied early morning hours spread into a mezzanine area, but damage to the building was minimal. The sprinkler system was credited with containing the fire and preventing it from extending into library collection materials. An alarm to the fire department from the building was delayed because the fire detection systems were still not connected more than two weeks after dedication ceremonies for the renovated and expanded building. The fire department found the fire nearly extinguished by the automatic sprinkler system. Damage was limited to smoke, carpet, elevator and elevator shaft, and glass windows to the main entrance door and rooftop skylights.

B.3.2.2.3 Bailey-Howe Library, University of Vermont, Burlington, VT, March 21, 1990. Staff arriving at 7:30 a.m. smelled an electrical burning odor. An electrical fault ignited the fabric wrapping on an air supply duct in the air return plenum above the suspended ceiling. By the time the source of the smoke was discovered, the fire had burned itself out. At the time of the fire there was no interconnection between the automatic smoke detection system and the air handling system to shut it down upon detection of smoke. Damage to the library was limited to the effects of the smoke and the removal of parts of the ceiling. Final cost to the institution was $105,965. The library reopened two days later, and the most affected part of the building was off-limits to students for the balance of that spring semester. An automatic sprinkler system was retrofitted to the building in 1981, but it was below the suspended ceiling.

B.3.2.2.4 Saint Joseph State Hospital, Saint Joseph, MO, July 31, 1982. Fire of incendiary origin in the second floor library of this three-story medical care facility was controlled with the operation of two automatic sprinklers. The minimal damage was confined to the room of origin.

B.3.2.2.5 University of Utah, Salt Lake City, UT, December 17, 1981. Fire resulting from an overheated slide projector in the basement of the Eccles Health Sciences Library was extinguished with the operation of two automatic sprinklers. Notification of the public fire department was prompt through the action of smoke detectors. An estimated loss of $2600 was confined for the most part to visual aid equipment.

B.3.2.2.6 New York University Library, New York City, January 1965. Fire in a library book stack was extinguished with the operation of one automatic sprinkler. Total loss was approximately $7000.

B.3.2.2.7 New York University Library, New York City, February 1951. Fire in the book stacks of a 10-story, completely sprinklered, fire-resistive building was extinguished with the operation of one sprinkler. Total loss was approximately $1000.

B.3.2.3 Note that in the last four fires described in B.3.2.2, sprinkler operation was credited for prompt control and extinguishment with minimal damage. Many similar incidents have occurred without attracting public notice.

B.3.3 Causes and Prevention of Library Fires.

B.3.3.1 Incendiarism.

B.3.3.1.1 The deliberate setting of fires has been identified as the cause of most fires in libraries in the last 50 years, accounting for as many as 80 percent of all library fires. The average annual fire loss due to incendiary or suspicious causes between 1980 and 1998 exceeded $4 million. *[See Table B.3.1(b).]*

B.3.3.1.2 The disgruntled or unstable employee or patron can be the most difficult type of fire setter to recognize. Physically strengthening doors and windows, improving security, and installing intrusion alarms to make unauthorized entry and vandalism difficult can defeat vandals who break in while the library is closed. Those fire setters who place burning materials in book returns can be turned away simply by improving the book return or eliminating it in favor of an outside receiving bin, something that thousands of libraries have done in recent years. See Morris, *Library Disaster Preparedness Handbook*.

B.3.3.2 Control of Ignition Sources.

B.3.3.2.1 After incendiarism, the most common causes of fire in libraries involve the failure to control the ignition sources that are inherent in building operations (e.g., heating systems, electrical faults, hot work of contractors in construction and remodeling, heating systems, and lightning). Each of these categories has produced destructive fires in recent years. Another common cause of fire is the exposure fire that spreads to the library from an adjacent building or another occupancy in the same building.

B.3.3.2.2 These causes suggest preventive programs to minimize fire damage. Electrical wiring and appliances require proper installation and maintenance. Open-flame devices should be permitted only on the basis of written authorization signed by the responsible management official after evaluation of the risks and prescribing of specific protective measures are included as conditions of the authorization. Contractors must be held by contract specifications to stringent discipline in protecting cutting and welding operations, a prolific source of fires, and in other hot work. Standard lightning protection should be provided as well.

B.3.3.2.3 Chapter 16 in Section 13 of the NFPA's *Fire Protection Handbook* (19th edition) provides guidance for control of ignition sources in library collections.

B.3.3.3 Control of Fuel. A fire prevention program in the library should provide for control of fuel as well as of ignition sources. It should include inspections by designated supervisory persons to maintain good housekeeping and see to the proper removal of combustible trash, proper storage of flammable materials, and other housekeeping procedures. It should also acquaint employees with emergency routines for fire: sounding the alarm, calling the fire department, and using whatever first-aid appliances (e.g., fire extinguishers) might be available. The program should invite fire service officers into the library for inspection and orientation.

B.4 Places of Worship. Fire losses in places of worship are not a modern phenomenon, nor are the relatively high proportion of these that are purposely set. Looking back to the Crusades during the Middle Ages, we find numerous stories of

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churches and cathedrals being set on fire by opposing armies. Destruction of the enemy's centers of community and symbols of their religious faith and culture was found to be a strong factor in weakening their morale and winning the battle. Today our places of worship remain a target for destructive individuals who wish to attack a particular social, political, or moral position that the structure represents to them. From 1987 to 1998, according to a recent NFPA study of fires in the United States, an average of 1580 churches, chapels, and synagogues were seriously damaged or destroyed by fire every year, an average of four properties per day. The annual average for direct property damage was $44.2 million.

B.4.1 How Fires Have Started in Places of Worship. In addition to fires that have been purposely set, places of worship are susceptible to the wide variety of common hazards associated with fires in most properties. A 1980–1998 study by NFPA includes fire loss data for churches and other places of worship. *(See Table B.4.1.)* Numerous other fires occurred in associated occupancies, such as kitchens, schools, orphanages, shelters, and so on, that were not included in this study.

Table B.4.1 shows the major causes of structure fires in churches, chapels, temples, or mosques. These are fires reported to U.S. municipal fire departments and so exclude fires reported only to federal or state agencies or industrial fire brigades. Fires are rounded to the nearest 10, civilian deaths and civilian injuries are expressed to the nearest 1, and property damage is rounded to the nearest hundred thousand dollars. Sums may not equal totals due to rounding. Property damage figures have not been adjusted for inflation. The 12 major-cause categories are based on a hierarchy developed by the U.S. Fire Administration. Fires in which the cause was unknown were allocated proportionally among fires of known cause.

B.4.1.1 Arson. Places of worship are either unoccupied or only partially occupied a large part of the time. Customarily, many of them are left unlocked at all times; thus, they are accessible not only to casual worshipers and well-intentioned visitors but also to arsonists, thieves, and vandals. Arson is the leading cause of fire in places of worship. The best defenses against arson fires are improved security and access limitations and provision of automatic sprinkler protection throughout the facility.

B.4.1.2 Electrical Systems. Overloaded, incorrectly installed, and old or damaged electrical systems are the second most frequent cause of fires in places of worship. Periodic inspections by an electrical engineer or licensed electrician, in conjunction with the required self-inspection program, can eliminate most of these losses.

B.4.1.3 Heating Equipment. Proper installation and maintenance of heating equipment combined with a regular inspection program should substantially reduce losses.

B.4.1.4 Open Flame. Most fires attributed to open flame occur during building repair and alteration work. Members of the congregation often volunteer assistance in building alterations and repairs. Where those volunteers possess specialized skills and talents, their services are of great value. It is important, however, that only fully qualified licensed professionals perform such tasks as heating, plumbing, and electrical work. For additional precautions during these operations, refer to Chapter 13. And, of course, unsupervised use of candles and other open flames outside of renovation work should not be permitted.

B.4.2 Why Fires in Places of Worship Spread. If all fires were confined to their areas of origin, there would be few major losses. Most buildings comprise a connected series of compartments. As such, they are inherently fire safe if a fire can be contained to the compartment of origin. Unfortunately, in places of worship, design, construction, and use practices create many avenues for fire spread.

Table B.4.1 Major Causes of Structural Fires in Churches, Chapels, Temples, or Mosques, 1980–1998 (Annual Averages)

	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage (in Millions)	
Major Cause	No. of Fires	Percent	No. of Deaths	Percent	No. of Injuries	Percent	Loss	Percent
Incendiary or suspicious origin	510	32.3	1	52.3	3	17.8	$18.4	41.5
Electrical distribution	230	14.8	0	0.0	2	13.5	$ 5.8	13.1
Heating equipment	180	11.7	0	16.0	3	14.3	$ 5.9	13.4
Open flame, ember, or torch	120	7.3	0	5.8	2	8.5	$ 2.0	4.5
Other equipment	110	7.1	0	0.0	5	25.0	$ 3.6	8.1
Natural causes	90	5.5	0	8.3	1	4.6	$ 4.0	8.9
Exposure (to other hostile fire)	70	4.6	0	0.0	0	0.4	$ 0.7	1.5
Cooking equipment	70	4.5	0	9.2	1	7.6	$ 0.4	1.0
Appliance, tool, or air conditioning	60	3.9	0	0.0	0	1.4	$ 1.3	2.9
Other heat source	50	3.3	0	0.0	1	3.9	$ 1.2	2.6
Smoking materials	40	2.8	0	8.5	0	0.9	$ 0.6	1.4
Child playing	40	2.4	0	0.0	0	2.1	$ 0.5	1.1
Total	1,580	100.0	1	100.0	18	100.0	$44.2	100.0

Source: National estimates based on NFIRS and NFPA surveys.

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B.4.2.1 Building Use.

B.4.2.1.1 One of the primary reasons fires in places of worship generally result in great amounts of damage or a total loss of the facility is due to a delay in discovering and reporting the fire. The ability to detect and begin extinguishment during the first moments following ignition of a fire is generally critical, because it frequently takes only very few minutes for a small fire to grow large enough that even a very responsive fire department cannot extinguish it before major damage has been wrought.

B.4.2.1.2 More than three-fourths of fires in places of worship occur while the building is unoccupied; almost all of them occur in structures lacking automatic sprinkler protection or automatic fire detection and alarm systems. Nearly half of them happen between 11 p.m. and 7 a.m., when few people pass by the area. These statistics, coupled with simple logic, highlight the urgency and prudence of providing places of worship with effective fire detection and protection equipment that automatically notifies the fire department and begins fire extinguishment.

B.4.2.2 Design and Construction.

B.4.2.2.1 A fire needs only two ingredients to enable it to spread: air and combustible materials. Most places of worship are provided with both in great abundance. In addition to delayed detection and alarm, the principal factors affecting the spread of fires in places of worship are undivided open areas, concealed spaces, combustible construction, combustible interior finishes, and combustible furnishings. Undivided open areas and concealed spaces provide air to an incipient fire, and combustible structural parts, finishes, and furnishings provide fuel. Each of the following accounts of fires illustrates the effect of one or more of these factors. These accounts demonstrate why fire fighters particularly dislike fires in these facilities and why places of worship are often said to be "built to burn."

B.4.2.2.2 Large open areas are traditional and perhaps largely unavoidable, yet there are ways to minimize their effect. In some cases, for instance, fire separations can be introduced without altering the essential character of the building or its usefulness for religious purposes. Doors customarily left open could be kept closed, other unprotected or inadequately protected floor and wall openings could be more effectively protected, concealed spaces could be provided with adequate fire-stopping or fire divisions, and combustible interior finishes could be replaced with less hazardous, aesthetically acceptable materials. Very few of the fires reported were in buildings in which such measures had been taken. This illustrates how rarely fires that are serious enough to be reported occur in places of worship with such protection.

B.4.2.2.3 A properly designed automatic sprinkler system is the most effective single means of preventing serious fires. Automatic sprinklers combined with good building design and fire-resistive construction, finishes, and furnishings are the best way to ensure safer places of worship.

B.4.3 Illustrative Fires in Places of Worship. The following descriptions of fires illustrate some of the more common sources of ignition, factors contributing to fire spread, and the enormity of the losses suffered. It is important to note that these destructive fires are not limited to a particular geographical area or population but occur across the country and in rural areas as well as big cities. Similarly, these fires do not occur disproportionally in facilities occupied by a particular religious organization or creed.

B.4.3.1 Kansas Church, 1999. Workers were using a circular saw with a metal cutting blade to cut a metal rod that operated several windows on a second-floor balcony in a church under renovation, when showering sparks ignited a fire. This type of work qualifies as hot work per NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*. If NFPA 51B had been followed, a fire watch with an extinguisher would have been established after a hot work permit was issued. The workers tried to extinguish the blaze, but a short delay in fire department notification and the lack of a standby fire extinguisher allowed the fire to spread.

The two-story church was of wood-frame construction, with stone walls and a slate roof. It did not have sprinklers or fire detection equipment and was open at the time of the fire.

A worker saw the sparks fall onto several wooden structural members exposed at the roofline. The wood ignited easily because it suffered from dry rot and termite infestation, and the fire spread under the roof as workers tried to find water to extinguish it.

Fire fighters, responding to a 911 call from the construction crew at 9:24 a.m., found flames and smoke coming from the corner of the church roof. A fire department official observed that no fire extinguisher was on hand. If workers had had access to an extinguisher, it may have been possible to save the building. Estimated structural loss was reported at $2 million, with contents loss at $500,000. There were no injuries.

B.4.3.2 Pennsylvania Church, 1998. This two-and-a-half story church was constructed of heavy timber. Its ground-floor area was not reported. The church was closed for the night when the fire occurred. The church had no automatic suppression system, and its complete-coverage automatic detection system, of unreported type, failed to actuate. However, at 4:52 a.m., a burglar alarm system actuated and summoned police, who spotted the fire when they responded. The blaze started in a ceiling/floor assembly over the janitor's room in the basement when an unreported electrical source ignited wood framing material. The fire spread to the sanctuary. Two fire fighters were injured. A contributing factor to the rapid growth of the fire was that the ceiling over the janitor's room collapsed, allowing the fire to spread through voids in the construction. The loss was $6 million.

B.4.3.3 Wisconsin Church, 1998. A church worker called 911 at 9:19 p.m. to report a fire in this two-story, wood frame church. The structure measured 61 m × 15 m (200 ft × 50 ft), and the walls, floor framing, roof framing, and roof deck were wood; the roof was covered with asphalt shingles. Several volunteers had been attempting to eliminate bees or hornets from under the eaves. One individual sprayed ether into about 12 joist pockets. In one pocket, a cigarette lighter was used to create a blowtorch effect with the ether can, with the intention of burning out the insects. This created a small fireball, which workers attempted to pat out with their hands. Believing the fire was out, they continued to spray other joists. The volunteers noticed smoke coming from the roof peak 15 to 20 minutes later. They entered the church, tore down a piece of suspended ceiling, and found fire in the concealed space. They tried to put the fire out with several extinguishers. When these efforts were unsuccessful, the fire department was called.

The extensive use of ether caused the fire to spread quickly and far. Before a significant interior attack could be launched,

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fire fighters had to ventilate the building of ether vapors. There was about 16 in. of space from the plywood roof deck to the bottom of the joist. About 14 in. of insulation was in this space, leaving a 2 in. to 3 in. air space above the insulation and below the plywood. This space acted like a chimney to draw the fire and fumes toward the peak of this 36 ft tall structure. Fire fighters were able to open a small area of the roof in an attempt to ventilate the structure and reach the fire, but the fire's rapid acceleration forced them off the roof before completing the task.

Fire fighters used large exterior streams from ladder trucks and conducted difficult interior operations in an attempt to control the fire. The fire was shielded from the hose streams by the roof until the roof burned off. A large interior balcony also shielded the fire and made it difficult to get water into the ceiling area. Direct property damage to the $1.5 million structure was estimated at $1 million. Damage to the $250,000 in contents was estimated at $135,000. No injuries were reported. Smoke alarms were present in the interior of the structure, but they were not in the roof joist area and did not operate.

B.4.3.4 Texas Church, 1998. At about 4:30 a.m., a motion-sensor burglar alarm in this 30 m × 30 m (100 ft × 100 ft), single-story church sounded at an alarm company and was relayed to the police station. The police who arrived at the scene notified the fire department of a fire at the site. The structure had brick veneer, concrete floors, and a metal roof deck with dropped ceiling. The roof was covered with tar and gravel. The church was closed for the night. No fire protection systems were present.

Investigators learned that four males, including one juvenile, broke a glass door panel with a hammer and entered the church. They squirted lighter fluid on the carpet in the hallway leading to fellowship hall and lit it. This fire was not intense enough to satisfy them, so they returned, poured gasoline inside the building, and threw Molotov cocktails inside. Direct property damage to the structure, valued at $1.5 million, was estimated at $165,000. Damage to the $500,000 in contents was estimated at $135,000. No injuries were reported.

All four suspects pled guilty to charges of arson in a place of worship. Two were sentenced to federal prison, one to a state prison, and the juvenile to a juvenile facility. Prior to setting this fire, the perpetrators had spent the night drinking, using drugs, and vandalizing cars and homes.

B.4.3.5 Illinois Church, 1998. A maintenance worker called 911 at 12:06 p.m. to report a fire in this two-story church that was undergoing exterior renovations. The church had wood frame, balloon construction. The walls, roof framing, and roof deck were wood, and the floors were wood joists. The roof was covered with asphalt shingles.

The worker smelled smoke in the chapel area and found fire inside the wall. He tried to put out the fire with an extinguisher but was forced back by smoke. A smoke alarm also sounded, but actuation was delayed because of the fire location. A partial sprinkler system in the basement was not a factor in the fire.

When fire fighters arrived, they found heavy black smoke coming from the roof and bell tower. On entering the building, they found heavy fire overhead and were ordered out of the building.

Workers using a heat gun to strip paint from windows had stopped working at about 11:45 a.m. but left the heat gun plugged in and lying on the scaffolding. Heat from the gun ignited wood and/or dust on the scaffolding. The fire quickly traveled through the balloon construction to the attic and through the common space. Damage to the structure was estimated at $2 million, and loss to the contents was also estimated at $2 million. Both represented total losses. One civilian and one fire fighter were injured in this fire.

B.4.3.6 Michigan Church, 1997. A passerby called 911 at 8:25 p.m. to report a fire in this church. The one-story church measured 13 m × 19 m (42 ft × 62 ft) with an additional entry section measuring 3.4 m × 6 m (11 ft × 20 ft). It also had a finished basement. Exterior walls were brick; interior walls were wood and plaster; the floor, roof framing, and roof deck were wood; and the roof was shingled. No fire protection systems were present.

Arriving fire fighters found smoke showing on all sides. An interior attack was begun, but due to heavy fire conditions, all personnel were evacuated and fire fighting went to a defensive mode.

The fire originated in the floor joists under the pulpit, between the finished floor of the chapel and the finished ceiling of the basement. The only heat source in that area was electrical wiring, and it appeared that the wiring overheated and ignited floor joints and subflooring, where the fire burned for quite awhile. The fire spread into the walls, traveled horizontally across the attic, and vented out the roof. When the fire entered the chapel, combustible materials, including seating and wood walls, fed it. When the roof collapsed, the entire first floor was destroyed, and the basement suffered water and smoke damage. Direct property damage was estimated at $200,000, equal to the total value. No injuries were reported.

B.4.3.7 Kentucky Church, 1997. At 1:54 a.m., a passerby called 911 to report a fire at this two-story church of unprotected ordinary construction. The church had brick veneer on the walls, the floor framing was concrete with tile, the roof framing and deck were wood, and asphalt shingles covered the roof. The structure had a ground floor area of 232 m^2 (2500 ft^2). No fire protection systems were present, and the church was closed for the night.

The fire started in a confessional after the thermostat kicked on the heater. The heat spread to cardboard boxes containing wine. The cardboard ignited, and flames spread to the wood veneer, curtains, and other items in the confessional. The fire spread upward and outward to other interior finishes and then spread throughout the church. Heavy winds fanned the fire after it vented through the roof. The fire caused an estimated $700,000 in direct property damage. No injuries were reported.

B.4.3.8 Oklahoma Church, 1996. At 4:01 a.m., a passerby called 911 to report a fire in this one-story frame structure with brick veneer. The structure was 46 m × 15 m (150 ft × 50 ft) and was closed for the night.

Arriving fire fighters found heavy smoke conditions and fire showing. The west wing was fully involved, and the fire had vented through the south side of the gable roof. The roof of the west side collapsed 20 to 30 minutes later. The fire spread to the east section of the building and that portion of the roof collapsed onto the floor area.

The structure, valued at $225,000, and the contents, valued at $125,000, were totally destroyed. No injuries were reported.

An investigation revealed that a window had been broken out, and a glass container filled with gasoline had been tossed inside the dining room area. The arsonist used a match to light the gasoline. Two days later, a 35-year-old white male was

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arrested for arson. The suspect had been arrested for arson twice as a teenager in another state. He was judged incompetent to stand trial and transferred to a mental hospital. Given the perpetrator's condition, law enforcement officials felt the crime was not racially motivated, although the church had a predominantly African-American congregation.

B.4.3.9 Minnesota Church, 1996. A passerby notified the fire department of a fire at this one-story wood frame, balloon construction church. The structure, built in 1961, was 102 ft long and 60 ft wide. The church had a full basement under it. The school/office area had just a slab and footings. There were no detection or suppression systems. The church was closed up about an hour before the fire was reported.

A farmer several miles away saw smoke and flames coming from the church and used his cellular phone to notify the fire department. When the fire department arrived, they found heavy fire and smoke coming from the front school addition of the church.

As the fire progressed, the roof of the main church collapsed, the first floor collapsed into the basement, and the roof on the fellowship hall partially collapsed. The fire department fought the fire all night. The structure and its contents, valued at $850,000, were totally destroyed. No injuries were reported.

An investigation revealed that the fire had started in a closet under the balcony when an electrical outlet and associated wiring shorted out or faulted and ignited the adjacent combustible material. The fire smoldered in the wall cavity for a long period of time before spreading to the exterior and then traveled up the wall to the roof.

B.4.3.10 Arizona Church, 1996. At 5:19 a.m. a neighbor called the fire department to report smoke and flames coming from the church. The structure was 45 m (148 ft) long, 19 m (62 ft) wide, and approximately 10.7 m (35 ft) high at the roof peak. It was brick masonry construction, with brick masonry walls, concrete slab floor, metal truss roof framing, wood plank roof deck, and built-up rolled roof covering. The structure was closed at the time.

Investigators found multiple points of origin, including artificial flowers in the hallway outside the conference room and hymnals scattered in pew areas in the sanctuary. No sign of forcible entry was found, and it appeared that the front middle doors were not secured at the time of the fire. Because of the numerous activities in the building, investigators believed it likely that a door or window could be easily overlooked when locking up. The wood pews, with upholstered and foam cushioned seats, and books facilitated rapid fire growth and flame spread. The large uncompartmentalized sanctuary and the stained glass windows allowed the fire to burn and grow for a significant period of time before the upper windows failed and flames became visible to the outside.

The incendiary fire caused an estimated $1.2 million in direct property damage to the $6 million structure and $600,000 in damage to the contents, which were valued at $1 million. No injuries were reported. No automatic detection or suppression systems were present in the structure. HVAC system fire dampers operated and probably slowed the spread of fire through the attic space. Draft stops in the attic space above the ceiling ran wall to wall and roof to ceiling and also helped slow the fire.

B.4.3.11 Wisconsin Church, 1996. At 3:10 a.m., a passerby notified the fire department of a possible fire at this brick and heavy timber structure. The three-and-a-half-story building was 24.4 m (80 ft) long and 30.5 m (100 ft) wide. Walls were made of brick and tile, the floor framing was heavy timber, the roof framing was wood and steel, the roof deck was wood, and the roof covering was asphalt. No fire protection systems were present, and the facility was closed for the night.

Arriving fire fighters found the fire in the basement women's room. Fire fighters were able to knock down most of the fire in the room. However, parts of the ceiling came down and showed that fire had spread to the next floor, so the fire fighters backed out and went into a defensive mode.

An investigation revealed that, during the evening's service, two 15-year-olds had passed a note in their confirmation class stating that the church would be burned down by morning. The girls had used a lighter to light a candle and then had started a fire in some silk flowers in the powder room. From there, the fire spread up into the false ceiling and extended from one floor to the next and out through the roof. It also extended to the main worship area ceiling and caused the ceiling to burn and fall down. People in the area had smelled wood burning, but assumed it was a fireplace. It is believed that the fire burned for at least 5 hours before it was discovered.

The structure, valued at $2.6 million, and its contents, valued at $1.9 million, were completely destroyed. Two fire fighters were injured when they slipped on ice. The two girls were sentenced to 100 hours of community service to the church, probation for one year, and $2,000 in restitution to the church.

B.4.3.12 Church, October 1995. A fire that resulted from roofing work being done in conjunction with a major renovation project destroyed this 103-year-old Victorian church, listed on the National Historic Register. It took 90 fire fighters to bring the blaze under control. Luckily, the 110 people who were attending meetings inside at the time the fire started managed to escape unharmed. The loss was total.

B.4.3.13 Church, May 1986. An incendiary fire was started in three places on the church's wooden benches. The one-story building measured 18.3 m by 30.5 m (60 ft by 100 ft) and was of mixed construction with brick and concrete walls, wood and metal roof sections, and both asphalt shingle and built-up roof covering. The building was closed for the night when fire was discovered and reported by a police patrol at 2:13 a.m. There was no automatic detection or suppression equipment. There were no injuries. The loss was $2.5 million out of $2.5 million value.

B.5 When Fire Prevention Fails. Due to factors beyond the control of even the most effective fire prevention program (especially programs against incendiarism), the risk of fire is always a distinct possibility, and any library depending entirely on fire prevention activities will be perpetually at risk of major disaster. According to Table B.5, nearly half of the fires in U.S. libraries during 1980 to 1997 and more than half of the resulting fire losses occurred during the hours when most libraries are either closed or at minimum staffing levels. What determines the fate of the building and the collections when fire strikes in the middle of the night is the integrity of the structure in terms of proper design, fire-resistive construction, and automatic systems for protection.

Table B.5 shows structure fires in libraries by time of day. These are fires reported to U.S. municipal fire departments and so exclude fires reported only to federal or state agencies or industrial fire brigades. Fires, deaths, and injuries are rounded to the nearest 1; direct property damage is rounded

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to the nearest thousand dollars. Property damage has not been adjusted for inflation. Sums might not equal totals due to rounding.

B.5.1 Fire Suppression Systems.

B.5.1.1 Automatic Sprinklers.

B.5.1.1.1 Automatic sprinklers have proved their value in the reduction of fire losses in cultural resource institutions. They are designed to perform the following functions:

(1) Detect fires at the point of origin
(2) Cause the sounding of alarms
(3) Control or extinguish the fire
(4) Summon fire department assistance immediately when connected directly to a central station, auxiliary, proprietary, or remote station fire alarm system

B.5.1.1.2 Some cultural resource institutions have been reluctant to install automatic sprinklers for fear of water damage to their collections. Yet in actual fires, the most extensive water damage has resulted from fire department operations with hose lines. Sprinkler protection minimizes water damage by placing a small amount of water directly on the fire and alerting the fire department at the same time. The sprinkler system controls the fire and reduces the need for a full-scale attack by the fire service. Many important libraries and museums built since 1970 have incorporated automatic sprinkler systems in the design. Many others have installed sprinklers to upgrade existing fire protection.

B.5.1.1.3 Some cultural resource institutions prefer preaction systems that can reduce the possibility of inadvertent sprinkler discharge. *[See Table D.3(d), Glossary of Fire Extinguishing Systems, in Annex D.]* Also, water detection systems are available that provide further protection against extraneous water damage from other sources as well as the automatic sprinklers. They provide an early warning alarm in the presence of water and locate the point of water ingress. Such systems should be considered for potentially flood-prone areas such as below-ground-level collections, areas not protected against domestic water accidents, areas near water boilers, or areas in which water pipe or drain leakage are of concern. In a typical single interlock preaction system, a separate detection system must activate to release water into the piping system.

B.5.1.1.4 In a library it is desirable to use no more water than is necessary to control or extinguish the fire. When a fire occurs in an area protected by an automatic sprinkler system, heat opens the sprinkler or sprinklers nearest the fire. Only those close enough to the fire to be heated to the operating temperature will discharge water. Records show that 70 percent of fires in sprinklered buildings have been controlled or extinguished by four sprinklers or fewer. NFPA 13, *Standard for the Installation of Sprinkler Systems*, should be followed for the installation of any sprinkler system, and NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, should be used for system maintenance.

Table B.5 Structural Fires in Libraries by Time of Day, 1980–1997 (Annual Averages)

Time of Day	No. of Fires	No. of Civilian Deaths	No. of Civilian Injuries	Property Damage
Midnight–1:00 a.m.	3	0	0	$ 5,000
1:00–2:00 a.m.	3	0	0	$ 28,000
2:00–3:00 a.m.	5	0	0	$ 731,000
3:00–4:00 a.m.	2	0	0	$ 924,000
4:00–5:00 a.m.	2	0	0	$ 122,000
5:00–6:00 a.m.	2	0	0	$ 7,000
6:00–7:00 a.m.	3	0	0	$ 9,000
7:00–8:00 a.m.	4	0	0	$ 22,000
8:00–9:00 a.m.	8	0	0	$ 28,000
9:00–10:00 a.m.	10	0	0	$ 18,000
10:00–11:00 a.m.	11	0	0*	$2,105,000
11:00 a.m –noon	11	0	0*	$ 19,000
Noon–1:00 p.m.	12	0	0*	$ 15,000
1:00–2:00 p.m.	13	0	0*	$ 61,000
2:00–3:00 p.m.	11	0	0	$ 152,000
3:00–4:00 p.m.	15	0	0	$ 18,000
4:00–5:00 p.m.	21	0	0*	$ 29,000
5:00–6:00 p.m.	14	0	0	$ 64,000
6:00–7:00 p.m.	13	0	0	$ 315,000
7:00–8:00 p.m.	9	0	0	$ 31,000
8:00–9:00 p.m.	10	0	0	$ 23,000
9:00–10:00 p.m.	6	0	0*	$ 172,000
10:00–11:00 p.m.	5	0	0	$ 4,000
11:00–midnight	6	0	0	$ 70,000
Total	198	0	1	$4,972,000
Hourly average	11	0	0*	$ 276,000

*Not zero, but rounds to zero.
Source: National estimates based on NFIRS and NFPA surveys.

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B.5.1.1.5 Where sprinkler systems are retrofitted into existing buildings, system specifications can call for an air test prior to the system hydrostatic test. Such tests are typically conducted at 2.8 kPa (40 psi) and can serve to identify missing piping, improperly connected fittings, or substandard joints that might otherwise result in water damage to the property.

B.5.1.1.6 Some methods of sprinkler installation require high-temperature brazing that introduces a potential source of fire ignition. Where automatic sprinklers are installed in existing book stacks, only mechanical methods of assembly should be permitted unless collections are removed.

B.5.1.1.7 A minimum clearance of 0.5 m (18 in.) is generally required between sprinklers and the top of storage. However, alternative provisions are described in NFPA 13, *Standard for the Installation of Sprinkler Systems*, for retrofit design of sprinkler systems in library stack rooms where shelves are installed continuously from floor to ceiling, for example, multitier book stacks. *(See Annex D for further information on the installation of fire protection systems.)*

B.5.2 Clean Agent Systems.

B.5.2.1 Special fixed systems using a halogenated agent, clean agent, water mist, carbon dioxide, high-expansion foam, or other extinguishing agents can provide needed protection for areas where especially valuable contents might be damaged by water. These systems can be automatically activated by a suitable smoke detection system.

B.5.2.2 Total-flooding, fixed gaseous-agent systems depend on achieving and maintaining the concentration of the agent required for effective extinguishment. Openings in the fire compartment (e.g., open windows or doors or a ventilation system that continues to operate) can prevent the achievement of an effective extinguishing concentration. Where a high reliability of operation is required for protection of high-value collections, an automatic sprinkler system in combination with a total-flooding gaseous-agent system should be considered.

B.5.2.3 It is good engineering practice to use total-flooding gaseous systems in combination with, rather than as an alternative to automatic sprinkler systems. The combination of a total-flooding gaseous system with an automatic sprinkler system provides a higher probability of confining fire growth to an area less than that typically covered by the operation of one sprinkler head [e.g., 9.3 m^2 (100 ft^2)]. The total-flooding gaseous system becomes a reliable substitute for manual suppression in the window of time between early warning detection and sprinkler operation. Human response (i.e., occupant manual extinguishing action) is the least reliable means of fire suppression, especially considering periods when the building is not occupied and therefore most vulnerable.

B.5.2.4 Total-flooding carbon dioxide systems are generally prohibited in normally occupied areas because they create an atmosphere immediately hazardous to life. Where these systems are installed, the life hazard exposure should be carefully evaluated. Explicit warning information and instructions for building occupants should be conspicuously posted. Similar precautions might be required for other special extinguishing systems.

B.5.2.5 The requirements in NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*; NFPA 17, *Standard for Dry Chemical Extinguishing Systems*; NFPA 11A, *Standard for Medium- and High-Expansion Foam Systems*; and NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, should be followed.

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Annex D Basics of Fire and Fire Protection Systems

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

D.1 Classification of Fires. Most fires that occur in cultural resource properties can be expected to fall into one or more of the following categories:

(1) Class A fires involve ordinary combustible materials, such as paper, wood, and textile fibers, where a cooling, blanketing, or wetting extinguishing agent is needed.
(2) Class B fires involve oils, greases, paints, and flammable liquids, where a smothering or blanketing action is needed for extinguishment.
(3) Class C fires involve live electrical equipment, where a nonconducting gaseous clean agent or smothering agent is needed.

D.2 Fire Detection and Alarm Systems. Technology is available to customize a fire detection system for the particular needs of specific properties. Early detection of fires affords the opportunity for occupant intervention and potentially faster response by automatic fire suppression.

D.3 Glossary of Fire Protection Systems. Table D.3(a), Table D.3(b), Table D.3(c), and Table D.3(d) describe detection, alarm, and extinguishing systems that are appropriate for use in cultural resource properties. Included are comments about the intended or optimum applications of each system and recommendations for system applications. Insofar as possible, nontechnical terminology has been used so that the information presented can be readily understood by persons who have been delegated fire safety responsibility.

Table D.3(a) Classification of Fire Detection Systems by Method of Detection

Type	Description	Comments
Smoke detection systems	These systems use devices that respond to the smoke particles produced by a fire. They operate on the ionization, photoelectric, cloud chamber, or other smoke particle analysis principle of operation. Spot-type smoke detectors use either the ionization principle of operation or the photoelectric principle. Line-type smoke detectors use the photoelectric principle. Aspiration-type smoke detectors use either the ionization, photoelectric, cloud chamber, or other particle analysis principle of operation.	These systems are intended for early warning. Some are designed for installation in ventilation ducts. *(See NFPA 72, National Fire Alarm Code.)* Properly installed, smoke detectors can detect smoke particles in very early stages of fire in the areas where they are located. The selection of a particular detector or mixture of detectors should be made by a fire protection specialist and based on building and fire-load conditions.
Heat detection systems	These systems use heat-responsive devices of either the spot or line type. They are mounted on exposed ceiling surfaces or on a sidewall near the ceiling. Heat detectors are designed to respond when the operating element reaches a predetermined temperature (fixed temperature detector), when the temperature rises at a rate exceeding a predetermined value (rate-of-rise detector), or when the temperature of the air surrounding the device reaches a predetermined level, regardless of the rate of temperature rise (rate compensation detector). Some devices incorporate both fixed temperature and rate-of-rise detection principles. Spot-type detectors are usually small devices a few inches in diameter. Line-type detectors are usually lengths of heat-sensitive cable or small bore metal tubing.	These systems are relatively low cost. They cannot detect small, smoldering fires. Line-type detectors can be installed in a relatively inconspicuous manner by taking advantage of ceiling designs and patterns. *(See NFPA 72, National Fire Alarm Code.)* The air temperature surrounding a fixed temperature device at the time it operates usually is considerably higher than the rated temperature, because it takes time for the air to raise the temperature of the operating element to its set point. This is called *thermal lag*. Rate compensation devices compensate for thermal lag and respond more quickly when the surrounding air reaches the set point. Given the monetary value and irreplaceable nature of typical museum collections, early-warning, air-sampling-type detector systems should be considered for optimum protection. These systems are also less conspicuous and minimize disruption to architectural integrity. Proper selection of a particular detector or a mixture of detectors should be made by a fire protection specialist and based on building and fire-load conditions.
Flame detection systems	These systems use devices that respond to radiant energy visible to the human eye (approximately 4000 to 7000 angstroms) or to radiant energy outside the range of human vision [usually infrared (IR), ultraviolet (UV), or both]. Flame detectors are sensitive to glowing embers, coals, or actual flames with energy of sufficient intensity and spectral quality to initiate the detector.	Because flame detectors are essentially line-of-sight devices, special care should be taken in their application to ensure that their ability to respond to the required area of fire in the zone that is to be protected will not be unduly compromised by the permanent or temporary presence of intervening structural members or other opaque objects or materials. *(See NFPA 72, National Fire Alarm Code.)*

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Table D.3(b) Classification of Fire Alarm Systems by Method of Operation

Type	Description	Comments
Local fire alarm system	This system operates in the protected premises and is responsive to the operation of a manual fire alarm box, waterflow in a sprinkler system, or detection of a fire by a smoke, heat, or flame-detecting system.	The main purpose of this type of system is to provide an evacuation alarm for the occupants of the building. Someone must always be present to transmit the alarm to fire authorities. *(See NFPA 72, National Fire Alarm Code.)*
Auxiliary fire alarm system	This system utilizes a standard municipal fire alarm box to transmit a fire alarm from a protected property to municipal fire headquarters. The alarms are received on the same municipal equipment and are carried over the same transmission lines as are used to connect fire alarm boxes located on streets. Operation is initiated by the local fire detection and alarm system installed at the protected property.	Some communities accept this type of system, but others do not. *(See NFPA 72, National Fire Alarm Code, and NFPA 1221, Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems.)*
Central station fire alarm system	This type of alarm system connects protected premises to a privately owned central station, monitors the connecting lines constantly, and records any indication of fire, supervisory, or other trouble signals from the protected premises. When a signal is received, the central station takes such action as is required, such as informing the municipal fire department of a fire or notifying the police department of intrusion.	This is a flexible system. It can handle many types of alarms, including trouble within systems at protected premises. *(See NFPA 72, National Fire Alarm Code.)*
Remote station fire alarm system	This system connects protected premises over telephone lines to a remote station, such as a fire station or a police station. It includes a separate receiver for individual functions being monitored, such as fire alarm signal or sprinkler waterflow alarm.	See *NFPA 72, National Fire Alarm Code.*
Proprietary fire alarm system	This system serves contiguous or noncontiguous properties under one ownership from a central supervising station at the protected property. It is similar to a central station system but is owned by the protected property.	This system requires 24-hour attendance at a central supervising station. *(See NFPA 72, National Fire Alarm Code.)*
Emergency voice/alarm communication systems	This system is used to supplement any of the other systems listed in this table by permitting voice communication throughout a building so that instructions can be given to building occupants. During a fire emergency, prerecorded messages can be played, fire department personnel can transmit live messages, or both.	See *NFPA 72, National Fire Alarm Code.*

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Table D.3(c) Classification of Fire Detection and Alarm Systems by Type of Control

Type	Description	Comments
Conventional system	This type of fire detection system utilizes copper wire to interconnect all initiating devices and signaling appliances to the fire alarm control panel. The wiring must be installed in a closed-loop fashion for each zone circuit to ensure proper electrical supervision or monitoring of the circuit conductors for integrity.	This is the most common type of fire alarm system. It provides basic alarm, trouble, and supervisory signal information and is used for small- to medium-size systems.
Microprocessor-based system	This system is identical to the conventional system, with the exception that the fire alarm control panel has more features available, such as smoke detector alarm verification and system walk test. Some of these systems "multiplex" information to their attached remote annunciators over four conductors, rather than one conductor per zone.	Most modern systems are microprocessor based in order to provide features desired by installers, owners, and fire departments.
Addressable multiplex system	This system utilizes initiating devices and control points, each assigned a unique three- or four-digit number that is the detector's "address." The fire alarm control panel's microprocessor is programmed with this address number. All activity by or affecting the device is monitored and recorded at the control panel.	This type of system provides more detailed information about alarm, trouble, or supervisory conditions. Essentially, the system is zoned by device rather than by an entire floor or area. The equipment for addressable multiplex systems is more costly, but generally installation costs are reduced substantially, operations are more flexible, and maintenance is more efficient.
Addressable analog multiplex system	This type of system is identical to the addressable multiplex system, with the exception that the smoke and heat detectors connected to the microprocessor are analog devices. The analog devices sense the fire signature and continuously send information to the control panel microprocessor, which determines the sensitivity, alarm point, and maintenance window of the analog device. Accordingly, this system is also called "intelligent" or "smart."	Analog systems provide the maximum flexibility and information that can be obtained from a fire alarm system. These computer-based systems do require sophisticated technical expertise to maintain and service, so this should be considered in the design process. Addressable fire detection systems allow for the execution of preprogrammed sensitivity levels for smoke detectors based on the time of day or days of the week, ranging from a low-sensitivity level during the period the premise is occupied to a high-sensitivity level when only employees are present or the protected premise is vacant.
Wireless system	This system uses battery-powered initiating devices, which transmit the alarm or trouble signal to a receiver/control panel. Each initiating device can be individually identified by the control panel for annunciation purposes.	The battery in each initiating device will last for a minimum of 1 year but needs to be replaced whenever the initiating device transmits a battery depletion signal to the control panel. Wireless systems can be used where it is not possible or feasible to install the electrical cable needed by hard-wired systems.

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Table D.3(d) Glossary of Fire Extinguishing Systems

Type	Description	Comments
Wet-pipe automatic sprinkler system	This permanently piped water system is under pressure and uses heat-actuated sprinklers. When a fire occurs, the sprinklers exposed to the high heat operate and discharge water individually to control or extinguish the fire.	This type of system automatically detects and controls fire. It should not be installed in spaces subject to freezing and might not be the best choice in spaces where the likelihood of mechanical damage to sprinklers or piping is high, such as in low-ceiling areas, and could result in accidental discharge of water. Where there is a potential for water damage to contents, such as books, works of art, records, and furnishings, the system can be equipped with mechanically operated on-off or cycling heads to minimize the amount of water discharged *(see on-off automatic sprinkler system).* In most instances, the operation of only one sprinkler will control a fire until the arrival of fire fighters. Often the operation of a sprinkler system will make the use of hose lines by fire fighters unnecessary, thus reducing the amount of water put onto the fire and the subsequent amount of water damage. *(See NFPA 13, Standard for the Installation of Sprinkler Systems, and NFPA 22, Standard for Water Tanks for Private Fire Protection.)*
Preaction automatic sprinkler system	This system employs automatic sprinklers attached to a piping system containing air that might or might not be under pressure, with a supplemental fire detection system installed in the same area as the sprinklers. When the fire detection system is actuated by a fire, a valve opens allowing water to flow into the sprinkler system piping and to be discharged from any sprinklers that are opened subsequently by the heat from the fire.	This system which automatically detects and controls fire, can be installed in areas subject to freezing. It minimizes the accidental discharge of water due to mechanical damage to sprinklers or piping and thus is useful in areas where system leaks could pose a hazard to works of art, books, records, and other materials susceptible to damage or destruction by water. However, such water damage is rare; only 1.6 accidental discharges occur per year per 1 million sprinklers in use. Failure of the actuation system would prevent operation of the preaction sprinkler system, except by manual operation of the water supply valve, and thus presents a potential failure mode that reduces the reliability of this system compared with wet-pipe systems. Furthermore, the preaction system requires a significantly higher level of regular maintenance, involving additional potential failure modes that further reduce its reliability relative to wet-pipe systems. Most of these water-sensitive items can be salvaged from wetting, but no one has found a way to recover them from ashes. *(See NFPA 13, Standard for the Installation of Sprinkler Systems, and NFPA 22, Standard for Water Tanks for Private Fire Protection.)*

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Table D.3(d) ***Continued***

Type	Description	Comments
On-off automatic sprinkler system	This system is similar to the preaction system, except that the fire detector operation acts as an electrical interlock, causing the control valve to open at a predetermined temperature and close when normal temperature is restored. If the fire rekindles after its initial control, the valve reopens, and water again flows from the opened sprinklers. The valve continues to open and close in accordance with the temperatures sensed by the fire detectors. Another type of on-off system is a standard wet-pipe system with on-off sprinklers. Each individual sprinkler is equipped with a temperature-sensitive device that causes the sprinkler to open at a predetermined temperature and to close automatically when the temperature at the sprinkler is restored to normal.	In addition to the favorable feature of the automatic wet-pipe system, these systems have the ability to automatically stop the flow of water when it is no longer needed, thus eliminating unnecessary water damage. *(See NFPA 13, Standard for the Installation of Sprinkler Systems, and NFPA 22, Standard for Water Tanks for Private Fire Protection.)*
Dry-pipe automatic sprinkler system	This type of system employs automatic sprinklers attached to a piping system that contains air under pressure. When a sprinkler operates, the air pressure is reduced, thus allowing the dry-pipe valve to open and water to flow through any opened sprinklers.	*(See the comments for wet-pipe automatic sprinkler system.)* This system can protect areas subject to freezing. Water supply must be in a heated area. *(See NFPA 13, Standard for the Installation of Sprinkler Systems, and NFPA 22, Standard for Water Tanks for Private Fire Protection.)*
Standpipe and hose system	This is a piping system in a building to which hoses are connected for emergency use by building occupants or the fire department.	This system is a desirable complement to an automatic sprinkler system. Staff must be trained to use hose effectively. *(See NFPA 14, Standard for the Installation of Standpipe and Hose Systems.)*
Clean agent system	This permanently piped system uses a limited, stored supply of a gaseous extinguishant under pressure and discharge nozzles to totally flood an enclosed space. The extinguishant is released automatically by a suitable detection system, and fire is extinguished by chemical or mechanical means.	This system causes no agent damage to protected books, manuscripts, records, paintings, or other valuable objects; it also leaves no agent residue. Clean agents are low in toxicity, but the products of decomposition of some agents during a fire could be hazardous. Therefore, the fire area should be promptly evacuated when a fire alarm sounds prior to agent discharge. Clean agents might not extinguish deep-seated fires in ordinary solid combustibles, such as paper and fabrics, but they are effective on surface fires in these materials. These systems need special precautions to avoid damaging effects caused by their extremely rapid release. The high-velocity discharge from nozzles might be sufficient to dislodge substantial objects directly in the path. Where carbon dioxide systems are used, personnel should evacuate before agent discharge to avoid suffocation. *(See NFPA 12, Standard on Carbon Dioxide Extinguishing Systems; NFPA 12A, Standard on Halon 1301 Fire Extinguishing Systems; and NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems.)*

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Table D.3(d) ***Continued***

Type	Description	Comments
Dry chemical system	This permanently piped system discharges a dry chemical from fixed nozzles by means of an expellant gas. The system either totally floods an enclosed space or applies the dry chemical directly onto the fire in a local application. The dry chemical extinguishes fires by the interaction of the dry chemical particles to stop the chain reaction that takes place in flame combustion. The dry chemical is released mechanically or with a suitable detection system.	Because this system leaves a powdery deposit on all exposed surfaces in and around the hazard being protected, it requires cleanup. This type of system provides excellent protection from fire when it is installed in the ducts and hood over cooking equipment such as deep fat fryers, range griddles, and broilers that could be a source of ignition. It might not extinguish deep-seated fires, but it is effective on surface fires. *(See NFPA 17, Standard for Dry Chemical Extinguishing Systems.)*
High-expansion foam system	This fixed extinguishing system generates a foam agent for total flooding of confined spaces and for volumetric displacement of vapor, heat, and smoke. It acts on a fire in the following ways: (1) Prevents free movement of air (2) Reduces the oxygen concentration at the fire (3) Cools (4) Is released automatically by a suitable detection system	Where personnel might be exposed to a high-expansion foam discharge, suitable safeguards should be provided to ensure prompt evacuation of the area. The discharge of large amounts of high-expansion foam can inundate personnel, blocking vision, making hearing difficult, and creating discomfort in breathing. It also leaves residue and requires cleanup. Properly designed, a high-expansion foam system used in conjunction with water sprinklers provides more positive control and extinguishment than either extinguishment system used independently. *(See NFPA 11A, Standard for Medium- and High-Expansion Foam Systems.)*
Wet chemical extinguishing system	This system operates in the same way as halon systems *(see clean agent system)*, except that it uses a liquid agent usually released by automatic mechanical thermal linkage. It is effective for restaurant, commercial, and institutional hoods, plenums, ducts, and associated cooking appliances.	This system leaves agent residue that is confined to the protection area(s) and requires cleanup. It is excellent for service facilities having range hoods and ducts. *(See NFPA 17A, Standard for Wet Chemical Extinguishing Systems.)*
Fine water mist system	In general, this piped system or modular, pressurized container system delivers a fine water mist. Water droplet size ranges to a maximum 1000 μm.	

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Annex E Resources for Protection of Cultural Resource Property Projects

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

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

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

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

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

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

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

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

NFPA maintains a list of fire protection consultants.

E.3 SFPE. Society of Fire Protection Engineers, 7315 Wisconsin Avenue, Suite 1225 W, Bethesda, MD 20814.

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

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

NICET certifies technicians in the following areas of fire protection: automatic sprinkler system layout; special hazards system layout (i.e., automatic and manual foam water, halon, carbon dioxide, and dry chemical systems); and fire detection and alarm systems. People with a NICET certification can also assist in the selection and use of fire protection systems. NICET provides certification for four levels of competence in all three of the listed areas of fire protection.

E.5 UL. Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062.

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

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Annex F Sample Ordinance Adopting NFPA 909

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

F.1 The following sample ordinance is provided to assist a jurisdiction in the adoption of this code and is not part of this code.

ORDINANCE NO. _____

An ordinance of the *[jurisdiction]* adopting the *[year]* edition of NFPA *[document number]*, *[complete document title]*, and documents listed in Chapter 2 of that [*code, standard*]; prescribing regulations governing conditions hazardous to life and property from fire or explosion; providing for the issuance of permits and collection of fees; repealing Ordinance No. _____ of the *[jurisdiction]* and all other ordinances and parts of ordinances in conflict therewith; providing a penalty; providing a severability clause; and providing for publication; and providing an effective date.

BE IT ORDAINED BY THE *[governing body]* OF THE *[jurisdiction]*:

SECTION 1 That the *[complete document title]* and documents adopted by Chapter 2, three (3) copies of which are on file and are open to inspection by the public in the office of the *[jurisdiction's keeper of records]* of the *[jurisdiction]*, are hereby adopted and incorporated into this ordinance as fully as if set out at length herein, and from the date on which this ordinance shall take effect, the provisions thereof shall be controlling within the limits of the *[jurisdiction]*. The same are hereby adopted as the [*code, standard*] of the *[jurisdiction]* for the purpose of prescribing regulations governing conditions hazardous to life and property from fire or explosion and providing for issuance of permits and collection of fees.

SECTION 2 Any person who shall violate any provision of this code or standard hereby adopted or fail to comply therewith; or who shall violate or fail to comply with any order made thereunder; or who shall build in violation of any detailed statement of specifications or plans submitted and approved thereunder; or fail to operate in accordance with any certificate or permit issued thereunder; and from which no appeal has been taken; or who shall fail to comply with such an order as affirmed or modified by a court of competent jurisdiction, within the time fixed herein, shall severally for each and every such violation and noncompliance, respectively, be guilty of a misdemeanor, punishable by a fine of not less than $ _____ nor more than $_____ or by imprisonment for not less than _____ days nor more than _____ days or by both such fine and imprisonment. The imposition of one penalty for any violation shall not excuse the violation or permit it to continue; and all such persons shall be required to correct or remedy such violations or defects within a reasonable time; and when not otherwise specified the application of the above penalty shall not be held to prevent the enforced removal of prohibited conditions. Each day that prohibited conditions are maintained shall constitute a separate offense.

SECTION 3 Additions, insertions, and changes — that the *[year]* edition of NFPA *[document number]*, *[complete document title]* is amended and changed in the following respects:

List Amendments

SECTION 4 That ordinance No. _____ of *[jurisdiction]* entitled *[fill in the title of the ordinance or ordinances in effect at the present time]* and all other ordinances or parts of ordinances in conflict herewith are hereby repealed.

SECTION 5 That if any section, subsection, sentence, clause, or phrase of this ordinance is, for any reason, held to be invalid or unconstitutional, such decision shall not affect the validity or constitutionality of the remaining portions of this ordinance. The *[governing body]* hereby declares that it would have passed this ordinance, and each section, subsection, clause, or phrase hereof, irrespective of the fact that any one or more sections, subsections, sentences, clauses, and phrases be declared unconstitutional.

SECTION 6 That the *[jurisdiction's keeper of records]* is hereby ordered and directed to cause this ordinance to be published.

[NOTE: An additional provision may be required to direct the number of times the ordinance is to be published and to specify that it is to be in a newspaper in general circulation. Posting may also be required.]

SECTION 7 That this ordinance and the rules, regulations, provisions, requirements, orders, and matters established and adopted hereby shall take effect and be in full force and effect *[time period]* from and after the date of its final passage and adoption.

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Annex G Informational References

G.1 Referenced Publications. The following documents or portions thereof are referenced within this code for informational purposes only and are thus not part of the requirements of this document unless also listed in Chapter 2.

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

NFPA 1, *Uniform Fire Code*™, 2003 edition.

NFPA 10, *Standard for Portable Fire Extinguishers*, 2002 edition.

NFPA 11A, *Standard for Medium- and High-Expansion Foam Systems*, 1999 edition.

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

NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*, 2004 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2002 edition.

NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*, 2003 edition.

NFPA 17, *Standard for Dry Chemical Extinguishing Systems*, 2002 edition.

NFPA 17A, *Standard for Wet Chemical Extinguishing Systems*, 2002 edition.

NFPA 22, *Standard for Water Tanks for Private Fire Protection*, 2003 edition.

NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, 2002 edition.

NFPA 40, *Standard for the Storage and Handling of Cellulose Nitrate Film*, 2001 edition.

NFPA 42, *Code for the Storage of Pyroxylin Plastic*, 2002 edition.

NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*, 2003 edition.

NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, 2002 edition.

NFPA 72®, *National Fire Alarm Code*®, 2002 edition.

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

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 2002 edition.

NFPA 92A, *Recommended Practice for Smoke-Control Systems*, 2000 edition.

NFPA 92B, *Standard for Smoke Management Systems in Malls, Atria, and Large Spaces*, 2005 edition.

NFPA *101*®, *Life Safety Code*®, 2003 edition.

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

NFPA 204, *Standard for Smoke and Heat Venting*, 2002 edition.

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

NFPA 232, *Standard for the Protection of Records*, 2000 edition.

NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations*, 2004 edition.

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

NFPA 269, *Standard Test Method for Developing Toxic Potency Data for Use in Fire Hazard Modeling*, 2000 edition.

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

NFPA 914, *Code for Fire Protection of Historic Structures*, 2001 edition.

NFPA 1221, *Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems*, 2002 edition.

NFPA 1600, *Standard on Disaster/Emergency Management and Business Continuity Programs*, 2004 edition.

NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, 2004 edition.

Burklin, R. W., and R. G. Purington, *Fire Terms: A Guide to Their Meaning and Use*, 1980.

Fire Protection Handbook, 19th edition, 1997.

Isner, M. S., "Investigation Report: Fire in Los Angeles Central Library Causes $22 Million Loss," *NFPA Fire Journal*, Vol. 81, No. 2, March/April 1987.

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Willey, A. E., "Investigation Report: The Charles Klein Law Library Fire," *NFPA Fire Journal*, Vol. 66, No. 6, November 1972.

G.1.2 Other Publications.

G.1.2.1 ASTM Publications. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*, 2004.

ASTM E 1472, *Standard Guide for Documenting Computer Software for Fire Models*, 2003.

G.1.2.2 BSI Publication. British Standards Institution, 389 Chiswick High Road, London W4 4AL, England.

DD 240, *Firesafety Engineering in Buildings, Part 1: Guide to the Application of Fire Safety Engineering Principles*, 1997.

G.1.2.3 HUD Publication. National Institute of Building Sciences for the Department of Housing and Urban Development, 1201 L Street, NW, Suite 400, Washington, DC 20005-4024.

"Egress Guideline for Residential Rehabilitation."

"Guideline on Fire Ratings of Archaic Materials and Assemblies."

G.1.2.4 SPNHC Publication. Society for the Preservation of Natural History Collections, c/o Lisa Palmer, P.O. Box 797, Washington, DC 20044-0797, www.spnhc.org.

Rose, C., C. A. Hawks, and H. H. Genoways, *Storage of Natural History Collections: A Preventative Conservation Approach*, .

G.1.2.5 U.S. Government Publications. U.S. Government Printing Office, Washington, DC 20402.

"How to Define Categories of Historic Properties," *National Register Bulletin 15, How to Apply the National Register Criteria for Evaluation*, 1991.

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G.1.2.6 Other Publications.

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G.2 Informational References. The following documents or portions thereof are listed here as informational resources only. They are not a part of the requirements of this document.

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

NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*, 2003 edition.

NFPA 30, *Flammable and Combustible Liquids Code*, 2003 edition.

NFPA 70, *National Electrical Code®*, 2005 edition.

NFPA 80A, *Recommended Practice for Protection of Buildings from Exterior Fire Exposures*, 2001 edition.

NFPA 230, *Standard for the Fire Protection of Storage*, 2003 edition.

NFPA 291, *Recommended Practice for Fire Flow Testing and Marking of Hydrants*, 2002 edition.

NFPA 299, *Standard for Protection of Life and Property from Wildfire*, 1997 edition.

NFPA 551, *Guide for the Evaluation of Fire Risk Assessments*, 2004 edition.

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G.2.2 ASTM Publications. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, 1991.

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G.2.3 Other Publications.

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G.3 References for Extracts. The following documents are listed here to provide reference information, including title and edition, for extracts given throughout the nonmandatory sections of this code as indicated by a reference in brackets [ ] following a section or paragraph. These documents are not a part of the requirements of this document unless also listed in Chapter 2 for other reasons.

NFPA 1, *Uniform Fire Code*™, 2003 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2002 edition.

NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, 2002 edition.

NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*, 2003 edition.

NFPA 72®, *National Fire Alarm Code®*, 2002 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 2002 edition.

NFPA *101®*, *Life Safety Code®*, 2003 edition.

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

NFPA 472, *Standard for Professional Competence of Responders to Hazardous Materials Incidents*, 2002 edition.

NFPA 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, 2001 edition.

NFPA 914, *Code for Fire Protection of Historic Structures*, 2001 edition.

NFPA 921, *Guide for Fire and Explosion Investigations*, 2004 edition.

NFPA 1141, *Standard for Fire Protection in Planned Building Groups*, 2003 edition.

NFPA 5000®, *Building Construction and Safety Code®*, 2003 edition.

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Annex H Compact Storage Fire Tests

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

H.1 Introduction. The test reports and summary included in this annex provide fire size, site-specific information, storage configurations, and automatic fire suppression systems design information.

The following features were found to have a significant impact on this type of hazard:

(1) Fuel type and arrangement; for instance, a slow fire was observed in the 1979 tests in densely packed archive storage boxes (ordinary hazard sprinkler system design), and a fast fire growth was observed in the 1992 tests with loosely stored newspaper and corrugated cartons (extra hazard sprinkler system design)
(2) Configuration of storage including a gap between storage units
(3) Storage height
(4) Overhead clearance above storage
(5) Room height
(6) Open shelving versus closed shelving
(7) Sprinkler density and sprinkler response time

The following article, "Full-Scale Fire Tests and the Development of Design Criteria for Sprinkler Protection of Mobile Shelving Units," is from *Fire Technology,* Volume 30, No. 1 (1994).

Full-Scale Fire Tests and the Development of Design Criteria for Sprinkler Protection of Mobile Shelving Units

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Abstract

In early 1991, a new sprinkler system was planned for the existing National Archives/National Library of Canada building in Ottawa. A major challenge in the design and installation of the sprinkler systems was to protect mobile compact shelving units located in the three levels below grade. Storage of documents in these shelving units is typically within 178 mm of the concrete slab ceiling. The minimum clearance permitted by the sprinkler system installation standard is 457 mm from the sprinkler deflector to the top of the storage. To conform with the sprinkler design standard, the top level or levels of storage would have had to be removed and additional storage space acquired. Because of the annual cost of this additional storage, an investigation was begun to determine feasible alternatives that would permit a reduction in clearances between sprinklers and storage, while maintaining an acceptable level of fire safety. This paper describes the series of five full-scale fire tests that were conducted to assess various fire protection options. Based on these tests, design criteria were developed for a sprinkler system using quick response horizontal sidewall sprinklers to protect the mobile shelving units. An overview of this technically based fire protection system for use in protecting shelving units with reduced clearance is also presented.

Introduction

In early 1991, a new sprinkler system was planned for the existing National Archives/National Library of Canada building in Ottawa. A major challenge in the design and installation of the sprinkler systems was to protect mobile compact shelving units located in the three levels below grade in the building. Storage of documents in these shelving units is typically within 178 mm of the concrete slab ceiling. Since the minimum clearance permitted by the sprinkler system installation standard [1] is 457 mm from the sprinkler to the top of the storage, the potential impact on existing storage practices and space requirements for the National Archives/Library was significant. In order to comply with the sprinkler installation standard and to ensure adequate fire protection, the library faced the prospect of removing all storage from the top shelves and, in many cases, the top two shelving rows throughout the stacks. In addition to the library staff that would be needed to remove and reorganize files, there would also be considerable annual costs for additional storage space.

Because of the tremendous cost involved in fully protecting the building in accordance with the standard, Public Works Canada and the National Library of Canada began an investigation to determine feasible alternatives that would permit a reduction in clearances between the sprinklers and the storage, while maintaining an acceptable level of fire safety. The question was whether a sprinkler system could extinguish or control a fire in the shelving units, taking into consideration the specific geometry and nature of the fuel package.

Based on discussions with the Fire Commissioner of Canada, who was the authority having jurisdiction, it was determined that technically based alternatives to strict compliance with the applicable installation standard would be considered. However, any alternative arrangements would have to be evaluated on the basis of full-scale fire tests, which would demonstrate that the proposed sprinkler installation could extinguish or control a fire at least as well as an installation that conformed to the installation standard. This approach, based on equivalents, is allowed within the terms of the *National Building Code of Canada.*[2]

This paper describes the five full-scale fire tests that were conducted at the National Fire Laboratory's full-scale test facility near Almonte, Ontario. These tests were used to assess various sprinkler system options for protecting the compact shelving units. Based on the results of these tests, design criteria were developed for a fire protection system to be used in the basement levels of the library. This fire protection system would result in a minimal loss of effective storage space and was recommended to Public Works Canada as a technically based alternative.

Previous Work

Before the tests discussed in this paper were undertaken, two series of fire tests on compact mobile shelving units were conducted. The first series, conducted at Factory Mutual Research Corporation in 1978,[3] indicated that, with the available state-of-the-art sprinkler technology, the records stored in the shelving were substantially damaged by the fire despite "successful" sprinkler operation.

The second series of fire tests was conducted at Underwriters Laboratories Inc. in 1989 to develop the sprinkler protection system for a new U.S. Archives building in Washington, D.C. (Archives II). These tests showed that quick response sprinklers, along with enhancements in the operation and construction of the mobile shelving units, could limit fire damage to the archival records located near the ignition source.[4]

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The sprinkler system developed for Archives II was intended for use in a new facility designed to meet current codes and standards. As such, it was possible to specify the requirements for both the sprinkler system and the shelving units to provide an optimum fire protection system. The sprinkler system developed as part of this current study was intended for retrofit in an existing facility in which a sprinkler system could not be installed to meet installation standards without a substantial loss of storage capacity.

Description of Hazard

The mobile stack units present in the basement levels of the National Library were "Compactur" mobile shelving units.† (See footnote at the end of extract.) These were entirely open units; that is, the shelves had no tops, and there were no internal partitions. The shelving units were typically 4.6 m long. Fixed shelves were spaced approximately 6.1 m on center, with five to seven mobile shelves between them (see Figure H.1).

The basic stack units were arranged to provide access aisles 1.2 m wide at the ends of the shelves. There was minimal clearance between the shelving units of stack arrays adjacent to walls and the walls themselves. Access to these stack arrays was from one end only.

Each mobile shelving unit consisted of a mobile carriage mounted on rails (see Figure H.2). Six upright columns equispaced along the center line of the carriage were used to support cantilever shelves mounted on both sides. Typically, there were six levels of shelving mounted on each unit, for a total of 60 shelving sections per unit.

The contents of the shelves were predominantly paper documents, such as letters, reports, memos, and journals, stored in corrugated cardboard document boxes with closed lids. There were a number of plastic plan canisters in the building, but these were confined to a limited area and were not considered to represent a typical fuel load. There was no storage of micro-fiche, film, or cassettes.

FIGURE H.1 Layout for Basement Levels of National Library of Canada.

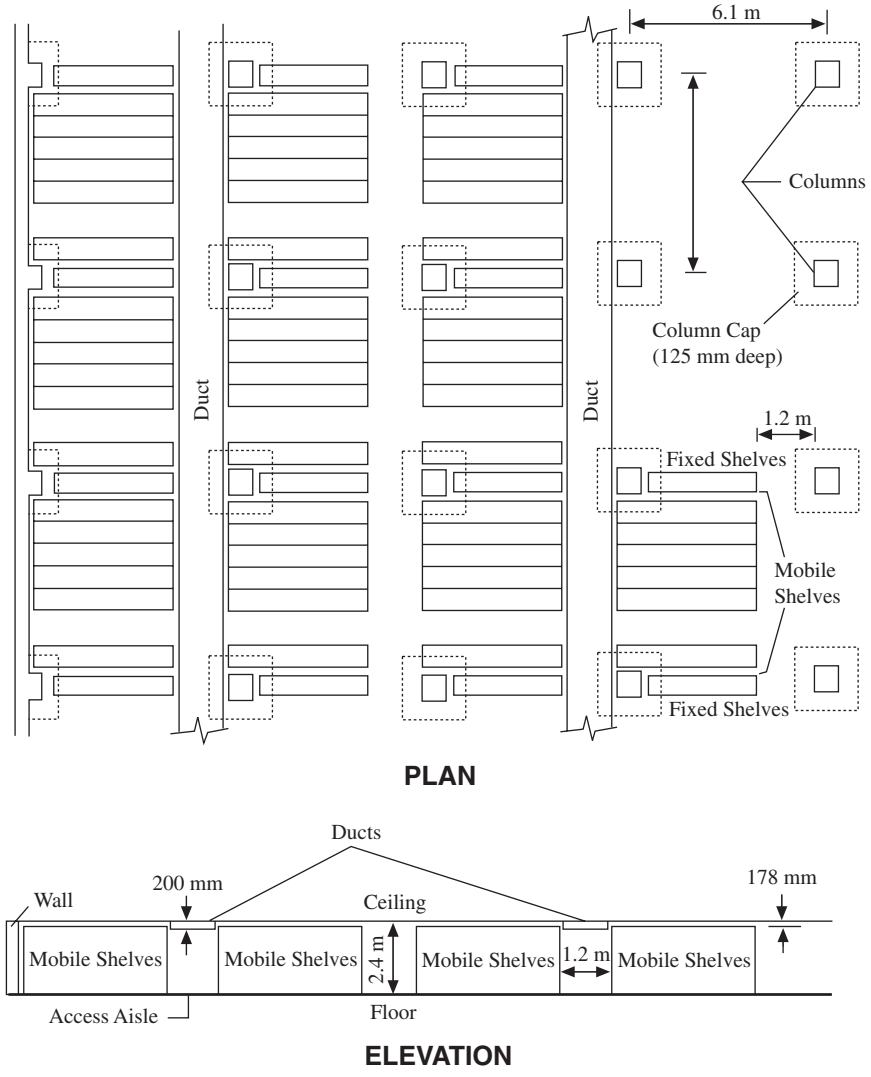

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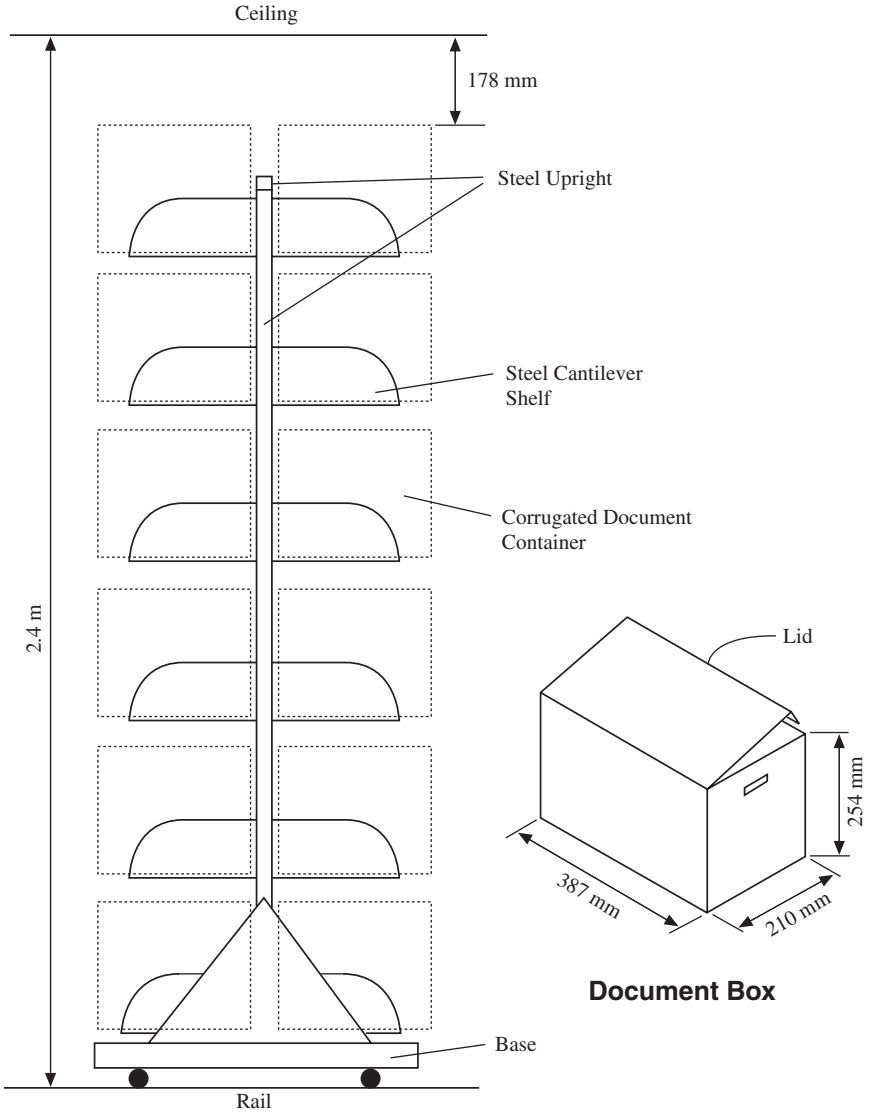
FIGURE H.2 End View of Mobile Shelving Unit



The cardboard document boxes, which were 210 mm wide by 387 mm long and 254 mm high (see Figure H.2), were packed side-by-side with four boxes on each shelf section and up to 240 boxes on each mobile unit. For the most part, they were partially filled with an average weight of 6.8 kg, including the box. The total fuel load on each mobile unit was thus approximately 1,650 kg. For a typical shelving area consisting of two fixed shelves and five mobile shelves, the fuel load density was approximately 375 kg/m^2 averaged over the shelving area.

In localized areas, there was also extensive storage of folded newspapers in open-topped, cloth-covered periodical boxes 102 mm wide by 228 mm long and 298 mm high. The average weight of each periodical box was 2.3 kg. When the shelves were closed, the boxes on adjacent mobile shelves were grouped so tightly that sprinkler spray could not penetrate below the top level. This was not the case where the mobile shelves faced fixed shelves, however. Rubber stops, which were placed at the ends of the rails to keep the mobile units from running off the tracks, also maintained a minimum clearance of 102 mm between the material stored on the fixed shelves and the first adjacent mobile shelf. The newspapers were packed tightly together in the periodical boxes. When the shelves were closed, the ends of the newspaper touched such that sprinkler spray could not penetrate below the top level.

The Test Facility

A full-scale mock-up of a shelving array typical of those found in the basement of the National Library was constructed at the National Fire Laboratory's full-scale test facility. The National Library of Canada provided typical shelving units that consisted of two fixed shelves and five double-row mobile units. The stack array covered an area approximately 4.6 mm by 6.7 m. The test facility is shown in Figures H.3 and H.4. As a basis for instrumentation and recording observations, each shelving section was labeled using an alphanumeric system. For this system, each side of a shelving unit was assumed to be a single row of shelves and was labeled alphabetically. The numbering system for Row H is illustrated in Figure H.3.

Four wall assemblies, constructed using wood studs and gypsum wallboard with approximately 25% of the wall area left uncovered, were positioned around the shelving bay to simu-

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late adjacent shelving units. This partially closed perimeter was intended to replicate obstructions, such as adjacent columns and other stack units, that could affect air movement in the building. Two walls 4.6 m long were positioned 0.75 m from the fixed shelving unit to simulate mobile shelves in adjacent shelving bays. Two wall sections 8.2 m long were located 1.2 m from the sides of the shelving unit to simulate the normal access aisles and adjacent shelving bays.

The test facility was covered with a noncombustible ceiling assembly. The ceiling in the shelving area and above one corridor was 2.4 m high. In the other corridor, the ceiling height was reduced to 2.2 m to simulate the ventilation ducts that are located in every second corridor in the library and that are as wide as the aisle. There was minimal clearance (25 to 50 mm) between the sides of these ducts and the shelving units. The ducts act as barriers to the flow of hot gases and sprinkler spray; as such, they have a considerable impact on both the location and activation of the sprinklers.

A series of 600 mm square structure columns, with column caps 1.83 m square by 125 mm deep, were located throughout the basement, as shown in Figure H.1. These columns, which are located at the end of the fixed shelving units, did not have an impact on the fire scenario used in the test program and were not simulated in the test facility. Because of the very limited clearances above the storage and the depth of the column caps, these columns limited the arrangement of sprinkler piping in the library and had to be taken into account when the sprinkler system design criteria were developed.

FIGURE H.3 Test Facility.

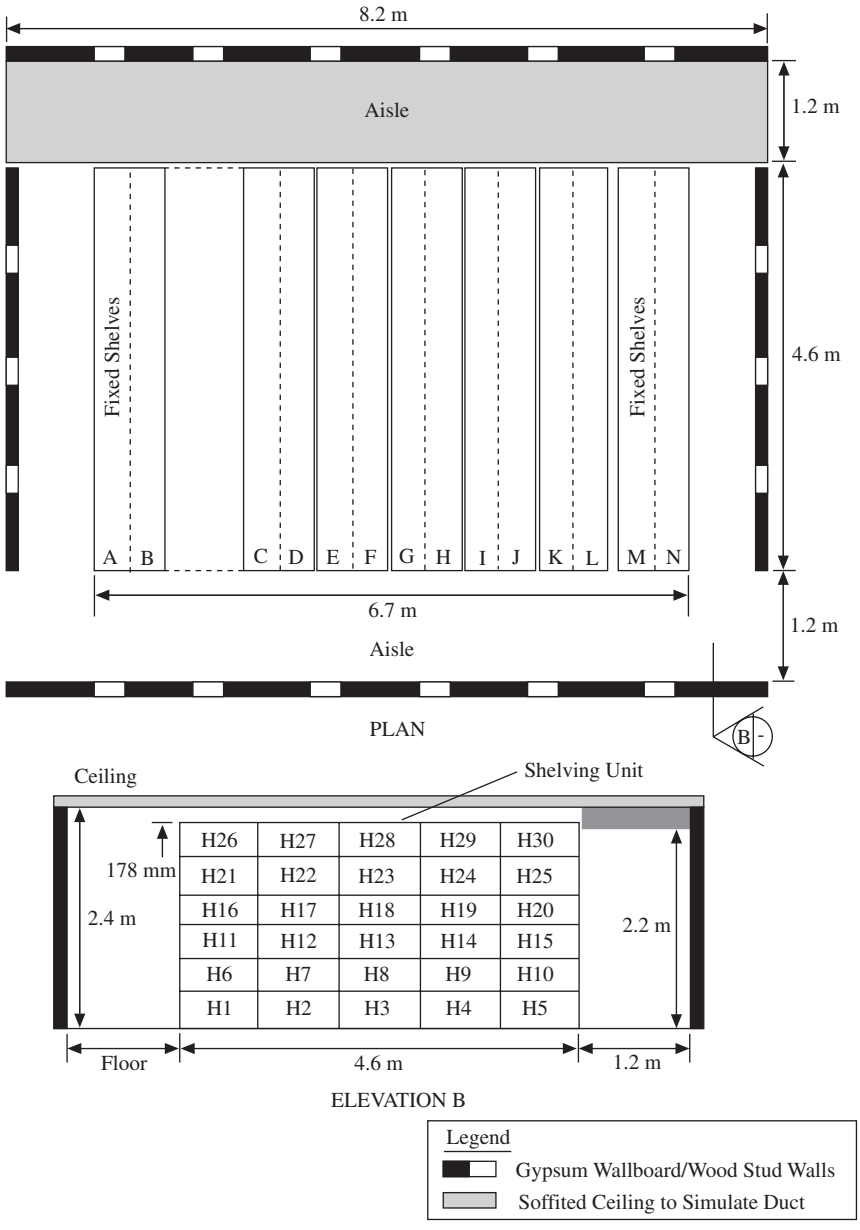

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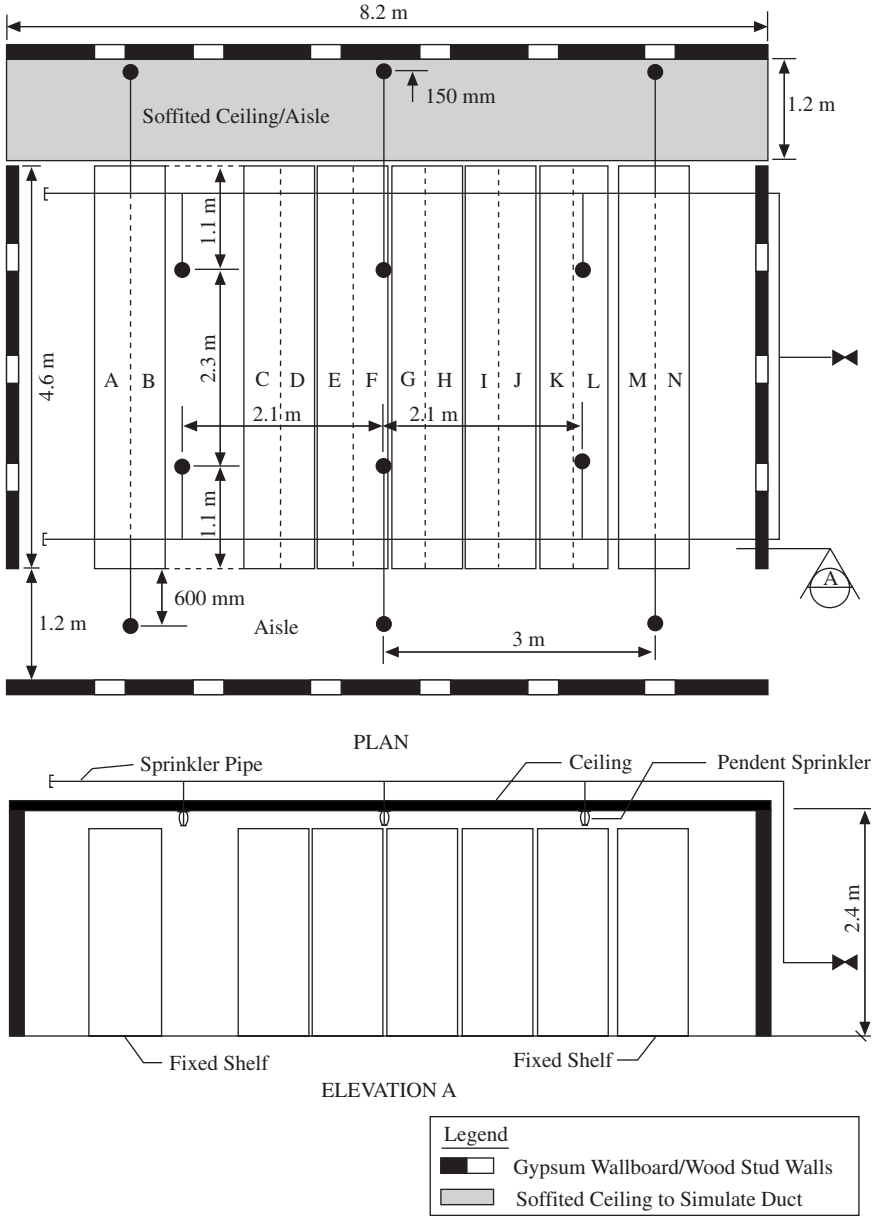
FIGURE H.4 Pendent Sprinkler Layout.



Fire Scenario

Based on an assessment of the hazard as a result of the observations in the library, an initial worst-case fire scenario was developed for the full-scale fire tests:

(1) All the mobile units would be pushed tightly together with minimal or no space between the storage on adjacent shelves.

(2) The fire would start at the bottom center of the closed mobile units at the maximum distance from the nearest sprinklers. Such a fire could involve the maximum fuel before sprinkler activation. It would also be in the area to which there would be the least amount of sprinkler penetration.

(3) The shelving units and the fuel load would be typical of that observed in the library.

(4) A fuel load combination consisting of the open newspaper storage on the mobile units adjacent to the fire source and document boxes on the remaining shelves was thought to present the maximum challenge to the sprinkler system. In developing this scenario, it was assumed that the exposed edges of the newspaper would result in a very rapid initial fire spread. This rapidly developing fire could burrow into areas with high fuel load densities (the document boxes), thus posing the possibility of a sustained, high-severity fire.

(5) The clearance between the ceiling and the top level of storage on the shelves would be 178 mm + 25 mm.

Despite the fact that there were areas in the library where there were clearances of only 102 mm, the 178 mm clearance for the initial tests was chosen for two reasons. First, Public Works Canada and the National Library of Canada asked that

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on-off sprinklers be used for the first sprinkler system tested, and such sprinklers are quite large in comparison to conventional pendent sprinklers. Assuming commercially available copper fittings and the copper tubing installed as close to the concrete ceiling as possible, along with the dimensions of the specified sprinkler, it was estimated that the sprinkler deflector would be a minimum of 133 mm below the ceiling in the closed position. When activated, the deflector extended 18 mm further. The specified clearance of 178 mm thus provided a minimum 25 mm clearance between the sprinkler deflector and the top of the storage. Second, the library would have had to remove the top level of shelves to provide a clearance greater than 178 mm.

Thus, the specified clearance of 178 mm would provide at least a minimum clear space for the development of the sprinkler spray without reducing the storage capacity in the library.

Sprinkler Layouts

The first sprinkler arrangement used pendent sprinklers to protect the stack area (see Figure H.4). In developing the pendent sprinkler layout, it was assumed that the combination of the following factors would make it very difficult to get effective sprinkler coverage for all areas:

(1) The minimal clearance between the sprinkler deflector and the material on the top shelves, and

(2) The presence of obstructions such as light fixtures and column caps in the library stack areas.

In an attempt to improve the sprinkler coverage in the confined space between ceiling and storage, the sprinklers were spaced much closer together than would normally be the case for an NFPA 13 sprinkler system (see Figure H.4). Each sprinkler covered an area of less than 4.5 m^2; normally, they would be permitted to cover up to at least 12 m^2 for this occupancy.

The on-off sprinklers were installed with the deflector 133 mm below the ceiling in the closed position. In the operating position, the deflector was 151 mm below the ceiling, providing a clearance of 27 mm between the sprinkler and the top of the storage. The quick response sprinklers were installed with the deflector 125 mm below the ceiling. This provided an additional 26 mm clearance between the top of the storage and the sprinkler.

The second sprinkler arrangement used horizontal sidewall sprinklers (HSW) to protect the stack array (see Figure H.5). Even though NFPA 13, *Standard for the Installation of Sprinkler Systems*, does not recognize the use of horizontal sidewall sprinklers in this configuration, it was anticipated that HSW sprinklers would be able to provide a uniform spray distribution in the 178 mm clear space. The layout for the horizontal sprinklers was designed to maximize water spray coverage and minimize the possibility of spray from one sprinkler delaying the activation of adjacent sprinklers. To achieve this, the sprinklers were arranged in a staggered array on opposite sides of the shelving units. On the side of the stack array with three sprinklers, the two end sprinklers were centered on the gap between the fixed shelving unit and the first mobile unit. This ensured maximum water spray penetration into the one area where, because of the stops installed on the rails, relatively "good" penetration of water spray to the lower shelving levels was possible. The third sprinkler on that side was located on the center of the shelving array, giving a 2.6 m spacing between the sprinklers. The two sprinklers on the opposite side of the stack array were staggered so as to be exactly half way between the sprinklers on the opposite side.

For the initial tests with horizontal sidewall sprinklers, the sprinklers were installed with the deflectors a nominal 100 mm ± 12 mm below the ceiling. This is in accordance with the standard for the installation of sidewall sprinklers.[1] The distance between the ceiling and the top of the storage was 178 mm.

The fifth test investigated the possibility of providing sprinkler coverage over a stack array with only 100 mm clearance instead of 178 mm. In this test, the HSW sprinklers were positioned closer to the ceiling, with a nominal 50 mm clearance between the ceiling and the sprinkler deflector. It was thought that this arrangement could be achieved with commercially available fittings, and it ensured that the sprinkler deflector was at least 25 mm above the top level of storage.

In order to maximize spray coverage, the horizontal sprinklers were positioned with the deflectors as close as possible to the end of the shelving array. For the end with the HSW sprinkler against the aisle duct (soffited ceiling), it was assumed that, using commercially available hardware, the sprinkler would protrude 150 mm to 200 mm into the shelving array.

For both sprinkler layouts — that is, those using either pendent or HSW sprinklers — six pendent sprinklers were used in the aisles. These sprinklers were located at the centers of the fixed shelves and at the center of the stack array, giving a nominal spacing of 3.05 m along the length of the aisle. For the aisle with the higher ceiling, the three sprinklers were positioned on the center line of the aisle. In the second aisle, where the duct reduced the headroom, it was assumed that the sprinklers would be positioned near one side of the aisle for safety purposes. For the purpose of this test program, a worst-case scenario with the sprinklers positioned along the side of the corridor opposite the test array was selected. The pendent sprinklers under the duct were installed with the deflector 133 mm below the duct for the on-off sprinklers and 125 mm below the duct for the quick response sprinklers.

The sprinkler system was connected to the laboratory's 2,080 L/min fire pump with a maximum static pressure of 895 kPa. Provisions were made to control and measure the pressure and water flow rate at the base of the 50 mm diameter riser used to feed the test facility's sprinkler system. A series of flow measurement tests was carried out to map the water supply/demand curves for the system. These tests indicated that, for the five to seven sprinklers that typically activated during these tests, maximum flow rates of 870 to 1,040 L/min at pressures of 669 to 552 kPa could be supplied to the sprinkler system.

The specifications for the sprinklers used in all tests are given in Table H.1. The two quick response glass-bulb-type sprinklers were from the same manufacturer.

Spray Distribution Tests

Preliminary spray distribution tests were conducted with the three types of sprinklers used for the full-scale tests. These tests concentrated on the sprinklers' ability to wet the top level of storage on the shelving array. The assessments were qualitative in nature, with the primary criterion being the ability of the sprinklers to wet the corrugated document boxes placed on the top level of shelving. No effort was made to determine the actual water spray distribution. However, these tests did play an important role in determining the sprinkler flow rates used for the full-scale tests.

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FIGURE H.5 Horizontal Sidewall and Pendent Sprinkler Layout.

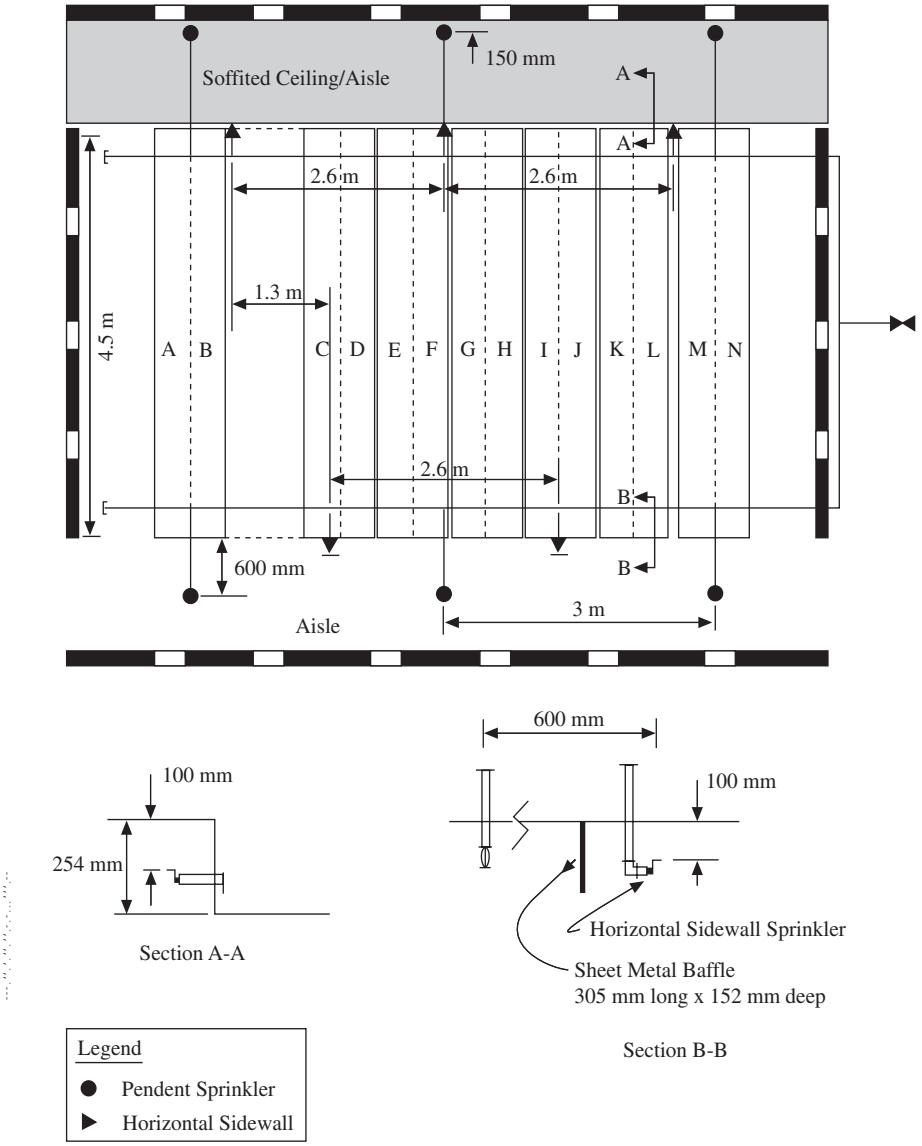

Table H.1 Sprinkler Specifications

Sprinkler	Activation Mechanism	Temperature Rating (°C)	Orifice (mm)	K-factor [L/min/(bar)$^{1/2}$]
On/off pendent	Fusible alloy	60	12.5	80
	Bimetallic disk	74		
QR pendent	Glass bulb	68	12.5	80
QR horizontal sidewall	Glass bulb	68	12.5	80

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On-Off Pendent Sprinklers

The spray distribution test was conducted with three of the four sprinklers closest to the fire source. The sprinklers were mechanically "opened," and the flow was initially set at an average of 58 L/min each. At a "K" factor of 80 L/min/(bar)$^{1/2}$, the pressure at each sprinkler was approximately 50 kPa, which is the minimum pressure necessary to operate according to product listing/approval standards and NFPA 13. The average density at this flow rate was 12.2 (L/min)/m^2. This is higher than the minimum required by NFPA 13 but is consistent with the densities used to protect similar stack systems in the Archives II test series. The test at this flow rate indicated that substantial portions of the upper level of the storage would receive minimal or no water spray.

In a second test, the average flow rate per sprinkler was increased to 84.4 L/min, and the pressure was increased to 108 kPa. With the given spacing, this flow rate resulted in a density of 18.7 (L/min)/m^2, which is greater than the density NFPA 13 requires for facilities classified as "Extra Hazard." Although some improvement in the wetting pattern was observed, an unwetted area remained at the center of the sprinkler array.

With the limited clearance between the deflector of the on-off pendent sprinkler and the top of the storage and with the predominantly downward direction of the spray, most of the spray hit the boxes very close to the sprinkler. Wetting at the center of the sprinkler array was primarily due to splashing from the top of the boxes.

Based on the water spray tests, it was concluded that control probably would not be achieved using the lower flow rate. With the minimum spacing between the sprinkler deflector and the storage, it was also felt that any further increase in the flow rate would not result in a significant improvement in the spray pattern. As a result, the 84.4 L/min flow rate per sprinkler was chosen for the full-scale test.

Quick Response Pendent Sprinklers

Spray distribution tests were also conducted with the quick response (QR) pendent sprinklers. Three flow rates providing densities of 12.6 (L/min)/m^2, 15.8 (L/min)/m^2, and 18.7 (L/min)/m^2 were used. The results of these tests indicated that the added clearance provided by the low-profile sprinklers allowed for more effective wetting across the top of the storage than was achieved with the on-off sprinklers. However, wetting at the center of the array was only achieved with the higher flow rates. For Test 2, in which the QR pendent sprinklers were used, a density of 18.7 (L/min)/m^2 was selected.

Quick Response Horizontal Sidewall Sprinklers

Spray distribution tests were carried out using only the three horizontal sidewall sprinklers closest to the fire source. Flow rates providing densities of 14.3 (L/min)/m^2 and 16.0 (L/min)/m^2 were assessed. The horizontal sprinklers were able to provide uniform wetting over the entire shelf area at both pressures.

Sprinkler Response Times

Before the full-scale tests were conducted, the activation times for the pendent and horizontal sprinklers were estimated using the sprinkler/detector response model in FPETOOL.[5] For the fire scenarios used in the full-scale tests, the nearest pendent and sidewall sprinklers were 1.5 m and 2.5 m from the center line of the plume, respectively. An RTI of 28 (ms)$^{1/2}$ was assumed for both sprinklers.

For the sprinkler/detector response routine, the fire growth rate and the height of the ceiling above the fire must be input. With the limited flammability data available for the fuel package involved in the test, it was impossible to model the initial fire development. The four standard fire growth models — slow, medium, fast, and ultra-fast growth rates[5] — included with FPETOOL were used to compare the activation times for the pendent and horizontal sidewall sprinklers.

During preliminary tests with the fuel package in the test array, it was observed that, once it began, the fire spread rapidly upward on the material stored on the shelves above the fire source. Thus, there was fire at all levels of the shelving between the floor and the ceiling very early in the test. For these simulations, it was assumed that the base of the fire was located 1.5 m below the ceiling.

The results for the four simulations using FPETOOL are shown in Table H.2. These calculations were conducted using the 68°C quick response glass bulb sprinklers. Based on these results, it was estimated that the sidewall sprinklers would require 25% more time to activate than the pendent sprinklers. Since it was assumed that early sprinkler activation could be a crucial factor in controlling the fire, it was decided that the pendent sprinkler arrangement should be tested, even though it provided a very poor water spray distribution.

The results of the FPETOOL simulations were later confirmed by the full-scale tests. The temperatures measured at the sprinklers during the first 60 to 90 seconds of the full-scale tests were comparable to those calculated using the "fast" fire growth rate. The observed activation times for the sprinklers closest to the fire were comparable to those estimated by the computer model. That is, the pendent and sidewall sprinklers nearest the fire plume were typically activated within 50 to 60 seconds and 70 to 90 seconds, respectively, during the full-scale tests.

Table H.2 Sprinkler Activation Times for 68°C Quick Response Glass Bulb Sprinklers

Distance from Fire Source (m)	Minimum Fire for Activation (kW)	Activation Time Medium Fire (sec)	Activation Time Fast Fire (sec)	Activation Time Ultra-Fast Fire (sec)	Sprinkler Activation Fire Tests (sec)
1.5	67	106	62	36	50–60
2.5	112	134	78	46	70–90

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In addition to using FPETOOL to predict sprinkler response times, preliminary fire tests were conducted to assess the response times of the sprinklers. A propane gas burner, capable of generating 95 kW, was positioned in the same location as the ignition source for the full-scale tests. For these activation tests, sprinklers were mounted in the four pendent and three sidewall locations closest to the fire source. The horizontal sidewall sprinklers were located 1 m further from the fire source than the pendent sprinklers. The 95 kW heat release rate provided by the propane burner was lower than the minimum required to bring about early activation of the sidewall sprinklers. The sidewall sprinklers mounted in the open, below the smooth ceiling, required considerably more time to activate than the pendent sprinklers. However, it was noted that the sidewall sprinklers which were mounted against the duct at the low ceiling side of the test facility activated approximately 50% earlier than the sprinklers mounted in the open on the opposite side of the stack unit. It was decided, therefore, to mount a sheet metal baffle 152 mm deep behind the horizontal sprinklers located on the side of the shelving unit with the smooth ceiling. This baffle was intended to provide the same effect as the soffit created by the duct. The baffles also minimized the possibility that back spray from the sidewall sprinklers would affect the aisle sprinklers.

Full-Scale Tests

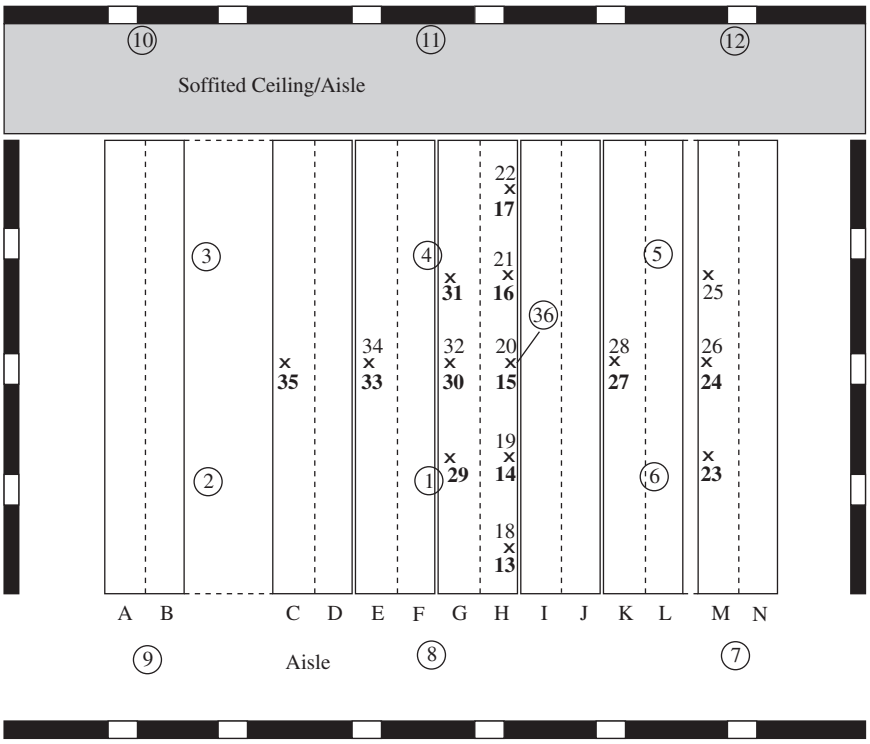
It should be emphasized that this was an engineering study directed at developing a sprinkler system that would provide protection equivalent to that intended by compliance with standards. This paper will not give detailed results for each of the five full-scale tests conducted. Instead, it will emphasize those results and observations that illustrate the sprinkler system's ability — or, in some cases, inability — to control or extinguish the fire.

For all full-scale tests, ignition was provided by 500 mL of 95% ethanol placed in a pan, measuring 305 mm, that was placed at floor level. This represented a small, low-heat release, flaming ignition source with minimal impact on sprinkler activation. The alcohol fire was started with an electric igniter that was remotely operated.

Instrumentation

Thermocouples were mounted at various locations in the test facility to monitor the temperatures within the stack array and at the ceiling. The locations of the thermocouples for the tests with pendent sprinklers (Tests 1 and 2) and for the tests with sidewall sprinklers (Tests 3, 4, and 5) are shown in Figures H.6 and H.7, respectively.

FIGURE H.6 Thermocouple Locations for Tests 1 and 2.



Thermocouples at Lower Level
13, 14, 15, 16, 17,23, 24, 25, 27, 29, 30, 31, 33, 35

Thermocouples at Mid Level
18, 19, 20, 21, 22
26, 28, 32, 34

Thermocouples at Ceiling
36

Thermocouples on Sprinklers
1 2 3 4 5 6
7 8 9 10 11 12

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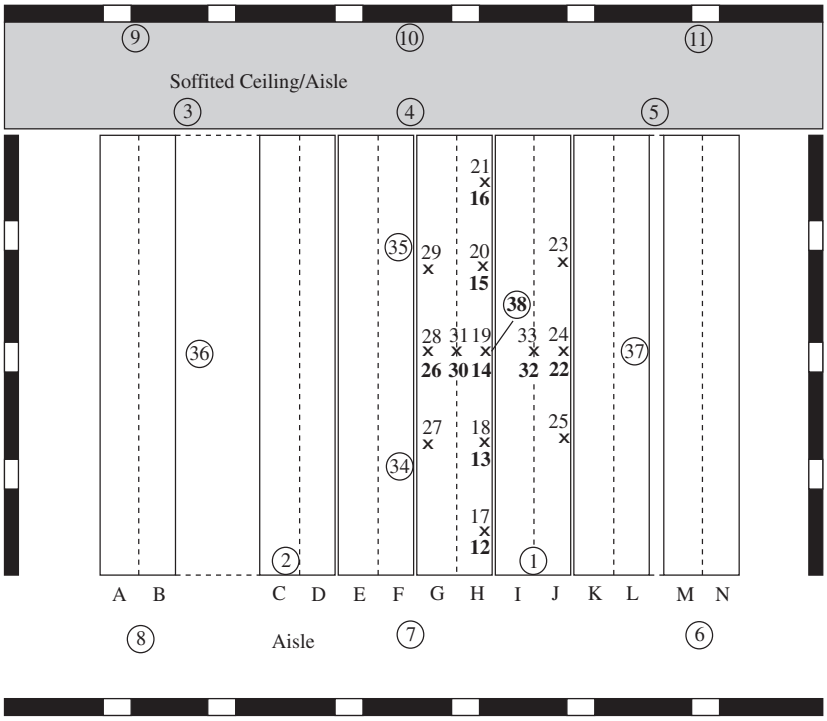
FIGURE H.7 Thermocouple Locations for Tests 3, 4, and 5.



Thermocouples on Barrier
Mid-level **30**, **32**
Upper level 31, 33

Thermocouples on Sprinklers
(1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11)

Thermocouples at Ceiling
(34) (35) (36) (37) (38)

Thermocouples at Lower Level
12, 13, 14, 15, 16, 22, 26

Thermocouples at Mid Level
17, 18, 19, 20, 21, 23
24, 25, 27, 28, 29

Thermocouples were mounted at two levels within the stack array, as shown in Figure H.8. These thermocouples not only monitored the temperature within the stack array, but also gave an indication of fire spread along the row of fire origin and between mobile shelving units. (A particular concern noted during the evaluation of the hazard in the library was the possibility of a shielded fire in the lower levels spreading horizontally into adjacent shelving units.) The thermocouples were installed with the wire attached to the center of a shelving section and the thermocouple bead 12.5 mm below the outer edge of the shelf to measure the air temperature in the open space between two levels of shelving. The thermocouples were cross-referenced to the alphanumeric system used for labeling the shelving sections (see Table H.3) with the shelving designation indicating that the thermocouple was positioned in the open space above the storage on the specified shelving section. In Test 1, for example, Thermocouple 20, shown in Figure H.6, was located in the open space above the boxes on Shelf H13 and was thus at mid-level in the shelving unit directly above the initial fire source.

For Tests 3, 4, and 5, four thermocouples were used to monitor the temperature on the non-fire side of the barriers that were installed in the center of the two mobile units on either side of the fire source. These thermocouples are labeled 30, 31, 32, and 33 in Figure H.7. For each barrier, thermocouples were placed on the vertical centerline of the barrier at mid-height and at the fifth shelving level above the floor.

Thermocouples were also placed near each sprinkler. These thermocouples were used to not only monitor the temperatures at the ceiling, but also to record when the sprinklers operated. For the on-off sprinklers, the thermocouples were located just below the deflector in the closed position. For all other tests, the thermocouples were located near, but not in contact with, the sprinkler elements.

For all the tests, a thermocouple was located at the ceiling directly above the fire source. For Tests 3, 4, and 5, additional ceiling thermocouples were installed to monitor the temperature above the stack array. The location of these thermocouples is shown in Figure H.7.

Provisions were also made to measure the smoke obscuration in the test facility using He-Ne lasers. In all tests, the obscuration was measured at the 1.5 m level in an access aisle. For this measurement, the laser was positioned at one end of the test facility. The measuring diode was positioned at the opposite end of the aisle 8.2 m away. A collimator was used to minimize beam divergence. For all tests, the mobile units were placed close together and positioned near one of the fixed units. This arrangement left a space of approximately 1 m between the other fixed shelf and the nearest mobile unit. In Tests 1 and 2, the smoke obscuration was measured in this open area. For this measurement, the He-Ne laser was mounted at the 1.5 m level at one side wall of the test facility. The detector was positioned at the opposite side of the facility.

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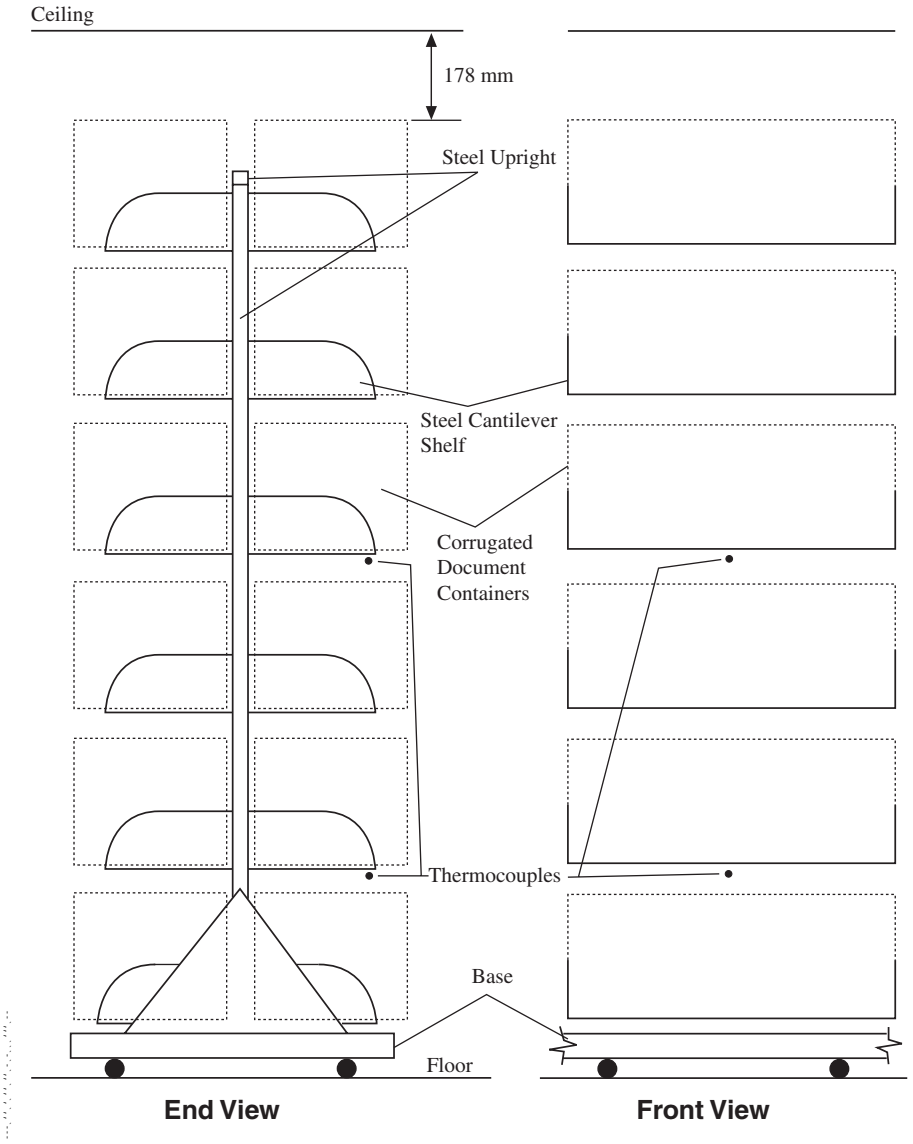
FIGURE H.8 Thermocouple Locations on Mobile Units.



Test 1: On-Off Pendent Sprinkler

As indicated previously, the analysis of the hazard in the library indicated that folded newspapers stored in periodical boxes could result in the most rapid fire spread and, thus, the most challenging fire scenario for the sprinklers. For the initial test, the mobile shelving units on either side of the fire source were completely filled with newspapers (Rows G, H, I, and J in Figure H.9). The remaining shelving rows were filled with partially filled document boxes. The alcohol pan ignition source was located at the center of the closed units between Rows H and I.

After ignition, the flames rapidly involved the newspapers above the fire source. Within 50 seconds, the four pendent sprinklers nearest the fire source — Sprinklers 1, 4, 5, and 6 — were activated (see Figure H.6). Eventually, Sprinklers 3, 7, and 9 were also activated.

Despite the early response of the sprinklers, the fire continued to spread the length of Rows H and I on all levels and eventually involved the entire fuel load in these rows. There was also very early involvement in Rows F, G, J, and K. Within 6 minutes, it was clear that the sprinklers were not going to control the fire, and the test was terminated.

The lack of control is illustrated by some key temperature measurements. First, the temperature at the ceiling directly above the fire remained above 600°C, even with the four closest sprinklers operating (see Figure H.10). Second, there was rapid fire spread at the mid-height of the row of fire origin, with sustained flames and temperatures of 800°C throughout the length of the row within 3 minutes 30 seconds (see Figure H.11). Finally, there was rapid fire spread to the next mobile unit (Row K) with sustained temperatures of 700°C measured at the mid-height within 3 minutes (see Figure H.12). The temperature measured at the lower level indicated substantial fire penetration within 3 minutes and sustained temperature of 700°C within 5 minutes.

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Table H.3 Thermocouple Locations

Channel Number	Location Tests 1 and 2	Location Tests 3, 4, and 5
1	Sprinkler 1	Sprinkler 1
2	Sprinkler 2	Sprinkler 2
3	Sprinkler 3	Sprinkler 3
4	Sprinkler 4	Sprinkler 4
5	Sprinkler 5	Sprinkler 5
6	Sprinkler 6	Sprinkler 6
7	Sprinkler 7	Sprinkler 7
8	Sprinkler 8	Sprinkler 8
9	Sprinkler 9	Sprinkler 9
10	Sprinkler 10	Sprinkler 10
11	Sprinkler 11	Sprinkler 11
12	Sprinkler 12	Shelving Section H1
13	Shelving Section H1	Shelving Section H2
14	Shelving Section H2	Shelving Section H3
15	Shelving Section H3	Shelving Section H4
16	Shelving Section H4	Shelving Section H5
17	Shelving Section H5	Shelving Section H11
18	Shelving Section H11	Shelving Section H12
19	Shelving Section H12	Shelving Section H13
20	Shelving Section H13	Shelving Section H14
21	Shelving Section H14	Shelving Section H15
22	Shelving Section H15	Shelving Section J3
23	Shelving Section M2	Shelving Section J12
24	Shelving Section M3	Shelving Section J13
25	Shelving Section M4	Shelving Section J14
26	Shelving Section M13	Shelving Section G3
27	Shelving Section K3	Shelving Section G12
28	Shelving Section K13	Shelving Section G13
29	Shelving Section G2	Shelving Section G14
30	Shelving Section G3	G13 Barrier (non-fire side)
31	Shelving Section G4	G23 Barrier (non-fire side)
32	Shelving Section G13	J13 Barrier (non-fire side)
33	Shelving Section E3	J23 Barrier (non-fire side)
34	Shelving Section E13	Ceiling
35	Shelving Section C3	Ceiling
36	Ceiling above ignition source	Ceiling
37		Ceiling
38		Ceiling above ignition source

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FIGURE H.9 Fire Scenario for Test 1.

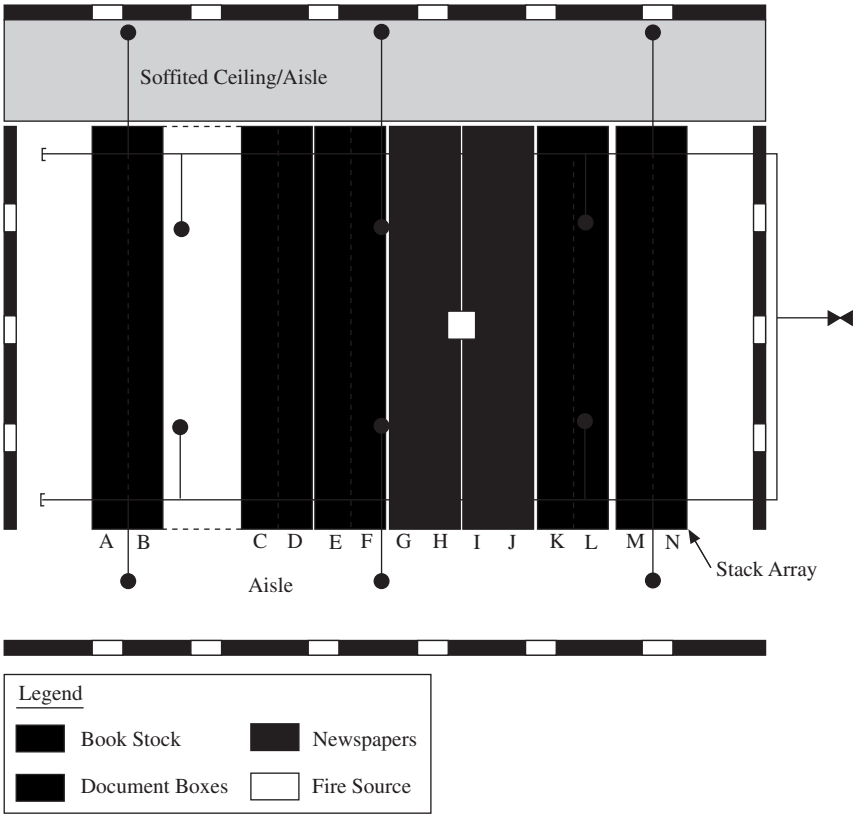

FIGURE H.10 Ceiling Temperature in Test 1.

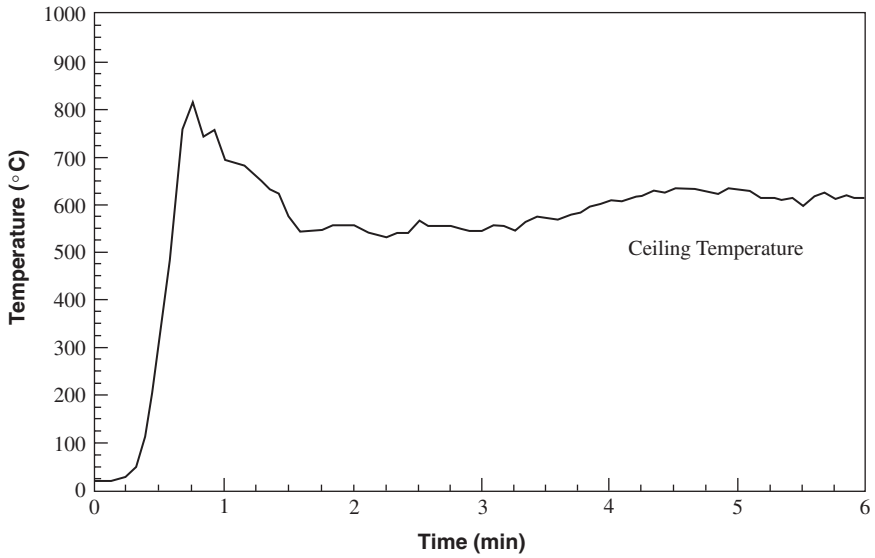

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FIGURE H.11 Shelving Section H Temperatures in Test 1.

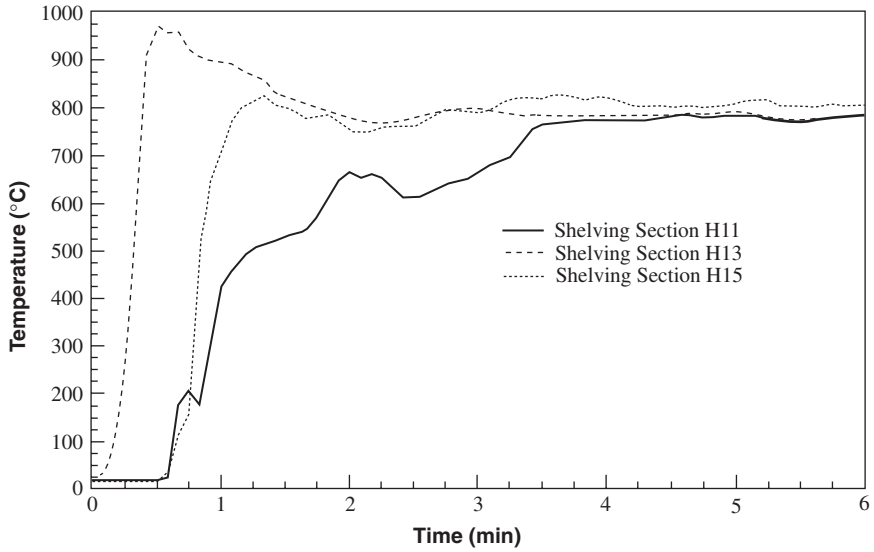
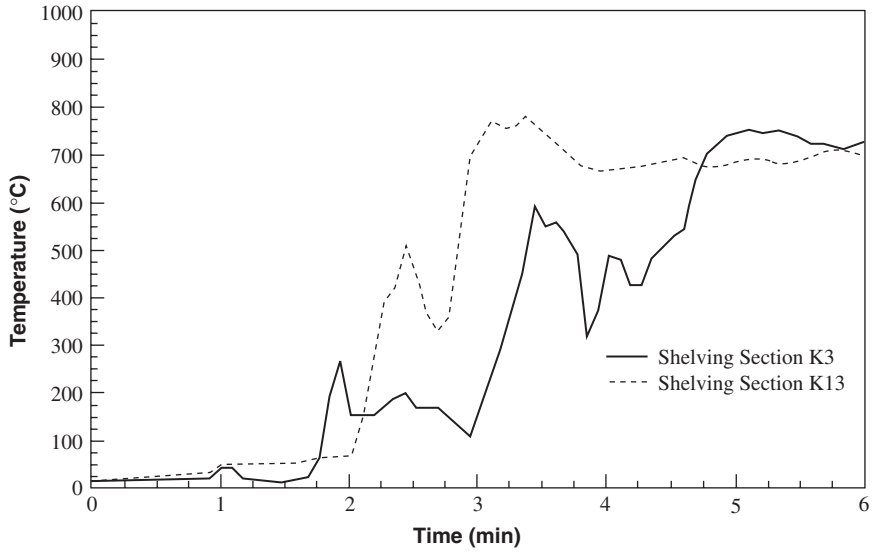


FIGURE H.12 Shelving Section K Temperatures in Test 1.



Based on a review of the test observations, videos, and temperature data, the major findings for Test 1 are summarized [as follows].

As expected, the fire involvement of the open, folded newspapers was rapid and sustained, despite early sprinkler activation and the use of relatively high sprinkler flow rates. The high percentage of exposed surfaces of combustibles throughout the stacks resulted in very rapid fire spread along the row of fire origin and to adjacent shelving units.

The close proximity of the fuel on adjacent shelves, with the shelves in the closed position, allowed the fire to spread readily without the sprinkler spray being able to penetrate and cool the fire. Sustained temperatures of 700°C and higher were measured within the stack array.

It was also noted that tremendous quantities of smoke were generated during the test. The entire 20,400 m^3 volume of the burn hall was filled within a few minutes of ignition. It is possible that the ink content of the newspapers contributed to the production of the thick, dark smoke. It was also noted that the cooling effect provided by the sprinklers resulted in a more rapid build-up of smoke at lower levels of the burn hall. This smoke could present a threat to evacuation in the area of the fire and would probably make it difficult for the fire brigade to gain access to the area, find the fire, and complete extinguishment.

Test 2: Quick Response Pendent Sprinklers

Based on the results of Test 1, it was determined that it would be necessary to change the sprinkler arrangement to provide a more effective water spray coverage to the shelving area. In addition, it was determined that a part of the fire protection strategy would have to include modifications to the shelving units.

Three specific changes were incorporated into the test arrangement for Test 2. First, quick response pendent sprinklers

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were used for all areas of the test facility instead of on-off sprinklers. Second, the "worst-case" scenario with newspapers stored in open boxes was eliminated. It was recommended that the newspapers be stored in closed-top, corrugated cardboard document boxes similar to those used to store other materials. Third, sheet metal would be used to subdivide the shelving units lengthwise. It was expected that these barriers would act as firestops to slow the spread of fire between the rows of shelving. For Test 2, barriers were installed in the two fixed shelving units and in the center mobile unit, thus separating rows, AB, GH, and MN.

All other conditions in Test 1 applied, except that it was considered unnecessary to completely load rows A, B, C, D, E, M, and N. The fire protection system would be deemed to have failed if the fire spread to these rows, and the test would be stopped. However, empty boxes were placed on the top level of all these shelving rows to ensure that the spray distribution from the sprinklers would not be compromised. The sprinkler flow rates were established to maintain a minimum density of 18.7 $(L/min)/m^2$, the same as that used in Test 1.

After ignition, the initial fire developed in the same pattern as the fire in Test 1, with a very rapid vertical fire spread on the boxes on Rows H and I above the ignition source. The four pendent sprinklers closest to the fire operated at approximately 50 seconds. Several aisle sprinklers activated later.

The spread of fire along the length of Rows H and I was very rapid and nearly as intense as the fire in Test 1 (see Figure H.13). These results indicate sustained burning, with temperatures greater than 800°C at the mid-level of these rows after 6 minutes. There was also rapid fire spread to the adjacent rows (Row K) that were not protected by the steel barrier. This is illustrated in Figure H.14, where sustained burning is indicated at the mid-level of Row K after 5 minutes and at the lower level after 9 minutes.

FIGURE H.13 Shelving Section H Temperatures in Test 2.

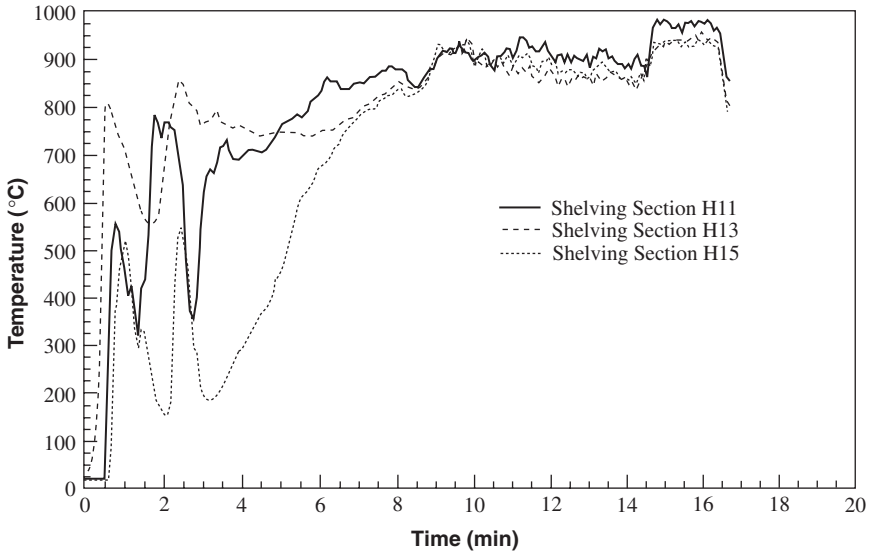
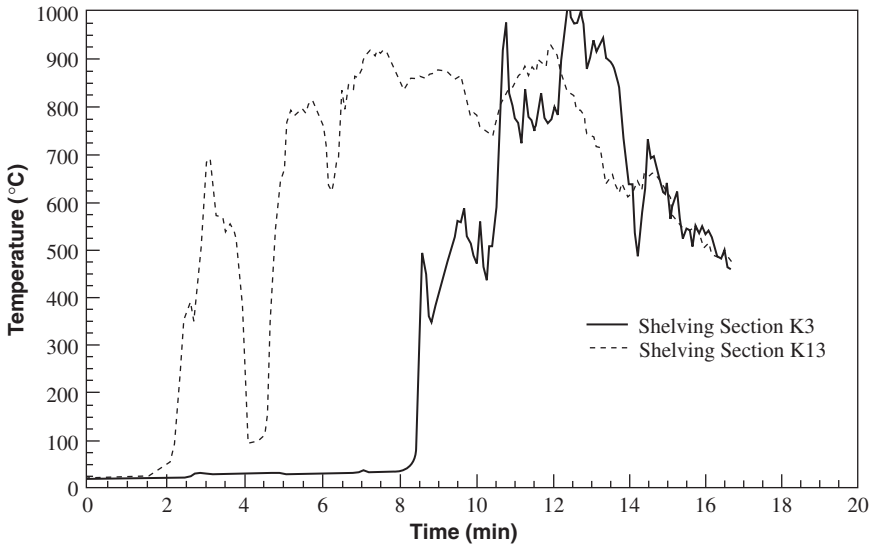


FIGURE H.14 Shelving Section K Temperatures in Test 2.



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The fire barrier between Rows G and H delayed the fire spread to Row G. Figure H.15 indicates that the barrier was penetrated at approximately 10 minutes, with sustained burning after 12 minutes.

The ceiling temperature directly above the ignition source is shown in Figure H.16. After an initial "knockdown," the ceiling temperature increased slowly as the fire began to involve more fuel. Despite the continued operation of the sprinklers, the ceiling temperature began to increase rapidly after 6 minutes; sustained temperatures greater than 800°C were reached within 10 minutes.

Based on a review of test observations, videos, and temperature data, the major findings for Test 2 are summarized as follows.

First, with the mobile shelving units close together, the faces of the document boxes touched. The close-packed document boxes in adjoining units prevented sprinkler spray from reaching the burning fuel package stored on lower shelving levels. Despite the early response of the sprinklers, there was minimal "prewetting" of the boxes on the shelving rows adjacent to the fire rows.

Second, there was relatively rapid fire spread on the corrugated cardboard document boxes, even though the removal of the open newspaper storage decreased the initial fire growth rate. The rapid involvement in the lower shelving levels allowed the fire to overcome the limited firestopping benefits of the single sheet-steel barrier. This barrier did delay fire spread by approximately 7 minutes, however.

Third, this storage represents a significant fire load, even though the boxes were only partially filled with documents. There was considerable structural damage to the shelving frames, and the shelves in the central portion of Rows I and J collapsed completely.

FIGURE H.15 Shelving Section G Temperatures in Test 2.

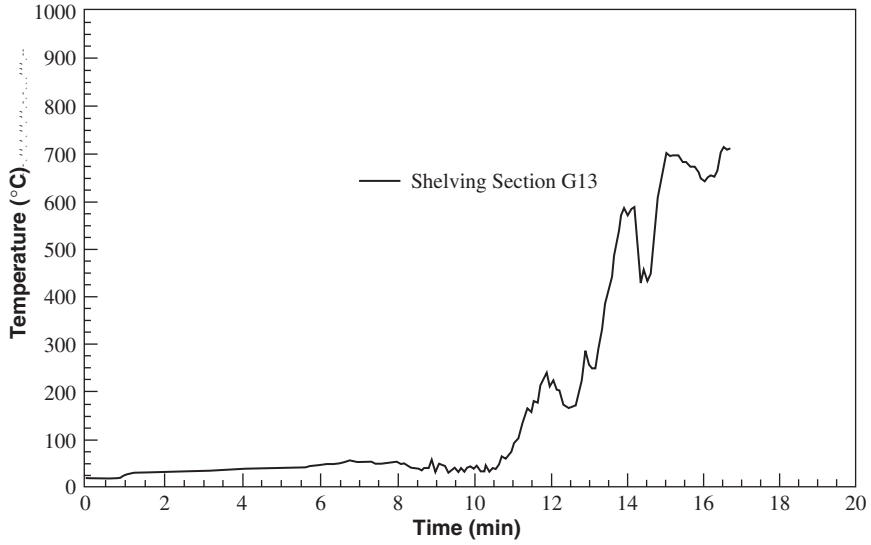
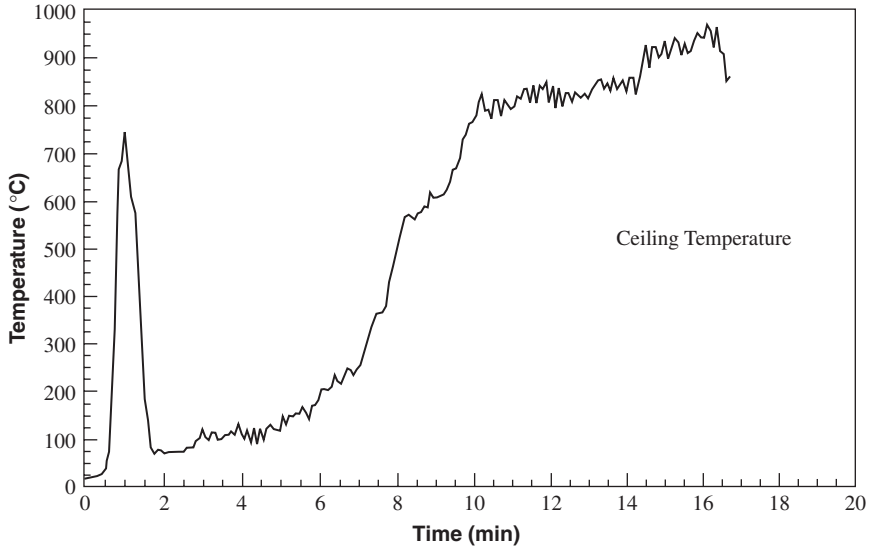


FIGURE H.16 Ceiling Temperature in Test 2.



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Test 3: Quick Response Horizontal Sprinklers

Test 3 was primarily intended to examine the ability of QR horizontal sidewall sprinklers to protect the shelving array (see Figure H.5). QR pendent sprinklers were used to protect the aisle areas.

As a result of the analysis of Test 2, three further changes were made for this test. First, the fire barrier separating Rows G and H was upgraded to improve fire resistance. The barrier consisted of mineral insulating board 12.5 mm thick sandwiched between two 26-gauge sheet steel panels. In addition, a fire barrier consisting of two layers of 26-gauge sheet steel separated by a 3 mm air gap was installed between Rows I and J.

Next, spacers were used to prevent the mobile shelving units from closing so that adjacent storage touched. In this manner, a minimum 26 mm gap was maintained between the boxes stored on adjacent shelves.

Finally, the water flow rate was increased to provide a minimum density of 28.5 $(L/min)/m^2$ over the mobile shelving units.

After ignition, the initial fire developed in the same pattern as it did in Tests 1 and 2, with a very rapid vertical fire spread on the boxes on Rows H and I above the ignition source. The three closest horizontal sidewall sprinklers and one aisle sprinkler — Sprinklers 1, 4, 5, and 7 — operated between 1 minute 15 seconds and 1 minute 22 seconds after ignition (see Figure H.7). The sprinklers were able to control and extinguish the fire quickly. This is illustrated by the rapid decrease in temperatures measured at the mid-level of Row H (see Figure H.17) and at the ceiling directly above the fire (see Figure H.18). The fire damage was limited to the center portions of Rows H and I.

FIGURE H.17 Shelving Section H Temperatures in Test 3.

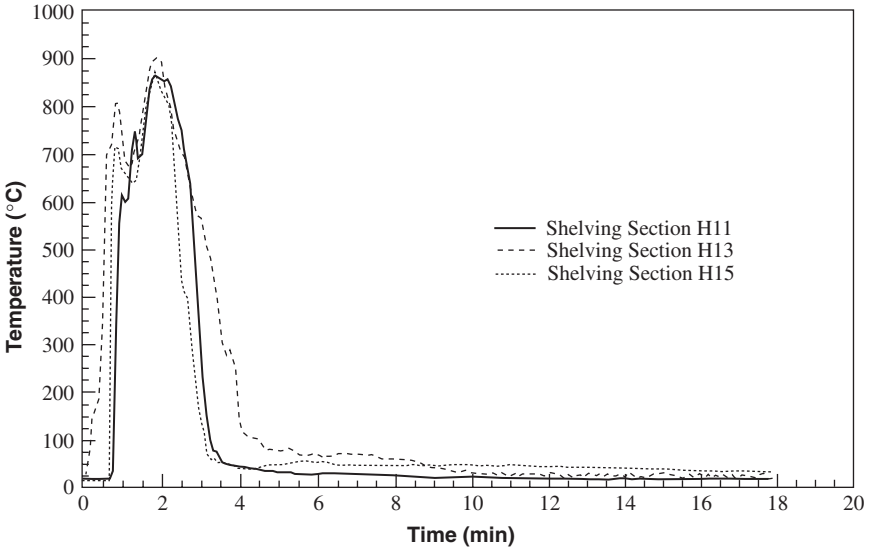
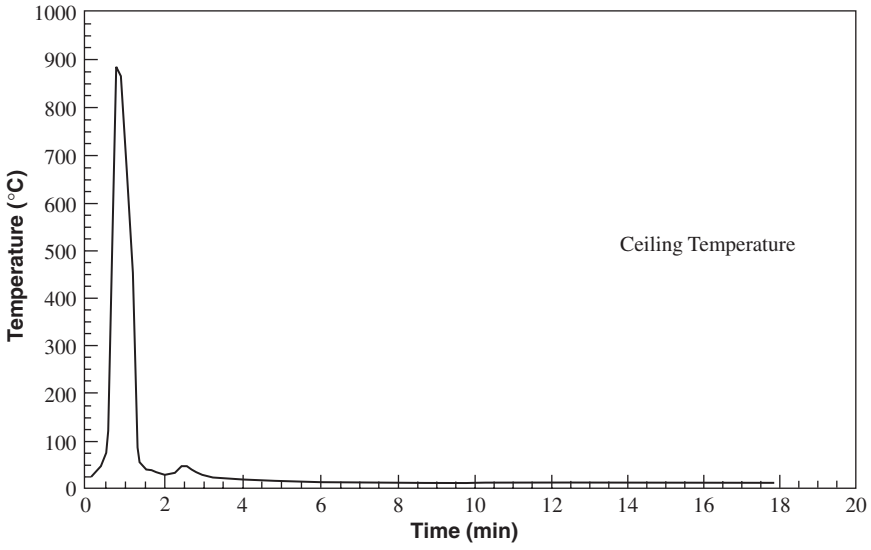


FIGURE H.18 Ceiling Temperature in Test 3.



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The horizontal sidewall sprinklers, in combination with the fire barriers and the 26 mm gap between the mobile units, allowed for effective cooling and extinguishment in the initial area involved in the fire. Further, the high spray density, combined with the favorable water spray projection pattern, provided cooling at the ceiling and prevented the operation of an excessive number of sprinklers.

Test 4: Quick Response Horizontal Sprinklers at Lower Density

Test 4 was arranged to duplicate the conditions in Test 3, except the water flow rate was reduced. The initial flow rate was set to provide a density of 20.5 $(L/min)/m^2$.

The initial fire development duplicated the conditions observed in Test 3, with the sprinklers operating at precisely the same time. With the lower flow rate, however, the fire was not immediately extinguished. The temperatures measured at the mid-level of Row H indicate that there was sustained burning at the lower levels of Rows H and I (see Figure H.19). The thermocouples mounted on the non-fire side of the fire barrier separating Rows I and J indicated that the fire penetrated this barrier at approximately 15 minutes (see Figure H.20). However, this delay was sufficient to allow water to drip down the 26 mm gap between facing shelves and prewet the boxes on the lower levels. With the extended period of prewetting, the fire did not spread rapidly after breaching the barrier. There was a continued decrease in the temperatures in the stack array throughout the test.

FIGURE H.19 Shelving Section H Temperatures in Test 4.

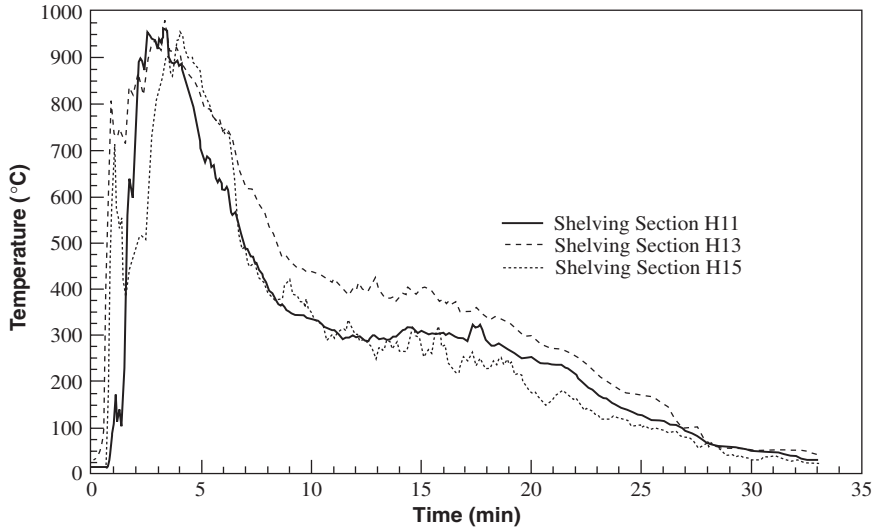
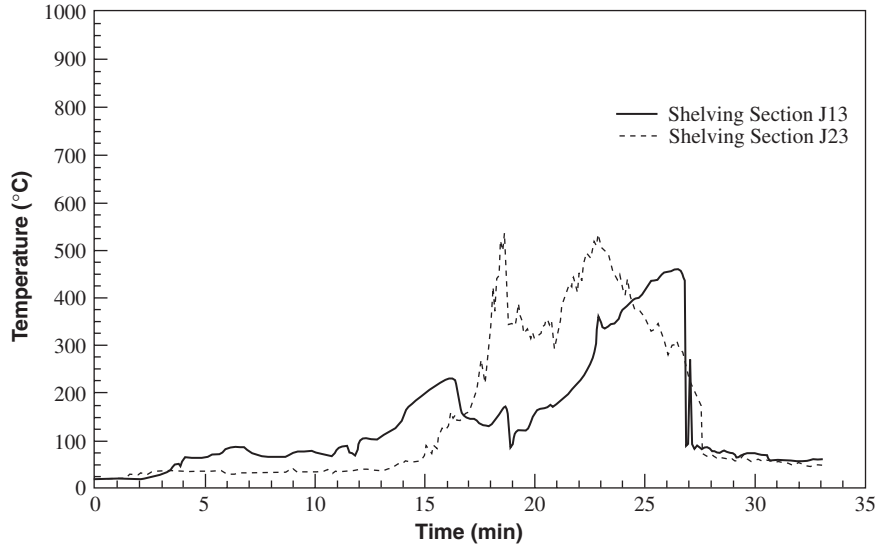


FIGURE H.20 Shelving Section J Temperatures in Test 4.



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At 25 minutes, the water flow rate was increased to 24.6 (L/min)/m^2. With the increased flow rate, the fire was extinguished within 5 minutes.

The results of Test 4 indicated that, with the reduced water application density, the HSW sprinklers were unable to rapidly extinguish the fire. However, the fire barriers limited initial fire spread, allowing for an extended period of prewetting throughout all levels of the shelving. The continued decrease in temperatures indicated that the sprinklers were able to control the fire. It is probable that the fire would have been extinguished eventually.

Taking into consideration the importance of limiting fire and water damage to the archival material, it was decided to recommend use of the higher density used in Test 3 to ensure complete extinction in the shortest possible time. This provided for a considerable degree of engineering safety for the system. In addition, the fire barriers and spacer blocks on the mobile shelving bases allowed effective prewetting of the fuel on the shelves surrounding the fire and were thus essential elements in the fire protection system.

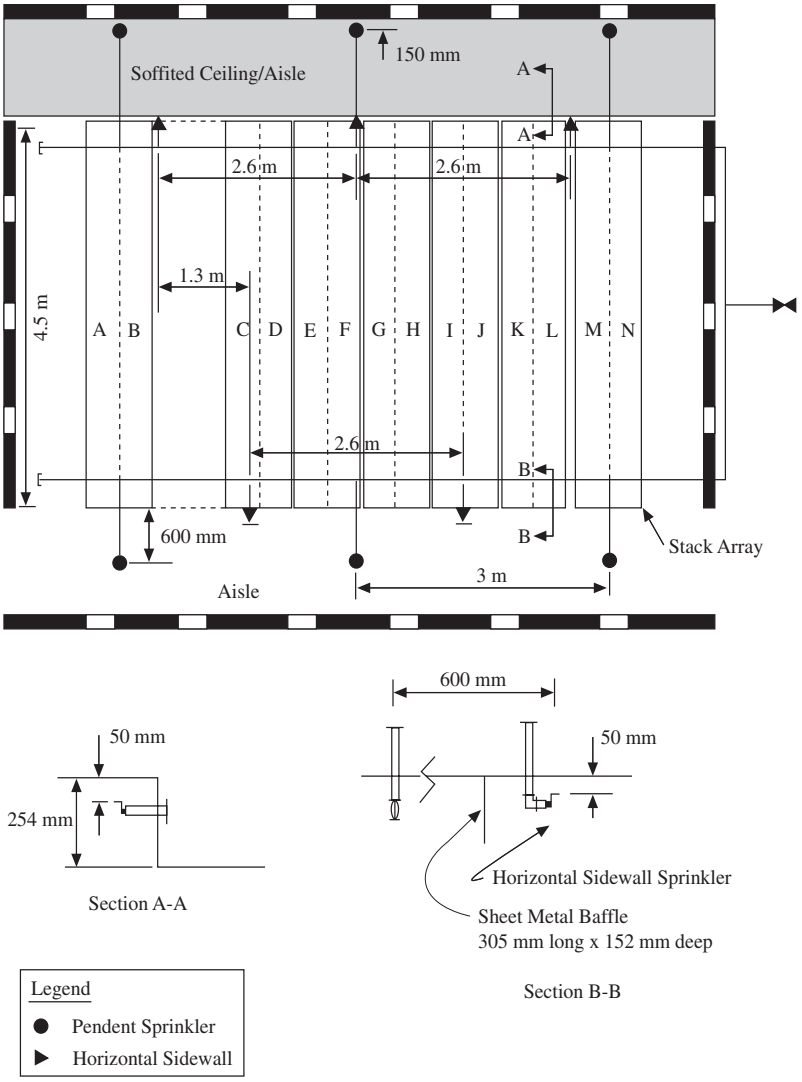
Test 5: Quick Response Horizontal Sidewall Sprinklers with Reduced Clearance

As noted previously, the clearance between the top of the storage and the ceiling in some areas in the library was 76 to 100 mm. To address this reduced clearance, a fifth test was conducted to determine whether the sprinkler system could control the fire with less clearance. For this test, the top storage was raised to within 100 mm ± 25 mm of the ceiling.

The horizontal sidewall sprinklers were installed with the deflectors within 50 mm of the ceiling (see Figure H.21). All other conditions were the same as those in Test 3.

The initial fire development replicated that observed in Tests 3 and 4. However, the close proximity of the storage to the ceiling affected the convective flow above the shelving, so that one of the three sidewall sprinklers closest to the fire did not operate for several minutes. This was Sprinkler 4, which was located on the soffit at the center of the stack array (see Figure H.7). It did not operate until 9 minutes into the test. The other two sprinklers located on the soffit operated within 90 seconds, even though Sprinkler 3 was located considerably further from the ignition source than Sprinkler 4.

FIGURE H.21 Horizontal Sidewall and Pendent Sprinkler Layout for Test 5.



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As is shown in Figures H.22 and H.23, the fire was able to regain some momentum approximately 8 minutes into the test, with high temperatures, measured in shelving Row H and at the ceiling. Once Sprinkler 4 activated at 9 minutes, the sprinklers were able to control and extinguish the fire. The 15 minutes required for the sprinklers to control the fire provided the fire with enough time to break through the fire barrier separating Rows G and H. However, the ability of the sprinkler system to regain control of the fire indicates that there is an inherent safety margin in the protection system.

Substantially more damage was sustained in this test than in Test 3. Based on the results of Test 5, it was decided that the 178 mm clearance between the ceiling and the top of the storage used in Test 3 would be specified as the minimum for general use. However, it was also noted that control, and eventually extinguishment, was obtained with the reduced clearance of 100 mm.

Smoke Production

As an additional point of interest, it was observed that large quantities of smoke were produced during all five fire tests, particularly in those tests in which the sprinklers could not immediately extinguish the fire. It was also noted that the cooling of the smoke by the sprinklers resulted in a very rapid build-up at lower levels. This is illustrated by the smoke obscuration measurements from Test 1 shown in Figure H.24, which shows a very rapid increase in obscuration at the 1.5 m level within 2 minutes 30 seconds of ignition. In low ceiling spaces, smoke build-up could be very fast and could rapidly obscure exit routes, making it very difficult for the fire brigade to operate in the floor area.

FIGURE H.22 Shelving Section H Temperatures in Test 5.

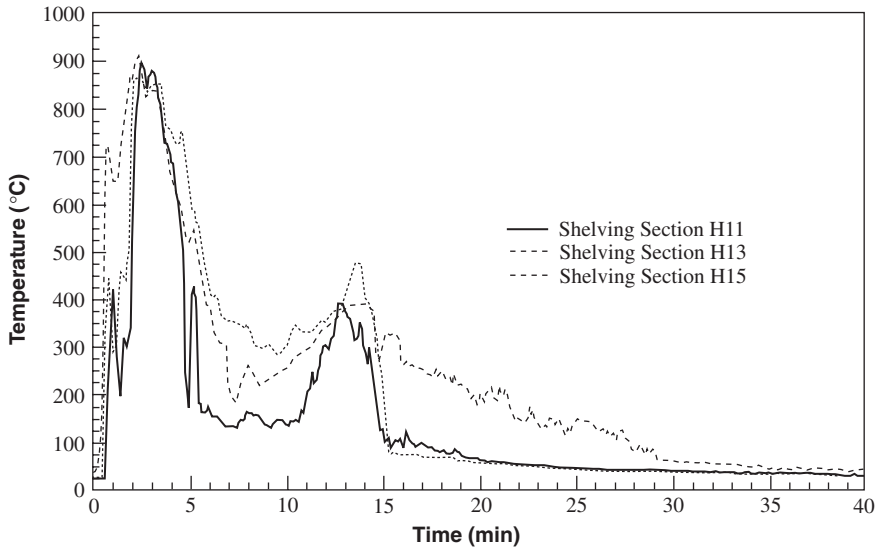
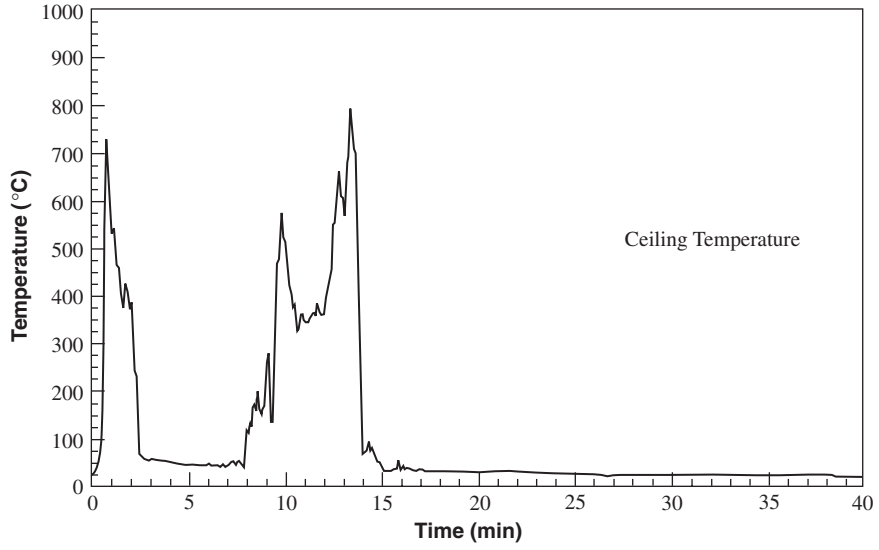


FIGURE H.23 Ceiling Temperature in Test 5.



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Design Criteria

As a result of these investigations, criteria were recommended for the design of the sprinkler systems over the mobile shelving in the basement of the library. These criteria were based on the findings from spray distribution tests, sprinkler activation tests, a survey and analysis of existing stack systems and fuel loads, and a series of full-scale fire tests involving stack systems with document storage and shelving.

It is beyond the scope of this paper to provide a detailed description of the design criteria recommended for the library. However, the general principles used to develop the design guide are summarized.

Modifications to the Shelving Units

The full-scale fire tests indicated that it would be very difficult or impossible to control a fire in the compact shelving area using only sprinklers. Several modifications to the shelving units and storage practices were recommended as essential aspects of the fire protection system.

Provisions should be made to ensure that a minimum clearance of 26 mm is maintained at all times between document boxes or other materials on adjacent mobile shelves when they are moved to the "closed" position. The purpose of the 26 mm space is to permit sprinkler water to drip down the face of shelving materials, thus ensuring good wetting at lower levels.

Each back-to-back stack unit should be subdivided lengthwise with a steel firestopping barrier that extends the full length and height of each section of the mobile and fixed stack units. These barriers will inhibit rapid fire spread through intermediate levels to adjacent shelving units. The barriers were of particular importance immediately after sprinkler operations, when the rapid cooling at the ceiling level tends to cause large horizontal flame extension at various levels within the shelving units. The barriers also delay the spread of fire into adjacent shelves and provide time for sprinkler water to drip down the 26 mm space between shelves to wet the lower levels. If fire penetrates the barrier, it encounters prewetted fuel and does not grow as rapidly.

Newspapers should no longer be stored in open periodical boxes. During Test 1, it was noted that the newspaper hazard exposed a large quantity of loosely packed fuel to the fire. This resulted in a rapid lateral fire spread within the shelving unit which allowed the fire to involve a large quantity of fuel during the initial fire growth. By eliminating the open newspaper scenario, the initial fire growth was reduced, thus decreasing the fire challenge for the sprinkler system.

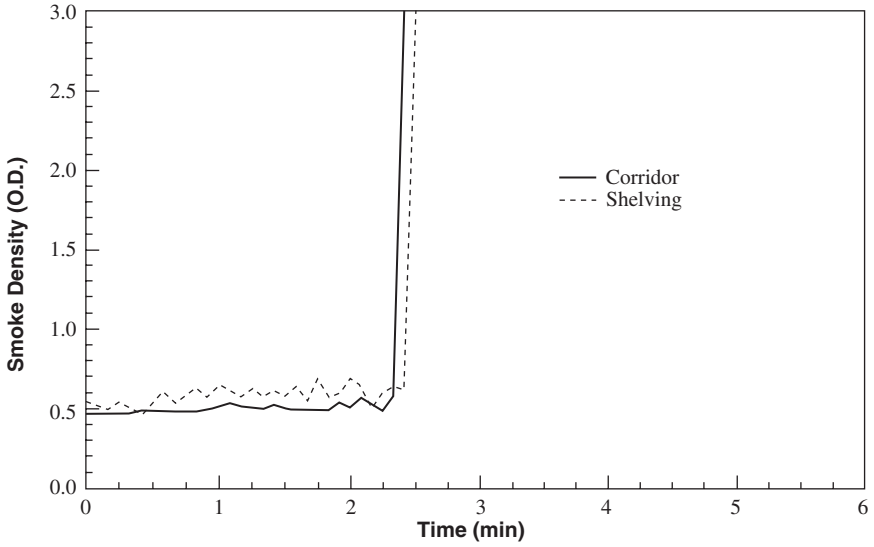
Sprinkler System Design

The design criteria for the sprinkler system is based on the sprinkler configuration used in Test 3. In this configuration, six quick response pendent sprinklers with 57 to 77°C ratings, nominal 12.5 mm orifices, K factors of 5.3 to 5.8 in U.S. units, and a 3.05 m spacing were used to protect the aisle. Five quick response horizontal sidewall sprinklers with 57 to 77°C ratings, nominal 12.5 mm orifices, and K factors of 5.3 to 5.8 in U.S. units were used to protect the mobile shelving area.

The layout for the horizontal sprinklers is designed to maximize water spray coverage and to minimize the possibility of spray from one sprinkler delaying the activation of adjacent sprinklers. To achieve this, the sprinklers are arranged in a staggered array on opposite sides of the shelving units. The spray distribution tests demonstrated that, with the geometry used in this test series, there was no direct spray impingement on a sprinkler from adjacent sprinklers. As a result, reproducible activation of the three sprinklers closest to the fire source was obtained in Tests 3 and 4, the two tests with the 178 mm clearance between the ceiling and the storage.

The horizontal sidewall sprinklers are arranged to maximize water spray coverage in critical shelving areas. On the side of the stack array with three sprinklers, the two end sprinklers are centered on the gap between the fixed shelving unit and the first mobile unit. This ensures maximum water spray penetration into the one area where, because of the stops installed on the rails, relatively good penetration of water spray to the lower shelving levels was possible. The third sprinkler on that side is located at the center of the shelving array, giving a 2.6 m spacing between the sprinklers. The two sprinklers on the opposite side of the stack array are staggered so as to be exactly halfway between the two sprinklers on the opposite side, 4.5 m away. The spray distribution tests showed that, with the horizontal sprinklers mounted a nominal 100 mm below the ceiling, the sprinklers were able to provide uniform wetting over the entire mobile shelving area.

FIGURE H.24 Smoke Obscuration at 1.5 m Level in Test 1.



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Even with the newspaper scenario removed, relatively fast fire development was observed in the full-scale fire tests. The results of Tests 3 and 4 demonstrated that, in order for the sprinklers to control the fire and minimize damage to the shelving contents, it was essential that water be applied as early as possible with a relatively high spray density. For this reason, it is recommended that a wet pipe sprinkler system be used in the library.

Two levels of coverage are needed for the design of the sprinkler system:

(1) A minimum average density of 28.5 (L/min)/m^2 from five HSW sprinklers over a single bay of compact shelves. Each sprinkler is assumed to cover approximately 5.92 m^2.
(2) A minimum average density of 12.3 (L/min)/m^2 over a 139 m^2 design area. This design area includes both sidewall sprinklers and pendent aisle sprinklers.

Such a system will provide the high application density required to control the rapidly developing fire in the shelving area while minimizing the demand on the water supply system.

For Test 5, the clearance between the storage on the mobile shelving units and the ceiling was 100 mm ± 25 mm. The HSW sprinkler deflectors were located 50 mm below the ceiling. This test showed that a fire could be controlled for this scenario. However, this test also showed that localized cool areas may occur above the mobile units, delaying the activation of some sprinklers and thus increasing fire spread and fire damage. The delay in controlling the fire could result in the activation of an increased number of sprinklers. Because the reduced clearances increased the potential fire and water damage to the contents of the shelving, it was strongly recommended that the sprinkler layout conform to the conditions used in Test 3 wherever possible — that is, that a 178 mm clearance be maintained between storage and the ceiling.

Summary

This paper provides a technical solution for sprinkler protection of the compact shelving units in the basement of the National Library of Canada. The fundamental basis for accepting an equivalent to a sprinkler installation that conforms to the standards is that the proposed arrangement demonstrate a high probability that it can extinguish or control the fire in the fuel package. Based on this criterion, the sprinkler layouts with pendent sprinklers used Tests 1 and 2 did not provide an acceptable level of performance.

The sprinkler layout in Test 3, which used horizontal sidewall sprinklers and a high spray density to protect the mobile shelving units, extinguished the fire with minimal fire damage to the shelving contents. This system formed the basis for general design criteria for shelving units in which the clearance from the top of the document boxes to the ceiling was at least 178 mm.

Tests 4 and 5 investigated the boundary conditions for the sprinkler system and showed that the average density and the clearance height above the shelving unit used in Test 3 were critical elements in determining the performance of the sprinkler system. In these tests, the sprinkler system took longer to control and eventually extinguish the fire, which resulted in greater damage to the stack's contents.

The effectiveness of the sprinkler system, as outlined in this paper, depended on implementing all the recommendations noted: vertical fire barriers in all shelving units, bumpers or other measures to ensure a minimum 26 mm clearance between commodities on adjacent mobile shelving units, and no storage of newspapers in open document boxes.

It should be emphasized that this was an engineering study directed at developing a sprinkler system that would provide protection equivalent to that provided by a system in full compliance with standards. This investigation did not evaluate all alternative sprinkler arrangements or the impact of all parameters on the effectiveness of the fire protection system.

Although useful information can be inferred from these tests, the criteria presented in this paper are intended to apply to the conditions found in the National Library of Canada. The technology outlined can certainly form the basis for fire protection systems for other situations, including retrofits where it is difficult to obtain explicit compliance with current installation standards. However, changes in types of storage, ceiling construction, and room elevations could all influence a sprinkler system's ability to control a fire. The authors suggest, therefore, that considerable caution be used in adapting the solutions presented here for other applications and suggest that full-scale fire testing be required if any major changes are made to the design.

Acknowledgment

The authors acknowledge the contribution of G.P. Crampton in carrying out the fire tests. Thanks are also due D.W. Carpenter, V.F. Fortington, R.A. MacDonald, B.C. Taber, M. Ryan, and M. Wright, who assisted in the tests.

Footnote

[†]Certain commercial products are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendations or endorsement by the National Research Council, nor does it imply that the product or material identified is the best available for the purpose.

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4. O'Neill, J., private communication.

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Annex I Compact Storage Test Program

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

I.1 The following are excerpts from "Engineering Analysis of Compact Storage Fire Tests" by Harold R. Cutler, an unpublished report prepared by Firepro Inc. for the Library of Congress in 1979.

Abstract

A series of three full-scale tests involving a mobile shelving storage system of the moving aisle type has been conducted by Factory Mutual Research Corporation under contract to the General Services Administration. The objective of the tests was to determine the nature of fire development within archival materials in this storage format and to determine the effectiveness of a specific automatic sprinkler system configuration in controlling that fire development.

These tests show a moderate rate of fire development when ignition involves materials in the open aisle of the storage module and the packing density (number of boxes per shelf) is high. They also show a relatively slow rate of development when ignition is in the closed portion of the module and the packing density of materials is high.

The tests reveal that there is a high probability that automatic sprinkler protection will prevent serious flame and heat damage outside the storage module of origin but will not significantly limit production of smoke and fire gases. The tests also indicate a low probability that automatic sprinkler protection will limit flame involvement to a portion of the storage module of origin in the storage configuration tested.

Several characteristics of the moving-aisle-type compact storage situation are analyzed. Tentative conclusions concerning fire development and fire protection for compact storage based on those characteristics are presented. The most important tentative conclusion drawn is that a combination of carriage subdivision by sheet metal panels and greater vertical openness such as provided by louvered or perforated module tops and shelves should permit limitation of open flaming to a portion of a module.

Several specific tests are proposed to allow assessment of the validity of the tentative conclusions.

Compact Storage Systems — The Problem

High-density storage of files, records, or books has become increasingly popular in recent years as cost considerations force users to seek the higher storage efficiencies available in special arrangements of storage hardware. This type of storage is especially appropriate where only limited access is required to the materials in storage. These storage systems are known by such names as "compact storage," "mobile shelving," "moving aisle storage," or "moving shelf storage."

There are two principal arrangements of shelving utilized to achieve these higher storage densities. For the purposes of this report, these arrangements are called moving aisle storage and moving shelf storage. These two storage types are described below.

Moving Aisle Storage. In moving aisle storage, several ranges of shelves are placed on carriages between a pair of fixed ranges, as illustrated in Figure I.1. Space for a single aisle is also left between the fixed ranges. Access to the shelving of a specific range is obtained by moving the carriages to a position that places the aisle along the specific face of the desired range. In such storage, a typical ratio of aisle space to storage space is 1:10.

Moving Shelf Storage. In typical moving shelf storage, a single fixed aisle serves two or more ranges of shelving on one or both sides of the aisle, as illustrated in Figure I.2. The rear range of shelving is fixed. One section of shelves in each of the front ranges is omitted and all other shelves of those ranges are mounted on carriages that allow them to travel to the left and right. Thus, the front ranges of shelves can be moved to permit access to any range of shelves. The ratio of aisle space to storage space in such a system with two ranges of shelving is approximately 1:2.

Typical standard fixed shelving [one 30-in. (762-mm) aisle providing access to two 15-in. (381-mm) shelves] has an aisle-to-storage area ratio of 1:1.

Characteristics Affecting Fire

Several characteristics of compact storage systems are expected to affect the pattern of fire development and the effectiveness of detection and suppression systems (manual and automatic) as compared to standard fixed shelving. These characteristics include the following:

(1) Module components, especially shelves and module tops that discourage vertical fire development and encourage horizontal fire development

(2) Module components, especially shelves and module contents that restrict movement of fresh air, smoke, and fire gases within the structure

(3) Module components, especially shelves and module tops that restrict distribution of water discharged from sprinklers within the storage module

(4) A module "envelope" consisting of the top and end panels of moveable ranges and the top, end, and back panels of fixed ranges that can hinder movement of heat, smoke, and fire gases from within the module and hinder penetration of extinguishing agent into the module

(5) Module construction materials that can be either energy absorbing (metal) or energy generating (wood, plastics)

(6) High fuel loading resulting in the possibility of fire duration, possibly threatening structural elements

Materials in storage can also have an impact upon fire development and the effectiveness of detection and suppression activities and equipment. Some of these characteristics include the following:

(1) Packing density

(2) Moisture content

(3) Fuel type (cellulosic, plastic)

The tests that are the subject of this analysis were performed utilizing moving-aisle-type storage. The characteristics of the combustible contents of the shelving module were varied as discussed for the specific test.

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FIGURE I.1 Moving Aisle Storage.

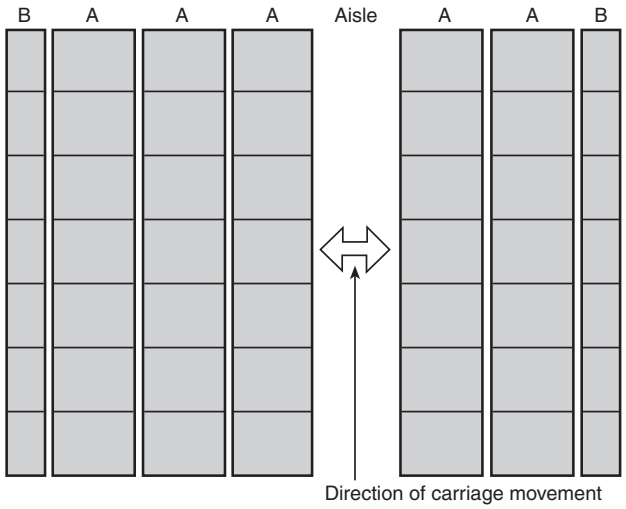
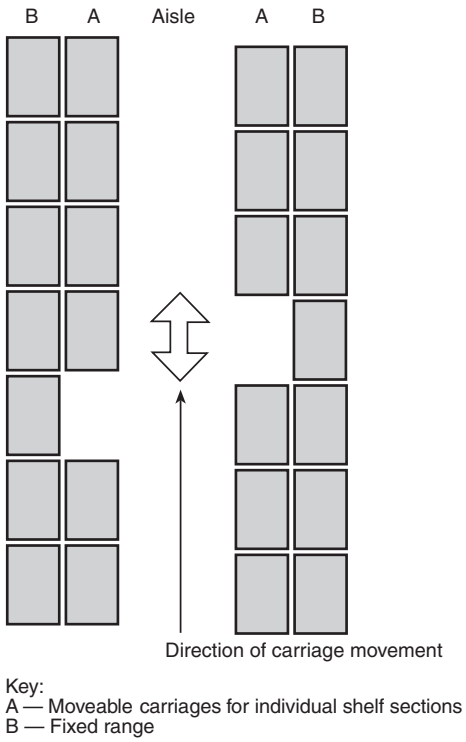


FIGURE I.2 Moving Shelf Storage.



Summary of Conclusions

This summary will list the conclusions drawn as a result of analysis of the specific General Services Administration/Factory Mutual test program and the tentative conclusions drawn by extrapolation of the test results beyond characteristics of the storage situation examined by the specific tests, as follows:

(1) Analysis of Test Results

(a) There is a high probability that automatic sprinklers (including on/off sprinklers) installed on an ordinary hazard basis over a compact storage module will prevent structural damage to building structural elements when structural elements are not enclosed partially or wholly by the storage module. (It is not possible to conclude whether or not sprinkler protection will adequately protect structural elements that are enclosed partially or wholly by the module.)

(b) The relatively low rate of heat release observed in these fires will permit the use of 165°F (74°C) sprinklers without overtaxing water supplies.

(c) There is a high probability that the combined effects of automatic sprinklers and spatial separation will prevent fire spread across a 4-ft (1.2-m) wide aisle at the end of compact storage modules to the end of an adjacent module where sprinklers are installed on an ordinary hazard basis.

(d) There is a high probability that the fire will not spread between back-to-back shelves of the fixed ranges of adjacent modules when each shelf is backed by a sheet metal panel and the panels are separated by 1 in. (25 mm) or more.

(e) Test No. 3 produced a more severe fire than Test No. 2 because of the higher degree of openness and the more severe burning characteristics of the fuels in Test No. 3 as compared to Test No. 2. (It is not possible to separate the effect of openness from the effect of burning characteristics on the basis of this test series.)

(f) Manual overhaul of a fire in a compact storage module will be required to extinguish all combustion before total consumption of fuels not directly wetted by sprinkler discharge.

(g) Mechanical or effective natural draft smoke removal will be required to permit manual overhaul operations.

(h) The effect of test room humidity and the moisture content of the test materials could not be judged in these tests.

(2) Extrapolation of Test Results

(a) Single-thickness metal dividers between back-to-back shelves within a movable carriage will reduce the rate of fire development. (It is not possible to conclude whether or not a single-thickness sheet metal divider between back-to-back shelves on a movable carriage will prevent fire spread between combustibles on those shelves.)

(b) Improved vertical openness as provided by louvered, perforated, or rolled bar module tops and shelves can improve the effectiveness of ceiling-mounted sprinklers.

(c) A combination of improved vertical openness, as provided by louvered or perforated module tops and shelves and decreased horizontal openness resulting from installation of longitudinal carriage dividers, can allow ceiling-mounted automatic sprinkler protection to limit flame damage to a portion of a storage module.

(d) The use of wooden structural framing and shelving can increase the rate and duration of burning and can also lead to earlier structural collapse of shelves than the use of steel framing and shelving.

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(e) Chemical and physical characteristics of materials in storage will have a major impact upon the rate of fire development and the fire duration experienced in compact storage modules.

(f) The moisture content of a material in storage will affect its ease of ignition and the rate of subsequent flame spread over its surface.

(g) A smoke detection system can be utilized to provide relatively early warning of a fire in a compact storage module if properly engineered to take into account ventilation conditions, and if it is recognized that the slow release of smoke from the module can lead to apparently delayed detection compared to a fire unconfined by a compact storage module.

(h) It is highly unlikely that thermal detection would take place in time to permit manual fire fighting without self-contained breathing apparatus and without incurring serious visibility problems.

(i) Given the difficulty of achieving Halon 1301 saturation of the compact storage module and the smoldering nature of fires in compact storage, Halon 1301 does not appear to be well suited for protection of materials in compact storage.

(j) Limitation of the quantity of the material in a common enclosure can limit the extent of flame, heat, smoke, and fire gas damage to the materials.

Additional Testing

A series of limited and full-scale fire tests are depicted in Figures I.3 through I.5 that would permit assessment of the validity of the tentative conclusions drawn concerning various module and protection system characteristics.

FIGURE I.3 Mobile Shelving Array Terminology and Dimensions.

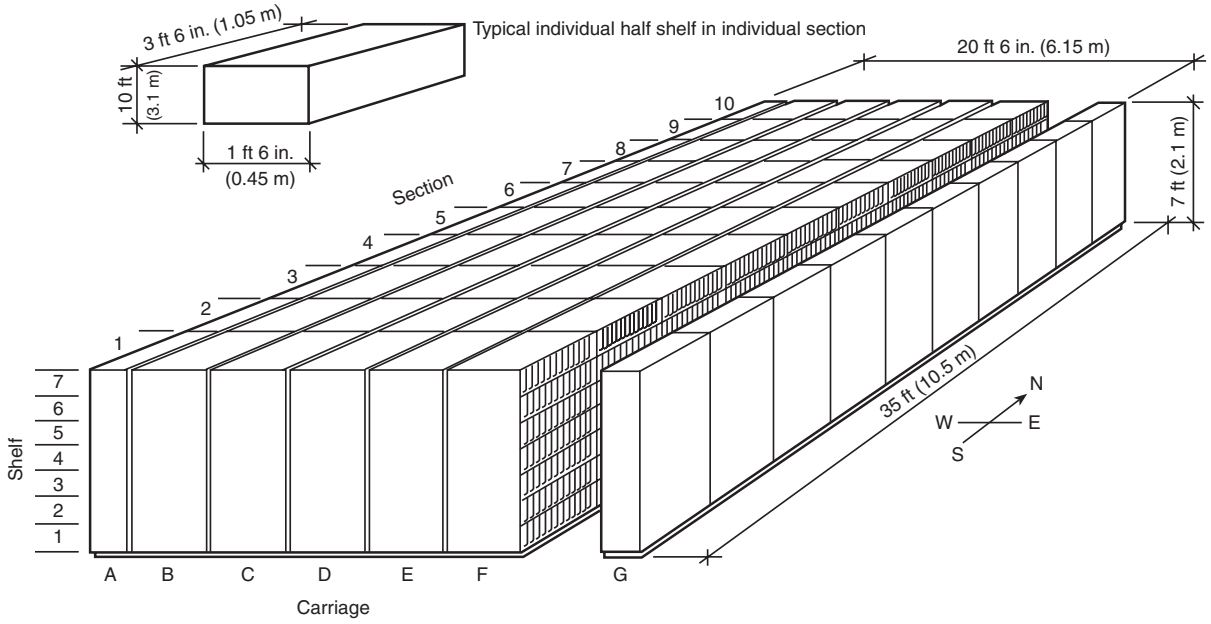

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FIGURE I.4 Multiple Module Storage.

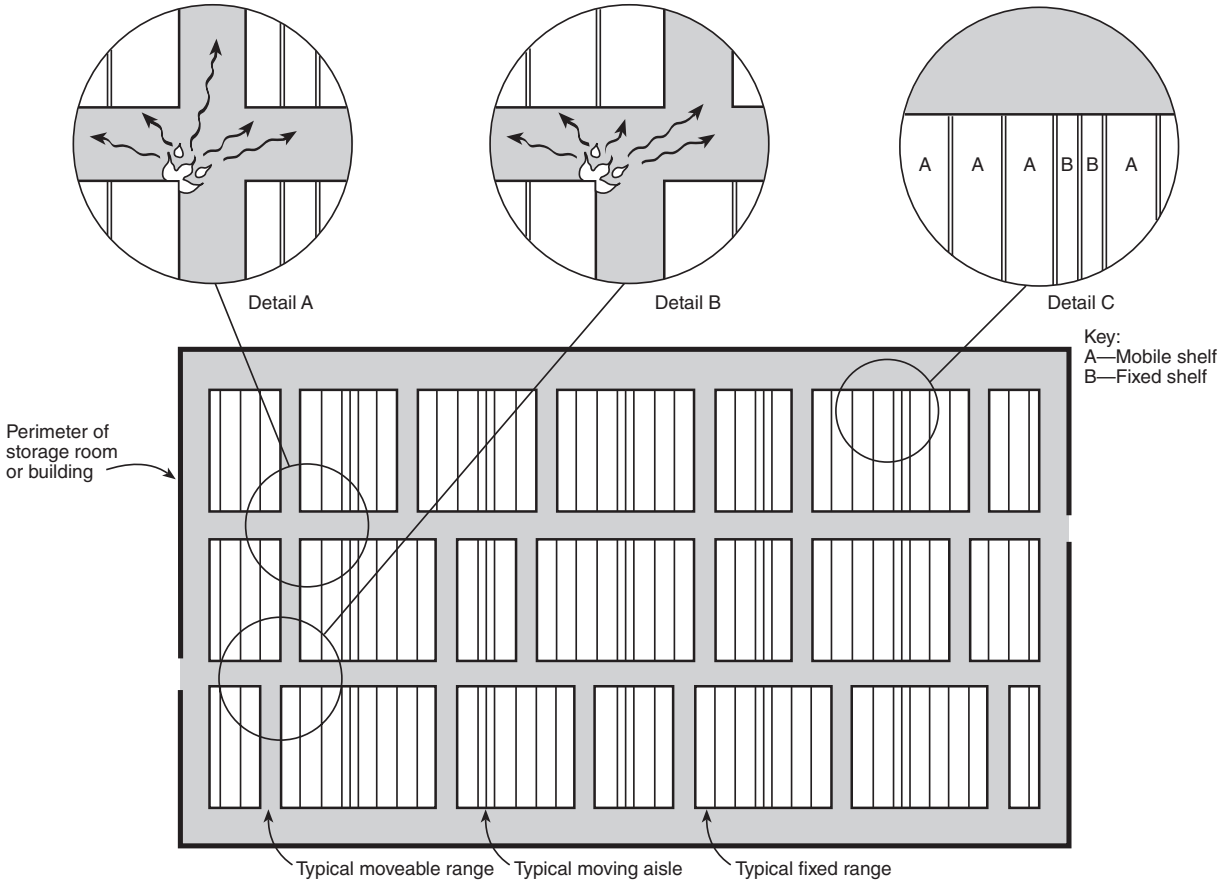

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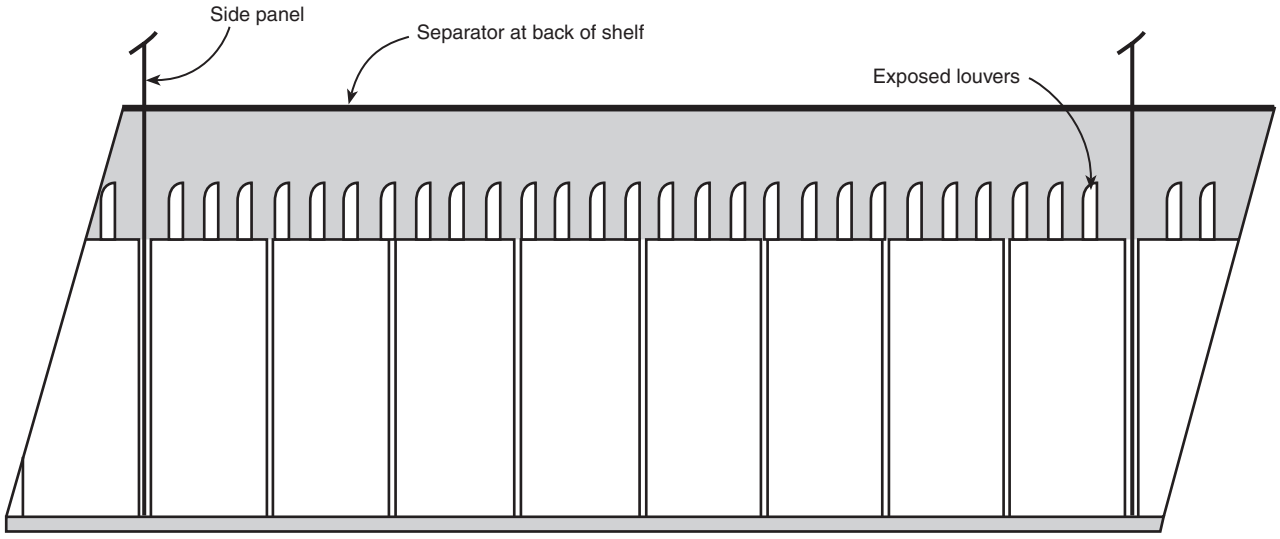
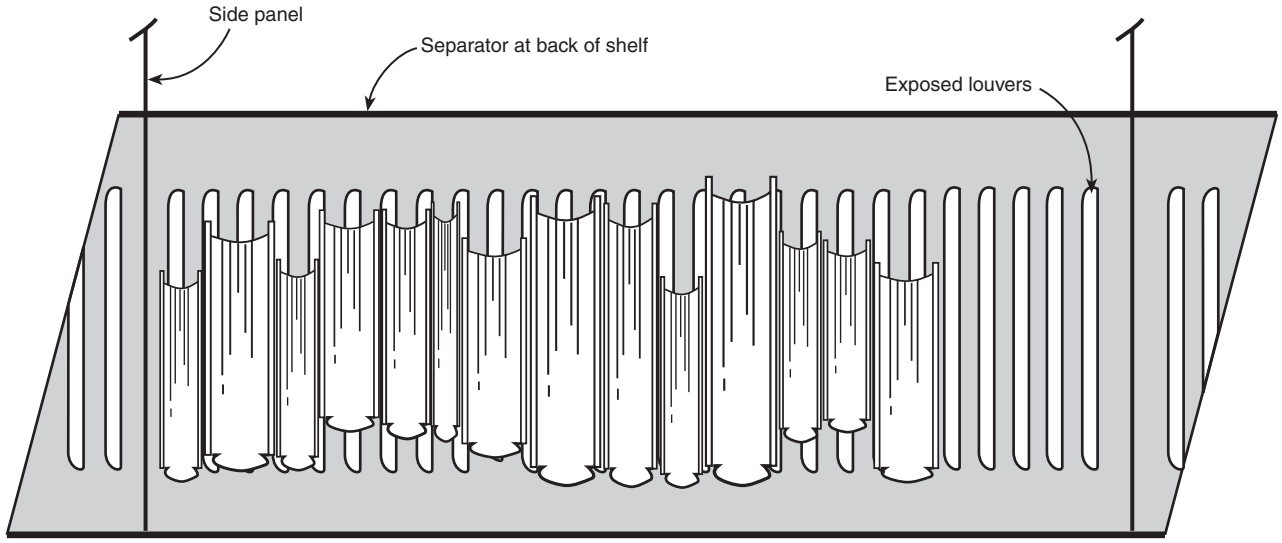
FIGURE I.5 Potential Improvement in Vertical Openness.



Plan view—archival boxes, 100% packing density



Plan view—library books, 80% packing density

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Annex J Fire Safety Inspection Forms

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J.1 Monthly Fire Protection Self-Inspection Checklist. The following checklist should be used as a reminder during inspections. Items requiring corrective action should be reported on a Notice of Fire Hazard form (see Figure J.1).

X Satisfactory 0 Correction required / Not applicable

Life Safety

- ❑ Ability to use exit doors is not hampered by security measures during occupancy.
- ❑ Stairwell and hallway fire doors are kept in the closed position.
- ❑ Stairwells and evacuation routes are free and clear of obstructions.
- ❑ Fire escape stairs appear to be in good condition.
- ❑ Emergency lighting units operate when tested.
- ❑ Exterior emergency exit routes are clear and free from snow and ice.
- ❑ Illuminated exit signs are all lit, not blocked, and can be easily seen.

Fire Protection Equipment

- ❑ Portable fire extinguishers are in their proper location and fully charged and tagged.
- ❑ A space of at least 457 mm (18 in.) is kept between sprinklers and materials.
- ❑ Fire hose cabinets are in good order, easily visible, and accessible.
- ❑ Fire detectors are free from obstructions.
- ❑ Sprinkler control valves are open and locked/secured, and dry pipe systems register at normal air pressures.
- ❑ Sprinkler tanks, piping, and supports appear in good condition.
- ❑ Alarm systems function and are tested regularly.
- ❑ Lightning arrestors appear in good condition.

Housekeeping and Storage

- ❑ Rubbish is not left to accumulate in excessive quantities; trash receptacles are emptied daily.
- ❑ Storage areas are kept clean and orderly; cleaning materials are safely stored.
- ❑ Combustible materials are not kept in unprotected areas such as a crawlspace.
- ❑ Roof scuppers and drains are unobstructed. Roof covering is in good condition.
- ❑ Aisles are unobstructed.

Hazardous Liquids

- ❑ Emergency measures are posted in case of accidental spills.
- ❑ Flammable/combustible liquids are kept in approved safety containers.
- ❑ Flammable/combustible liquids are stored in an approved cabinet.
- ❑ Safety storage cabinet vents are clear of obstructions.
- ❑ Soiled rags are kept in an approved self-closing waste container.
- ❑ Portable fire extinguishers are in their place and of the proper type.

Exhibits/Collections/Book Stacks

- ❑ Exhibits and collections are not overcrowded.
- ❑ Exhibit case lights do not show signs of overheating.
- ❑ Exhibits are not blocking exit routes and/or access to fire protection equipment.
- ❑ Extension cords are not used.
- ❑ All vertical/horizontal openings in fire barriers are firestopped.
- ❑ Salvage equipment and materials are provided and accessible.
- ❑ The fire department is familiar with and has access to these areas.
- ❑ Smoking regulations are enforced with employees and visitors.
- ❑ Temporary wiring conforms with NFPA 70, *National Electrical Code®*.

Auditoriums and Classrooms

- ❑ Safe capacity is posted and enforced.
- ❑ Standing and sitting in aisles is prohibited.
- ❑ Smoking regulations are enforced.

Restaurants and Eating Areas

- ❑ Safe capacity is posted and enforced.
- ❑ Aisles and exit routes are unobstructed and illuminated.
- ❑ Ranges, hoods, and exhaust ducts are clean.

Shops/Laboratories/Packing Areas

- ❑ Laboratory wastes are disposed of daily, using appropriate precautions.
- ❑ Spray coating facilities are safely ventilated, and scrubbers/filters are clean.
- ❑ Electrical equipment in areas near where flammable liquids are in use are explosionproof.
- ❑ Electrical appliances have warning lights and are unplugged when not in use.
- ❑ Employees are aware of special hazards and trained in any special precautions necessary.
- ❑ Entry is limited to authorized persons.
- ❑ Power tools and machines are grounded.
- ❑ Woodworking equipment dust collectors are functioning adequately and collector bins emptied regularly.
- ❑ Power tools are unplugged when not in use.

Exterior and Environment

- ❑ All exits, emergency exits, and fire escapes afford unobstructed passage to a safe area.
- ❑ Grounds surrounding the facility are clear of accumulations of combustible material and brush.
- ❑ Fire service access is maintained clear.
- ❑ Fire hydrants and sprinkler system siamese connections are visible, accessible, and operable.

Personnel/Training

- ❑ All staff members know how to transmit a fire alarm.
- ❑ All emergency team members have received training and are aware of their assigned duties.
- ❑ All staff members have received training in the use of portable extinguishers and fire prevention.

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Building Changes Since Last Inspection

- ❑ Do not interfere with fire detection and/or fire suppression systems.
- ❑ Do not contribute unreasonable fire loading.
- ❑ Do not create vertical and horizontal openings in fire-rated walls and ceilings.
- ❑ **Items requiring action have been noted on a Notice of Hazard form.** (See Figure J.1.)

Area inspected: _____

Inspected by: _____

Date of inspection:_____

FIGURE J.1 Form for Reporting Fire Hazards Requiring Corrective Action.

NOTICE OF FIRE HAZARD

DATE REPORTED:_____ **HAZARD CONTROL NO.:** _____
AREA WHERE HAZARD WAS NOTICED: _____

THE FOLLOWING HAZARD WAS NOTICED:

_____
_____
_____
_____
_____
_____

THE POTENTIAL RISK IS AS FOLLOWS:

_____
_____
_____
_____
_____
_____

THE FOLLOWING ACTION IS RECOMMENDED:

_____
_____
_____
_____

Reported to:	**Reported by:**
_____	_____
(print name)	(print name)

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Annex K Fire System Maintenance Checklists

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

K.1 Maintenance of Automatic Sprinkler and Standpipe Systems. Each alarm, dry pipe, preaction, and deluge valve should have maintenance tags (annual, 5-year, 50-year, and so forth) attached for recording the inspector's initials, date, pressure readings, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the office responsible for maintenance. All problems noted should be corrected before initialing the maintenance tag.

During any renovation or inspection of an automatic sprinkler system, the following should be reported to the facility manager for correction:

(1) Sprinklers that are damaged, blocked by storage, painted, or otherwise impaired. (Construction, occupancy changes and changes to heating, lighting, and air-conditioning systems might require relocating, adding, or replacing sprinklers.)
(2) Pipe hangers with mechanical injury and corrosion.

General Requirements for All Sprinkler and Standpipe Systems

- ❑ Annually, inspect water pressure and air pressure gauges to make sure they are within normal range. Investigate a loss of pressure of more than 10 percent. Record new pressure readings on the attached tag.
- ❑ Annually, inspect control valve labels to ensure they are accurate. Replace missing signs and relabel inaccurate signs.
- ❑ Annually, inspect fire department connections to make sure that inlets are unobstructed, that the protective caps are in place, that the connections are conspicuously marked and accessible for the fire department, and that hose threads are in good condition.
- ❑ Annually, lubricate each valve stem and reseal to prevent leaks.
- ❑ Annually, close and reopen each post indicator and Outside Stem and Yoke (OS&Y) valve.
- ❑ Annually, inspect fire department connections before freezing weather. The connection should be drained through the ball drip from the check valve to ensure it will not freeze.
- ❑ Every 5 years, replace the gaskets in check valves.
- ❑ Every 5 years, recalibrate and/or replace pressure gauges, if necessary.
- ❑ Fifty years after installation, remove a representative sample of sprinklers (at least two per floor) and have them operationally tested at a testing laboratory. Based on tests, replace sprinklers if necessary. Test a sampling of the sprinklers every 10 years thereafter.
- ❑ Fifty years after installation, inspect the sprinkler system in at least five remote and low-point locations to determine the degree of pipe corrosion. Where corrosion is found, have a fire protection engineer or sprinkler designer determine the hydraulic performance of the sprinkler system.

Wet Pipe and Antifreeze Systems

- ❑ Annually, open the inspector's test connection and test all alarms (water motor alarm and/or flow/pressure switch).
- ❑ Annually, before freezing weather, test the freezing point of antifreeze solutions with a hydrometer. Maintain the solution below the estimated minimum temperature.
- ❑ Annually, make sure wet pipe systems are properly protected from freezing.

Dry, Deluge, and Preaction Systems

- ❑ Annually, before freezing weather, operate the heating system in enclosures housing valves to ensure temperature can be maintained above 5.5°C (42°F).
- ❑ Annually, before freezing weather, open all low-point drains to remove condensation and clean plugged or obstructed sprinklers.
- ❑ Annually, remove face plates of dry, deluge, and preaction valves and examine interior for corrosion and condition of gasket.
- ❑ Annually, trip test the dry pipe, deluge, or preaction valve. Ensure quick opening devices operate properly. Once the main valve trips, quickly close the control valve.
- ❑ Every 3 years, flush system with water. The system should be filled with water for 2 days before flushing to allow pipe scale and deposits to soften. Drain system and then flush. Flush cross mains first by attaching 50 mm (2 in.) fire hose at the end of the cross main. Flow water until clear. Also, record the residual water pressure from the supply-side water pressure gauge. Remove and reinstall all pendent sprinklers after flushing is complete.
- ❑ Annually, activate preaction and deluge systems by operating the fire detection devices. Close the control valve to prohibit water from entering the system.
- ❑ Annually, lubricate air compressors on preaction and dry systems in accordance with manufacturer recommendations.
- ❑ Annually, test low air pressure alarm on preaction and dry systems. Close the water supply valve. Slowly release air from the system by slowly opening the inspector's test valve. Release enough pressure to sound the alarm. Avoid tripping the dry pipe valve.
- ❑ Quarterly, determine dry pipe system priming water level by slowly opening the priming water level test valve. If only air escapes, close the test valve and add about one quart of water. Repeat the procedure until water comes out of the test valve.
- ❑ Annually, flow test open sprinklers on deluge sprinkler systems during warm weather.

K.2 Maintenance of Fire Detection and Alarm Systems. Fire detection and alarm systems should be tested at regular intervals. Test methods and frequency of tests should be in accordance with *NFPA 72®*, *National Fire Alarm Code®*. Some of the tests that should be performed are as follows.

Alarms

- ❑ Annually, test audible devices, visible devices, and emergency voice/alarm communication equipment.

Control and Annunciation Units

- ❑ Quarterly, for unmonitored systems, and annually, for monitored systems, test all functions, interfaced equipment, main and standby power supply, and fuses.

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Batteries

- ❑ Annually, test the charger. Conduct a 30-minute discharge test semiannually, for lead acid batteries, and annually, for nickel-cadmium batteries.

Alarm Initiation Devices

- ❑ Annually, test all smoke detectors, fire alarm boxes, and restorable heat detectors. Smoke detector sensitivity should be checked as detailed in *NFPA 72*.
- ❑ Other tests, depending on the type of fire alarm system installed, should be conducted as detailed in *NFPA 72*.

K.3 Maintenance of Fire Hose Stations. Where fire hose is allowed, hose stations should have monthly and annual (all-weather) maintenance tags attached for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the office responsible for maintenance. All problems noted should be corrected before initialing the maintenance tag.

- ❑ Inspect fire hose stations monthly. Hose stations need to contain a minimum of 45 m (150 ft) of hose, a hose nozzle, and a hydrant wrench. Hose should not be damaged or show mildew. Hose needs to be neatly rolled or racked.
- ❑ Test nozzles monthly to confirm that they can be easily opened and closed.
- ❑ Rerack or rewind hose annually.

K.4 Maintenance of Fire Hydrants. Fire hydrants should have annual maintenance tags attached for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the office responsible for maintenance. All problems noted should be corrected before initialing the maintenance tag.

- ❑ Annually, inspect fire hydrants in the fall to ensure the following:
  - (1) Tightness of hydrant outlet
  - (2) No leaks in top of hydrant
  - (3) No cracks in hydrant barrel
  - (4) Hydrant drain is clear
  - (5) Turning nut is not worn down with rounded corners
  - (6) Undamaged nozzle threads
- ❑ Annually, lubricate operating nut, parking, and trust collars.
- ❑ Annually, perform a flow test to check for proper hydrant operation and to test the available water supply in accordance with NFPA 291, *Recommended Practice for Fire Flow Testing and Marking of Hydrants*. Flow water from each hydrant.

K.5 Maintenance of Fire Pumps. Fire pumps should have weekly and annual maintenance tags attached for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Water flow meters should have 5-year maintenance tags attached. Checklists detailing maintenance should be kept by the museum. All problems noted should be corrected before initialing the maintenance tag.

Weekly

- ❑ Close system valve to avoid pressurizing the automatic sprinkler system. Turn jockey pump off and gradually release pressure in the sprinkler system to confirm that low system pressure turns fire pump on. Run pump for 10 minutes. Check for excessive heat or water leakage at packing glands. At the end of the test, confirm that the fire pump and jockey pump controllers are on automatic and that the pump supply and discharge valves and the sprinkler system valves are open.
- ❑ Record suction and discharge pressure on the maintenance tag.

Annually

- ❑ Perform annual flow test in accordance with NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*.
- ❑ Turn jockey pump off and gradually release pressure in the sprinkler system to confirm that low system pressure turns fire pump on.
- ❑ Confirm proper operation of remote annunciation for pump on and power supervision on fire alarm control unit.
- ❑ Close and open control valves to ensure proper operation. Also, confirm that tamper switches on control valves are operational.
- ❑ Lubricate motors and engines in accordance with manufacturer recommendations.

Every 5 Years

- ❑ Calibrate the water flow meter, if one is installed, during the annual flow test.

K.6 Maintenance of Water Storage Tanks Used for Fire Protection. Water storage tanks used for fire protection should have monthly, annual, and 5-year maintenance tags attached at the main control valve for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the office responsible for maintenance. All problems noted should be corrected before initialing maintenance tag.

- ❑ Check water level in storage tanks monthly.
- ❑ Operate control valves monthly to ensure that they are properly arranged (generally open) and operational.
- ❑ Inspect storage tanks annually for the following:
  - (1) General condition of the tank, including loose scale, leaky seams or rivets, and paint
  - (2) Ladders on tanks for structural adequacy and the presence of rust
  - (3) The roof of storage tanks for structural stability and the presence of rust
  - (4) Sway bracing for elevated water storage tanks for structural adequacy and the presence of rust
- ❑ Conduct a flow test annually to make sure that equipment is performing properly, pipes are unobstructed, and appropriate valves are open. Perform in conjunction with fire hydrant annual tests (see K.4).
- ❑ Approximately every 5 years, thoroughly clean the interior and exterior of the tank and repaint. Temporary water supplies for fire protection need to be provided before the tank is drained.

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K.7 Maintenance of Halon Systems. Halon systems should have monthly, annual, and 5-year maintenance tags attached to the halon cylinders for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the office responsible for maintenance. All problems found should be corrected before initialing the maintenance tag. (Fire alarm functions should be maintained in accordance with K.1.)

Monthly

- ❑ Inspect the halon cylinders and piping for physical damage.
- ❑ Record the new pressure reading on the maintenance tag. Pressure must be within 10 percent of previous reading on the maintenance tag. Low readings require weighing the tank to confirm low pressure. Report confirmed low readings. Do not refill system.

Annually

- ❑ Weigh cylinders, and determine if weight is within 5 percent of previous reading on the maintenance tag. Record pressure on maintenance tag. Report low readings. Do not refill system.
- ❑ Operate control valves and correct any problems found.
- ❑ Perform an operational test on the system without discharging halon. (Remove the control heads from the halon cylinders and operate the fire detectors.) Correct any problems found.

Every 5 Years

- ❑ Replace rubber hoses.
- ❑ Perform a fan pressurization test in the room.

K.8 Maintenance of Emergency Generator and Emergency Lighting. Emergency generators should have weekly and annual maintenance tags attached for recording the inspector's initials, date, and confirmation of maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the office responsible for maintenance.

- ❑ Operate emergency generators weekly. Correct potential operational problems.
- ❑ Operate emergency generator under a simulated load biannually.
- ❑ Lubricate motors and engines annually in accordance with manufacturer recommendations.
- ❑ Perform an emergency lighting test biannually using the emergency generator. Fire pump(s), fire alarm systems, and electronic exit locking systems should be tested on emergency power concurrently.

K.9 Maintenance of Waterspray Systems for Kitchens. Annually, inspect contracts to confirm waterspray systems are being maintained in accordance with manufacturer recommendations, including the following:

(1) The monthly inspection of systems is done by a company specializing in the maintenance of these systems.
(2) Sprinklers are clean of grease.
(3) Gas and electric power shutoff are tested.
(4) Water-wash hood cleaning systems are operational.
(5) Sprinklers need to be replaced in accordance with manufacturer recommendations.
(6) Manual pull stations send a signal to the control room.
(7) Sprinklers are of the correct temperature rating and located directly above grease-producing equipment at the correct height.
(8) Monthly and annual maintenance tags are attached for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the responsible office.

K.10 Maintenance of Dry Chemical Systems. Annually, inspect contracts to ensure dry chemical systems are being maintained in accordance with manufacturer recommendations, including the following:

(1) The monthly inspection of a system is done by a company specializing in the maintenance of these systems.
(2) Nozzles are clean of grease.
(3) Gas and electric power shutoff are tested.
(4) Water-wash hood cleaning systems are operational.
(5) Fusible links are replaced annually.
(6) Manual pull stations send a signal to the control room.
(7) Fusible links are of the correct temperature rating.
(8) Nozzles are located directly above grease-producing equipment at the correct height.
(9) Pressure on gauge is adequate.
(10) Manual release stations are operational and accessible.
(11) Monthly and annual maintenance tags are attached for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the responsible office.

K.11 Maintenance of Fire Doors and Fire Dampers. Personnel responsible for maintenance should have location maps of fire doors and fire dampers and checklists detailing maintenance on each door or damper.

Fire Doors

- ❑ Annually, inspect fire doors for the following items. Correct any problems found.
  (1) Door envelope does not have punctures or broken seams.
  (2) Self-closer is intact and allows door to latch closed.
  (3) Sliding door, chains, and cables should operate smoothly over all pulleys and guides.
  (4) Doors have not been modified in the field (e.g., by the installation of louvers).
  (5) Coordinators are securely attached and adjusted properly.
  (6) Clearances around the door do not exceed the following:
    (a) Between door and frame — 3.2 mm ($^1/_8$ in.)
    (b) Between meeting edges of doors — 3.2 mm ($^1/_8$ in.)
    (c) Between bottom of door and raised sill — 9.5 mm ($^3/_8$ in.)
    (d) Between bottom of door and floor (no sill) — 19.0 mm ($^3/_4$ in.)
- ❑ Annually, test doors normally held open by automatic closing devices to confirm proper operation. Sliding doors need to be allowed to close completely to check the operation of the guides and rollers. Correct any problems found.
- ❑ Annually, lubricate guides and bearings.

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Fire Dampers

- ❑ Annually, test fire dampers to ensure that hinges and other moving parts operate properly. Remove fusible links; operate damper; and check latch (if provided). It is desirable to operate dampers with normal system air flow to ensure that they are not held open by the air stream. Correct any problems found.
- ❑ Annually, lubricate moving parts of fire damper.

Note that smoke dampers should be tested with the operation of fire detectors in accordance with K.2.

K.12 Maintenance of Stair Pressurization and Smoke Venting Systems. Fans used for stairwell pressurization and smoke venting should have annual maintenance tags attached for recording the inspector's initials, date, and confirmation on maintenance/inspections performed on the system. Checklists detailing maintenance should be kept by the office responsible for maintenance.

- ❑ Annually, perform an air pressure test in stairwells having pressurization fans to make sure all system parts and controls are operational and design air pressures (not to exceed NFPA *101®, Life Safety Code®,* requirements) are obtained. Correct any problems found before initialing the maintenance tag.
- ❑ Annually, lubricate fan motors in accordance with manufacturer recommendations.

K.13 Maintenance of Portable Fire Extinguishers.

- ❑ Each extinguisher needs to have an inspection tag.
- ❑ Monthly, inspect extinguishers. An extinguisher inspection includes ensuring that extinguishers are fully charged, in their designated locations, physically undamaged, not tampered with, and not obstructed, and that the hydrostatic test is up to date. The inspector should initial the inspection tag after the extinguisher is found in good working order and should perform the following as needed:
  - (1) Report obstructed or out-of-place extinguishers to the building manager.
  - (2) Replace any extinguisher that is physically damaged or that has a broken or missing tamper indicator (plastic seal around the handle).
  - (3) Replace any extinguisher on which the gauge indicates "recharge" or, in the case of carbon dioxide extinguishers, when there is a weight loss of 10 percent or more (the weight is listed on the label of the extinguisher). For example, if the label indicates 15.2 kg ($33^1/_2$ lb), replace the extinguisher when the weight goes below 14.0 kg (31 lb). The weight should be checked semiannually.
  - (4) Replace any extinguisher requiring a hydrostatic test in accordance with the following dates given. Each extinguisher is marked with the date of the last hydrostatic test (e.g., 1/26/80 or 1@80). Look for the most recent date, and calculate when the extinguisher needs to be tested again. For example, a carbon dioxide extinguisher dated 1@80 should be retested in January 1985. (When an extinguisher needs to be replaced, use a spare extinguisher of the same type and at least equal rating as the one being replaced.)

Extinguisher Types	Hydrostatic Test Period
Dry chemical	12 years
Carbon dioxide	5 years
Stored water pressure	5 years
Halon	12 years

K.14 Maintenance of Lightning Protection Systems. Those responsible for maintenance/inspection should have detailed drawings of lightning protection systems and checklists detailing maintenance.

- ❑ Annually, inspect system for mechanical damage.
- ❑ Annually, test all connections for electrical resistance. If resistance to ground is more than 5 ohms, make necessary changes to reduce it to 5 ohms or less.

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Annex L Salvage of Water-Damaged Library Materials

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

L.1 The following material is extracted from *Procedures for Salvage of Water-Damaged Library Materials* by Peter Waters, Restoration Officer, Library of Congress, 1975 (an LC Publication on Conservation of Library Materials). The reader will find additional references on this topic in G.2.

Assessment of Damage and Planning for Salvage.

Weather is the critical factor in determining what course to take after any flood or fire in which museum, archival, or library materials are damaged. When it is hot and humid, salvage must be initiated with a minimum of delay to prevent or control the growth of mold. When the weather is cold, more time can be taken to plan salvage operations and experiment with various drying procedures.

The first step is to establish the character and degree of damage. Once an accurate assessment of the damage has been made, firm priorities and plans for salvaging the damaged materials can be drawn up. These plans must include a determination of the special facilities and equipment required. Overcautious, unrealistic, or inadequate appraisals of damage can result in the loss of valuable materials. Speed is of the utmost importance, but careful planning is equally essential in the salvage effort.

Where water damage has resulted from fire-fighting measures, cooperation with the fire marshal is vital for a realistic appraisal of the feasibility of salvage efforts. Fire marshals and safety personnel will decide when a damaged building is safe to enter. In some cases, areas involved in the fire can require a week or longer before they are cool enough to be entered. Occasionally, parts of a collection can be identified early in the salvage planning effort as being especially vulnerable to destruction unless they receive attention within a few hours after the fire has abated. If the fire marshal appreciates such needs, the marshal can provide means of access to the area even when other parts of the building remain hazardous.

Once all entrances and aisles are cleared, the most important collections, including rare materials and those of permanent research value, should be salvaged first, unless other materials would be more severely damaged by prolonged immersion in water. Examples of the latter are books printed on paper of types widely produced between 1880 and 1946, now brittle or semi-brittle. However, materials in this category that can be replaced should be left until last.

Salvage operations must be planned so that the environment of flooded areas can be stabilized and controlled both before and during the removal of the damaged materials. In warm, humid weather, mold growth can be expected to appear in a water-damaged area within 48 hours. In any weather, mold will appear within 48 hours in unventilated areas made warm and humid by recent fire in adjacent parts of the building. For this reason, every effort should be made to reduce high temperatures and vent the areas as soon as the water has receded or been pumped out. Water-soaked materials must be kept as cool as possible by good air circulation until they can be stabilized. To leave such materials more than 48 hours in temperatures above 70°F (21°C) and humidity above 70 percent will almost certainly result in heavy mold growth and lead to high restoration costs.

Damaged most by these conditions are volumes printed on coated stock and such highly proteinaceous materials as leather and vellum bindings. Starch-impregnated cloths, glues, adhesives, and starch pastes are affected to a lesser degree. As long as books are tightly shelved, mold will develop only on the outer edges of the bindings. Thus no attempt should be made in these conditions to separate books and fan them open. Archival files packed closely together on the shelves in cardboard boxes or in metal file cabinets are the least affected.

As a general rule, damp books located in warm and humid areas without ventilation will be subject to rapid mold growth. Archival files that have not been disturbed will not be attacked as quickly by mold. Very wet materials, or those still under water, will not develop mold. As they begin to dry after removal from the water, however, both the bindings and the edges of books will be quickly attacked by mold, especially when in warm, unventilated areas. A different problem exists for books printed on coated stock, since if they are allowed to dry in this condition, the leaves will be permanently fused together.

Summary of Emergency Procedures.

(1) It is imperative to seek the advice and help of trained conservators with experience in salvaging water-damaged materials as soon as possible. The Library of Congress is an excellent information source for technical advice where needed. Contact: Preservation Office, Library of Congress, Washington, DC, Telephone (202) 707-5212.
(2) Turn off heat and create free circulation of air.
(3) Keep fans and air conditioning on at night, except when a fungicidal fogging operation is in process, because a constant flow of air is necessary to reduce the threat of mold.
(4) Brief each worker carefully before salvage operations begin, giving full information on the dangers of proceeding except as directed. Emphasize the seriousness of timing and the priorities and aims of the whole operation. Instruct workers on means of recognizing manuscripts, materials with water-soluble components, leather and vellum bindings, materials printed on coated paper stock, and photographic materials.
(5) Do not allow workers to attempt restoration of any items on site. (This was a common error in the first 10 days after the Florence flood, when rare and valuable leather- and vellum-bound volumes were subjected to scrubbing and processing to remove mud. This resulted in driving mud into the interstices of leather, vellum, cloth, and paper, caused extensive damage to the volumes, and made the later work of restoration more difficult, time consuming, and extremely costly.)
(6) Carry out all cleaning operations, whether outside the building or in controlled environment rooms, by washing gently with fresh, cold running water and soft cellulose sponges to aid in the release of mud and filth. Use sponges with a dabbing motion; do not rub. These instructions do not apply to materials with water-soluble components. Such materials should be frozen as quickly as possible.

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(7) Do not attempt to open a wet book. (Wet paper is very weak and will tear at a touch.) Hold a book firmly closed when cleaning, especially when washing or sponging. A closed book is highly resistant to impregnation and damage.

(8) Do not attempt to separate single-sheet materials unless they are supported on polyester film or fabric.

(9) Do not attempt to remove all mud by sponging. Mud is best removed from clothes when dry; this is also true of library materials.

(10) Do not remove covers from books, as they will help to support the books during drying. When partially dry, books can be hung over nylon lines to finish drying. Do not hang books from lines while they are very wet because the weight will cause damage to the inside folds of the sections.

(11) Do not press books and documents mechanically when they are water soaked. This can force mud into the paper and subject the materials to stresses that will damage their structures.

(12) Use soft pencils for making notes on slips of paper but do not attempt to write on wet paper or other artifacts.

(13) Clean, white blotter paper, white paper towels, strong toilet paper, and unprinted newsprint paper can be used for interleaving in the drying process. When nothing better is available, all but the color sections of printed newspapers can be used. Great care must be taken to avoid rubbing the inked surface of the newspaper over the material being dried; otherwise some offsetting of the ink could occur.

(14) Under no circumstances should newly dried materials be packed in boxes and left without attention for more than a few days.

(15) Do not use bleaches, detergents, water-soluble fungicides, wire staples, paper or bulldog clips, adhesive tape, or adhesives of any kind. Never use felt-tipped fiber or ballpoint pens or any marking device on wet paper. Never use colored blotting paper or colored paper of any kind to dry books and other documents.

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Annex M Factory Mutual Engineering Division Laboratory Report

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

M.1 This report is by P. E. Cotton, 14000/Res., December 21, 1959.

E. W. Cousins, Chief Research Engineer, and J. M. Rhodes, Director, Engineering and Laboratories, of the Factory Mutual Engineering Division.

Fire Tests of Library Book Stacks.

Consideration of library fire protection usually brings out two questions. First, would fire be expected to spread in a book stack? And second, if so, will automatic sprinklers keep the damage to a minimum? Two tests were made to show the answers. In both cases it was emphatically, yes.

The stack used in the tests is illustrated by Figures M.1, M.2, and M.3. It is a segment of a typical library stack, consisting of a steel structure supporting steel shelves that hold discarded library books. This structure was purchased from and erected by a manufacturer of library equipment. In the plan, the segment contains four ranges (lines of shelving) 12 ft (3.72 m) long facing on two aisles $4^1/_2$ ft (1.4 m) on centers. Thus, the area occupied is 9 ft (2.79 m) wide by 12 ft (3.72 m) long. In elevation there are four tiers or stories, each $7^1/_2$ ft (2.3 m) high, making a total height of 30 ft (9.3 m).

Test 1 — With Standard Automatic Sprinklers.

For the first fire test, standard automatic sprinklers were installed in both aisles in all four tiers of the stack. Since the sprinklers were spaced the maximum practical distance apart in the aisles [15 ft (4.6 m)], platforms were provided at each end of the stack to extend its effective length insofar as the sprinklers were concerned.

The fire was started in a small quantity of paper contained in a wooden book cart arranged as shown in Figure M.4.

Its location in one aisle of the lowest tier of the stack is illustrated in Figures M.5 through M.8, which also show the fire growth, the action of the sprinklers, and the limitation of damage.

In this test, one sprinkler opened in the second tier at 3 minutes, 43 seconds after the fire was lighted and one sprinkler opened in the first tier 7 minutes, 53 seconds after the start. The sprinkler discharge stopped the spread of fire in the books almost immediately and gradually extinguished the fire.

There was fire damage to books in 10 percent of the storage space of the stack (see Figure M.9), and this damage would be repairable for practically all of the books involved. Books in an additional 27 percent of the storage space of the test segment were wet in varying degrees ranging from dampness to soaking. All books so involved would be repairable by drying. Nine 3 ft (0.93 m) long shelf sections were deformed by heating, although the structural members of the stack were unharmed except for paint damage.

FIGURE M.1 General View of Four-Tier Book Stack Loaded With 11,200 Books.

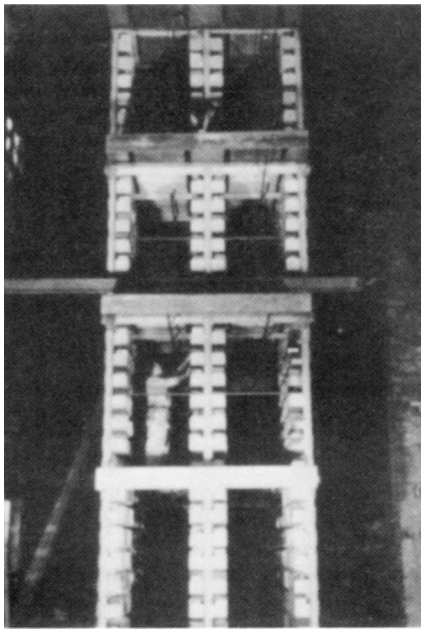

FIGURE M.2 Illustration of Structural Elements of Stack; Note One Sprinkler Position.

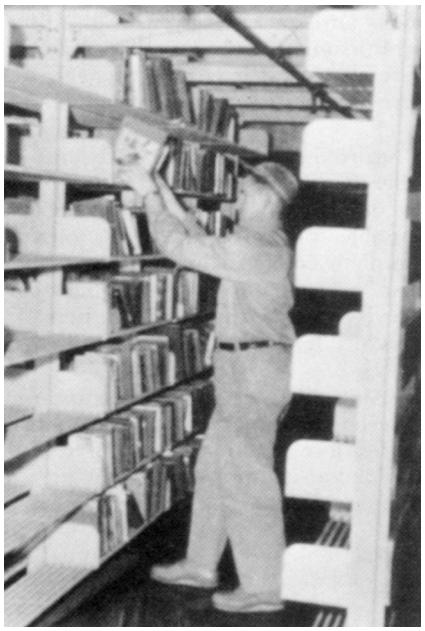

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FIGURE M.3 General View of Books in the First and Second Tiers Before Tests.

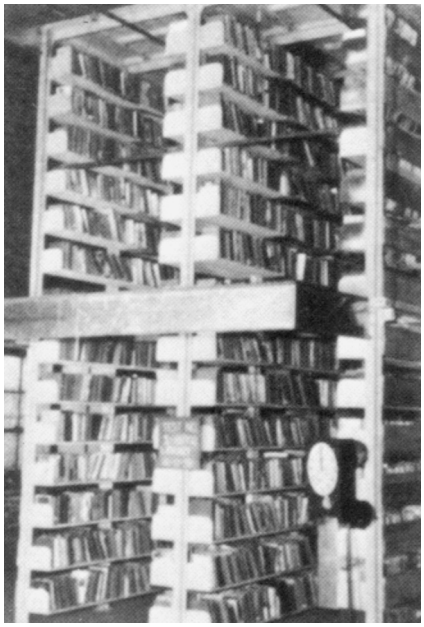

FIGURE M.4 Wood Book Cart Before Being Placed in Aisle of First Tier. (After placement, books were put on top shelf of book cart. The fire was started with an ordinary match by igniting the crumpled piece of paper between the two cartons on the bottom shelf of the cart.)

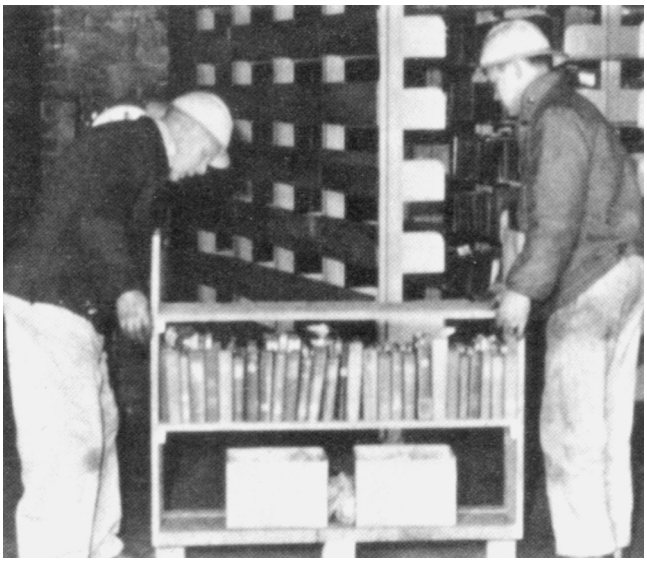

FIGURE M.5 One Minute, 10 Seconds; Flame Showing Above Book Cart; Sprinklers Not Yet Operating.

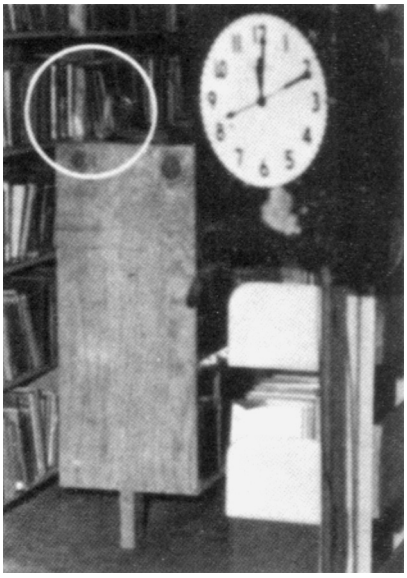

FIGURE M.6 Three Minutes, 25 Seconds; Active Burning in First Tier; Sprinklers Not Yet Operating.



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FIGURE M.7 Eight Minutes, 3 Seconds; Two Sprinklers Operating; Fire in Stack Under Control.

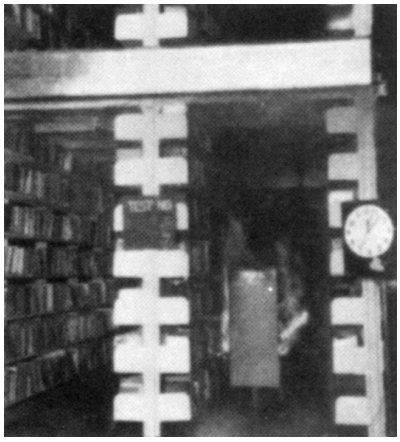

FIGURE M.8 After Fire Extinguishment by Sprinklers; Fire Damage to Books in Only 10 Percent of Space.

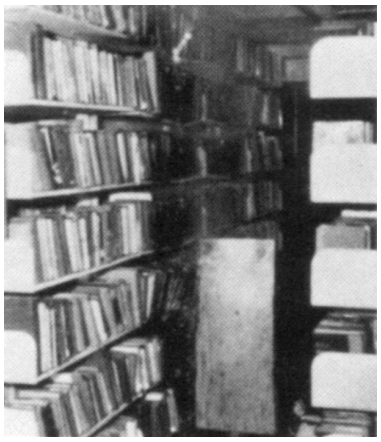

FIGURE M.9 Close-up of Extent of Fire Damage After Test 1 with Automatic Sprinklers. (Note limited area of fire damage.)



Test 2 — No Automatic Sprinkler System.

After replacing all fire- and water-damaged books and shelving following the first test, a second test was made using the same method of ignition as in the first test.

The spread of fire upward through the four tiers of the book stack is described best by Figures M.10 through M.13. Added to this are the visual observations that books in the second tier began burning at approximately $3^1/_4$ minutes, in the third tier at $7^1/_2$ minutes, and in the fourth tier at 9 minutes. By 10 minutes, there was intense fire in all areas of the book stacks except at the lower shelves of the first tier in the aisle not containing the ignition source. A 1 in. (25 mm) hose line was used to attack the fire at 10 minutes, 23 seconds, followed by a $2^1/_2$ in. (63 mm) hose line at 10 minutes, 40 seconds since the first hose stream was only slightly effective. Together, these hose streams controlled and essentially extinguished the fire, although smoldering continued for hours afterward.

FIGURE M.10 One Minute, 48 Seconds; Books in Stack Ignited; No Sprinklers.

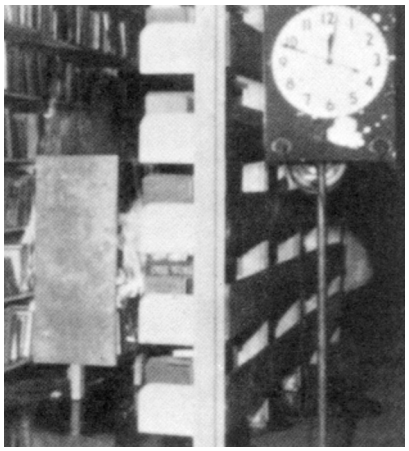

FIGURE M.11 After Approximately 3 Minutes; Active Burning in First Tier; No Sprinklers.



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FIGURE M.12 After Approximately $7^1/_2$ Minutes, Fire Involved Second and Third Tiers.

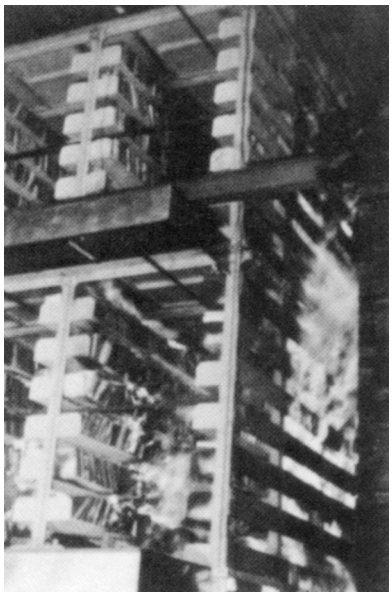
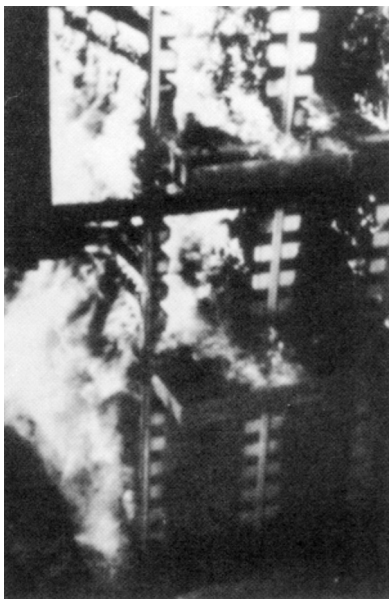


FIGURE M.13 After About $9^1/_2$ Minutes, Flame Spread to Top Tier and Across Aisles on Lower Tiers.



Some indication of the extent of the damage to the books and stacks is given by the photographs in Figures M.14 through M.16. Quantitatively, 89 percent of the books were charred deeply or completely destroyed, $2^1/_2$ percent were scorched, and the remaining $8^1/_2$ percent were soaked.

Approximately three-fourths of the shelving was irreparably damaged. Some of the structural elements were visibly deformed (see Figure M.17); others would not be safely reusable for live loads. These observations indicate that complete collapse of the structure was imminent when hose streams were applied. Figure M.18 gives a comparison of temperatures of various points in the structure for both tests. (See Figure M.19 for summary information.)

FIGURE M.14 General View of First and Second Tiers After Test 2; No Sprinklers.

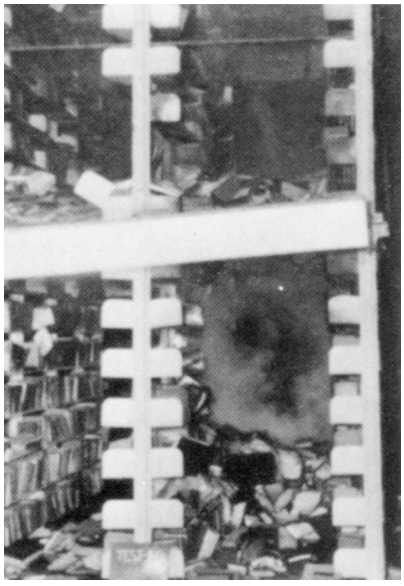


FIGURE M.15 General View of Third and Fourth Tiers; All Exposed Book Surfaces Charred.

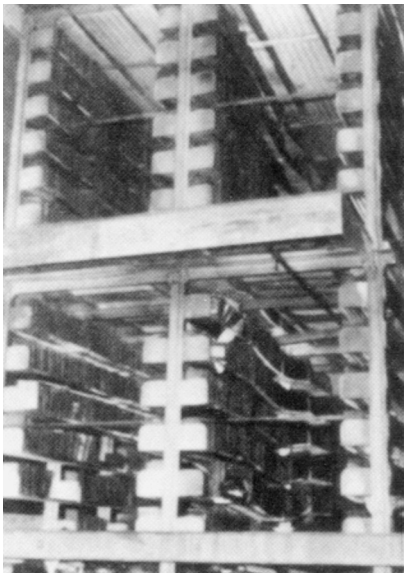


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FIGURE M.16 Extent of Damage to Shelving After Test 2 on Second Tier, Right Aisle; No Sprinklers. (Note severe charring of books and collapse of shelving.)

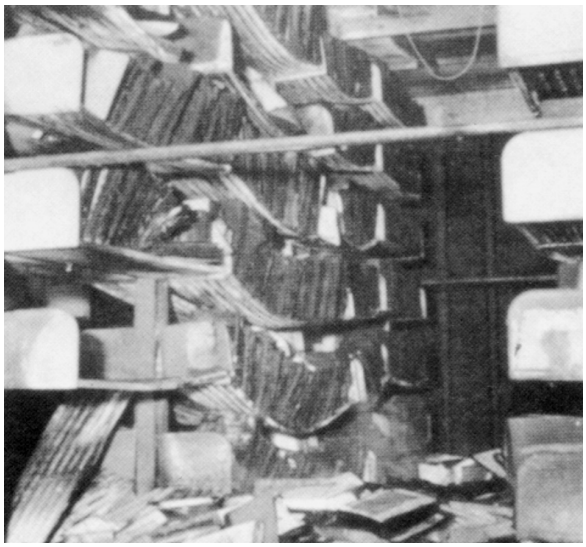

FIGURE M.17 View of First Tier, Left Aisle After Test 2; No Sprinklers. [The temperatures reached 1500°F (780°C) in each recorded location, whereas in Test 1 (with sprinklers) temperatures did not go above 500°F (260°C). Note failure of column (center of photo).]

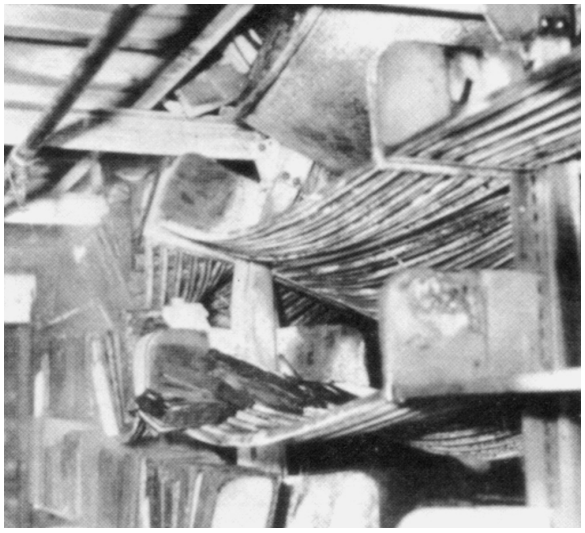

FIGURE M.18 Temperatures at Various Locations in Book Stacks.

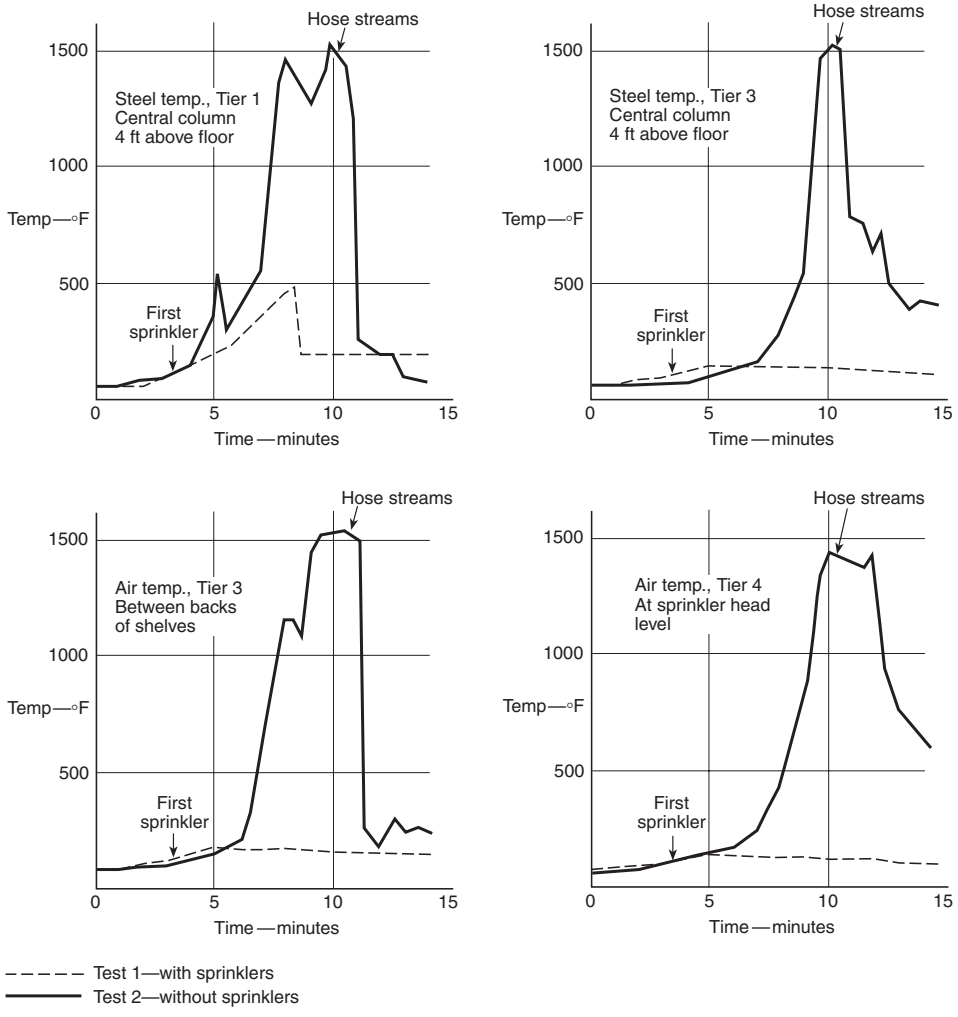

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FIGURE M.19 Summary of Contents Structural Information.

Book Stack

Size:	9 feet wide; 12 feet long; 30 feet high (four 7½ ft-high tiers)
Book Storage:	Four ranges of four compartments each in each tier
Shelves:	Seven shelves in each compartment; all U-bar type except floor shelf, which is solid
	Shelves are 3 feet long by 8 inches deep; spaced 1 foot apart vertically; except at floor and ceiling, where spacing is 15 inches
	112 shelves per tier; 448 shelves total
Aisles:	3 feet wide; two 3-in. slots plus 30-in. walkway
Weight of Structure:	7000 pounds

Books

Average:	25 per shelf; 175 per compartment; 700 per single range; 2800 per tier; 11,200 total
Approximate Average Weight per Book:	1 pound dry; 2½ pounds soaking wet
Moisture Content of Books:	5 percent to 9 percent

Book Cart and Contents

Book cart (shown in Figure M.4) was made of wood (moisture content: 7 percent) and was 15 inches wide, 42 inches long, and 36 inches high. During the tests, 120 books were placed on the two top shelves (fully loaded), and the bottom shelf contained two open-top cardboard cartons (12 by 12 by 8 inches). Each carton contained two crumpled wrapping papers that were 3 feet by 3 feet each and between cartons was crumpled wrapping paper 1½ feet by 3 feet. The weight of the cartons and paper was 2 pounds; the weight of the book cart empty was 57 pounds. The test engineers considered this book cart fire "a modest local ignition source" for these library tests.

Sprinkler Protection

The sprinklers used were 160° standard sprinklers, pendent mounted, on 4½-ft by 15-ft spacing staggered vertically and horizontally. There were sprinklers in all tiers and all aisles of the test library book stack setup.

Sprinkler deflectors were located 10 inches below the ceiling and 6 inches off center to allow for fluorescent lighting in actual library installations.

The pressures were designed so that the static pressure at the end sprinkler was 5 psi on the fourth tier, 14¾ psi on the first tier, 11½ psi on the second tier, and 8¼ psi on the third tier.

The approximate discharge per sprinkler was 22 gallons per minute on the first tier, 19 gpm on the second tier, 16 gpm on the third tier, and 13 gpm on the fourth tier.

From these results, it is apparent that fire can be expected to spread quickly through library stacks from a modest local ignition source. It is also apparent that standard automatic sprinklers will fill their normal industrial role of minimizing the consequent damage from such a fire.

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Annex N Secretary of the Interior's Standards

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

N.1 General. In the United States, the Interior Secretary provides guidelines for rehabilitation and operation of historic sites. The following information is provided as an example of national criteria:

(1) Every reasonable effort shall be made to provide a compatible use for a property that requires minimal alteration of the building, structure, or site and its environment, or to use a property for its originally intended purpose.

(2) The distinguishing original qualities or character of a building, structure, or site and its environment shall not be destroyed. The removal or alteration of any historic material or distinctive architectural feature should be avoided when possible.

(3) All buildings, structures, and sites shall be recognized as products of their own time. Alterations that have no historical basis and that seek to create an earlier appearance shall be discouraged.

(4) Changes that could have taken place in the course of time are evidence of the history and development of a building, structure, or site and its environment. These changes could have acquired significance in their own right, and this significance shall be recognized and respected.

(5) Distinctive stylistic features or examples of skilled craftsmanship that characterize a building, structure, or site shall be treated with sensitivity.

(6) Deteriorated architectural features shall be repaired rather than replaced wherever possible. In the event replacement is necessary, the new material should match the material being replaced in composition, design, color, texture, and other visual qualities. Repair or replacement of missing architectural features should be based on accurate duplications of features, substantiated by historic, physical, or pictorial evidence rather than on conjectural designs or the availability of different architectural elements from other buildings or structures.

(7) The surface cleaning of structures shall be undertaken with the gentlest means possible. Sandblasting and other cleaning methods that will damage the historic building materials shall not be undertaken.

(8) Every reasonable effort shall be made to protect and preserve archaeological resources affected by or adjacent to any project.

(9) Contemporary design for alterations and additions to existing properties shall not be discouraged when such alterations and additions do not destroy significant historical, architectural, or cultural material, and such design is compatible with the size, scale, color, material, and character of the property, neighborhood, or environment.

(10) Wherever possible, new additions or alterations to structures shall be done in such a manner that if such additions or alterations were to be removed in the future, the essential form and integrity of the structure would be unimpaired.

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Annex O Guideline on Fire Ratings of Archaic Materials and Assemblies

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

Prepared by the National Institute of Building Sciences, Washington, DC, for the U.S. Department of Housing and Urban Development Office of Policy Development and Research under Cooperative Agreement H-5033. The contents of this publication do not necessarily reflect the views and policies of the Department of Housing and Urban Development or the U.S. Government.

Acknowledgments

The material herein was prepared by the National Institute of Building Sciences on the basis of research conducted by Brady Williamson, principal author, and Cecile Grant, editor, of the J. Bradford Corporation; Joseph Zicherman, Fred Fisher, and Harry Hasegawa, of IFT, Inc., coauthors; and Herman Spaeth, Harriet Watson, Vytenis Babrauskas, and Norman Kornsand, consultants. Technical reviewers for the Institute included Harold Nelson, Richard Bletzacker, and Russel Parks. Final editing of the guideline was performed by Howard Markman, aided by Ruth Fidelman and Duncan Wilson.

Overall management and production of the Rehabilitation Guidelines was directed by William Brenner of the Institute, with David Hattis of Building Technology, Inc., the principal technical consultant.

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Introduction

The *Guideline on Fire Ratings of Archaic Materials and Assemblies* focuses upon the fire-related performance of archaic construction. "Archaic" encompasses construction typical of an earlier time, generally prior to 1950. "Fire-related performance" includes fire resistance, flame spread, smoke production, and degree of combustibility.

The purpose of this guideline is to update the information that was available at the time of original construction, for use by architects, engineers, and code officials when evaluating the fire safety of a rehabilitation project. In addition, information relevant to the evaluation of general classes of materials and types of construction is presented for those cases when material or assembly cannot be found.

It has been assumed that the building materials and their fastening, joining, and incorporation into the building structure are mechanically sound. Therefore, some determination must be made that the original manufacture, the original construction practice, and the rigors of aging and use have not weakened the building. The assessment can often be difficult because process and quality control was poor in many industries, and variations among locally available raw materials and manufacturing techniques often resulted in a product that varied widely in its strength and durability. The properties of iron and steel, for example, varied widely, depending on the mill and the process used.

There is nothing inherently inferior about archaic materials or construction techniques. The pressures that promote fundamental change are most often economic or technological and do not necessarily relate to concerns for safety. The high cost of labor has made wood lath and plaster uneconomical. The high cost of land and the congestion of the cities provided the impetus for high-rise construction; improved technology made it possible. The difficulty with archaic materials is not a question of suitability, but familiarity.

Code requirements for the fire performance of key building elements (e.g., walls, floor/ceiling assemblies, doors, shaft enclosures) are stated in performance terms: hours of fire resistance. It does not matter whether these elements were built in 1908 or 1980, only that they provide the required degree of fire resistance. The level of performance will be defined by the local community, primarily through the enactment of a building or rehabilitation code. This guideline is only a tool to help evaluate the various building elements, regardless of what the level of performance is required to be.

The problem with archaic materials is simply that documentation of their fire performance is not readily available. The application of engineering judgment is more difficult because building officials might not be familiar with the materials or construction method involved. As a result, either a full-scale fire test is required or the archaic construction in question must be removed and replaced. Both alternatives are time consuming and wasteful.

This guideline is designed to help fill this information void. By providing the necessary documentation, there will be a firm basis for the continued acceptance of archaic materials and assemblies.

O.1 Fire-Related Performance of Archaic Materials and Assemblies.

O.1.1 Fire Performance Measures. This guideline does not specify the level of performance required for the various building components. These requirements are controlled by the building occupancy and use and are set forth in the local building or rehabilitation code.

The fire resistance of a given building element is established by subjecting a sample of the assembly to a "standard" fire test that follows a "standard" time-temperature curve. This test method has changed little since the 1920s. The test results tabulated in O.4 have been adjusted to reflect current test methods.

The current model building codes cite other fire-related properties not always tested for in earlier years, such as flame

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spread, smoke production, and degree of combustibility. However, they can generally be assumed to fall within well-defined values because the principal combustible component of archaic materials is cellulose. Smoke production is more important today because of the increased use of plastics. However, the early flame spread tests, developed in the early 1940s, also included a test for smoke production.

"Plastics," one of the most important classes of contemporary materials, were not found in the review of archaic materials. If plastics are to be used in a rehabilitated building, they should be evaluated by contemporary standards. Information and documentation of their fire-related properties and performance is widely available.

Flame spread, smoke production, and degree of combustibility are discussed in detail in the following subsections. Test results for eight common species of lumber, published in an Underwriters Laboratories report, are noted in Table O.1.1.

Table O.1.1 Tunnel Test Results for Eight Species of Lumber

Species of Lumber	Flame Spread	Fuel Contributed	Smoke Developed
Western White Pine	75	50–60	50
Northern White Pine	120–215	120–140	60–65
Ponderosa Pine	80–215	120–135	100–110
Yellow Pine	180–190	130–145	275–305
Red Gum	140–155	125–175	40–60
Yellow Birch	105–110	100–105	45–65
Douglas Fir	65–100	50–80	10–100
Western Hemlock	60–75	40–65	40–120

O.1.1.1 Flame Spread. The flame spread of interior finishes is most often measured by the ASTM E 84, *Standard Test Method for Surface Burning Characteristics of Building Materials,* "tunnel test." This test measures how far and how fast the flames spread across the surface of the test sample. The resulting flame spread rating (FSR) is expressed as a number on a continuous scale where cement-asbestos board is 0 and red oak is 100. (Materials with a flame spread greater than red oak have a FSR greater than 100.) The scale is divided into distinct groups or classes. The most commonly used flame spread classifications are Class I or A (some codes use roman numerals, while others use letters), with a 0–25 FSR, Class II or B, with a 26–75 FSR, and Class III or C, with a 76–200 FSR. NFPA *101, Life Safety Code*, also has a Class D (201–500 FSR) and Class E (over 500 FSR) interior finish.

These classifications are typically used in modern building codes to restrict the rate of fire spread. Only the first three classifications are normally permitted, though not all classes of materials can be used in all places throughout a building. For example, the interior finish of building materials used in exits or in corridors leading to exits is more strictly regulated than materials used within private dwelling units.

In general, inorganic archaic materials (e.g., bricks or tile) can be expected to be in Class I. Materials of whole wood are mostly Class II. Whole wood is defined as wood used in the same form as sawn from the tree. This is in contrast to the contemporary reconstituted wood products such as plywood, fiberboard, hardboard, or particle board. If the organic archaic material is not whole wood, the flame spread classification could be well over 200 and thus would be particularly unsuited for use in exits and other critical locations in a building. Some plywoods and various wood fiberboards have flame spreads over 200. Although they can be treated with fire retardants to reduce their flame spread, it would be advisable to assume that all such products have a flame spread over 200 unless there is information to the contrary.

O.1.1.2 Smoke Production. The evaluation of smoke density is part of the ASTM E 84, *Standard Test Method for Surface Burning Characteristics of Building Materials,* tunnel test. For the eight species of lumber shown in Table O.1.1, the highest levels are 275–305 for yellow pine, but most of the others are less smoky than red oak, which has an index of 100. The advent of plastics caused substantial increases in the smoke density values measured by the tunnel test. The ensuing limitation of the smoke production for wall and ceiling materials by the model building codes has been a reaction to the introduction of plastic materials. In general, cellulosic materials fall in the 50–300 range of smoke density, which is below the general limitation of 450 adopted by many codes.

O.1.1.3 Degree of Combustibility. The model building codes tend to define "noncombustibility" on the basis of having passed ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C,* or if the material is totally inorganic. The acceptance of gypsum wallboard as noncombustible is based on limiting paper thickness to not over $^1/_8$ in. (3.2 mm) and a 0–50 flame spread rating by ASTM E 84, *Standard Test Method for Surface Burning Characteristics of Building Materials.* At times there were provisions to define a Class I or A material (0–25 FSR) as noncombustible, but this is not currently recognized by most model building codes.

If there is any doubt whether or not an archaic material is noncombustible, it would be appropriate to send out samples for evaluation. If an archaic material is determined to be noncombustible according to ASTM E 136, it can be expected that it will not contribute fuel to the fire.

O.1.2 Combustible Construction Types. One of the earliest forms of timber construction used exterior load-bearing masonry walls with columns and/or wooden walls supporting wooden beams and floors in the interior of the building. This form of construction, often called "mill" or "heavy timber" construction, has approximately 1-hour fire resistance. The exterior walls will generally contain the fire within the building.

With the development of dimensional lumber, there was a switch from heavy timber to "balloon frame" construction. The balloon frame uses load-bearing exterior wooden walls, which have long timbers often extending from foundation to roof. When longer lumber became scarce, another form of construction, "platform" framing, replaced the balloon framing. The difference between the two systems is significant because platform framing is automatically fire-blocked at every floor while balloon framing commonly has concealed spaces that extend unblocked from basement to attic. The architect, engineer, and code official must be alert to the details of construction and the ease with which fire can spread in concealed spaces.

O.2 Building Evaluation.

O.2.1 Introduction. A given rehabilitation project will most likely go through several stages. The preliminary evaluation process involves the designer in surveying the prospective build-

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ing. The fire resistance of existing building materials and construction systems is identified; potential problems are noted for closer study. The final evaluation phase includes developing design solutions to upgrade the fire resistance of building elements, if necessary; preparing working drawings and specifications; and the securing of the necessary code approvals.

O.2.2 Preliminary Evaluation. A preliminary evaluation should begin with a building survey to determine the existing materials, the general arrangement of the structure and the use of the occupied spaces, and the details of construction. The designer needs to know what is there before a decision can be reached about what to keep and what to remove during the rehabilitation process. This preliminary evaluation should be as detailed as necessary to make initial plans. The fire-related properties need to be determined from the applicable building or rehabilitation code, and the materials and assemblies existing in the building then need to be evaluated for these properties. See Tables O.2.2(a) and O.2.2(b) for two worksheets that are shown in order to facilitate the preliminary evaluation.

Two possible sources of information helpful in the preliminary evaluation are the original building plans and the building code in effect at the time of original construction. Plans might be on file with the local building department or in the offices of the original designers (e.g., architect, engineer) or their successors. If plans are available, the investigator should verify that the building was actually constructed as called for in the plans, as well as incorporated any later alterations or changes to the building. Earlier editions of the local building code should be on file with the building official. The code in effect at the time of construction will contain fire performance criteria. While this is no guarantee that the required performance was actually provided, it does give the investigator some guidance as to the level of performance that can be expected. Under some code administration and enforcement systems, the code in effect at the time of construction also defines the level of performance that must be provided at the time of rehabilitation.

Table O.2.2(a) illustrates one method for organizing preliminary field notes. Space is provided for the materials, dimensions, and condition of the principal building elements. Each floor of the structure should be visited and the appropriate information obtained. In practice, there will often be identical materials and construction on every floor, but the exception could be of vital importance. A schematic diagram should be prepared of each floor showing the layout of exits and hallways and indicating where each element described in the field notes fits into the structure as a whole. The exact arrangement of interior walls within apartments is of secondary importance from a fire safety point of view and need not be shown on the drawings unless these walls are required by code to have a fire resistance rating.

The location of stairways and elevators should be clearly marked on the drawings. All exterior means of escape (e.g., fire escapes) should be identified. (Problems providing adequate exiting are discussed at length in the "Egress Guideline for Residential Rehabilitation.")

Table O.2.2(a) Preliminary Evaluation Field Notes

Building Element		Materials	Thickness	Condition	Notes
Exterior Bearing Walls					
Interior Bearing Walls					
Exterior Nonbearing Walls					
Interior Nonbearing Walls or Partitions	A				
	B				
Structural Frame: Columns					
Beams					
Other					
Floor/Ceiling Structural System Spanning					
Roofs					
Doors (including frame and hardware): Enclosed vertical exit way					
Enclosed horizontal exit way					
Other					

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The following notes explain the entries in Table O.2.2(a).

Note 1. Exterior Bearing Walls. Many old buildings utilize heavily constructed walls to support the floor/ceiling assemblies at the exterior of the building. There could be columns and/or interior bearing walls within the structure, but the exterior walls are an important factor in assessing the fire safety of a building.

The field investigator should note how the floor/ceiling assemblies are supported at the exterior of the building. If columns are incorporated in the exterior walls, the walls can be considered nonbearing.

Note 2. Interior Bearing Walls. It can be difficult to determine whether or not an interior wall is load bearing, but the field investigator should attempt to make this determination. At a later stage of the rehabilitation process, this question will need to be determined exactly. Therefore, the field notes should be as accurate as possible.

Note 3. Exterior Nonbearing Walls. The fire resistance of the exterior walls is important for two reasons. These walls (both bearing and nonbearing) are depended upon for one of the following purposes:

(1) To contain a fire within the building of origin
(2) To keep an exterior fire outside the building

It is therefore important to indicate on the drawings where any openings are located, as well as the materials and construction of all doors or shutters. The drawings should indicate the presence of wired glass and its thickness and framing, and should identify the materials used for windows and door frames. The protection of openings adjacent to exterior means of escape (e.g., exterior stairs, fire escapes) is particularly important. The ground floor drawing should locate the building on the property and indicate the precise distances to adjacent buildings.

Note 4. Interior Nonbearing Walls (Partitions). A partition is a "wall that extends from floor to ceiling and subdivides space within any story of a building." Table O.2.2(a) has two categories (A and B) for interior nonbearing walls (partitions) that can be used for different walls, such as hallway walls as compared to inter-apartment walls. Under some circumstances there might be only one type of wall construction; in others, three or more types of wall construction might occur.

The field investigator should be alert for differences in function as well as in materials and construction details. In general, the details within apartments are not as important as the major exit paths and stairwells. The preliminary field investigation should attempt to determine the thickness of all walls. A term introduced below, called "thickness design," will depend on an accurate [$^1/_4$ in. (6.3 mm)] determination. Even though this initial field survey is called "preliminary," the data generated should be as accurate and complete as possible.

The field investigator should note the exact location from which his or her observations are recorded. For instance, if a hole is found through a stairwell wall that allows a cataloging of the construction details, the field investigation notes should reflect the location of the "find." At the preliminary stage it is not necessary to core every wall; the interior details of construction can usually be determined at some location.

Note 5. Structural Frame. There might be a complete skeletal frame, but usually there are columns, beams, trusses, or other like elements. The dimensions and spacing of the structural elements should be measured and indicated on the drawings. For instance, if there are 10-in. square columns located on a 30-ft square grid throughout the building, this should be noted. The structural material and cover or protective materials should be identified wherever possible. The thickness of the cover materials should be determined to an accuracy of $^1/_4$ in. (6.3 mm). As discussed previously, the preliminary field survey usually relies on accidental openings in the cover materials rather than a systematic coring technique.

Note 6. Floor/Ceiling Structural Systems. The span between supports should be measured. If possible, a sketch of the cross section of the system should be made. If there is no location where accidental damage has opened the floor/ceiling construction to visual inspection, it is necessary to make such an opening. An evaluation of the fire resistance of a floor/ceiling assembly requires detailed knowledge of the materials and their arrangement. Special attention should be paid to the cover on structural steel elements and the condition of suspended ceilings and similar membranes.

Note 7. Roofs. The preliminary field survey of the roof system is initially concerned with watertightness. However, once it is apparent that the roof is sound for ordinary use and can be retained in the rehabilitated building, it becomes necessary to evaluate the fire performance. The field investigator must measure the thickness and identify the types of materials that have been used. Be aware that there could be several layers of roof materials.

Note 8. Doors. Doors to stairways and hallways represent some of the most important fire elements to be considered within a building. The uses of the spaces separated largely controls the level of fire performance necessary. Walls and doors enclosing stairs or elevator shafts would normally require a higher level of performance than between the bedroom and bath. The various uses are differentiated in Table O.2.2(a).

Careful measurements of the thickness of door panels must be made, and the type of core material within each door must be determined. It should be noted whether doors have self-closing devices; the general operation of the doors should be checked. The latch should engage and the door should fit tightly in the frame. The hinges should be in good condition. If glass is used in the doors, it should be identified as either plain glass or wired glass mounted in either a wood or a steel frame.

Note 9. Materials. The field investigator should be able to identify ordinary building materials. In situations where an unfamiliar material is found, a sample should be obtained. This sample should measure at least 10 in.^{3} (164 cm^3) so that an ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C,* fire test can be conducted to determine if it is combustible.

Note 10. Thickness. The thickness of all materials should be measured accurately since, under certain circumstances, the level of fire resistance is very sensitive to the material thickness.

Note 11. Condition. The method attaching the various layers and facings to one another or to the supporting structural element should be noted under the appropriate building element. The "secureness" of the attachment and the general condition of the layers and facings should be noted here.

Note 12. Notes. The "Notes" column can be used for many purposes, but it might be a good idea to make specific references to other field notes or drawings.

After the building survey is completed, the data collected must be analyzed. Table O.2.2(b) is a suggested worksheet for organizing this information.

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Table O.2.2(b) Preliminary Evaluation Worksheet

Building Element		Required Fire Resistance	Required Flame Spread	Estimated Fire Resistance	Estimated Flame Spread	Method of Upgrading	Estimated Upgraded Protection	Notes
Exterior Bearing Walls								
Interior Bearing Walls								
Exterior Nonbearing Walls								
Interior Nonbearing Walls or Partitions	A							
	B							
Structural Frame: Columns								
Beams								
Other								
Floor/Ceiling Structural System Spanning								
Roofs								
Doors (including frame and hardware): Enclosed vertical exit way								
Enclosed horizontal exit way								
Others								

The required fire resistance and flame spread for each building element is normally established by the local building or rehabilitation code. The fire performance of the existing materials and assemblies should then be estimated, using one of the following techniques. If the fire performance of the existing building element(s) is equal to or greater than that required, the materials and assemblies can remain. If the fire performance is less than required, then corrective measures must be taken.

The most common methods of upgrading the level of protection are either to remove and replace the existing building element(s) or to repair and upgrade the existing materials and assemblies. Other fire protection measures, such as automatic sprinklers or detection and alarm systems, also could be considered, though they are beyond the scope of this guideline. If the upgraded protection is still less than that required or deemed to be acceptable, additional corrective measures must be taken. This process must continue until an acceptable level of performance is obtained.

O.2.3 Fire Resistance of Existing Building Elements. The fire resistance of the existing building elements can be estimated from the tables and histograms contained in O.4. This section is organized first by type of building element (i.e., walls, columns, floor/ceiling assemblies, beams, and doors). Within each building element, the tables are organized by type of construction (e.g., masonry, metal, wood frame), and then further divided by minimum dimensions or thickness of the building element.

A histogram precedes every table that has 10 or more entries. The X-axis measures fire resistance in hours; the Y-axis shows the number of entries in that table having a given level of fire resistance. The histograms also contain the location of each entry within that table, for easy cross-referencing.

The histograms, because they are keyed to the tables, can speed the preliminary investigation. For example, Table O.4.5.13, Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick, contains 96 entries. Rather than study each table entry, the histogram shows that every wall assembly listed in that table has a fire resistance of less than 2 hours. If the building code required the wall to have 2-hour fire resistance, the designer, with a minimum of effort, is made aware of a problem that requires closer study.

Suppose the code had only required a wall of 1-hour fire resistance. The histogram shows far fewer complying elements (19) than noncomplying ones (77). If the existing assembly is not one of the 19 complying entries, there is a strong possibility the existing assembly is deficient. The histograms can also

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be used in the converse situation. If the existing assembly is not one of the smaller number of entries with a lower-than-required fire resistance, there is a strong possibility the existing assembly will be acceptable.

At some point the existing building component or assembly must be located within the tables. Otherwise, the fire resistance must be determined through one of the other techniques presented in the guideline. Locating the building component in the tables in O.4 not only guarantees the accuracy of the fire resistance rating, but also provides a source of documentation for the building official.

O.2.4 Effects of Penetrations in Fire-Resistant Assemblies. There are often many features in existing walls or floor/ceiling assemblies that were not included in the original certification or fire testing. The most common examples are pipes and utility wires passed through holes poked through an assembly. During the life of the building many penetrations are added, and by the time a building is ready for rehabilitation it is not sufficient just to consider the fire resistance of the assembly as originally constructed. It is necessary to consider all penetrations and their relative impact upon fire performance. For instance, the fire resistance of the corridor wall might be less important than the effect of plain glass doors or transoms. In fact, doors are the most important single class of penetrations.

A fully developed fire generates substantial quantities of heat and excess gaseous fuel capable of penetrating any holes that might be present in the walls or ceiling of the fire compartment. In general, this leads to a severe degradation of the fire resistance of those building elements and to a greater potential for fire spread. This is particularly applicable to penetrations located high in a compartment, where the positive pressure of the fire can force the unburned gases through the penetration.

Penetrations in a floor/ceiling assembly will generally completely negate the barrier qualities of the assembly and will lead to rapid spread of fire to the space above. It will not be a problem, however, if the penetrations are filled with noncombustible materials strongly fastened to the structure. The upper half of walls is similar to the floor/ceiling assembly in that a positive pressure can reasonably be expected in the top of the room, and this will push hot and/or burning gases through the penetration unless it is completely sealed.

Building codes require doors installed in fire-resistive walls to resist the passage of fire for a specified period of time. If the door to a fully involved room is not closed, a large plume of fire will typically escape through the doorway, preventing anyone from using the space outside the door while allowing the fire to spread. This is why door closers are so important. Glass in doors and transoms can be expected to rapidly shatter unless constructed of listed or approved wire glass in a steel frame. As with other building elements, penetrations or nonrated portions of doors and transoms must be upgraded or otherwise protected.

Table O.4.5.58 in Section V of O.4 contains 41 entries of doors mounted in sound, tight-fitting frames. Part O.3.4 outlines one procedure for evaluating and possibly upgrading existing doors.

O.3 Final Evaluation and Design Solution.

O.3.1 Introduction. The final evaluation begins after the rehabilitation project has reached the final design stage and the choices have been made to keep certain archaic materials and assemblies in the rehabilitated building. The final evaluation process is essentially a more refined and detailed version of the preliminary evaluation. The specific fire resistance and flame spread requirements are determined for the project. This can involve local building and fire officials reviewing the preliminary evaluation as depicted in Tables O.2.2(a) and O.2.2(b) and the field drawings and notes. When necessary, provisions must be made to upgrade existing building elements to provide the required level of fire performance.

There are several approaches to design solutions that can make possible the continued use of archaic materials and assemblies in the rehabilitated structure. The simplest case occurs when the materials and assembly in question are found within the tables in O.4 and the fire performance properties satisfy code requirements. Other approaches must be used, though, if the assembly cannot be found within the tables in O.4 or the fire performance needs to be upgraded. These approaches have been grouped into two classes, experimental and theoretical.

O.3.2 The Experimental Approach. If a material or assembly found in a building is not listed in the tables in O.4, there are several other ways to evaluate fire performance. One approach is to conduct the appropriate fire test(s) and thereby determine the fire-related properties directly. There are a number of laboratories in the United States that routinely conduct the various fire tests. A current list can be obtained by writing the Center for Fire Research, National Institute of Standards and Technology, Washington, DC 20234.

The contract with any of these testing laboratories should require their observation of specimen preparation as well as the testing of the specimen. A complete description of where and how the specimen was obtained from the building, the transportation of the specimen, and its preparation for testing should be noted in detail so that the building official can be satisfied that the fire test is representative of the actual use.

The test report should describe the fire test procedure and the response of the material or assembly. The laboratory usually submits a cover letter with the report to describe the provisions of the fire test that were satisfied by the material or assembly under investigation. A building official will generally require this cover letter, but will also read the report to confirm that the material or assembly complies with the code requirements. Local code officials should be involved in all phases of the testing process.

The experimental approach can be costly and time consuming because specimens must be taken from the building and transported to the testing laboratory. When a load-bearing assembly has continuous reinforcement, the test specimen must be removed from the building, transported, and tested in one piece. However, when the fire performance cannot be determined by other means, there might be no alternative to a full-scale test.

A "nonstandard" small-scale test can be used in special cases. Sample sizes need only be 10 ft^2 to 25 ft^2 (0.93 m^2 to 2.3 m^2), while full-scale tests require test samples of either 100 ft^2 (9.3 m^2) or 180 ft^2 (16.7 m^2) in size. This small-scale test is best suited for testing non-load-bearing assemblies against thermal transmission only.

O.3.3 The Theoretical Approach. There will be instances when materials and assemblies in a building undergoing rehabilitation cannot be found in the tables in O.4. Even where test results are available for more or less similar construction, the proper classification might not be immediately apparent. Variations in dimensions, loading conditions, materials, or workmanship can markedly affect the performance of the individual building elements, and the extent of such a possible effect cannot be evaluated from the tables.

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Theoretical methods being developed offer an alternative to the full-scale fire tests discussed previously. For example, Section 4302(b) of the 1979 edition of the *Uniform Building Code* specifically allows an engineering design for fire resistance in lieu of conducting full-scale tests. These techniques draw upon computer simulation and mathematical modeling, thermodynamics, heat-flow analysis, and materials science to predict the fire performance of building materials and assemblies.

One theoretical method known as the "Ten Rules of Fire Endurance Ratings" was published by T. Z. Harmathy in the May 1965 edition of *Fire Technology*. Harmathy's Rules provide a foundation for extending the data within the tables in O.4 to analyze or upgrade current as well as archaic building materials or assemblies.

Harmathy's Ten Rules

Rule 1: The "thermal" fire endurance of a construction consisting of a number of parallel layers is greater than the sum of the "thermal" fire endurances characteristic of the individual layers when exposed separately to fire.

The "thermal" fire endurance is the time at which the average temperature on the unexposed side of a construction exceeds its initial value by 250°F (121°C) when the other side is exposed to the "standard" fire specified by ASTM E 119, *Standard Methods of Tests of Fire Endurance of Building Construction and Materials*.

The minimum performance of an untested assembly can be estimated if the fire endurance of the individual components is known. Though the exact rating of the assembly cannot be stated, the endurance of the assembly is greater than the sum of the endurance of the components.

When a building assembly or component is found to be deficient, the fire endurance can be upgraded by providing a protective membrane. This membrane could be a new layer of brick, plaster, or drywall. The fire endurance of this membrane is called the "finish rating." Tables O.3.3(a) and O.3.3(b) contain the finish ratings for the most commonly employed materials. (See also the notes to Rule 2.)

Table O.3.3(a) Finish Ratings — Inorganic Materials

Item Code	Thickness	Construction Details	Performance	Reference Number			Notes	Rec F.R. (min)
			Finish Rating	Pre-BMS-92	BMS-92	Post-BMS-92		
F.R.-I-1	9/16"	3/8" gypsum wallboard faced with 3/16" cement asbestos board	20 min		1		1,2	15
F.R.-I-2	11/16"	1/2" gypsum sheathing faced with 3/16" cement asbestos board	20 min		1		1,2	20
F.R.-I-3	3/16"	3/16" cement asbestos board over uninsulated cavity	10 min		1		1,2	5
F.R.-I-4	3/16"	3/16" cement asbestos board over insulated cavities	5 min		1		1,2	5
F.R.-I-5	3/4"	3/4" thick 1:2, 1:3 gypsum plaster over paper backed metal lath	20 min		1		1–3	20
F.R.-I-6	3/4"	3/4" thick portland cement plaster on metal lath	10 min		1		1,2	10
F.R.-I-7	3/4"	3/4" thick 1:5, 1:7.5 lime plaster on metal lath	10 min		1		1,2	10
F.R.-I-8	1 "	1 " thick neat gypsum plaster on metal lath	35 min		1		1,2,4	35
F.R.-I-9	3/4"	3/4" thick neat gypsum plaster on metal lath	30 min		1		1,2,4	30
F.R.-I-10	3/4"	3/4" thick 1:2, 1:2 gypsum plaster on metal lath	15 min		1		1–3	15
F.R.-I-11	1/2"	Same as F.R.-I-7, except 1/2" thick on wood lath	15 min		1		1–3	15
F.R.-I-12	1/2"	1/2" thick 1:2, 1:3 gypsum plaster on wood lath	15 min		1		1–3	15
F.R.-I-13	7/8"	1/2" thick 1:2, 1:2 gypsum plaster on 3/8" perforated gypsum lath	30 min		1		1–3	30
F.R.-I-14	7/8"	1/2" thick 1:2, 1:2 gypsum plaster on 3/8" thick plain or indented gypsum plaster	20 min		1		1–3	20
F.R.-I-15	3/8"	3/8" gypsum wallboard	10 min		1		1,2	10
F.R.-I-16	1/2"	1/2" gypsum wallboard	15 min		1		1,2	15

Notes:
1. The finish rating is the time required to obtain an average temperature rise of 250°F, or a single point rise of 325°F, at the interface between the material being rated and the substrate being protected.
2. Tested in accordance with the *Standard Specifications for Fire Tests of Building Construction and Materials,* ASA A2.
3. Mix proportions for plaster as follows: first ratio, dry weight of plaster to dry weight of sand for scratch coat; second ratio, plaster to sand for brown coat.
4. *Neat plaster* means unsanded wood-fiber gypsum plaster.

General Note: The finish rating of modern building materials can be found in the current literature.

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Table O.3.3(b) Finish Ratings — Organic Materials

Item Code	Thickness	Construction Details	Performance	Reference Number			Notes	Rec F.R. (min)
			Finish Rating	Pre-BMS-92	BMS-92	Post-BMS-92		
F.R.-0-1	$^{9}/_{16}$"	$^{7}/_{16}$ wood fiber board faced with $^{1}/_{8}$" cement-asbestos board	15 min		1		1,2	15
F.R.-0-2	$^{29}/_{32}$"	$^{3}/_{4}$" wood sheathing, asbestos felt weighing 14 lb/100 ft^2, and $^{5}/_{32}$" cement-asbestos shingles	20 min		1		1,2	20
F.R.-0-3	$1^{1}/_{2}$"	1" thick magnesium oxysulfate wood fiberboard faced with 1:3, 1:3 gypsum plaster, $^{1}/_{2}$" thick	20 min		1		1–3	20
F.R.-0-4	$^{1}/_{2}$"	$^{1}/_{2}$" thick wood fiberboard	5 min		1		1,2	5
F.R.-0-5	$^{1}/_{2}$"	$^{1}/_{2}$" thick flameproofed wood fiberboard	10 min		1		1,2	10
F.R.-0-6	1 "	$^{1}/_{2}$" thick wood fiberboard faced with $^{1}/_{2}$" thick 1:2, 1:2 gypsum plaster	15 min		1		1–3	15
F.R.-0-7	$1^{3}/_{8}$"	$^{7}/_{8}$" thick flameproofed wood fiberboard faced with $^{1}/_{2}$" thick 1:2, 1:2 gypsum plaster	30 min		1		1–3	30
F.R.-0-8	$1^{1}/_{4}$"	$1^{1}/_{4}$" thick plywood	30 min		1	35		30

Notes:
1. The finish rating is the time required to obtain an average temperature rise of 250°F, or a single point rise of 325°F, at the interface between the material being rated and the substrate being protected.
2. Tested in accordance with the *Standard Specifications for Fire Tests of Building Construction and Materials,* ASA A2.
3. Plaster ratios as follows: first ratio is for the scratch coat, weight of dry plaster to weight of dry sand; second ratio is for the brown coat.
General Note: The finish rating of thinner materials, particularly thinner woods, has not been listed because the possible effects of shrinkage, warpage, and aging cannot be predicted.

The test criterion for the finish rating is the same as for the thermal fire endurance of the total assembly: average temperature increases of 250°F (121°C) above ambient, or 325°F (163°C) above ambient at any one place with the membrane being exposed to the fire. The temperature is measured at the interface of the assembly and the protective membrane.

Rule 2: The fire endurance of a construction does not decrease with the addition of further layers.

Harmathy notes that this rule is a consequence of the previous rule. Its validity follows from the fact that the additional layers increase both the resistance to heat flow and the heat capacity of the construction. This, in turn, reduces the rate of temperature rise at the unexposed surface.

This rule is not just restricted to "thermal" performance but affects the other fire test criteria: direct flame passage, cotton waste ignition, and load-bearing performance. This means that certain restrictions must be imposed on the materials to be added and on the loading conditions. One restriction is that a new layer, if applied to the exposed surface, must not produce additional thermal stresses in the construction (i.e., its thermal expansion characteristics must be similar to those of the adjacent layer). Each new layer must also be capable of contributing enough additional strength to the assembly to sustain the added dead load. If this requirement is not fulfilled, the allowable live load must be reduced by an amount equal to the weight of the new layer. Because of these limitations, this rule should not be applied without careful consideration.

Particular care must be taken if the material added is a good thermal insulator. Properly located, the added insulation could improve the "thermal" performance of the assembly. Improperly located, the insulation could block necessary thermal transmission through the assembly, thereby subjecting the structural elements to greater temperatures for longer periods of time and possibly causing premature structural failure of the supporting members.

Rule 3: The fire endurance of constructions containing continuous air gaps or cavities is greater than the fire endurance of similar constructions of the same weight, but containing no air gaps or cavities.

By providing for voids in a construction, additional resistances are produced in the path of heat flow. Numerical heat flow analyses indicate that a 10 to 15 percent increase in fire endurance can be achieved by creating an air gap at the midplane of a brick wall. Since the gross volume is also increased by the presence of voids, the air gaps and cavities have a beneficial effect on stability as well. However, constructions containing combustible materials within an air gap can be regarded as exceptions to this rule because of the possible development of burning in the gap.

There are numerous examples of this rule in the tables. The following are examples:

Table O.4.5.4, item W-8-M-82: Cored concrete masonry, nominal 8 in. (0.20 m) thick wall with one unit in wall thickness and with 62 percent minimum of solid material in each unit, load bearing [80 psi (5.5 bar)]. Fire endurance $2^{1}/_{2}$ hours.

Table O.4.5.5, item W-10-M-11: Cored concrete masonry, nominal 10 in. (0.25 m) thick wall with two units in wall thickness and a 2 in. (50 mm) air space, load bearing [80 psi (5.5 bar)]. The units are essentially the same as item W-8-M-82. Fire endurance $3^{1}/_{2}$ hours.

These walls show 1-hour greater fire endurance by the addition of the 2 in. (50 mm) air space.

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Rule 4: The farther an air gap or cavity is located from the exposed surface, the more beneficial is its effect on the fire endurance.

Radiation dominates the heat transfer across an air gap or cavity, and it is markedly higher where the temperature is higher. The air gap or cavity is thus a poor insulator if it is located in a region that attains high temperatures during fire exposure.

Some of the clay tile designs take advantage of these factors. The double cell design, for instance, ensures that there is a cavity near the unexposed face. Some floor/ceiling assemblies have air gaps or cavities near the top surface, and these enhance their thermal performance.

Rule 5: The fire endurance of a construction cannot be increased by increasing the thickness of a completely enclosed air layer.

Harmathy notes that there is evidence that if the thickness of the air layer is larger than about $^1/_2$ in. (12.5 mm), the heat transfer through the air layer depends only on the temperature of the bounding surfaces and is practically independent of the distance between them. This rule is not applicable if the air layer is not completely enclosed (i.e., if there is a possibility of fresh air entering the gap at an appreciable rate).

Rule 6: Layers of materials of low thermal conductivity are better utilized on that side of the construction on which fire is more likely to happen.

As in Rule 4, the reason lies in the heat transfer process, though the conductivity of the solid is much less dependent on the ambient temperature of the materials. The low thermal conductor creates a substantial temperature differential to be established across its thickness under transient heat flow conditions. This rule might not be applicable to materials undergoing physio-chemical changes accompanied by significant heat absorption or heat evolution.

Rule 7: The fire endurance of asymmetrical constructions depends on the direction of heat flow.

This rule is a consequence of Rules 4 and 6 as well as other factors. This rule is useful in determining the relative protection of corridors and stairwells from the surrounding spaces. In addition, there are often situations where a fire is more likely, or potentially more severe, from one side or the other.

Rule 8: The presence of moisture, if it does not result in explosive spalling, increases the fire endurance.

The flow of heat into an assembly is greatly hindered by the release and evaporation of the moisture found within cementitious materials such as gypsum, portland cement, or magnesium oxy-chloride. Harmathy has shown that the gain in fire endurance can be as high as 8 percent for each percent (by volume) of moisture in the construction. It is the moisture chemically bound within the construction material at the time of manufacture or processing that leads to increased fire endurance. There is no direct relationship between the relative humidity of the air in the pores of the material and the increase in fire endurance.

Under certain conditions there could be explosive spalling of low permeability cementitious materials such as dense concrete. In general, one can assume that extremely old concrete has developed enough minor cracking that this factor should not be significant.

Rule 9: Load-supporting elements, such as beams, girders, and joists, yield higher fire endurances when subjected to fire endurance tests as parts of floor, roof, or ceiling assemblies than they would when tested separately.

One of the fire endurance test criteria is the ability of a load-supporting element to carry its design load. The element will be deemed to have failed when the load can no longer be supported.

Failure usually results for two reasons. Some materials, particularly steel and other metals, lose much of their structural strength at elevated temperatures. Physical deflection of the supporting element, due to decreased strength or thermal expansion, causes a redistribution of the load forces and stresses throughout the element. Structural failure often results because the supporting element is not designed to carry the redistributed load.

Roof, floor, and ceiling assemblies have primary (e.g., beams) and secondary (e.g., floor joists) structural members. Since the primary load-supporting elements span the largest distances, their deflection becomes significant at a stage when the strength of the secondary members (including the roof or floor surface) is hardly affected by the heat. As the secondary members follow the deflection of the primary load-supporting element, an increasingly larger portion of the load is transferred to the secondary members.

When load-supporting elements are tested separately, the imposed load is constant and equal to the design load throughout the test. By definition, no distribution of the load is possible because the element is being tested by itself. Without any other structural members to which the load could be transferred, the individual elements cannot yield a higher fire endurance than they do when tested as parts of a floor, roof, or ceiling assembly.

Rule 10: The load-supporting elements (beams, girders, joists, etc.) of a floor, roof, or ceiling assembly can be replaced by such other load-supporting elements that, when tested separately, yielded fire endurances not less than that of the assembly.

This rule depends on Rule 9 for its validity. A beam or girder, if capable of yielding a certain performance when tested separately, will yield an equally good or better performance when it forms a part of a floor, roof, or ceiling assembly. It must be emphasized that the supporting element of one assembly must not be replaced by the supporting element of another assembly if the performance of this latter element is not known from a separate (beam) test. Because of the load-reducing effect of the secondary elements that results from a test performed on an assembly, the performance of the supporting element alone cannot be evaluated by simple arithmetic. This rule also indicates the advantage of performing separate fire tests on primary load-supporting elements. *(See Figure O.3.3.)*

Illustration of Harmathy's Rules. Harmathy provided one schematic figure that illustrated his rules. It should be useful as a quick reference to assist in applying his rules.

Example Application of Harmathy's Rules. The following examples, based in whole or in part upon those presented in Harmathy's paper, show how the rules can be applied to practical cases.

Example 1

Problem

A contractor would like to keep a partition that consists of a $3^3/_4$ in. (95 mm) thick layer of red clay brick, a $1^1/_4$ in. (32 mm) thick layer of plywood, and a $^3/_8$ in. (9.5 mm) thick layer of gypsum wallboard, at a location where 2-hour fire endurance is required. Is this assembly capable of providing a 2-hour protection?

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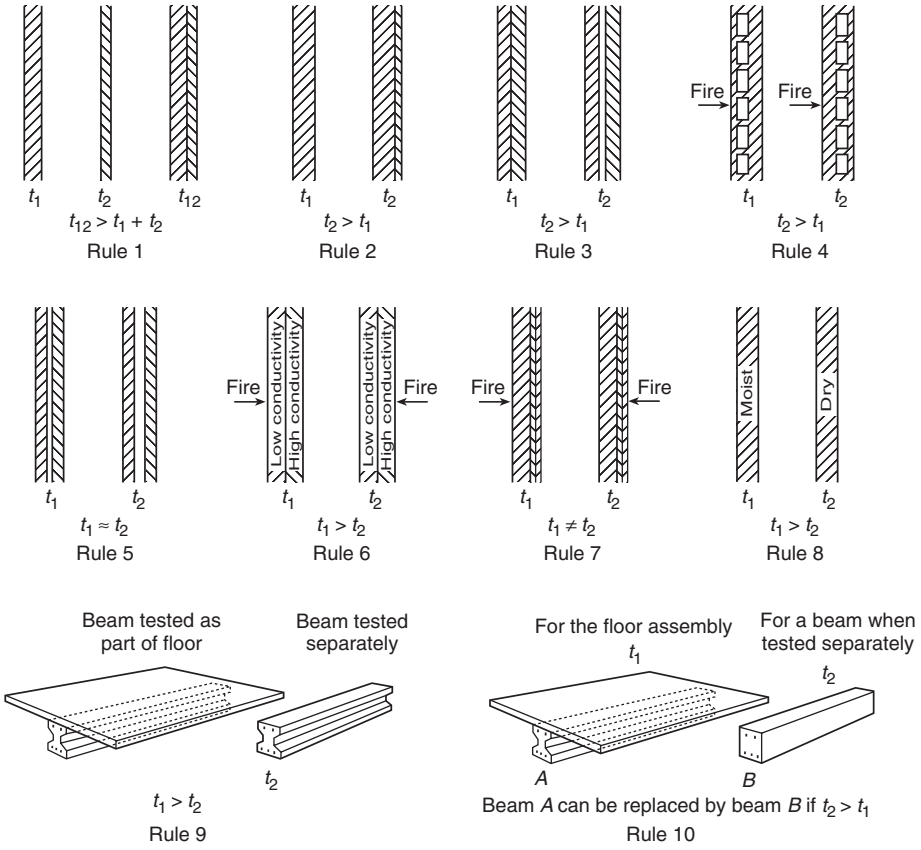
FIGURE O.3.3 Diagrammatic Illustration of 10 Rules (t = Fire Endurance).



Solution

(1) This partition does not appear in the tables in O.4.
(2) Bricks of this thickness yield fire endurances of approximately 75 minutes (Table O.4.5.2, item W-4-M-2).
(3) The $1^1/_4$ in. (32 mm) thick plywood has a finish rating of 30 minutes.
(4) The $^3/_8$ in. (9.5 mm) gypsum wallboard has a finish rating of 10 minutes.
(5) Using the recommended values from the tables and applying Rule 1, the fire endurance (*FI*) of the assembly is larger than the sum of the individual layers, or
FI > 75 + 30 + 10 = 115 minutes

Discussion

This example illustrates how the tables in O.4 can be utilized to determine the fire resistance of assemblies not explicitly listed.

Example 2

Problem

(1) A number of buildings to be rehabilitated have the same type of roof slab that is supported with different structural elements.
(2) The designer and contractor would like to determine whether or not this roof slab is capable of yielding a 2-hour fire endurance. According to a rigorous interpretation of ASTM E 119, *Standard Methods of Tests of Fire Endurance of Building Construction and Materials,* however, only the roof assembly, including the roof slab as well as the cover and the supporting elements, can be subjected to a fire test. Therefore, a fire endurance classification cannot be issued for the slabs separately.
(3) The designer and contractor believe this slab will yield a 2-hour fire endurance even without the cover, and any beam of at least 2-hour fire endurance will provide satisfactory support. Is it possible to obtain a classification for the slab separately?

Solution

(1) The answer to the question is *yes.*
(2) According to Rule 10 it is not contrary to common sense to test and classify roofs and supporting elements separately. Furthermore, according to Rule 2, if the roof slabs actually yield a 2-hour fire endurance, the endurance of an assembly, including the slabs, cannot be less than 2 hours.
(3) The recommended procedure would be to review the tables to see if the slab appears as part of any tested roof or floor/ceiling assembly. The supporting system can be regarded as separate from the slab specimen, and the fire endurance of the assembly listed in the table is at least the fire endurance of the slab. There would have to be an adjustment for the weight of the roof cover in the allowable load if the test specimen did not contain a cover.
(4) The supporting structure or element would have to have at least a 2-hour fire endurance when tested separately.

Discussion

If the tables did not include tests on assemblies that contained the slab, one procedure would be to assemble the roof slabs on any convenient supporting system (not regarded as

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part of the specimen) and to subject them to a load that, besides the usually required superimposed load, includes some allowances for the weight of the cover.

Example 3

Problem

A steel-joisted floor and ceiling assembly is known to have yielded a fire endurance of 1 hour and 35 minutes. At a certain location, a 2-hour endurance is required. What is the most economical way of increasing the fire endurance by at least 25 minutes?

Solution

(1) The most effective technique would be to increase the ceiling plaster thickness. Existing coats of paint would have to be removed and the surface properly prepared before the new plaster could be applied. Other materials (e.g., gypsum wallboard) could also be considered.
(2) There might be other techniques based on other principles, but an examination of the drawings would be necessary.

Discussion

(1) The additional plaster has at least the following three effects:
    a. The layer of plaster is increased and thus there is a gain of fire endurance (Rule 1).
    b. There is a gain due to shifting the air gap farther from the exposed surface (Rule 4).
    c. There is more moisture in the path of heat flow to the structural elements (Rules 7 and 8).
(2) The increase in fire endurance would be at least as large as that of the finish rating for the added thickness of plaster. The combined effects in (1) would further increase this by a factor of 2 or more, depending upon the geometry of the assembly.

Example 4

Problem

The fire endurance of item W-10-M-1 in Table O.4.5.5 is 4 hours. This wall consists of two $3^3/_4$ in. (95 mm) thick layers of structural tiles separated by a 2 in. (50 mm) air gap and $^3/_4$ in. (19 mm) portland cement plaster or stucco on both sides. If the actual wall in the building is identical to item W-10-M-1 except that it has a 4 in. (102 mm) air gap, can the fire endurance be estimated at 5 hours?

Solution

The answer to the question is *no*, for the reasons contained in Rule 5.

Example 5

Problem

In order to increase the insulating value of its precast roof slabs, a company has decided to use two layers of different concretes. The lower layer of the slabs, where the strength of the concrete is immaterial (all the tensile load is carried by the steel reinforcement), would be made with a concrete of low strength but good insulating value. The upper layer, where the concrete is supposed to carry the compressive load, would remain the original high strength, high thermal conductivity concrete. How will the fire endurance of the slabs be affected by the change?

Solution

The effect on the thermal fire endurance is beneficial as follows:

(1) The total resistance to heat flow of the new slabs has been increased due to the replacement of a layer of high thermal conductivity by one of low conductivity.
(2) The layer of low conductivity is on the side more likely to be exposed to fire, where it is more effectively utilized according to Rule 6. The layer of low thermal conductivity also provides better protection for the steel reinforcement, thereby extending the time before reaching the temperature at which the creep of steel becomes significant.

O.3.4 "Thickness Design" Strategy. The "thickness design" strategy is based upon Harmathy's Rules 1 and 2. This design approach can be used when the construction materials have been identified and measured, but the specific assembly cannot be located within the tables. The tables should be surveyed again for thinner walls of like material and construction detail that have yielded the desired or greater fire endurance. If such an assembly can be found, then the thicker walls in the building have more than enough fire resistance. The thickness of the walls thus becomes the principal concern.

This approach can also be used for floor/ceiling assemblies, except that the thickness of the cover and the slab becomes the central concern. The fire resistance of the untested assembly will be at least the fire resistance of an assembly listed in the table having a similar design but with less cover (the protective layer or membrane of material that slows the flow of heat to the structural elements) and/or thinner slabs. For other structural elements (e.g., beams and columns), the element listed in the table must also be of a similar design but with less cover thickness.

O.3.5 Evaluation of Doors. A separate section on doors has been included because the process for evaluation presented differs from those suggested previously for other building elements. The impact of unprotected openings or penetrations in fire-resistant assemblies has been detailed in O.2.4. It is sufficient to note that openings left unprotected will likely lead to failure of the barrier under actual fire conditions.

For other types of building elements (e.g., beams, columns), the tables in O.4 can be used to establish a minimum level of fire performance. The benefit to rehabilitation is that the need for a full-scale fire test is then eliminated. For doors, however, this cannot be done. The data contained in Table O.4.5.58, Resistance of Doors to Fire Exposure, can only provide guidance as to whether a successful fire test is even feasible.

For example, a door required to have 1-hour fire resistance is noted in the tables as providing only 5 minutes. The likelihood of achieving the required 1 hour, even if the door is upgraded, is remote. The ultimate need for replacement of the doors is reasonably clear, and the expense and time needed for testing can be saved. However, if the performance documented in the table is near or in excess of what is being required, then a fire test should be conducted. The test documentation can then be used as evidence of compliance with the required level of performance.

The table entries cannot be used as the sole proof of performance of the door in question because there are too many unknown variables that could measurably affect fire performance. The wood could have dried over the years, or coats of flammable varnish could have been added. Minor deviations in the internal construction of a door can result in significant differences in performance. Methods of securing inserts in

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panel doors can vary. The major nondestructive method of analysis, an x-ray, often cannot provide the necessary detail. It is for these, and similar, reasons that a fire test is still felt to be necessary.

It is often possible to upgrade the fire performance of an existing door. Sometimes "as is" and modified doors are evaluated in a single series of tests when failure of the unmodified door is expected. Because doors upgraded after an initial failure must be tested again, there is a potential savings of time and money.

The most common problems encountered are plain glass, panel inserts of insufficient thickness, and improper fit of a door in its frame. The latter problem can be significant because a fire can develop a substantial positive pressure, and the fire will work its way through otherwise innocent-looking gaps between door and frame.

One approach to solving these problems is as follows. The plain glass is replaced with approved or listed wire glass in a steel frame. The panel inserts can be upgraded by adding an additional layer of material. Gypsum wallboard is often used for this purpose. Intumescent paint applied to the edges of the door and frame will expand when exposed to fire, forming an effective seal around the edges. This seal, coupled with the generally even thermal expansion of a wood door in a wood frame, can prevent the passage of flames and other fire gases. Figure O.3.5 illustrates these solutions.

Because the interior construction of a door cannot be determined by a visual inspection, there is no absolute guarantee that the remaining doors are identical to the one(s) removed from the building and tested. But the same is true for doors constructed today, and reason and judgment must be applied. Doors that appear identical upon visual inspection can be weighed. If the weights are reasonably close, the doors can be assumed to be identical and therefore provide the same level of fire performance. Another approach is to fire test more than one door or to dismantle doors selected at random to see if they had been constructed in the same manner. Original building plans showing door details or other records showing that doors were purchased at one time or obtained from a single supplier can also be evidence of similar construction.

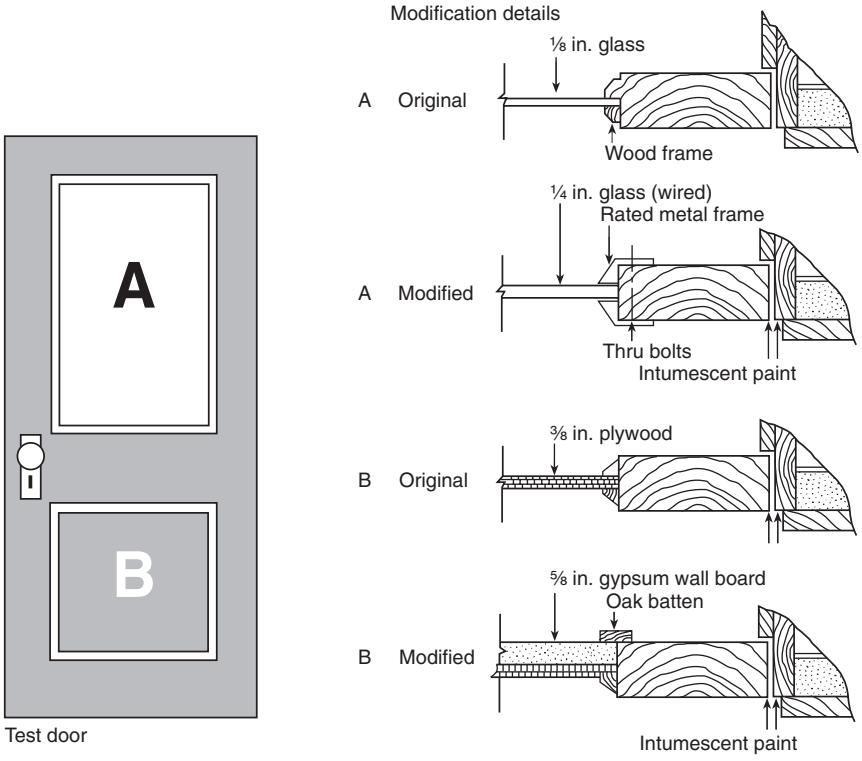
More often though, it is what is visible to the eye that is most significant. The investigator should carefully check the condition and fit of the door and frame and for frames out of plumb or separating from the wall. Door closers, latches, and hinges must be examined to see that they function properly and are tightly secured. If these are in order and the door and frame have passed a full-scale test, there can be a reasonable basis for allowing the existing doors to remain.

O.4 Summary.

O.4.1 Introduction. This section summarizes the various approaches and design solutions discussed in the preceding sections of the guideline. The term "structural system" includes frames, beams, columns, and other structural elements. "Cover" is a protective layer(s) of materials or membrane that slows the flow of heat to the structural elements. It cannot be stressed too strongly that the fire endurance of actual building elements can be greatly reduced or totally negated by removing part of the cover to allow pipes, ducts, or conduits to pass through the element. This must be repaired in the rehabilitation process.

The following approaches should be considered equivalent.

FIGURE O.3.5 Modifications to Existing Door to Increase Fire Protection Performance.



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O.4.2 The fire resistance of a building element can be established from the tables in O.4. This is subject to the following limitations:

(1) The building element in the rehabilitated building should be constructed of the same materials with the same nominal dimensions as stated in the tables.
(2) All penetrations in the building element or its cover for services such as electricity, plumbing, and HVAC should be packed with noncombustible cementitious materials and so fixed that the packing material will not fall out when it loses its water of hydration.
(3) The effects of age and wear and tear should be repaired so that the building element is sound and the original thickness of all components, particularly covers and floor slabs, is maintained.

This approach essentially follows the approach taken by model building codes. The assembly must appear in a table either published in or accepted by the code for a given fire resistance rating to be recognized and accepted.

O.4.3 The fire resistance of a building element that does not explicitly appear in the tables in O.4 can be established if one or more elements of same design but different dimensions have been listed in the tables. For walls, the existing element must be thicker than the one listed. For floor/ceiling assemblies, the assembly listed in the table must have the same or less cover and the same or thinner slab constructed of the same material as the actual floor/ceiling assembly. For other structural elements, the element listed in the table must be of a similar design but with less cover thickness. The fire resistance in all instances should be the fire resistance recommended in the table. This is subject to the following limitations:

(1) The actual element in the rehabilitated building must be constructed of the same materials as listed in the table. Only the following dimensions could vary from those specified: for walls, the overall thickness must exceed that specified in the table; for floor/ceiling assemblies, the thickness of the cover and the slab must be greater than or equal to that specified in the table; for other structural elements, the thickness of the cover must be greater than that specified in the table.
(2) All penetrations in the building element or its cover for services such as electricity, plumbing, or HVAC should be packed with noncombustible cementitious materials and so fixed that the packing material will not fall out when it loses its water of hydration.
(3) The effects of age and wear and tear should be repaired so that the building element is sound and the original thickness of all components, particularly covers and floor slabs, is maintained.

This approach is an application of the "thickness design" concept presented in Section O.3.4 of the guideline. There should be many instances when a thicker building element was utilized than the one listed in the tables in O.4. This guideline recognizes the inherent superiority of a thicker design. (Note: "thickness design" for floor/ceiling assemblies and structural elements refers to cover and slab thickness rather than total thickness.)

The "thickness design" concept is essentially a special case of Harmathy's Rules (specifically Rules 1 and 2). It should be recognized that the only source of data is the tables in O.4. If other data are used, the data must be in connection with the following approach.

O.4.4 The fire resistance of building elements can be established by applying Harmathy's Ten Rules of Fire Resistance Ratings as set forth in Section O.3.3 of the guideline. This is subject to the following limitations:

(1) The data from the tables can be utilized subject to the limitations in Section O.4.3.
(2) Test reports from recognized journals or published papers can be used to support data utilized in applying Harmathy's Rules.
(3) Calculations utilizing recognized and well-established computational techniques can be used in applying Harmathy's Rules. These include, but are not limited to, analysis of heat flow, mechanical properties, deflections, and load-bearing capacity.

O.4.5 Summary Tables and Figures. The summary tables and histograms that follow are to be used only within the analytical framework detailed in the main body of this guideline.

Histograms precede any summary table with 10 or more entries. The use and interpretation of these histograms is explained in O.2. The summary tables are in a format similar to that found in the model building codes. Table O.4.5, taken from an entry in Table O.4.5.2, best explains the summary table format.

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Table O.4.5 Example of Summary Table Format

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-M-50	$4^{5}/_{8}$"	Core: structural clay tile; see notes 12, 16, 21; facings on unexposed side only; see note 18	n/a	25 min		1		3,4,24	$^{1}/_{3}$

Notes:

1. Item Code: The item code consists of a four-place series in the general form w-x-y-z, in which each member of the series denotes the following:
   w = type of building element (e.g., W = walls; F = floors, etc.)
   x = the building element thickness rounded down to the nearest 1 in. increment (e.g., $4^{5}/_{8}$ in. is rounded off to 4 in.)
   y = the general type of material from which the building element is constructed (e.g., M = masonry; W = wood, etc.)
   z = the item number of the particular building element in a given table

   The item code shown in the example W-4-M-50 denotes the following:
   W = wall, as the building element
   4 = wall thickness, in the range of 4 in. to less than 5 in.
   M = masonry construction
   50 = the 50th entry in Table O.4.5.2
2. The specific name or heading of the second column identifies the dimensions that, if varied, have the greatest impact on fire resistance. The critical dimension for walls, the example here, is thickness. It is different for other building elements (e.g., depth for beams; membrane thickness for some floor/ceiling assemblies). The table entry is the named dimension of the building element measured at the time of actual testing to within $\pm\ ^{1}/_{8}$ in. tolerance. The thickness tabulated includes facings where facings are a part of the wall construction.
3. Construction Details: The construction details provide a brief description of the manner in which the building element was constructed.
4. Performance: This heading is subdivided into two columns. The column labeled "Load" will either list the load that the building element was subjected to during the fire test, or it will contain a note number that will list the load and any other significant details. If the building element was not subjected to a load during the test, this column will contain "n/a," which means "not applicable."
   The second column under "performance" is labeled "Time" and denotes the actual fire endurance time observed in the fire test.
5. Reference Number: This heading is subdivided into three columns: Pre-BMS-92, BMS-92, and Post-BMS-92. The table entry under this column is the number in the Bibliography shown in Appendix M of the original source reference for the test data.
6. Notes: Notes are provided at the end of each table to allow a more detailed explanation of certain aspects of the test. In certain tables the notes given to this column have also been listed under the "Construction Details" and/or "Load" columns.
7. Rec Hours: This column lists the recommended fire endurance rating, in hours, of a building element. In some cases, the recommended fire endurance will be less than that listed under the "Time" column. In no case is the "Rec Hours" greater than given in the "Time" column.

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The following is a list of the summary tables and figures.

Section I — Walls

O.4.5.1 Masonry 0"–4" thick
O.4.5.2 Masonry 4"–6" thick
O.4.5.3 Masonry 6"–8" thick
O.4.5.4 Masonry 8"–10" thick
O.4.5.5 Masonry 10"–12" thick
O.4.5.6 Masonry 12"–14" thick
O.4.5.7 Masonry 14" or more thick
O.4.5.8 Metal Frame 0"–4" thick
O.4.5.9 Metal Frame 4"–6" thick
O.4.5.10 Metal Frame 6"–8" thick
O.4.5.11 Metal Frame 8"–10" thick
O.4.5.12 Wood Frame 0"–4" thick
O.4.5.13 Wood Frame 4"–6" thick
O.4.5.14 Wood Frame 6"–8" thick
O.4.5.15 Miscellaneous Materials 0"–4" thick
O.4.5.16 Miscellaneous Materials 4"–6" thick
O.4.5.17 Finish Ratings/Inorganic Materials Thickness
O.4.5.18 Finish Ratings/Organic Materials Thickness

Section II — Columns

O.4.5.19 Reinforced Concrete Minimum Dimension 0"–6"
O.4.5.20 Reinforced Concrete Minimum Dimension 10"–12"
O.4.5.21 Reinforced Concrete Minimum Dimension 12"–14"
O.4.5.22 Reinforced Concrete Minimum Dimension 14"–16"
O.4.5.23 Reinforced Concrete Minimum Dimension 16"–18"
O.4.5.24 Reinforced Concrete Minimum Dimension 18"–20"
O.4.5.25 Reinforced Concrete Minimum Dimension 20"–22"
O.4.5.26 Hexagonal Reinforced Concrete Diameter 12"–14"
O.4.5.27 Hexagonal Reinforced Concrete Diameter 14"–16"
O.4.5.28 Hexagonal Reinforced Concrete Diameter — 16"–18"
O.4.5.29 Hexagonal Reinforced Concrete Diameter — 20"–22"
O.4.5.30 Round Cast Iron Column Minimum Dimension
O.4.5.31 Steel/Gypsum Encasements Minimum Area of Solid Material
O.4.5.32 Timber Minimum Dimension
O.4.5.33 Steel/Concrete Encasements Minimum Dimension less than 6"
O.4.5.34 Steel/Concrete Encasements Minimum Dimension 6"–8"
O.4.5.35 Steel/Concrete Encasements Minimum Dimension 8"–10"
O.4.5.36 Steel/Concrete Encasements Minimum Dimension 10"–12"
O.4.5.37 Steel/Concrete Encasements Minimum Dimension 12"–14"
O.4.5.38 Steel/Concrete Encasements Minimum Dimension 14"–16"
O.4.5.39 Steel/Concrete Encasements Minimum Dimension 16"–18"
O.4.5.40 Steel/Plaster Encasements Minimum Dimension 10"–12"
O.4.5.41 Steel/Brick and Block Encasements Minimum Dimension 12"–14"
O.4.5.42 Steel/Brick and Block Encasements Minimum Dimension 14"–16"
O.4.5.43 Steel/Plaster Encasements Minimum Dimension 6"–8"
O.4.5.44 Steel/Plaster Encasements Minimum Dimension 8"–10"
O.4.5.45 Steel/Miscellaneous Encasements Minimum Dimension 6"–8"
O.4.5.46 Steel/Miscellaneous Encasements Minimum Dimension 8"–10"
O.4.5.47 Steel/Miscellaneous Encasements Minimum Dimension 10"–12"
O.4.5.48 Steel/Miscellaneous Encasements Minimum Dimension 12"–14"

Section III — Floor/Ceiling Assemblies

O.4.5.49 Reinforced Concrete Assembly Thickness
O.4.5.50 Steel Structural Elements Membrane Thickness
O.4.5.51 Wood Joist Membrane Thickness
O.4.5.52 Hollow Clay Tile with Reinforced Concrete Assembly Thickness

Section IV — Beams

O.4.5.53 Reinforced Concrete Depth 10"–12"
O.4.5.54 Reinforced Concrete Depth 12"–14"
O.4.5.55 Reinforced Concrete Depth 14"–16"
O.4.5.56 Steel/Unprotected Depth 10"–12"
O.4.5.57 Steel/Concrete Protection Depth 10"–12"

Section V — Doors

O.4.5.58 Resistance of Doors to Fire Exposure Thickness

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FIGURE O.4.5.1 Masonry Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick.

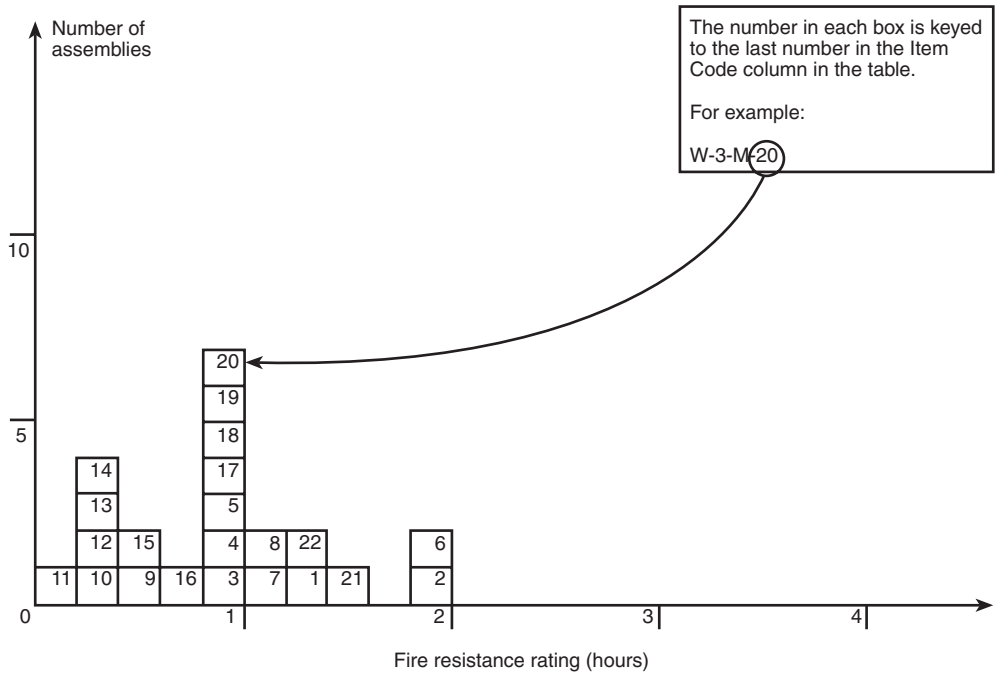

Table O.4.5.1 Masonry Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-2-M-1	$2^1/_4$"	Solid partition: $^3/_4$" gypsum plank 10' × 16"; $^3/_4$" + gypsum plaster each side	n/a	1 hr 22 min			7	1	$1^1/_4$
W-3-M-2	3"	Concrete block (18" × 9" × 3") of fuel ash, portland cement, and plasticizer; cement/sand mortar	n/a	2 hr			7	2,3	2
W-2-M-3	2"	Solid gypsum block wall; no facings	n/a	1 hr		1		4	1
W-3-M-4	3"	Solid gypsum blocks, laid in 1:3 sanded gypsum mortar	n/a	1 hr		1		4	1
W-3-M-5	3"	Magnesium oxysulfate wood fiber blocks 2" thick; laid in portland cement–lime mortar; facings $^1/_2$" of 1:3 sanded gypsum plaster on both sides	n/a	1 hr		1		4	1
W-3-M-6	3"	Magnesium oxysulfate bound wood fiber blocks 3" thick; laid in portland cement–lime mortar; facings $^1/_2$" of 1:3 sanded gypsum plaster on both sides	n/a	2 hr		1		4	2
W-3-M-7	3"	Clay tile: Ohio fire clay; single cell thick; face plaster $^5/_8$" (both sides) of 1:3 sanded gypsum; construction "A"; design "E"	n/a	1 hr 6 min			2	5,6,7, 11,12	1
W-3-M-8	3"	Clay tile: Illinois surface clay; single cell thick; face plaster $^5/_8$" (both sides) 1:3 sanded gypsum; design "A"; construction "E"	n/a	1 hr 1 min			2	5,8,9, 11,12	
W-3-M-9	3"	Clay tile: Illinois surface clay; single cell thick; no face plaster; construction "C"; design "A"	n/a	25 min			2	5,10, 11,12	$^1/_3$
W-3-M-10	$3^7/_8$"	8" × $4^7/_8$" glass blocks: width 4 lb each; portland cement–lime mortar; horizontal mortar joints reinforced with metal lath	n/a	15 min		1		4	$^1/_4$
W-3-M-11	3"	Core: structural clay tile; see notes 14, 18, 23; no facings	n/a	10 min		1		5,11, 26	$^1/_6$
W-3-M-12	3"	Core: structural clay tile; see notes 14, 19, 23; no facings	n/a	20 min		1		5,11, 26	$^1/_3$
W-3-M-13	$3^5/_8$"	Core: structural clay tile; see notes 14, 18, 23; facings on unexposed side per note 20	n/a	20 min		1		5,11, 26	$^1/_3$

(Sheet 1 of 2)

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Table O.4.5.1 Masonry Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-3-M-14	$3^5/_8$"	Core: structural clay tile; see notes 14, 19, 23; facings on unexposed side only per note 20	n/a	20 min		1		5,11, 26	$^1/_3$
W-3-M-15	$3^5/_8$"	Core: clay structural tile; see notes 14, 18, 23; facings on side exposed to fire per note 20	n/a	30 min		1		5,11, 26	$^1/_2$
W-3-M-16	$3^5/_8$"	Core: clay structural tile; see notes 14, 19, 23; facing on side exposed to fire per note 20	n/a	45 min		1		5,11, 26	$^3/_4$
W-2-M-17	2"	2" thick solid gypsum blocks; see note 27	n/a	1 hr		1		27	1
W-3-M-18	3"	Core: 3" thick gypsum blocks 70% solid; see note 2; no facings	n/a	1 hr		1		27	1
W-3-M-19	3"	Core: hollow concrete units; see notes 29, 35, 36, 38; no facings	n/a	1 hr		1		27	1
W-3-M-20	3"	Core: hollow concrete units; see notes 28, 35, 36, 37, 38; no facings	n/a	1 hr		1			1
W-3-M-21	$3^1/_2$"	Core: hollow concrete units; see notes 28, 35, 36, 37, 38; facings on one side, per note 37	n/a	$1^1/_2$ hr		1			$1^1/_2$
W-3-M-22	$3^1/_2$"	Core: hollow concrete units; see notes 29, 35, 36, 38; facings on one side per note 37	n/a	$1^1/_2$ hr		1			$1^1/_4$

(Sheet 2 of 2)

Notes:
1. Failure mode — flame thru.
2. Passed 2-hour fire test (Grade "C" fire resistance — British).
3. Passed hose stream test.
4. Tested at NBS under ASA. A2-1934 as non-load-bearing partitions.
5. Tested at NBS under ASA 42-1934 (ASTM C-19-53) except that hose stream testing, where carried out, was run on test specimens exposed for full test duration, not for a reduced period as is contemporarily done.
6. Failure by thermal criteria — maximum temperature rise 181°C (325°F).
7. Hose stream failure.
8. Hose stream — pass.
9. Specimen removed prior to any failure occurring.
10. Failure mode — collapse.
11. For clay tile walls, unless the source or density of the clay can be positively identified or determined, it is suggested that the lowest hourly rating for the fire endurance of a clay tile partition of that thickness be followed. Identified sources of clay showing longer fire endurance can lead to longer time recommendations.
12. See appendix of original report for construction and design details for clay tile walls.
13. Load — 80 psi for gross wall area.
14. One cell in wall thickness.
15. Two cells in wall thickness.
16. Double shells plus one cell in wall thickness.
17. One cell in wall thickness; cells filled with broken tile, crushed stone, slag, cinders, or sand mixed with mortar.
18. Dense hard-burned clay or shale tile.
19. Medium-burned clay tile.
20. Not less than $^5/_8$ in. thickness of 1:3 sanded gypsum plaster.
21. Units of not less than 30% solid material.
22. Units of not less than 40% solid material.
23. Units of not less than 50% solid material.
24. Units of not less than 45% solid material.
25. Units of not less than 60% solid material.
26. All tiles laid in portland cement-lime mortar.
27. Blocks laid in 1:3 sanded gypsum mortar; voids in blocks not to exceed 30%.
28. Units of expanded slag or pumice aggregates.
29. Units of crushed limestone, blast furnace slag, cinders, and expanded clay or shale.
30. Units of calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.
31. Units of siliceous sand and gravel; 90% or more quartz, chert, or flint.
32. Unit at least 49% solid.
33. Unit at least 62% solid.
34. Unit at least 65% solid.
35. Unit at least 73% solid.
36. Ratings based on one unit and one cell in wall thickness.
37. Minimum of $^1/_2$ in. — 1:3 sanded gypsum plaster.
38. Non-load-bearing.

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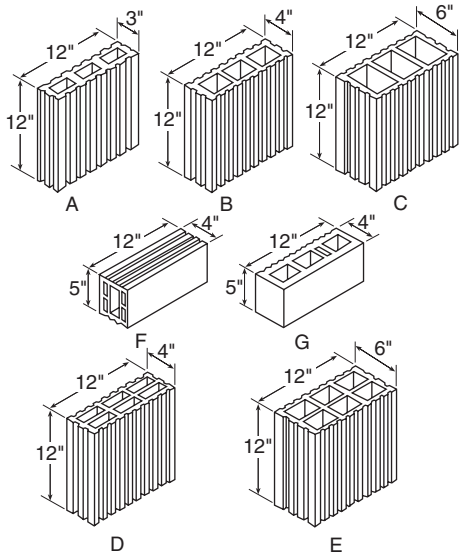
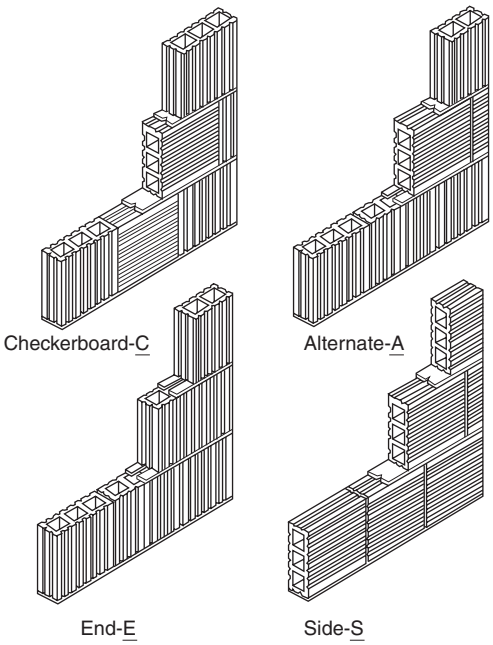
FIGURE O.4.5.2 Masonry Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick.



Designs of tiles used in fire-test partitions.



The four types of construction used in fire-test partitions.

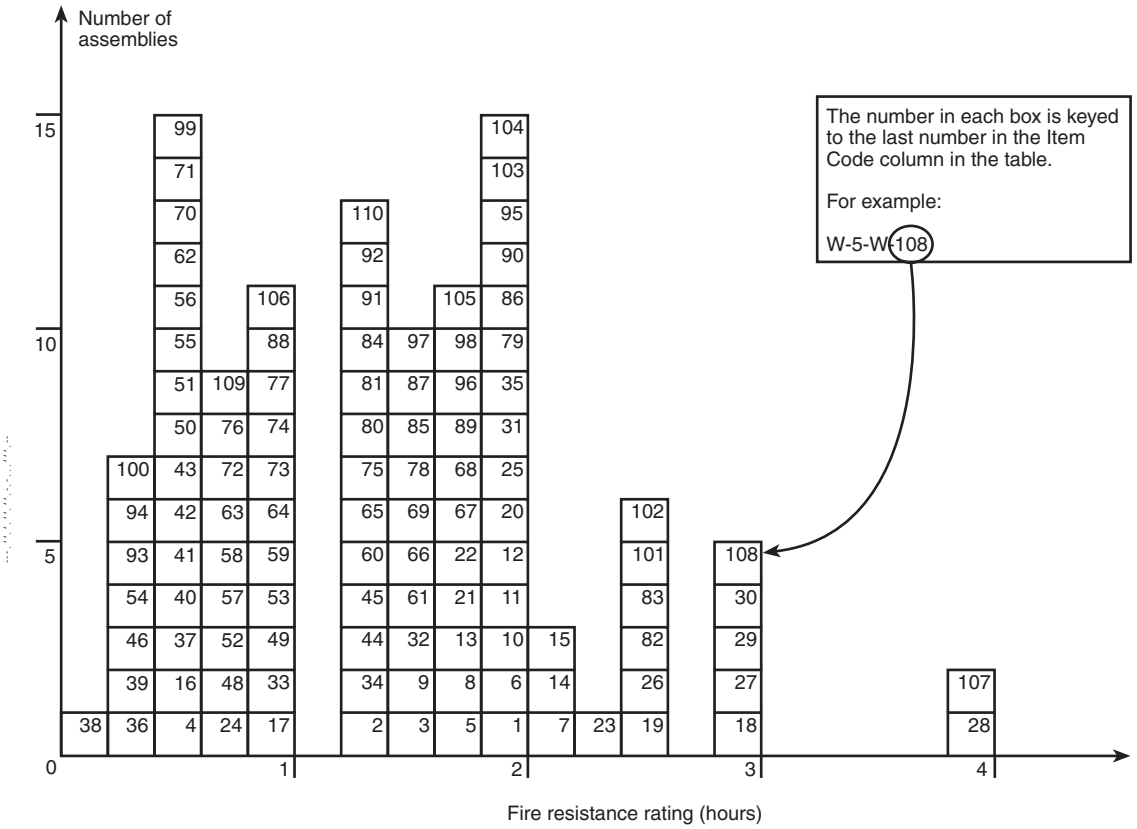


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Table O.4.5.2 Masonry Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-M-1	4"	Solid 3" thick gypsum blocks laid in 1:3 sanded gypsum mortar; facings: 1/2" of 1:3 sanded gypsum plaster (both sides)	n/a	2 hr		1		1	2
W-4-M-2	4"	Solid clay or shale brick	n/a	1 hr 15 min		1		1,2	1 1/4
W-4-M-3	4"	Concrete; no facings	n/a	1 hr 30 min		1		1	1 1/2
W-4-M-4	4"	Clay tile: Illinois surface clay; single cell thick; no face plaster; construction "C"; design "B"	n/a	25 min			2	3–7	1/3
W-4-M-5	4"	Solid sand-lime brick	n/a	1 hr 45 min		1		1	1 3/4
W-4-M-6	4"	Solid wall: 3" thick block; 1/2" plaster each side; 17 3/4" × 8 3/4" × 3" "breeze blocks"; portland cement and sand mortar	n/a	1 hr 52 min			7	2	1 3/4
W-4-M-7	4"	Concrete (4020 psi); reinforcement: vertical 3/8"; horizontal 1/4"; 6" × 6" grid	n/a	2 hr 10 min			7	2	2
W-4-M-8	4"	Concrete wall (4340 psi crush); reinforcement: 1/4" diam. rebar on 8" centers (vertical and horizontal)	n/a	1 hr 40 min			7	2	1 2/3
W-4-M-9	4 3/16"	4 3/16" × 2 5/8" cellular fletton brick (1873 psi) with 1/2" sand mortar; bricks are U-shaped, yielding hollow cover (approx. 2" × 4") in final (cross-section) configuration	n/a	1 hr 25 min			7	2	1 1/3
W-4-M-10	4 1/4"	4 1/4" × 2 1/2" fletton (1831 psi) brick in 1/2" sand mortar	n/a	1 hr 53 min			7	2	1 3/4
W-4-M-11	4 1/4"	4 1/4" × 2 1/2" London stock (683 psi) brick, 1/2" grout	n/a	1 hr 52 min			7	2	1 3/4
W-4-M-12	4 1/2"	4 1/4" × 2 1/2" Leicester red, wire-cut brick (4465 psi) in 1/2" sand mortar	n/a	1 hr 56 min			7	6	1 3/4
W-4-M-13	4 1/4"	4 1/4" × 2 1/2" stairfoot brick (7527 psi), 1/2" sand mortar	n/a	1 hr 37 min			7	2	1 1/2
W-4-M-14	4 1/4"	4 1/4" × 2 1/2" sand-lime brick (2603 psi), 1/2" sand mortar	n/a	2 hr 6 min			7	2	2
W-4-M-15	4 1/4"	4 1/4" × 2 1/2" concrete brick (2527 psi), 1/2" sand mortar	n/a	2 hr 10 min			7	2	2
W-4-M-16	4 1/2"	4" thick clay tile: Ohio fire clay; single cell thick; no plaster exposed face; 1/2" 1:2 gypsum back face; construction "S"; design "F"	n/a	31 min			2	3–6	1/2
W-4-M-17	4 1/2"	4" thick clay tile: Ohio fire clay; single cell thick; plaster exposed face: 1/2"; 1:2 sanded gypsum; back face: none; design "F"; construction "S"	80 psi	50 min			2	3–5,8	3/4
W-4-M-18	4 1/2"	Core: solid sand-lime brick; 1/2" sanded gypsum plaster facings on both sides	80 psi	3 hr		1		1,11	3
W-4-M-19	4 1/2"	Core: solid sand-lime brick; 1/2" sanded gypsum plaster facings on both sides	80 psi	2 hr 30 min		1		1,11	2 1/2
W-4-M-20	4 1/2"	Core: concrete brick; 1/2" of 1:3 sanded gypsum plaster facings on both sides	80 psi	2 hr		1		1,11	2
W-4-M-21	4 1/2"	Core: solid clay or shale bricks; 1/2" thick, 1:3 sanded gypsum plaster facings on fire sides	80 psi	1 hr 45 min		1		1,2, 11	1 3/4

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Table O.4.5.2 Masonry Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-M-22	$4^3/_4$"	4" thick clay tile: Ohio fire clay; single cell thick; cells filled with cement and broken tile concrete; no plaster on exposed face; $^3/_4$" 1:3 sanded gypsum on unexposed face; construction "E"; design "G"	n/a	1 hr 48 min			2	2,3–5,9	$1^3/_4$
W-4-M-23	$4^3/_4$"	4" thick clay tile: Ohio fire clay; single cell thick; cells filled with cement and broken tile concrete; no plaster on exposed face; $^3/_4$" neat gypsum plaster on unexposed face; design "G," construction "F"	n/a	2 hr 14 min			2	2,3–5,9	2
W-5-M-24	5"	3" × 13" air space; 1" thick metal reinforced concrete facings on both sides; faces connected with wood splines	2250 lb/ft	45 min		1		1	$^3/_4$
W-5-M-25	5"	Core: 3" thick void filled with "nodulated" mineral wool weighing 10 lb/ft^3; 1" thick metal reinforced concrete facings on both sides	2250 lb/ft	2 hr		1		1	2
W-5-M-26	5"	Core: solid clay or shale brick; $^1/_2$" thick 1:3 sanded gypsum plaster facings on both sides	40 psi	2 hr 30 min		1		1,2,11	$2^1/_2$
W-5-M-27	5"	Core: solid 4" thick gypsum blocks, laid in 1:3 sanded gypsum mortar; $^1/_2$" of 1:3 sanded gypsum plaster facings on both sides	n/a	3 hr		1		1	3
W-5-M-28	5"	Core: 4" thick hollow gypsum blocks with 30% voids; blocks laid in 1:3 sanded gypsum mortar; no facings	n/a	4 hr		1		1	4
W-5-M-29	5"	Core: concrete brick; $^1/_2$" of 1:3 sanded gypsum plaster facings on both sides	160 psi	3 hr		1		1	3
W-5-M-30	$5^1/_4$"	4" thick clay tile: Illinois surface clay; double cell thick; plaster: $^5/_8$" thick sanded gypsum 1:3, both faces; design "P"; construction "S"	n/a	2 hr 53 min			2	2–5,9	$2^3/_4$
W-5-M-31	$5^1/_4$"	4" thick clay tile: New Jersey fire clay; double cell thick; plaster: $^5/_8$" sanded gypsum 1:3, both faces; design "D"; construction "S"	n/a	1 hr 52 min			2	2-5,9	$1^3/_4$
W-5-M-32	$5^1/_4$"	4" thick clay tile: New Jersey fire clay; single cell thick; $^5/_8$" plaster on both sides, 1:3 sanded gypsum; design "D"; construction "S"	n/a	1 hr 34 min			2	2–5,9	$1^1/_2$
W-5-M-33	$5^1/_4$"	4" thick clay tile: New Jersey fire clay; single cell thick; face plaster: $^5/_8$" both sides, 1:3 sanded gypsum; construction "S"; design "B"	n/a	50 min			2	3–5,8	$^3/_4$
W-5-M-34	$5^1/_4$"	4" thick clay tile: Ohio fire clay; single cell thick; face plaster: $^5/_8$" both sides, 1:3 sanded gypsum; construction "A"; design "B"	n/a	1 hr 19 min			2	2–5,9	$1^1/_4$
W-5-M-35	$5^1/_4$"	4" thick clay tile: Illinois surface clay; single cell thick; face plaster: $^5/_8$" both sides, 1:3 sanded gypsum; construction "S"; design "B"	n/a	1 hr 59 min			2	2–5,10	$1^3/_4$
W-4-M-36	4"	Core: structural clay tile; see notes 12, 16, 21; no facings	n/a	15 min		1		3,4,24	$^1/_4$
W-4-M-37	4"	Core: structural clay tile; see notes 12, 17, 21; no facings	n/a	25 min		1		3,4,24	$^1/_3$

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Table O.4.5.2 Masonry Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-M-38	4"	Core: structural clay tile; see notes 12, 16, 20; no facings	n/a	10 min		1		3,4,24	1/6
W-4-M-39	4"	Core: structural clay tile; see notes 12, 17, 20; no facings	n/a	20 min		1		3,4,24	1/3
W-4-M-40	4"	Core: structural clay tile; see notes 13, 16, 23; no facings	n/a	30 min		1		3,4,24	1/2
W-4-M-41	4"	Core: structural clay tile; see notes 13, 17, 23; no facings	n/a	35 min		1		3,4,24	1/2
W-4-M-42	4"	Core: structural clay tile; see notes 13, 16, 21; no facings	n/a	25 min		1		3,4,24	1/3
W-4-M-43	4"	Core: structural clay tile; see notes 13, 17, 21; no facings	n/a	30 min		1		3,4,24	1/2
W-4-M-44	4"	Core: structural clay tile; see notes 15, 16, 20; no facings	n/a	1 hr 15 min		1		3,4,24	1 1/4
W-4-M-45	4"	Core: structural clay tile; see notes 15, 17, 20; no facings	n/a	1 hr 15 min		1		3,4,24	1 1/4
W-4-M-46	4"	Core: structural clay tile; see notes 14, 16, 22; no facings	n/a	20 min		1		3,4,24	1/3
W-4-M-47	4"	Core: structural clay tile; see notes 14, 17, 22; no facings	n/a	25 min		1		3,4,24	1/3
W-4-M-48	4 1/4"	Core: structural clay tile; see notes 12, 16, 21; facings on both sides; see note 18	n/a	45 min		1		3,4,24	3/4
W-4-M-49	4 1/4"	Core: structural clay tile; see notes 12, 17, 21; facings on both sides; see note 18	n/a	1 hr		1		3,4,24	1
W-4-M-50	4 5/8"	Core: structural clay tile; see notes 12, 16, 21; facings on unexposed side only; see note 18	n/a	25 min		1		3,4,24	1/3
W-4-M-51	4 5/8"	Core: structural clay tile; see notes 12, 17, 21; facings on unexposed side only; see note 18	n/a	30 min		1		3,4,24	1/2
W-4-M-52	4 5/8"	Core: structural clay tile; see notes 12, 16, 21; facings on exposed side only; see note 18	n/a	45 min		1		3,4,24	3/4
W-4-M-53	4 5/8"	Core: structural clay tile; see notes 12, 17, 21; facings on fire side only; see note 18	n/a	1 hr		1		3,4,24	1
W-4-M-54	4 5/8"	Core: structural clay tile; see notes 12, 16, 20; facings on unexposed side; see note 18	n/a	20 min		1		3,4,24	1/3
W-4-M-55	4 5/8"	Core: structural clay tile; see notes 12, 17, 20; facings on unexposed side; see note 18	n/a	25 min		1		3,4,24	1/3
W-4-M-56	4 5/8"	Core: structural clay tile; see notes 12, 16, 20; facings on fire side only; see note 18	n/a	30 min		1		3,4,24	1/2
W-4-M-57	4 5/8"	Core: structural clay tile; see notes 12, 17, 20; facings on fire side only; see note 18	n/a	45 min		1		3,4,24	3/4
W-4-M-58	4 5/8"	Core: structural clay tile; see notes 13, 16, 23; facings on unexposed side only; see note 18	n/a	40 min		1		3,4,24	2/3
W-4-M-59	4 5/8"	Core: structural clay tile; see notes 13, 17, 23; facing on unexposed side only; see note 18	n/a	1 hr		1		3,4,24	1
W-4-M-60	4 5/8"	Core: structural clay tile; see notes 13, 16, 23; facing on fire side only; see note 18	n/a	1 hr 15 min		1		3,4,24	1 1/4

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Table O.4.5.2 Masonry Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-M-61	$4^5/_8$"	Core: structural clay tile; see notes 13, 17, 23; facing on fire side only; see note 18	n/a	1 hr 30 min		1		3,4,24	$1^1/_2$
W-4-M-62	$4^5/_8$"	Core: structural clay tile; see notes 13, 16, 21; facing on unexposed side only; see note 18	n/a	35 min		1		3,4,24	$^1/_2$
W-4-M-63	$4^5/_8$"	Core: structural clay tile; see notes 13, 17, 21; facings on unexposed face only; see note 18	n/a	45 min		1		3,4,24	$^3/_4$
W-4-M-64	$4^5/_8$"	Core: structural clay tile; see notes 13, 16, 23; facing on exposed face only; see note 18	n/a	1 hr		1		3,4,24	1
W-4-M-65	$4^5/_8$"	Core: structural clay tile; see notes 13, 17, 21; facing on exposed side only; see note 18	n/a	1 hr 15 min		1		3,4,24	$1^1/_4$
W-4-M-66	$4^5/_8$"	Core: structural clay tile; see notes 15, 17, 20; facings on unexposed side only; see note 18	n/a	1 hr 30 min		1		3,4,24	$1^1/_2$
W-4-M-67	$4^5/_8$"	Core: structural clay tile; see notes 15, 16, 20; facings on exposed side only; see note 18	n/a	1 hr 45 min		1		3,4,24	$1^3/_4$
W-4-M-68	$4^5/_8$"	Core: structural clay tile; see notes 15, 17, 20; facings on exposed side only; see note 18	n/a	1 hr 45 min		1		3,4,24	$1^3/_4$
W-4-M-69	$4^5/_8$"	Core: structural clay tile; see notes 15, 16, 20; facings on unexposed side only; see note 18	n/a	1 hr 30 min		1		3,4,24	$1^1/_2$
W-4-M-70	$4^5/_8$"	Core: structural clay tile; see notes 14, 16, 22; facings on unexposed side only; see note 18	n/a	30 min		1		3,4,24	$^1/_2$
W-4-M-71	$4^5/_8$"	Core: structural clay tile; see notes 14, 17, 22; facings on unexposed side only; see note 18	n/a	35 min		1		3,4,24	$^1/_2$
W-4-M-72	$4^5/_8$"	Core: structural clay tile; see notes 14, 16, 22; facings on fire side of wall only; see note 18	n/a	45 min		1		3,4,24	$^3/_4$
W-4-M-73	$4^5/_8$"	Core: structural clay tile; see notes 14, 17, 22; facings on fire side of wall only; see note 18	n/a	1 hr		1		3,4,24	1
W-5-M-74	$5^1/_4$"	Core: structural clay tile; see notes 12, 16, 21; facings on both sides; see note 18	n/a	1 hr		1		3,4,24	1
W-5-M-75	$5^1/_4$"	Core: structural clay tile; see notes 12, 17, 21; facings on both sides; see note 18	n/a	1 hr 15 min		1		3,4,24	$1^1/_4$
W-5-M-76	$5^1/_4$"	Core: structural clay tile; see notes 12, 16, 20; facings on both sides; see note 18	n/a	45 min		1		3,4,24	$^3/_4$
W-5-M-77	$5^1/_4$"	Core: structural clay tile; see notes 12, 17, 20; facings on both sides; see note 18	n/a	1 hr		1		3,4,24	1
W-5-M-78	$5^1/_4$"	Core: structural clay tile; see notes 13, 16, 23; facings on both sides of wall; see note 18	n/a	1 hr 30 min		1		3,4,24	$1^1/_2$
W-5-M-79	$5^1/_4$"	Core: structural clay tile; see notes 13, 17, 23; facings on both sides of wall; see note 18	n/a	2 hr		1		3,4,24	2
W-5-M-80	$5^1/_4$"	Core: structural clay tile; see notes 13, 16, 21; facings on both sides of wall; see note 18	n/a	1 hr 15 min		1		3,4,24	$1^1/_4$

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Table O.4.5.2 Masonry Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-5-M-81	$5^1/_4$"	Core: structural clay tile; see notes 13, 16, 21; facings on both sides of wall; see note 18	n/a	1 hr 30 min		1		3,4,24	$1^1/_2$
W-5-M-82	$5^1/_4$"	Core: structural clay tile; see notes 15, 16, 20; facings on both sides; see note 18	n/a	2 hr 30 min		1		3,4,24	$2^1/_2$
W-5-M-83	$5^1/_4$"	Core: structural clay tile; see notes 15, 17, 20; facings on both sides; see note 18	n/a	2 hr 30 min		1		3,4,24	$2^1/_2$
W-5-M-84	$5^1/_4$"	Core: structural clay tile; see notes 14, 16, 22; facings on both sides of wall; see note 18	n/a	1 hr 15 min		1		3,4,24	$1^1/_4$
W-5-M-85	$5^1/_4$"	Core: structural clay tile; see notes 14, 17, 22; facings on both sides of wall; see note 18	n/a	1 hr 30 min		1		3,4,24	$1^1/_2$
W-4-M-86	4"	Core: 3" thick gypsum blocks 70% solid; see note 26; facings on both sides per note 25	n/a	2 hr		1			2
W-4-M-87	4"	Core: hollow concrete units; see notes 27, 34, 35; no facings	n/a	1 hr 30 min		1			$1^1/_2$
W-4-M-88	4"	Core: hollow concrete units; see notes 28, 33, 35; no facings	n/a	1 hr		1			1
W-4-M-89	4"	Core: hollow concrete units; see notes 28, 34, 35; facings on both sides per note 25	n/a	1 hr 45 min		1			$1^3/_4$
W-4-M-90	4"	Core: hollow concrete units; see notes 27, 34, 35; facings on both sides per note 25	n/a	2 hr		1			2
W-4-M-91	4"	Core: hollow concrete units; see notes 27, 32, 35; no facings	n/a	1 hr 15 min		1			$1^1/_4$
W-4-M-92	4"	Core: hollow concrete units; see notes 28, 34, 35; no facings	n/a	1 hr 15 min		1			$1^1/_4$
W-4-M-93	4"	Core: hollow concrete units; see notes 29, 32, 35; no facings	n/a	20 min		1			$^1/_3$
W-4-M-94	4"	Core: hollow concrete units; see notes 30, 34, 35; no facings	n/a	15 min		1			$^1/_4$
W-4-M-95	$4^1/_2$"	Core: hollow concrete units; see notes 27, 34, 35; facing on one side only; see note 25	n/a	2 hr		1			2
W-4-M-96	$4^1/_2$"	Core: hollow concrete units; see notes 27, 32, 35; facing on one side only; see note 25	n/a	1 hr 45 min		1			$1^3/_4$
W-4-M-97	$4^1/_2$"	Core: hollow concrete units; see notes 28, 33, 35; facing on one side per note 25	n/a	1 hr 30 min		1			$1^1/_2$
W-4-M-98	$4^1/_2$"	Core: hollow concrete units; see notes 28, 34, 35; facing on one side only per note 25	n/a	1 hr 45 min		1			$1^3/_4$
W-4-M-99	$4^1/_2$"	Core: hollow concrete units; see notes 29, 32, 35; facing on one side per note 25	n/a	30 min		1			$^1/_2$
W-4-M-100	$4^1/_2$"	Core: hollow concrete units; see notes 30, 34, 35; facing on one side per note 25	n/a	20 min		1			$^1/_3$
W-5-M-101	5"	Core: hollow concrete units; see notes 27, 34, 35; facings on both sides; see note 25	n/a	2 hr 30 min		1			$2^1/_2$
W-5-M-102	5"	Core: hollow concrete units; see notes 27, 32, 35; facings on both sides per note 25	n/a	2 hr 30 min		1			$2^1/_2$

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Table O.4.5.2 Masonry Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-5-M-103	5"	Core: hollow concrete units; see notes 28, 33, 35; facings on both sides per note 25	n/a	2 hr		1			2
W-5-M-104	5"	Core: hollow concrete units; see notes 28, 31, 35; facings on both sides per note 25	n/a	2 hr		1			2
W-5-M-105	5"	Core: hollow concrete units; see notes 29, 32, 35; facings on both sides per note 25	n/a	1 hr 45 min		1			$1\frac{3}{4}$
W-5-M-106	5"	Core: hollow concrete units; see notes 30, 34, 35; facings on both sides per note 25	n/a	1 hr		1			1
W-5-M-107	5"	Core: 5" thick solid gypsum blocks; see note 26; no facings	n/a	4 hr		1			4
W-5-M-108	5"	Core: 4" thick hollow gypsum blocks; see note 26; facings on both sides per note 25	n/a	3 hr		1			3
W-4-M-109	4"	Concrete with 4" × 4" No. 6 welded wire mesh at wall center	100 psi	45 min			43	2	$\frac{3}{4}$
W-4-M-110	4"	Concrete with 4" × 4" No. 6 welded wire mesh at wall center	n/a	1 hr 15 min			43	2	$1\frac{1}{4}$

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Notes:
1. Tested at NBS under ASA A2-1934.
2. Failure mode — maximum temperature rise.
3. Tested at NBS under ASA 42-1934 (ASTM C-19-53) except that hose stream testing, where carried out, was run on test specimens exposed for full test duration, not for a reduced period as is contemporarily done.
4. For clay tile walls, unless the source of the clay can be positively identified, it is suggested that the most pessimistic hour rating for the fire endurance of a clay tile partition of that thickness be followed. Identified sources of clay showing longer fire endurance can lead to longer time recommendations.
5. See appendix of original report for construction and design details for clay tile walls.
6. Failure mode — flame thru or crack formation showing flames.
7. Hole formed at 25 minutes; partition collapsed at 42 minutes on removal from furnace.
8. Failure mode — collapse.
9. Hose stream — pass.
10. Hose stream hole formed in specimen.
11. Load — 80 psi for gross wall cross-sectioned area.
12. One cell in wall thickness.
13. Two cells in wall thickness.
14. Double cells plus one cell in wall thickness.
15. One cell in wall thickness; cells filled with broken tile, crushed stone, slag, cinders, or sand mixed with mortar.
16. Dense hard-burned clay or shale tile.
17. Medium-burned clay tile.
18. Not less than $\frac{5}{8}$ in. thickness of 1:3 sanded gypsum plaster.
19. Units of not less than 30% solid material.
20. Units of not less than 40% solid material.
21. Units of not less than 50% solid material.
22. Units of not less than 45% solid material.
23. Units of not less than 60% solid material.
24. All tiles laid in portland cement-lime mortar.
25. Minimum $\frac{1}{2}$ in. 1:3 sanded gypsum plaster.
26. Laid in 1:3 sanded gypsum mortar. Voids in hollow units not to exceed 30%.
27. Units of expanded slag or pumice aggregate.
28. Units of crushed limestone, blast furnace slag, cinders, and expanded clay or shale.
29. Units of calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.
30. Units of siliceous sand and gravel; 90% or more quartz, chert, or flint.
31. Unit at least 49% solid.
32. Unit at least 62% solid.
33. Unit at least 65% solid.
34. Unit at least 73% solid.
35. Ratings based on one unit and one cell in wall thickness.

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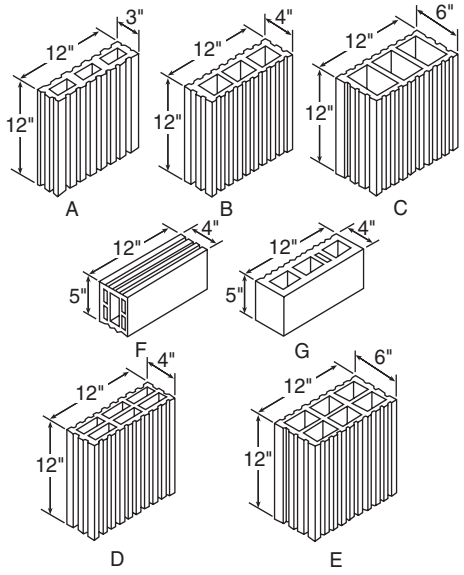
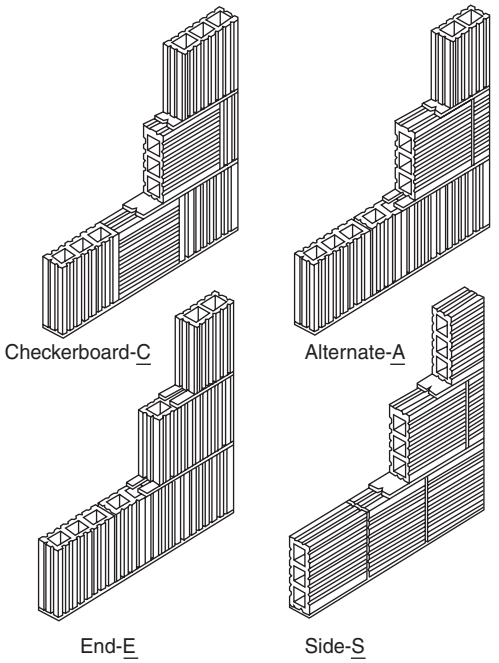
FIGURE O.4.5.3 Masonry Walls 6 in. (150 mm) to Less Than 8 in. (200 mm) Thick.



Designs of tiles used in fire-test partitions.



The four types of construction used in fire-test partitions.

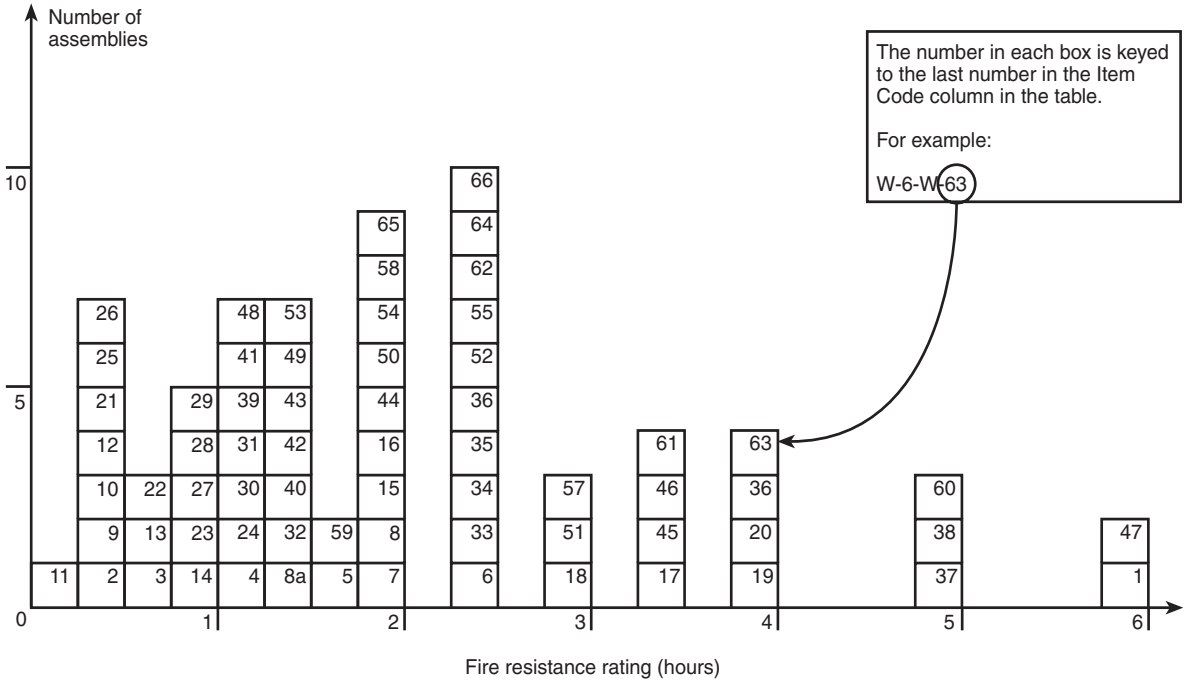


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Table O.4.5.3 Masonry Walls 6 in. (150 mm) to Less Than 8 in. Thick (200 mm)

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-6-M-1	6"	Core: 5" thick, solid gypsum blocks laid in 1:3 sanded gypsum mortar; 1/2" of 1:3 sanded gypsum plaster facings on both sides	n/a	6 hr		1			6
W-6-M-2	6"	6" clay tile: Ohio fire clay; single cell thick; plaster: none; design "C"; construction "A"	n/a	17 min			2	1,3,4,6	1/4
W-6-M-3	6"	6" clay tile: Illinois surface clay; double cell thick; no plaster; design "E"; construction "S"	n/a	45 min			2	1–4,7	3/4
W-6-M-4	6"	6" clay tile: New Jersey fire clay; double cell thick; no plaster; design "E"; construction "S"	n/a	1 hr 1 min			2	1–4,8	1
W-7-M-5	7 1/4"	6" clay tile: Illinois surface clay; double cell thick; plaster: 5/8" of 1:3 sanded gypsum both faces; design "E"; construction "A"	n/a	1 hr 41 min			2	1–4	1 2/3
W-7-M-6	7 1/4"	6" clay tile: New Jersey fire clay; double cell thick; plaster: 5/8" of 1:3 sanded gypsum both faces; design "E"; construction "S"	n/a	2 hr 23 min			2	1–4,9	2 1/3
W-7-M-7	7 1/4"	6" clay tile: Ohio fire clay; single cell thick; plaster: 5/8" of sanded gypsum, 1:3 both faces; design "C"; construction "A"	n/a	1 hr 54 min			2	1–4,9	2 3/4
W-7-M-8	7 1/4"	6" clay tile: Illinois surface clay; single cell thick; plaster: 5/8" of 1:3 sanded gypsum both faces; design "C"; construction "S"	n/a	2 hr			2	1,3,4, 9,10	2
W-7-M-8a	7 1/4"	6" clay tile: Illinois surface clay; single cell thick; plaster: 5/8" of 1:3 sanded gypsum both faces; design "C"; construction "E"	n/a	1 hr 23 min			2	1–4,9, 10,55	1 1/4
W-6-M-9	6"	Core: structural clay tile; see notes 12, 16, 20; no facings	n/a	20 min		1		3,5,25	1/3
W-6-M-10	6"	Core: structural clay tile; see notes 12, 17, 20; no facings	n/a	25 min		1		3,5,24	1/3
W-6-M-11	6"	Core: structural clay tile; see notes 12, 16, 19; no facings	n/a	15 min		1		3,5,24	1/4
W-6-M-12	6"	Core: structural clay tile; see notes 12, 17, 19; no facings	n/a	20 min		1		3,5,24	1/3
W-6-M-13	6"	Core: structural clay tile; see notes 13, 16, 22; no facings	n/a	45 min		1		3,5,24	3/4
W-6-M-14	6"	Core: structural clay tile; see notes 13, 17, 22; no facings	n/a	1 hr		1		3,5,24	1
W-6-M-15	6"	Core: structural clay tile; see notes 15, 17, 19; no facings	n/a	2 hr		1		3,5,24	2
W-6-M-16	6"	Core: structural clay tile; see notes 15, 16, 19; no facings	n/a	2 hr		1		3,5,24	2
W-6-M-17	6"	Cored concrete masonry; see notes 12, 34, 26, 38, 41; no facings	80 psi	3 hr 30 min		1		5,25	3 1/2
W-6-M-18	6"	Cored concrete masonry; see notes 12, 33, 36, 38, 41; no facings	80 psi	3 hr		1		5,25	3
W-6-M-19	6 1/2"	Cored concrete masonry; see notes 12, 34, 36, 38, 41; facings: see note 35 for side 1	80 psi	4 hr		1		5,25	4
W-6-M-20	6 1/2"	Cored concrete masonry; see notes 12, 33, 36, 38, 41; facings: see note 35 for side 1	80 psi	4 hr		1		5,25	4

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Table O.4.5.3 Masonry Walls 6 in. (150 mm) to Less Than 8 in. Thick (200 mm) ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-6-M-21	$6^5/_8$"	Core: structural clay tile; see notes 12, 16, 20; facing: unexposed face only; see note 18	n/a	30 min		1		3,5,24	$^1/_2$
W-6-M-22	$6^5/_8$"	Core: structural clay tile; see notes 12, 17, 20; facing: unexposed face only; see note 18	n/a	40 min		1		3,5,24	$^2/_3$
W-6-M-23	$6^5/_8$"	Core: structural clay tile; see notes 12, 16, 20; facing: exposed face only; see note 18	n/a	1 hr		1		3,5,24	1
W-6-M-24	$6^5/_8$"	Core: structural clay tile; see notes 12, 17, 20; facing: exposed face only; see note 18	n/a	1 hr 5 min		1		3,5,24	1
W-6-M-25	$6^5/_8$"	Core: structural clay tile; see notes 12, 16, 19; facing: unexposed side only; see note 18	n/a	25 min		1		3,5,24	$^1/_3$
W-6-M-26	$6^5/_8$"	Core: structural clay tile; see notes 12, 7, 19; facings: on unexposed side only; see note 18	n/a	30 min		1		3,5,24	$^1/_2$
W-6-M-27	$6^5/_8$"	Core: structural clay tile; see notes 12, 16, 19; facings: on exposed side only; see note 18	n/a	1 hr		1		3,5,24	1
W-6-M-28	$6^5/_8$"	Core: structural clay tile; see notes 12, 17, 19; facings: on fire side only; see note 18	n/a	1 hr		1		3,5,24	1
W-6-M-29	$6^5/_8$"	Core: structural clay tile; see notes 13, 16, 22; facings: on unexposed side only; see note 18	n/a	1 hr		1		3,5,24	1
W-6-M-30	$6^5/_8$"	Core: structural clay tile; see notes 13, 17, 22; facings: on unexposed side only; see note 18	n/a	1 hr 15 min		1		3,5,24	$1^1/_4$
W-6-M-31	$6^5/_8$"	Core: structural clay tile; see notes 13, 16, 22; facings: on fire side only; see note 18	n/a	1 hr 15 min		1		3,5,24	$1^1/_4$
W-6-M-32	$6^5/_8$"	Core: structural clay tile; see notes 13, 17, 22; facing: on fire side only; see note 18	n/a	1 hr 30 min		1		3,5,24	$1^1/_2$
W-6-M-33	$6^5/_8$"	Core: structural clay tile; see notes 15, 16, 19; facings: on unexposed side only; see note 18	n/a	2 hr 30 min		1		3,5,24	$2^1/_2$
W-6-M-34	$6^5/_8$"	Core: structural clay tile; see notes 15, 17, 19; facings: on unexposed side only; see note 18	n/a	2 hr 30 min		1		3,5,24	$2^1/_2$
W-6-M-35	$6^5/_8$"	Core: structural clay tile; see notes 15, 16, 19; facings: on fire side only; see note 18	n/a	2 hr 30 min		1		3,5,24	$2^1/_2$
W-6-M-36	$6^5/_8$"	Core: structural clay tile; see notes 15, 17, 19; facings: on fire side only; see note 18	n/a	2 hr 30 min		1		3,5,24	$2^1/_2$
W-7-M-37	7"	Cored concrete masonry; see notes 12, 34, 36, 38, 41; see note 35 for facings on both sides	80 psi	5 hr		1		5,25	5
W-7-M-38	7"	Cored concrete masonry; see notes 12, 33, 36, 38, 41; see note 35 for facings	80 psi	5 hr		1		5,25	5
W-7-M-39	$7^1/_4$"	Core: structural clay tile; see notes 12, 16, 20; see note 18 for facings on both sides	n/a	1 hr 15 min		1		3,5,24	$1^1/_4$
W-7-M-40	$7^1/_4$"	Core: structural clay tile; see notes 12, 17, 20; see note 18 for facings on both sides	n/a	1 hr 30 min		1		3,5,24	$1^1/_2$

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Table O.4.5.3 Masonry Walls 6 in. (150 mm) to Less Than 8 in. Thick (200 mm) *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-7-M-41	$7^1/_4$"	Core: structural clay tile; see notes 12, 16, 19; see note 18 for facings on both sides	n/a	1 hr 15 min		1		3,5,24	$1^1/_4$
W-7-M-42	$7^1/_4$"	Core: structural clay tile; see notes 12, 17, 19; see note 18 for facings on both sides	n/a	1 hr 30 min		1		3,5,24	$1^1/_2$
W-7-M-43	$7^1/_4$"	Core: structural clay tile; see notes 13, 16, 22; facing: on both sides of wall; see note 18	n/a	1 hr 30 min		1		3,5,24	$1^1/_2$
W-7-M-44	$7^1/_4$"	Core: structural clay tile; see notes 13, 17, 22; facings: on both sides of wall; see note 18	n/a	2 hr		1		3,5,24	2
W-7-M-45	$7^1/_4$"	Core: structural clay tile; see notes 15, 16, 19; facings: both sides; see note 18	n/a	3 hr 30 min		1		3,5,24	$3^1/_2$
W-7-M-46	$7^1/_4$"	Core: structural clay tile; see notes 15, 17, 19; facings: both sides; see note 18	n/a	3 hr 30 min		1		3,5,24	$3^1/_2$
W-6-M-47	6"	Core: 5" thick solid gypsum blocks; see note 45; facings: both sides per note 35	n/a	6 hr		1			6
W-6-M-48	6"	Core: hollow concrete units; see notes 46, 50, 54; no facings	n/a	1 hr 15 min		1			$1^1/_4$
W-6-M-49	6"	Core: hollow concrete units; see notes 46, 50, 54; no facings	n/a	1 hr 30 min		1			$1^1/_2$
W-6-M-50	6"	Core: hollow concrete units; see notes 41, 46, 54; no facings	n/a	2 hr		1			2
W-6-M-51	6"	Core: hollow concrete units; see notes 46, 53, 54; no facings	n/a	3 hr		1			3
W-6-M-52	6"	Core: hollow concrete units; see notes 47, 53, 54; no facings	n/a	2 hr 30 min		1			$2^1/_2$
W-6-M-53	6"	Core: hollow concrete units; see notes 47, 51, 54; no facings	n/a	1 hr 30 min		1			$1^1/_2$
W-6-M-54	$6^1/_2$"	Core: hollow concrete units; see notes 46, 50, 54; facing: one side only per note 35	n/a	2 hr		1			2
W-6-M-55	$6^1/_2$"	Core: hollow concrete units; see notes 4, 51, 54; facings: one side per note 35	n/a	2 hr 30 min		1			$2^1/_2$
W-6-M-56	$6^1/_2$"	Core: hollow concrete units; see notes 46, 53, 54; facings: one side per note 35	n/a	4 hr		1			4
W-6-M-57	$6^1/_2$"	Core: hollow concrete units; see notes 47, 53, 54; facings: one side per note 35	n/a	3 hr		1			3
W-6-M-58	$6^1/_2$"	Core: hollow concrete units; see notes 47, 51, 54; facings: one side per note 35	n/a	2 hr		1			2
W-6-M-59	$6^1/_2$"	Core: hollow concrete units; see notes 47, 50, 54; facings: one side per note 35	n/a	1 hr 45 min		1			$1^3/_4$
W-7-M-60	7"	Core: hollow concrete units; see notes 46, 53, 54; facings: both sides per note 35	n/a	5 hr		1			5
W-7-M-61	7"	Core: hollow concrete units; see notes 46, 51, 54; facings: both sides per note 35	n/a	3 hr 30 min		1			$3^1/_2$
W-7-M-62	7"	Core: hollow concrete units; see notes 46, 50, 54; facings: both sides per note 35	n/a	2 hr 30 min		1			$2^1/_2$
W-7-M-63	7"	Core: hollow concrete units; see notes 47, 53, 54; facings: both sides per note 35	n/a	4 hr		1			4
W-7-M-64	7"	Core: hollow concrete units; see notes 47, 51, 54; facings: both sides per note 35	n/a	2 hr 30 min		1			$2^1/_2$

(Sheet 3 of 4)

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Table O.4.5.3 Masonry Walls 6 in. (150 mm) to Less Than 8 in. Thick (200 mm) ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-7-M-65	7"	Core: hollow concrete units; see notes 47, 50, 54; facings: both sides per note 35	n/a	2 hr		1			2
W-6-M-66	6"	Concrete wall with 4" × 4" No. 6 wire fabric (welded) near wall center for reinforcement	300 psi	2 hr 30 min			43	2	$2^1/_2$

(Sheet 4 of 4)

Notes:
1. Tested at NBS under ASA 42-1934 (ASTM C-19-53) except that hose stream testing, where carried out, was run on test specimens exposed for full test duration, not for a reduced period as is contemporarily done.
2. Failure by thermal criteria — maximum temperature rise.
3. For clay tile walls, unless the source or density of the clay can be positively identified or determined, it is suggested that the lowest hourly rating for the fire endurance of a clay tile partition of that thickness be followed. Identified sources of clay showing longer fire endurance can lead to longer time recommendations.
4. See note 55 for construction and design details for clay tile walls.
5. Tested at NBS under ASA A2-1934.
6. Failure mode — collapse.
7. Collapsed on removal from furnace at 1 hour 9 minutes.
8. Hose stream — failed.
9. Hose stream — passed.
10. No end point met in test.
11. Wall collapsed at 1 hour 28 minutes.
12. One cell in wall thickness.
13. Two cells in wall thickness.
14. Double shells plus one cell in wall thickness.
15. One cell in wall thickness; cells filled with broken tile, crushed stone, slag, cinders, or sand mixed with mortar.
16. Dense hard-burned clay or shale tile.
17. Medium-burned clay tile.
18. Not less than $^5/_8$ in. thickness of 1:3 sanded gypsum plaster.
19. Units of not less than 30% solid material.
20. Units of not less than 40% solid material.
21. Units of not less than 50% solid material.
22. Units of not less than 45% solid material.
23. Units of not less than 60% solid material.
24. All tiles laid in portland cement–lime mortar.
25. Load — 80 psi for gross cross-sectional area of wall.
26. Three cells in wall thickness.
27. Minimum % of solid material in concrete units: 52.
28. Minimum % of solid material in concrete units: 54.
29. Minimum % of solid material in concrete units: 55.
30. Minimum % of solid material in concrete units: 57.
31. Minimum % of solid material in concrete units: 62.
32. Minimum % of solid material in concrete units: 65.
33. Minimum % of solid material in concrete units: 70.
34. Minimum % of solid material in concrete units: 76.
35. Not less than $^1/_2$ in. of 1:3 sanded gypsum plaster.
36. Noncombustible or no members framed into wall.
37. Combustible members framed into wall.
38. One unit in wall thickness.
39. Two units in wall thickness.
40. Three units in wall thickness.
41. Concrete units made with expanded slag or pumice aggregates.
42. Concrete units made with expanded burned clay or shale, crushed limestone, air cooled slag, or cinders.
43. Concrete units made with calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.
44. Concrete units made with siliceous sand and gravel; 90% or more quartz, chert, or flint.
45. Laid in 1:3 sanded gypsum mortar.
46. Units of expanded slag or pumice aggregate.
47. Units of crushed limestone, blast furnace slag, cinders, and expanded clay or shale.
48. Units of calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.
49. Units of siliceous sand and gravel; 90% or more quartz, chert, or flint.
50. Unit minimum 49% solid.
51. Unit minimum 62% solid.
52. Unit minimum 65% solid.
53. Unit minimum 73% solid.
54. Ratings based on one unit and one cell in wall section.

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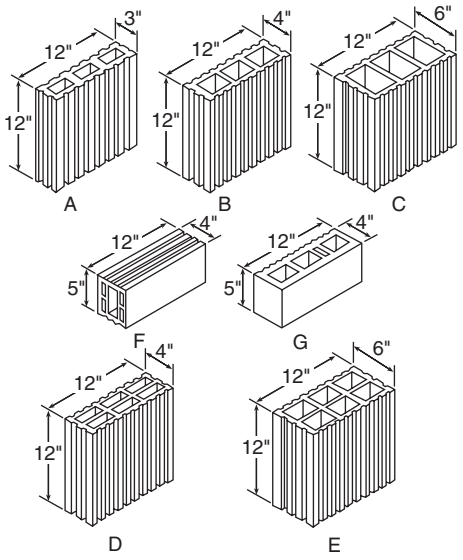
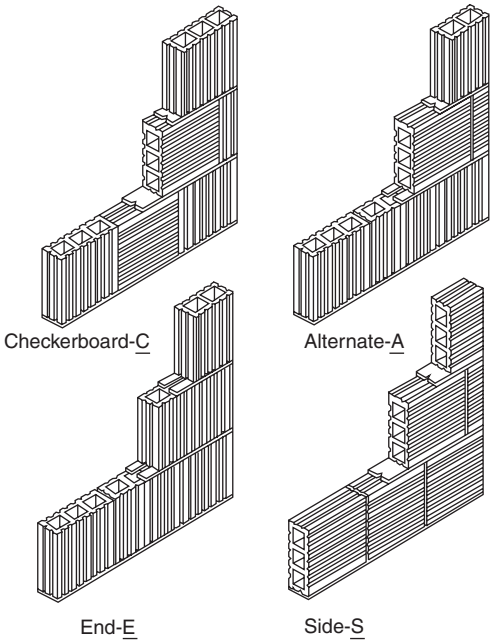
FIGURE O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick.



Designs of tiles used in fire-test partitions.



The four types of construction used in fire-test partitions.

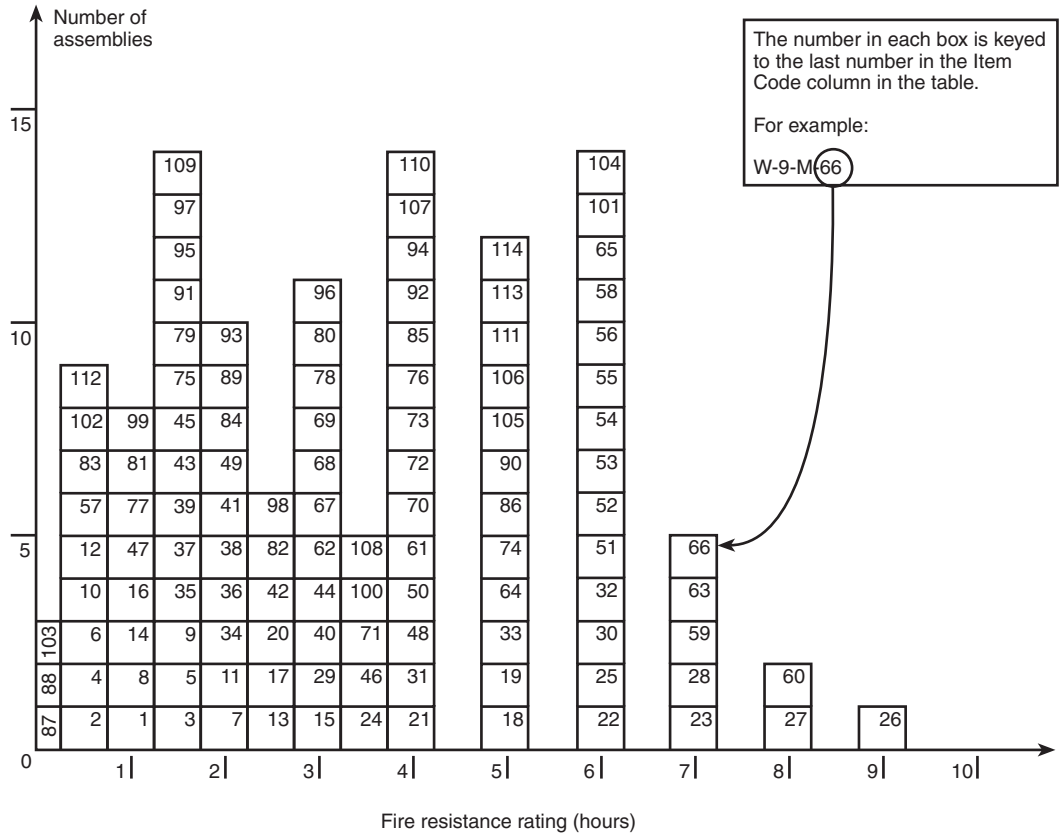


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Table O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-8-M-1	8"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 40	80 psi	1 hr 15 min		1		1,20	$1^1/_4$
W-8-M-2	8"	Core: clay or shale structural tile; units in wall thickness: 1; cell in wall thickness: 2; minimum % solids in units: 40; facings: none; result for wall with combustible members framed into interior	80 psi	45 min		1		1,20	$^3/_4$
W-8-M-3	8"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 43	80 psi	1 hr 30 min		1		1,20	$1^1/_2$
W-8-M-4	8"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 43; no facings; combustible members framed into wall	80 psi	45 min		1		1,20	$^3/_4$
W-8-M-5	8"	Core: clay or shale structural tile; no facings	See notes	1 hr 30 min		1		1,2,5, 10,18, 20,21	$1^1/_2$
W-8-M-6	8"	Core: clay or shale structural tile; no facings	See notes	45 min		1		1,2,5,10, 19–21	$^3/_4$
W-8-M-7	8"	Core: clay or shale structural tile; no facings	See notes	2 hr		1		1,2,5, 13,18, 20,21	2
W-8-M-8	8"	Core: clay or shale structural tile; no facings	See notes	1 hr 15 min		1		1,2,5, 13,19, 20,21	$1^1/_4$
W-8-M-9	8"	Core: clay or shale structural tile; no facings	See notes	1 hr 45 min		1		1,2,6,9, 18,20,21	$1^3/_4$
W-8-M-10	8"	Core: clay or shale structural tile; no facings	See notes	45 min		1		1,2,6,9, 19,20,21	$^3/_4$
W-8-M-11	8"	Core: clay or shale structural tile; no facings	See notes	2 hr		1		1,2,6, 10,18, 20,21	2
W-8-M-12	8"	Core: clay or shale structural tile; no facings	See notes	45 min		1		1,2,6, 10,19, 20,21	$^3/_4$
W-8-M-13	8"	Core: clay or shale structural tile; no facings	See notes	2 hr 30 min		1		1,3,6, 12,18, 20,21	$2^1/_2$
W-8-M-14	8"	Core: clay or shale structural tile; no facings	See notes	1 hr		1		1,2,6, 12,19, 20,21	1
W-8-M-15	8"	Core: clay or shale structural tile; no facings	See notes	3 hr		1		1,2,6, 16,18, 20,21	3
W-8-M-16	8"	Core: clay or shale structural tile; no facings	See notes	1 hr 15 min		1		1,2,6, 16,19, 20,21	$1^1/_4$
W-8-M-17	8"	Units in wall thickness: 1; cells in wall thickness: 1; minimum % solids: 70; cored clay or shale brick; no facings	See notes	2 hr 30 min		1		1,44	$2^1/_2$

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Table O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-8-M-18	8"	Cored clay or shale bricks; units in wall thickness: 2; cells in wall thickness: 2; minimum % solids, 87; no facings	See notes	5 hr		1		1,45	5
W-8-M-19	8"	Core: solid clay or shale brick; no facings	See notes	5 hr		1		1,22,45	5
W-8-M-20	8"	Core: hollow rolok of clay or shale	See notes	2 hr 30 min		1		1,22,45	$2^1/_2$
W-8-M-21	8"	Core: hollow rolok bak of clay or shale; no facings	See notes	4 hr		1		1,45	4
W-8-M-22	8"	Core: concrete brick; no facings	See notes	6 hr		1		1,45	6
W-8-M-23	8"	Core: sand-lime brick; no facings	See notes	7 hr		1		1,45	7
W-8-M-24	8"	Core: 4"; 40% solid clay or shale structural tile; 1 side 4" brick facing	See notes	3 hr 30 min		1		1,20	$3^1/_2$
W-8-M-25	8"	Concrete wall (3220 psi); reinforcing vertical rods 1" from each face and 1" diam.; horizontal rod $^3/_8$" diam.	22,200 lb/ft	6 hr			7		6
W-8-M-26	8"	Core: sand-lime brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	See notes	9 hr		1		1,45	9
W-8-M-27	$8^1/_2$"	Core: sand-lime brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	See notes	8 hr		1		1,45	8
W-8-M-28	$8^1/_2$"	Core: concrete; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	See notes	7 hr		1		1,45	7
W-8-M-29	$8^1/_2$"	Core: hollow rolok of clay or shale; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	See notes	3 hr		1		1,45	3
W-8-M-30	$8^1/_2$"	Core: solid clay or shale brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	See notes	6 hr		1		1,22,45	6
W-8-M-31	$8^1/_2$"	Core: cored clay or shale brick; units in wall thickness: 1; cells in wall thickness: 1; minimum % solids: 70; $^1/_2$" of 1:3 sanded gypsum plaster facing on both sides	See notes	4 hr		1		1,44	4
W-8-M-32	$8^1/_2$"	Core: cored clay or shale brick; units in wall thickness: 2; cells in wall thickness: 2; minimum % solids: 87; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	See notes	6 hr		1		1,45	6
W-8-M-33	$8^1/_2$"	Hollow rolok bak of clay or shale core; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	See notes	5 hr		1		1,45	5
W-8-M-34	$8^1/_2$"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 40; $^5/_8$" of 1:3 sanded gypsum plaster facing on one side	See notes	2 hr		1		1,20,21	2
W-8-M-35	$8^5/_8$"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 40; exposed face: $^5/_8$" of 1:3 sanded gypsum plaster	See notes	1 hr 30 min		1		1,20,21	$1^1/_2$

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Table O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-8-M-36	$8^5/_8$"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 43; $^5/_8$" of 1:3 sanded gypsum plaster facing on one side	See notes	2 hr		1		1,20,21	2
W-8-M-37	$8^5/_8$"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 43; $^5/_8$" of 1:3 sanded gypsum plaster on the exposed face only	See notes	1 hr 30 min				1,20,21	$1^1/_2$
W-8-M-38	$8^5/_8$"	Core: clay or shale structural tile; see note 17 for facing on side 1	See notes	2 hr		1		1,2,5, 10,18, 20,21	2
W-8-M-39	$8^5/_8$"	Core: clay or shale structural tile; facings on exposed side only; see note 17	See notes	1 hr 30 min		1		1,2,5, 10,19, 20,21	$1^1/_2$
W-8-M-40	$8^5/_8$"	Core: clay or shale structural tile; facings on exposed side only; see note 17	See notes	3 hr		1		1,2,5,13, 18,20,21	3
W-8-M-41	$8^5/_8$"	Core: clay or shale structural tile; facings on exposed side only; see note 17	See notes	2 hr		1		1,2,5, 13,19, 20,21	2
W-8-M-42	$8^5/_8$"	Core: clay or shale structural tile; facings on side 1; see note 17	See notes	2 hr 30 min		1		1,2,6,9, 18,20, 21	$2^1/_2$
W-8-M-43	$8^5/_8$"	Core: clay or shale structural tile; facings on exposed side per note 17	See notes	1 hr 30 min		1		1,2,6,9, 19,20,21	$1^1/_2$
W-8-M-44	$8^5/_8$"	Core: clay or shale structural tile; facings: side 1: see note 17; side 2: none	See notes	3 hr		1		1,2,6, 10,18, 20,21	3
W-8-M-45	$8^5/_8$"	Core: clay or shale structural tile; facings on fire side only; see note 17	See notes	1 hr 30 min		1		1,2,6, 10,19, 20,21	$1^1/_2$
W-8-M-46	$8^5/_8$"	Core: clay or shale structural tile; facings: side 1: see note 17; side 2: none	See notes	3 hr 30 min		1		1,2,6, 12,18, 20,21	$3^1/_2$
W-8-M-47	$8^5/_8$"	Core: clay or shale structural tile; facings on exposed side only; see note 17	See notes	1 hr 45 min		1		1,2,6, 12,19, 20,21	$1^3/_4$
W-8-M-48	$8^5/_8$"	Core: clay or shale structural tile; facings: side 1: see note 17; side 2: none	See notes	4 hr		1		1,2,6, 16,18, 20,21	4
W-8-M-49	$8^5/_8$"	Core: clay or shale structural tile; facings on fire side only; see note 17	See notes	2 hr		1		1,2,6, 16,19, 20,21	2
W-8-M-50	$8^5/_8$"	Core: 4"; 40% solid clay or shale structural tile; 4" brick plus $^5/_8$" of 1:3 sanded gypsum plaster facing on one side	See notes	4 hr		1		1,20	4
W-8-M-51	$8^3/_4$"	$8^3/_4$" × $2^1/_2$" and 4" × $2^1/_2$" cellular fletton (1873 psi) single and triple cell hollow bricks set in $^1/_2$" sand mortar in alt. courses	3.6 ton/ft	6 hr			7	23,29	6
W-8-M-52	$8^3/_4$"	$8^3/_4$" thick cement brick (2527 psi) with portland cement and sand mortar	3.6 ton/ft	6 hr			7	23,24	6

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Table O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-8-M-53	$8\frac{3}{4}$"	$8\frac{3}{4}" \times 2\frac{1}{2}$" fletton brick (1831 psi) in $\frac{1}{2}$" sand mortar	3.6 ton/ft	6 hr			7	23,24	6
W-8-M-54	$8\frac{3}{4}$"	$8\frac{3}{4}" \times 2\frac{1}{2}$" London stock brick (683 psi) in $\frac{1}{2}$" portland cement and sand mortar	7.2 ton/ft	6 hr			7	23,24	6
W-9-M-55	9"	$9" \times 2\frac{1}{2}$" Leicester red wire-cut brick (4465 psi) in $\frac{1}{2}$" portland cement and sand mortar	6.0 ton/ft	6 hr			7	23,24	6
W-9-M-56	9"	9" × 3" sand-lime brick (2603 psi) in $\frac{1}{2}$" portland cement and sand mortar	3.6 ton/ft	6 hr			7	23,24	6
W-9-M-57	9"	2 layers $2\frac{7}{8}$" fletton brick (1910 psi) with $3\frac{1}{4}$" air space; cement and sand mortar	1.5 ton/ft	32 min			7	23,25	$\frac{1}{3}$
W-9-M-58	9"	9" × 3" stairfoot brick (7527 psi) in $\frac{1}{2}$" sand-cement mortar	7.2 ton/ft	6 hr			7	23,24	6
W-9-M-59	9"	Core: solid clay or shale bricks; $\frac{1}{2}$" thick 1:3 sanded gypsum plaster facing on both sides	See notes	7 hr		1		1,22,45	7
W-9-M-60	9"	Core: concrete brick; $\frac{1}{2}$" of 1:3 sanded gypsum plaster facings on both sides	See notes	8 hr		1		1,45	8
W-9-M-61	9"	Core: hollow rolok of clay or shale; $\frac{1}{2}$" of 1:3 sanded gypsum plaster facings on both sides	See notes	4 hr		1		1,45	4
W-9-M-62	9"	Cored clay or shale brick; units in wall thickness: 1; cells in wall thickness: 1; minimum % solids: 70; $\frac{1}{2}$" of 1:3 sanded gypsum plaster facing on one side	See notes	3 hr		1		1,44	3
W-9-M-63	9"	Cored clay or shale bricks; units in wall thickness: 2; cells in wall thickness: 2; minimum % solids: 87; $\frac{1}{2}$" of 1:3 sanded gypsum plaster facing on both sides	See notes	7 hr		1		1,45	7
W-9-M-64	9"–10"	Core: cavity wall of clay or shale brick; no facings	See notes	5 hr		1		1,45	5
W-9-M-65	9"–10"	Core: cavity construction of clay or shale brick; $\frac{1}{2}$" of 1:3 sanded gypsum plaster facing on one side	See notes	6 hr		1		1,45	6
W-9-M-66	9"–10"	Core: cavity construction of clay or shale brick; $\frac{1}{2}$" of 1:3 sanded gypsum plaster facing on both sides	See notes	7 hr		1		1,45	7
W-9-M-67	$9\frac{1}{4}$"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 40; $\frac{5}{8}$" of 1:3 sanded gypsum plaster facing on both sides	See notes	3 hr		1		1,20,21	3
W-9-M-68	$9\frac{1}{4}$"	Core: clay or shale structural tile; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids in units: 43; $\frac{5}{8}$" of 1:3 sanded gypsum plaster facings on both sides	See notes	3 hr		1		1,20,21	3
W-9-M-69	$9\frac{1}{4}$"	Core: clay or shale structural tile; facings: sides 1 and 2 see note 17	See notes	3 hr		1		1,2,5, 10,18, 20,21	3

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Table O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-9-M-70	$9^1/_4$"	Core: clay or shale structural tile; facings: sides 1 and 2 see note 17	See notes	4 hr		1		1,2,5, 13,18, 20,21	4
W-9-M-71	$9^1/_4$"	Core: clay or shale structural tile; facings: sides 1 and 2 see note 17	See notes	3 hr 30 min		1		1,2,6,9, 18,20, 21	$3^1/_2$
W-9-M-72	$9^1/_4$"	Core: clay or shale structural tile; facings: sides 1 and 2 see note 17	See notes	4 hr		1		1,2,6, 10,18, 20,21	4
W-9-M-73	$9^1/_4$"	Core: clay or shale structural tile; facings: sides 1 and 2 see note 17	See notes	4 hr		1		1,2,6, 12,18, 20,21	4
W-9-M-74	$9^1/_4$"	Core: clay or shale structural tile; facings: sides 1 and 2 see note 17	See notes	5 hr		1		1,2,6, 16,18, 20,21	5
W-8-M-75	8"	Cored concrete masonry; see notes 2, 19, 26, 34, 40; no facings	80 psi	1 hr 30 min		1		1,20	$1^1/_2$
W-8-M-76	8"	Cored concrete masonry; see notes 2, 18, 26, 34, 40; no facings	80 psi	4 hr		1		1,20	4
W-8-M-77	8"	Cored concrete masonry; see notes 2, 19, 26, 31, 40; no facings	80 psi	1 hr 15 min		1		1,20	$1^1/_4$
W-8-M-78	8"	Cored concrete masonry; see notes 2, 18, 26, 31, 40; no facings	80 psi	3 hr		1		1,20	3
W-8-M-79	8"	Cored concrete masonry; see notes 2, 19, 26, 36, 41; no facings	80 psi	1 hr 30 min		1		1,20	$1^1/_2$
W-8-M-80	8"	Cored concrete masonry; see notes 2, 18, 26, 36, 41; no facings	80 psi	3 hr		1		1,20	3
W-8-M-81	8"	Cored concrete masonry; see notes 2, 19, 26, 34, 41; no facings	80 psi	1 hr		1		1,20	1
W-8-M-82	8"	Cored concrete masonry; see notes 2, 18, 26, 34, 41; no facings	80 psi	2 hr 30 min		1		1,20	$2^1/_2$
W-8-M-83	8"	Cored concrete masonry; see notes 2, 19, 26, 29, 41; no facings	80 psi	45 min		1		1,20	$^3/_4$
W-8-M-84	8"	Cored concrete masonry; see notes 2, 18, 26, 29, 41; no facings	80 psi	2 hr		1		1,20	2
W-8-M-85	$8^1/_2$"	Cored concrete masonry; see notes 3, 18, 26, 34, 41; facings: $2^1/_2$" brick	80 psi	4 hr		1		1,20	4
W-8-M-86	8"	Cored concrete masonry; see notes 3, 18, 26, 34, 41; facings: $3^3/_4$" brick face	80 psi	5 hr		1		1,20	5
W-8-M-87	8"	Cored concrete masonry; see notes 2, 19, 26, 30, 43; no facings	80 psi	12 min		1		1,20	$^1/_5$
W-8-M-88	8"	Cored concrete masonry; see notes 2, 18, 26, 30, 43; no facings	80 psi	12 min		1		1,20	$^1/_5$
W-8-M-89	$8^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 34, 40; facings: on fire side only; see note 38	80 psi	2 hr		1		1,20	2
W-8-M-90	$8^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 34, 40; facings: see note 38 for side 1	80 psi	5 hr		1		1,20	5
W-8-M-91	$8^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 31, 40; facings on fire side only; see note 38	80 psi	1 hr 45 min		1		1,20	$1^3/_4$
W-8-M-92	$8^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 31, 40; facings on one side; see note 38	80 psi	4 hr		1		1,20	4

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Table O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-8-M-93	$8^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 36, 41; facings on fire side only; see note 38	80 psi	2 hr		1		1,20	2
W-8-M-94	$8^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 36, 41; facings on fire side only; see note 38	80 psi	4 hr		1		1,20	4
W-8-M-95	$8^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 34, 41; facings on fire side only; see note 38	80 psi	1 hr 30 min		1		1,20	$1^1/_2$
W-8-M-96	$8^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 34, 41; facings on one side; see note 38	80 psi	3 hr		1		1,20	3
W-8-M-97	$8^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 29, 41; facings on fire side only; see note 38	80 psi	1 hr 30 min		1		1,20	$1^1/_2$
W-8-M-98	$8^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 29, 41; facings on one side; see note 38	80 psi	2 hr 30 min		1		1,20	$2^1/_2$
W-8-M-99	$8^1/_2$"	Cored concrete masonry; see notes 3, 19, 23, 27, 41; no facings	80 psi	1 hr 15 min		1		1,20	$1^1/_4$
W-8-M-100	$8^1/_2$"	Cored concrete masonry; see notes 3, 18, 23, 27, 41; no facings	80 psi	3 hr 30 min		1		1,20	$3^1/_2$
W-8-M-101	$8^1/_2$"	Cored concrete masonry; see notes 3, 18, 26, 34, 41; facings $3^3/_4$" brick face; one side only; see note 38	80 psi	6 hr		1		1,20	6
W-8-M-102	$8^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 30, 43; facings on fire side only; see note 38	80 psi	30 min		1		1,20	$^1/_2$
W-8-M-103	$8^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 30, 43; facings on one side only; see note 38	80 psi	12 min		1		1,20	$^1/_5$
W-9-M-104	9"	Cored concrete masonry; see notes 2, 18, 26, 34, 40; facings on both sides; see note 38	80 psi	6 hr		1		1,20	6
W-9-M-105	9"	Cored concrete masonry; see notes 2, 18, 26, 31, 40; facings on both sides; see note 38	80 psi	5 hr		1		1,20	5
W-9-M-106	9"	Cored concrete masonry; see notes 2, 18, 26, 36, 41; facings on both sides of wall; see note 38	80 psi	5 hr		1		1,20	5
W-9-M-107	9"	Cored concrete masonry; see notes 2, 18, 26, 34, 40; facings on both sides; see note 38	80 psi	4 hr		1		1,20	4
W-9-M-108	9"	Cored concrete masonry; see notes 2, 18, 26, 29, 41; facings on both sides; see note 38	80 psi	3 hr 30 min		1		1,20	$3^1/_2$
W-9-M-109	9"	Cored concrete masonry; see notes 3, 19, 23, 27, 40; facing on fire side only; see note 38	80 psi	1 hr 45 min		1		1,20	$1^3/_4$
W-9-M-110	9"	Cored concrete masonry; see notes 3, 18, 27, 23, 41; facings on one side only; see note 38	80 psi	4 hr		1		1,20	4
W-9-M-111	9"	Cored concrete masonry; see notes 3, 18, 26, 34, 41; $2^1/_2$" brick face on one side only; see note 38	80 psi	5 hr		1		1,20	5
W-8-M-112	9"	Cored concrete masonry; see notes 2, 18, 26, 30, 43; facings on both sides; see note 38	80 psi	30 min		1		1,20	$^1/_2$

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Table O.4.5.4 Masonry Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-9-M-113	$9^1/_2$"	Cored concrete masonry; see notes 3, 18, 23, 27, 41; facings on both sides; see note 38	80 psi	5 hr		1		1,20	5
W-8-M-114	8"		200 psi	5 hr			43	22	5

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Notes:
1. Tested at NBS under ASA 42-1934 (ASTM C-19-53).
2. One unit in wall thickness.
3. Two units in wall thickness.
4. Two or three units in wall thickness.
5. Two cells in wall thickness.
6. Three or four cells in wall thickness.
7. Four or five cells in wall thickness.
8. Five or six cells in wall thickness.
9. Minimum % of solid materials in units: 40.
10. Minimum % of solid materials in units: 43.
11. Minimum % of solid materials in units: 46.
12. Minimum % of solid materials in units: 48.
13. Minimum % of solid materials in units: 49.
14. Minimum % of solid materials in units: 45.
15. Minimum % of solid materials in units: 51.
16. Minimum % of solid materials in units: 53.
17. Not less than $^5/_8$ in. thickness of 1:3 sanded gypsum plaster.
18. Noncombustible or no members framed into wall.
19. Combustible members framed into wall.
20. Load: 80 psi for gross cross-sectional area of wall.
21. Portland cement–lime mortar.
22. Failure mode — thermal.
23. British test.
24. Passed all criteria.
25. Failed by sudden collapse with no preceding signs of impending failure.
26. One cell in wall thickness.
27. Two cells in wall thickness.
28. Three cells in wall thickness.
29. Minimum % of solid material in concrete units: 52.
30. Minimum % of solid material in concrete units: 54.
31. Minimum % of solid material in concrete units: 55.
32. Minimum % of solid material in concrete units: 57.
33. Minimum % of solid material in concrete units: 60.
34. Minimum % of solid material in concrete units: 62.
35. Minimum % of solid material in concrete units: 65.
36. Minimum % of solid material in concrete units: 70.
37. Minimum % of solid material in concrete units: 76.
38. Not less than $^1/_2$ in. of 1:3 sanded gypsum plaster.
39. Three units in wall thickness.
40. Concrete units made with expanded slag or pumice aggregates.
41. Concrete units made with expanded burned clay or shale, crushed limestone, air cooled slag, or cinders.
42. Concrete units made with calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.
43. Concrete units made with siliceous sand and gravel; 90% or more quartz, chert, and dolomite.
44. Load: 120 psi for gross cross-sectional area of wall.
45. Load: 160 psi for gross cross-sectional area of wall.

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FIGURE O.4.5.5 Masonry Walls 10 in. (250 mm) to Less Than 12 in. (300 mm) Thick.

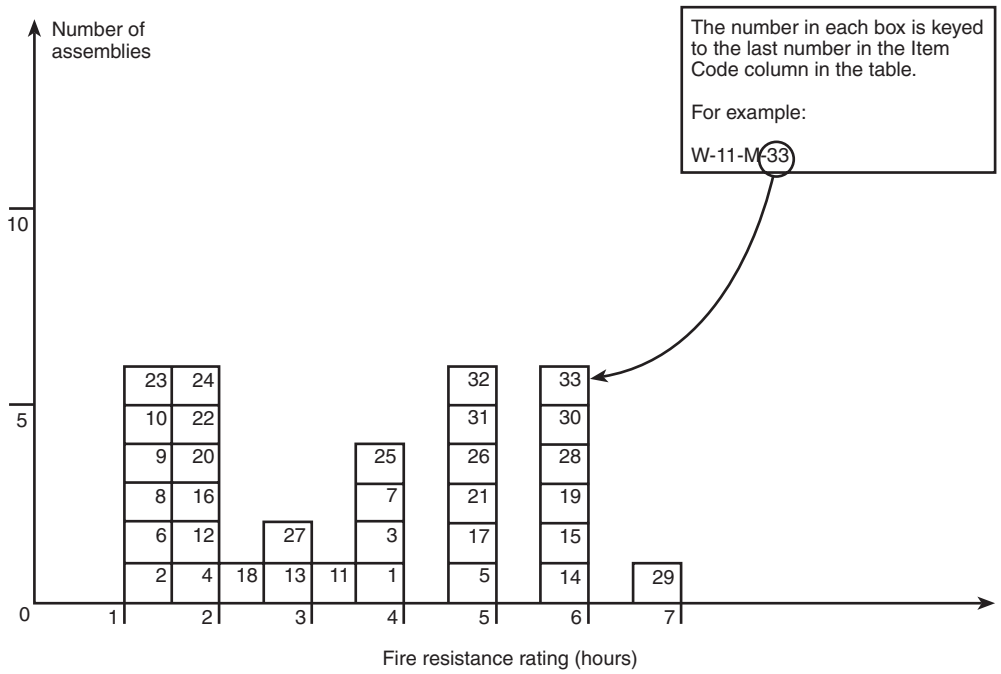

Table O.4.5.5 Masonry Walls 10 in. (250 mm) to Less Than 12 in. (300 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-10-M-1	10"	Core: two $3\frac{3}{4}$" 40% solid clay or shale structural tiles with 2" air space between; facings: $\frac{3}{4}$" portland cement plaster or stucco on both sides	80 psi	4 hr		1		1,20	4
W-10-M-2	10"	Cored concrete masonry, 2" air cavity; see notes 3, 19, 27, 34, 40; facings: none	80 psi	1 hr 30 min		1		1,20	$1\frac{1}{2}$
W-10-M-3	10"	Cored concrete masonry; see notes 3, 18, 27, 34, 40; facings: none	80 psi	4 hr		1		1,20	4
W-10-M-4	10"	Cored concrete masonry; see notes 2, 19, 26, 33, 40; facings: none	80 psi	2 hr		1		1,20	2
W-10-M-5	10"	Cored concrete masonry; see notes 2, 18, 26, 33, 40; no facings	80 psi	5 hr		1		1,20	5
W-10-M-6	10"	Cored concrete masonry; see notes 2, 19, 26, 33, 41; no facings	80 psi	1 hr 30 min		1		1,20	$1\frac{1}{2}$

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Table O.4.5.5 Masonry Walls 10 in. (250 mm) to Less Than 12 in. (300 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-10-M-7	10"	Cored concrete masonry; see notes 2, 18, 26, 33, 41; no facings	80 psi	4 hr		1		1,20	4
W-10-M-8	10"	Cored concrete masonry (cavity type 2" air space) see notes 3, 19, 27, 34, 42; no facings	80 psi	1 hr 15 min		1		1,20	$1\frac{1}{4}$
W-10-M-9	10"	Cored concrete masonry (cavity type 2" air space); see notes 3, 27, 34, 42; no facings	80 psi	1 hr 15 min		1		1,20	$1\frac{1}{4}$
W-10-M-10	10"	Cored concrete masonry (cavity type 2" air space); see notes 3, 19, 27, 34, 41; no facings	80 psi	1 hr 15 min		1		1,20	$1\frac{1}{4}$
W-10-M-11	10"	Cored concrete masonry (cavity type 2" air space); see notes 3, 18, 27, 34, 41; no facings	80 psi	3 hr 30 min		1		1,20	$3\frac{1}{2}$
W-10-M-12	10"	9" thick concrete block ($11\frac{3}{4}" \times 9" \times 4\frac{1}{4}"$) with two 2" thick voids included; $\frac{3}{8}$" portland cement plaster, $\frac{1}{8}$" neat gypsum	n/a	1 hr 53 min			7	23,24	$1\frac{3}{4}$
W-10-M-13	10"	Hollow clay tile block wall: $8\frac{1}{2}$" block with two 3" voids in each $8\frac{1}{2}$" section; $\frac{3}{4}$" gypsum plaster, each face	n/a	2 hr 42 min			7	23,25	$2\frac{1}{2}$
W-10-M-14	10"	2 layers $4\frac{1}{4}$" brick with $1\frac{1}{2}$" air space, no ties; sand-cement mortar (fletton brick, 1910 psi)	n/a	6 hr			7	23,24	6
W-10-M-15	10"	2 layers $4\frac{1}{4}$" thick fletton brick (1910 psi) with $1\frac{1}{2}$" air space; ties: 18" O.C. vertical; 3' O.C. horizontal	n/a	6 hr			7	23,24	6
W-10-M-16	$10\frac{1}{2}$"	Cored concrete masonry; 2" air cavity; see notes 3, 19, 27, 34, 40; facings: fire side only; see note 38	80 psi	2 hr		1		1,20	2
W-10-M-17	$10\frac{1}{2}$"	Cored concrete masonry; see notes 3, 18, 27, 34, 40; facings: only side 1; see note 38	80 psi	5 hr		1		1,20	5
W-10-M-18	$10\frac{1}{2}$"	Cored concrete masonry; see notes 2, 19, 26, 33, 40; facings on fire side only; see note 38	80 psi	2 hr 30 min		1		1,20	$2\frac{1}{2}$
W-10-M-19	$10\frac{1}{2}$"	Cored concrete masonry; see notes 2, 18, 26, 33, 40; facings on one side; see note 38	80 psi	6 hr		1		1,20	6
W-10-M-20	$10\frac{1}{2}$"	Cored concrete masonry; see notes 2, 19, 26, 33, 41; facings on fire side of wall only; see note 38	80 psi	2 hr		1		1,20	2

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Table O.4.5.5 Masonry Walls 10 in. (250 mm) to Less Than 12 in. (300 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-10-M-21	$10^{1}/_{2}$"	Cored concrete masonry; see notes 2, 18, 26, 33, 41; facings on one side only; see note 38	80 psi	5 hr		1		1,20	5
W-10-M-22	$10^{1}/_{2}$"	Cored concrete masonry (cavity type 2" air space); see notes 3, 19, 27, 34, 42; facing on fire side only; see note 38	80 psi	1 hr 45 min		1		1,20	$1^{3}/_{4}$
W-10-M-23	$10^{1}/_{2}$"	Cored concrete masonry (cavity type 2" air space); see notes 3, 18, 27, 34, 42; facings on one side only; see note 38	80 psi	1 hr 15 min		1		1,20	$1^{1}/_{4}$
W-10-M-24	$10^{1}/_{2}$"	Cored concrete masonry (cavity type 2" air space); see notes 3, 19, 27, 34, 41; facings on fire side only; see note 38	80 psi	2 hr		1		1,20	2
W-10-M-25	$10^{1}/_{2}$"	Cored concrete masonry (cavity type 2" air space); see notes 3, 18, 27, 34, 41; facings on one side only; see note 38	80 psi	4 hr		1		1,20	4
W-10-M-26	$10^{5}/_{8}$"	Core: 8" 40% solid tile plus 2" furring tile; $^{5}/_{8}$" sanded gypsum plaster between tile types; facings on both sides, $^{3}/_{4}$" portland cement plaster or stucco	80 psi	5 hr		1		1,20	5
W-10-M-27	$10^{5}/_{8}$"	Core: 8" 40% solid tile plus 2" furring tile; $^{5}/_{8}$" sanded gypsum plaster between tile types; facings on one side, $^{3}/_{4}$" portland cement plaster or stucco	80 psi	3 hr 30 min		1		1,20	$3^{1}/_{2}$
W-11-M-28	11"	Cored concrete masonry; see notes 3, 18, 27, 34, 40; facings on both sides; see note 38	80 psi	6 hr		1		1,20	6
W-11-M-29	11"	Cored concrete masonry; see notes 2, 18, 26, 33, 40; facings on both sides; see note 38	80 psi	7 hr		1		1,20	7
W-11-M-30	11"	Cored concrete masonry; see notes 2, 18, 26, 33, 41; facings on both sides of wall; see note 38	80 psi	6 hr		1		1,20	6
W-11-M-31	11"	Cored concrete masonry (cavity type 2" air space); see notes 3, 18, 27, 34, 42; facings on both sides; see note 38	80 psi	5 hr		1		1,20	5
W-11-M-32	11"	Cored concrete masonry (cavity type 2" air space); see notes 3, 18, 27, 34, 41; facings on both sides; see note 38	80 psi	5 hr		1		1,20	5

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Table O.4.5.5 Masonry Walls 10 in. (250 mm) to Less Than 12 in. (300 mm) Thick ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-11-M-33	11"	2 layers $4^1/_2$" fletton brick (2428 psi) with 2" air space; galv. ties: 18" O.C. horizontal; 3' O.C. vertical	3 ton/ft	6 hr			7	23,24	6

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Notes:
1. Tested at NBS under ASA A2-1934.
2. One unit in wall thickness.
3. Two units in wall thickness.
4. Two or three units in wall thickness.
5. Two cells in wall thickness.
6. Three or four cells in wall thickness.
7. Four or five cells in wall thickness.
8. Five or six cells in wall thickness.
9. Minimum % of solid materials in units: 40.
10. Minimum % of solid materials in units: 43.
11. Minimum % of solid materials in units: 46.
12. Minimum % of solid materials in units: 48.
13. Minimum % of solid materials in units: 49.
14. Minimum % of solid materials in units: 45.
15. Minimum % of solid materials in units: 51.
16. Minimum % of solid materials in units: 53.
17. Not less than $^5/_8$ in. thickness of 1:3 sanded gypsum plaster.
18. Noncombustible or no members framed into wall.
19. Combustible members framed into wall.
20. Load: 80 psi for gross cross-sectional area.
21. Portland cement–lime mortar.
22. Failure mode — thermal.
23. British test.
24. Passed all criteria.
25. Failed by sudden collapse with no preceding signs of impending failure.
26. One cell in wall thickness.
27. Two cells in wall thickness.
28. Three cells in wall thickness.
29. Minimum % of solid material in concrete units: 52.
30. Minimum % of solid material in concrete units: 54.
31. Minimum % of solid material in concrete units: 55.
32. Minimum % of solid material in concrete units: 57.
33. Minimum % of solid material in concrete units: 60.
34. Minimum % of solid material in concrete units: 62.
35. Minimum % of solid material in concrete units: 65.
36. Minimum % of solid material in concrete units: 70.
37. Minimum % of solid material in concrete units: 76.
38. Not less than $^1/_2$ in. of 1:3 sanded gypsum plaster.
39. Three units in wall thickness.
40. Concrete units made with expanded slag or pumice aggregates.
41. Concrete units made with expanded burned clay or shale, crushed limestone, air cooled slag, or cinders.
42. Concrete units made with calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.

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FIGURE O.4.5.6 Masonry Walls 12 in. (300 mm) to Less Than 14 in. (350 mm) Thick.

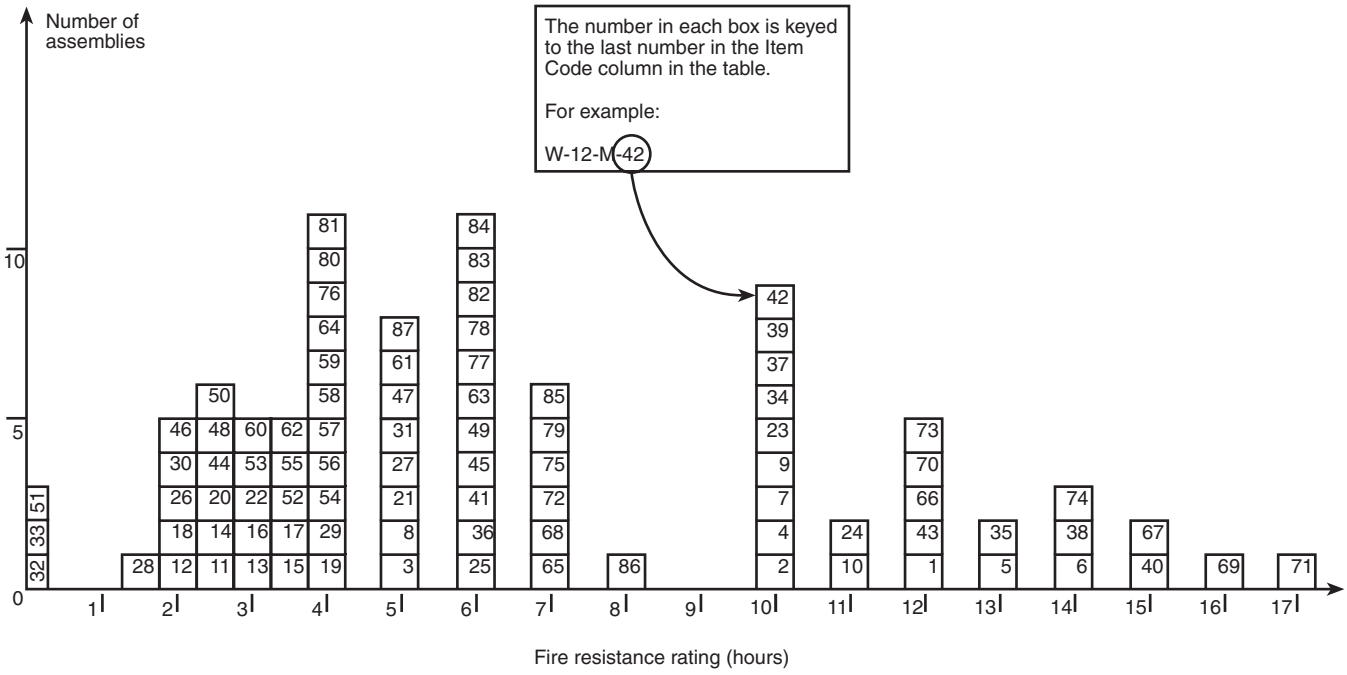

Table O.4.5.6 Masonry Walls 12 in. (300 mm) to Less Than 14 in. (350 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-12-M-1	12"	Core: solid clay or shale brick; no facings	n/a	12 hr		1		1	12
W-12-M-2	12"	Core: solid clay or shale brick; no facings	160 psi	10 hr		1		1,44	10
W-12-M-3	12"	Core: hollow rolok of clay or shale; no facings	160 psi	5 hr		1		1,44	5
W-12-M-4	12"	Core: hollow rolok bak of clay or shale; no facings	160 psi	10 hr		1		1,44	10
W-12-M-5	12"	Core: concrete brick; no facings	160 psi	13 hr		1		1,44	13
W-12-M-6	12"	Core: sand-lime brick; no facings	n/a	14 hr		1		1	14
W-12-M-7	12"	Core: sand-lime brick; no facings	160 psi	10 hr		1		1,44	10
W-12-M-8	12"	Cored clay or shale bricks; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids: 70; no facings	120 psi	5 hr		1		1,45	5
W-12-M-9	12"	Cored clay or shale bricks; units in wall thickness: 3; cells in wall thickness: 3; minimum % solids: 87; no facings	160 psi	10 hr		1		1,44	10
W-12-M-10	12"	Cored clay or shale bricks; units in wall thickness: 3; cells in wall thickness: 3; minimum % solids: 87; no facings	n/a	11 hr		1		1	11

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Table O.4.5.6 Masonry Walls 12 in. (300 mm) to Less Than 14 in. (350 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-12-M-11	12"	Core: clay or shale structural tile; see notes 2, 6, 9, 18; no facings	80 psi	$2^1/_2$ hr		1		1,20	$2^1/_2$
W-12-M-12	12"	Core: clay or shale structural tile; see notes 2, 4, 9, 19; no facings	80 psi	2 hr		1		1,20	2
W-12-M-13	12"	Core: clay or shale structural tile; see notes 2, 6, 14, 19; no facings	80 psi	3 hr		1		1,20	3
W-12-M-14	12"	Core: clay or shale structural tile; see notes 2, 6, 14, 18; no facings	80 psi	$2^1/_2$ hr		1		1,20	$2^1/_2$
W-12-M-15	12"	Core: clay or shale structural tile; see notes 2, 4, 13, 18; no facings	80 psi	$3^1/_2$ hr		1		1,20	$3^1/_2$
W-12-M-16	12"	Core: clay or shale structural tile; see notes 2, 4, 13, 19; no facings	80 psi	3 hr		1		1,20	3
W-12-M-17	12"	Core: clay or shale structural tile; see notes 3, 6, 9, 18; no facings	80 psi	$3^1/_2$ hr		1		1,20	$3^1/_2$
W-12-M-18	12"	Core: clay or shale structural tile; see notes 3, 6, 9, 19; no facings	80 psi	2 hr		1		1,20	2
W-12-M-19	12"	Core: clay or shale structural tile; see notes 3, 6, 14, 18; no facings	80 psi	4 hr		1		1,20	4
W-12-M-20	12"	Core: clay or shale structural tile; see notes 3, 6, 14, 19; no facings	80 psi	$2^1/_2$ hr		1		1,20	$2^1/_2$
W-12-M-21	12"	Core: clay or shale structural tile; see notes 3, 6, 16, 18; no facings	80 psi	5 hr		1		1,20	5
W-12-M-22	12"	Core: clay or shale structural tile; see notes 3, 6, 16, 19; no facings	80 psi	3 hr		1		1,20	3
W-12-M-23	12"	Core: 8" 70% solid clay or shale structural tile; 4" brick facing on one side	80 psi	10 hr		1		1,20	10
W-12-M-24	12"	Core: 8" 70% solid clay or shale structural tile; 4" brick facing on one side	n/a	11 hr		1		1	11
W-12-M-25	12"	Core: 8" 40% solid clay or shale structural tile; 4" brick facing on one side	80 psi	6 hr		1		1,20	6
W-12-M-26	12"	Cored concrete masonry; see notes 1, 9, 15, 16, 20; no facings	80 psi	2 hr		1		1,20	2
W-12-M-27	12"	Cored concrete masonry; see notes 2, 18, 26, 34, 41; no facings	80 psi	5 hr		1		1,20	5
W-12-M-28	12"	Cored concrete masonry; see notes 2, 19, 26, 31, 41; no facings	80 psi	$1^1/_2$ hr		1		1,20	$1^1/_2$
W-12-M-29	12"	Cored concrete masonry; see notes 2, 18, 26, 31, 41; no facings	80 psi	4 hr		1		1,20	4
W-12-M-30	12"	Cored concrete masonry; see notes 3, 19, 27, 31, 43; no facings	80 psi	2 hr		1		1,20	2
W-12-M-31	12"	Cored concrete masonry; see notes 3, 18, 27, 31, 43; no facings	80 psi	5 hr		1		1,20	5
W-12-M-32	12"	Cored concrete masonry; see notes 2, 19, 26, 32, 43; no facings	80 psi	25 min		1		1,20	$^1/_3$
W-12-M-33	12"	Cored concrete masonry; see notes 2, 18, 26, 32, 43; no facings	80 psi	25 min		1		1,20	$^1/_3$
W-12-M-34	$12^1/_2$"	Core: solid clay or shale brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	160 psi	10 hr		1		1,44	10
W-12-M-35	$12^1/_2$"	Core: solid clay or shale brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	n/a	13 hr		1		1	13

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Table O.4.5.6 Masonry Walls 12 in. (300 mm) to Less Than 14 in. (350 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-12-M-36	$12^1/_2$"	Core: hollow rolok of clay or shale; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	160 psi	6 hr		1		1,44	6
W-12-M-37	$12^1/_2$"	Core: hollow rolok bak of clay or shale; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	160 psi	10 hr		1		1,44	10
W-12-M-38	$12^1/_2$"	Core: concrete; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	160 psi	14 hr		1		1,44	14
W-12-M-39	$12^1/_2$"	Core: sand-lime brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	160 psi	10 hr		1		1,44	10
W-12-M-40	$12^1/_2$"	Core: sand-lime brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	n/a	15 hr		1		1	15
W-12-M-41	$12^1/_2$"	Units in wall thickness: 1; cells in wall thickness: 2; minimum % solids: 70; cored clay or shale brick; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	120 psi	6 hr		1		1,45	6
W-12-M-42	$12^1/_2$"	Cored clay or shale bricks; units in wall thickness: 3; cells in wall thickness: 3; minimum % solids: 87; $^1/_2$" of 1:3 sanded gypsum plaster facings on one side	160 psi	10 hr		1		1,44	10
W-12-M-43	$12^1/_2$"	Cored clay or shale bricks; units in wall thickness: 3; cells in wall thickness: 3; minimum % solids: 87; $^1/_2$" of 1:3 sanded gypsum plaster facing on one side	n/a	12 hr		1		1	12
W-12-M-44	$12^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 34, 41; facing on fire side only; see note 38	80 psi	$2^1/_2$ hr		1		1,20	$2^1/_2$
W-12-M-45	$12^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 34, 39, 41; facing on one side only; see note 38	80 psi	6 hr		1		1,20	6
W-12-M-46	$12^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 34, 41; facing on fire side only; see note 38	80 psi	2 hr		1		1,20	2
W-12-M-47	$12^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 31, 41; facings one side of wall only; see note 38	80 psi	5 hr		1		1,20	5
W-12-M-48	$12^1/_2$"	Cored concrete masonry; see notes 3, 19, 27, 31, 43; facing on fire side only; see note 38	80 psi	$2^1/_2$ hr		1		1,20	$2^1/_2$
W-12-M-49	$12^1/_2$"	Cored concrete masonry; see notes 3, 18, 27, 31, 43; facing one side only; see note 38	80 psi	6 hr		1		1,20	6
W-12-M-50	$12^1/_2$"	Cored concrete masonry; see notes 2, 19, 26, 32, 43; facing on fire side only; see note 38	80 psi	$2^1/_2$ hr		1		1,20	$2^1/_2$
W-12-M-51	$12^1/_2$"	Cored concrete masonry; see notes 2, 18, 26, 32, 43; facing one side only; see note 38	80 psi	25 min		1		1,20	$^1/_3$

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Table O.4.5.6 Masonry Walls 12 in. (300 mm) to Less Than 14 in. (350 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-12-M-52	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 2, 6, 9, 18; facing: side 1 see note 17; side 2 none	80 psi	$3^{1}/_{2}$ hr		1		1,20	$3^{1}/_{2}$
W-12-M-53	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 2, 6, 9, 19; facing on fire side only; see note 17	80 psi	3 hr		1		1,20	3
W-12-M-54	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 2, 6, 14, 19; facing: side 1 see note 17; side 2 none	80 psi	4 hr		1		1,20	4
W-12-M-55	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 2, 6, 14, 18; facings on exposed side only; see note 17	80 psi	$3^{1}/_{2}$ hr		1		1,20	$3^{1}/_{2}$
W-12-M-56	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 2, 4, 13, 18; facings: side 1 see note 17; side 2 none	80 psi	4 hr		1		1,20	4
W-12-M-57	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 1, 4, 13, 19; facings on fire side only; see note 17	80 psi	4 hr		1		1,20	4
W-12-M-58	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 3, 6, 9, 18; facings: side 1 see note 17; side 2 none	80 psi	4 hr		1		1,20	4
W-12-M-59	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 3, 6, 9, 19; facings on fire side only; see note 17	80 psi	3 hr		1		1,20	3
W-12-M-60	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 3, 6, 14, 18; facings: side 1 see note 17; side 2 none	80 psi	5 hr		1		1,20	5
W-12-M-61	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 3, 6, 14, 19; facings: fire side only; see note 17	80 psi	3 hr 30 min		1		1,20	$3^{1}/_{2}$
W-12-M-62	$12^{5}/_{8}$	Clay or shale structural tile; see notes 3, 6, 16, 18; facings: side 1 see note 17; side 2 none	80 psi	6 hr		1		1,20	6
W-12-M-63	$12^{5}/_{8}$"	Clay or shale structural tile; see notes 3, 6, 16, 19; facing fire side only; see note 17	80 psi	4 hr		1		1,20	4
W-12-M-64	$12^{5}/_{8}$"	Core: 8" 40% solid clay or shale structural tile; facings 4" brick plus $^{5}/_{8}$" of 1:3 sanded gypsum plaster on one side	80 psi	7 hr		1		1,20	7
W-13-M-65	13"	Core: solid clay or shale brick; $^{1}/_{2}$" of 1:3 sanded gypsum plaster facing on both sides	160 psi	12 hr		1		1,44	12
W-13-M-66	13"	Core: solid clay or shale brick; $^{1}/_{2}$" of 1:3 sanded gypsum plaster facing on both sides	n/a	15 hr		1		1,20	15
W-13-M-67	13"	Core: solid clay or shale brick; $^{1}/_{2}$" of 1:3 sanded gypsum plaster facings on both sides	n/a	15 hr		1		1	15
W-13-M-68	13"	Core: hollow rolok of clay or shale; $^{1}/_{2}$" of 1:3 sanded gypsum plaster facings on both sides	80 psi	7 hr		1		1,20	7
W-13-M-69	13"	Core: concrete brick; $^{1}/_{2}$" of 1:3 sanded gypsum plaster facings on both sides	160 psi	16 hr		1		1,44	16

(Sheet 4 of 6)

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Table O.4.5.6 Masonry Walls 12 in. (300 mm) to Less Than 14 in. (350 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-13-M-70	13"	Core: sand-lime brick; $^1/_2$" of 1:3 sanded gypsum plaster facings on both sides	160 psi	12 hr		1		1,44	12
W-13-M-71	13"	Core: sand-lime brick; $^1/_2$" of 1:3 sanded gypsum plaster facings on both sides	n/a	17 hr		1		1	17
W-13-M-72	13"	Cored clay or shale bricks; units in wall thickness: 1; cells in wall thickness: 2; minimum % solids: 70; $^1/_2$" of 1:3 sanded gypsum plaster facings on both sides	120 psi	7 hr		1		1,45	7
W-13-M-73	13"	Cored clay or shale bricks; units in wall thickness: 3; cells in wall thickness: 3; minimum % solids: 87; $^1/_2$" of 1:3 sanded gypsum plaster facings on both sides	160 psi	12 hr		1		1,44	12
W-13-M-74	13"	Cored clay or shale bricks; units in wall thickness: 3; cells in wall thickness: 2; minimum % solids: 87; $^1/_2$" of 1:3 sanded gypsum plaster facings on both sides	n/a	14 hr		1		1	14
W-13-M-75	13"	Cored concrete masonry; see notes 18, 23, 28, 39, 41; no facings	80 psi	7 hr		1		1,20	7
W-13-M-76	13"	Cored concrete masonry; see notes 19, 23, 28, 39, 41; no facings	80 psi	4 hr		1		1,20	4
W-13-M-77	13"	Cored concrete masonry; see notes 3, 18, 27, 31, 43; facings on both sides; see note 38	80 psi	6 hr		1		1,20	6
W-13-M-78	13"	Cored concrete masonry; see notes 2, 18, 26, 31, 41; facings on both sides; see note 38	80 psi	6 hr		1		1,20	6
W-13-M-79	13"	Cored concrete masonry; see notes 2, 18, 26, 34, 41; facings on both sides of wall; see note 38	80 psi	7 hr		1		1,20	7
W-13-M-80	13$^1/_4$"	Core: clay or shale structural tile: see notes 2, 6, 9, 18; facings: see note 17 for both sides	80 psi	4 hr		1		1,20	4
W-13-M-81	13$^1/_4$"	Core: clay or shale structural tile; see notes 2, 6, 14, 19; facings: see note 17 for both sides	80 psi	4 hr		1		1,20	4
W-13-M-82	13$^1/_4$"	Core: clay or shale structural tile; see notes 2, 4, 13, 18; facings: see note 17 for both sides	80 psi	6 hr		1		1,20	6
W-13-M-83	13$^1/_4$"	Core: clay or shale structural tile; see notes 3, 6, 9, 18; facings: see note 17 for both sides	80 psi	6 hr		1		1,20	6
W-13-M-84	13$^1/_4$"	Core: clay or shale structural tile; see notes 3, 6, 14, 18; facings: see note 17 for both sides	80 psi	6 hr		1		1,20	6
W-13-M-85	13$^1/_4$"	Core: clay or shale structural tile; see notes 3, 6, 16, 18; facings: see note 17 for both sides	80 psi	7 hr		1		1,20	7

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Table O.4.5.6 Masonry Walls 12 in. (300 mm) to Less Than 14 in. (350 mm) Thick ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-13-M-86	$13^1/_2$"	Cored concrete masonry; see notes 18, 23, 28, 39, 41; facing on one side only; see note 38	80 psi	8 hr		1		1,20	8
W-13-M-87	$13^1/_2$"	Cored concrete masonry; see notes 19, 23, 28, 39, 41; facing on fire side only; see note 38	80 psi	5 hr		1		1,20	5

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Notes:
1. Tested at NBS under ASA A2-1934.
2. One unit in wall thickness.
3. Two units in wall thickness.
4. Two or three units in wall thickness.
5. Two cells in wall thickness.
6. Three or four cells in wall thickness.
7. Four or five cells in wall thickness.
8. Five or six cells in wall thickness.
9. Minimum % of solid materials in units: 40.
10. Minimum % of solid materials in units: 43.
11. Minimum % of solid materials in units: 46.
12. Minimum % of solid materials in units: 48.
13. Minimum % of solid materials in units: 49.
14. Minimum % of solid materials in units: 45.
15. Minimum % of solid materials in units: 51.
16. Minimum % of solid materials in units: 53.
17. Not less than $^5/_8$ in. thickness of 1:3 sanded gypsum plaster.
18. Noncombustible or no members framed into wall.
19. Combustible members framed into wall.
20. Load: 80 psi for gross area.
21. Portland cement–lime mortar.
22. Failure mode — thermal.
23. British test.
24. Passed all criteria.
25. Failed by sudden collapse with no preceding signs of impending failure.
26. One cell in wall thickness.
27. Two cells in wall thickness.
28. Three cells in wall thickness.
29. Minimum % of solid material in concrete units: 52.
30. Minimum % of solid material in concrete units: 54.
31. Minimum % of solid material in concrete units: 55.
32. Minimum % of solid material in concrete units: 57.
33. Minimum % of solid material in concrete units: 60.
34. Minimum % of solid material in concrete units: 62.
35. Minimum % of solid material in concrete units: 65.
36. Minimum % of solid material in concrete units: 70.
37. Minimum % of solid material in concrete units: 76.
38. Not less than $^1/_2$ in. of 1:3 sanded gypsum plaster.
39. Three units in wall thickness.
40. Concrete units made with expanded slag or pumice aggregates.
41. Concrete units made with expanded burned clay or shale, crushed limestone, air cooled slag, or cinders.
42. Concrete units made with calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.
43. Concrete units made with siliceous sand and gravel; 90% or more quartz, chert, or flint.
44. Load: 160 psi of gross wall cross-sectional area.
45. Load: 120 psi of gross wall cross-sectional area.

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FIGURE O.4.5.7 Masonry Walls 14 in. (350 mm) or More Thick.

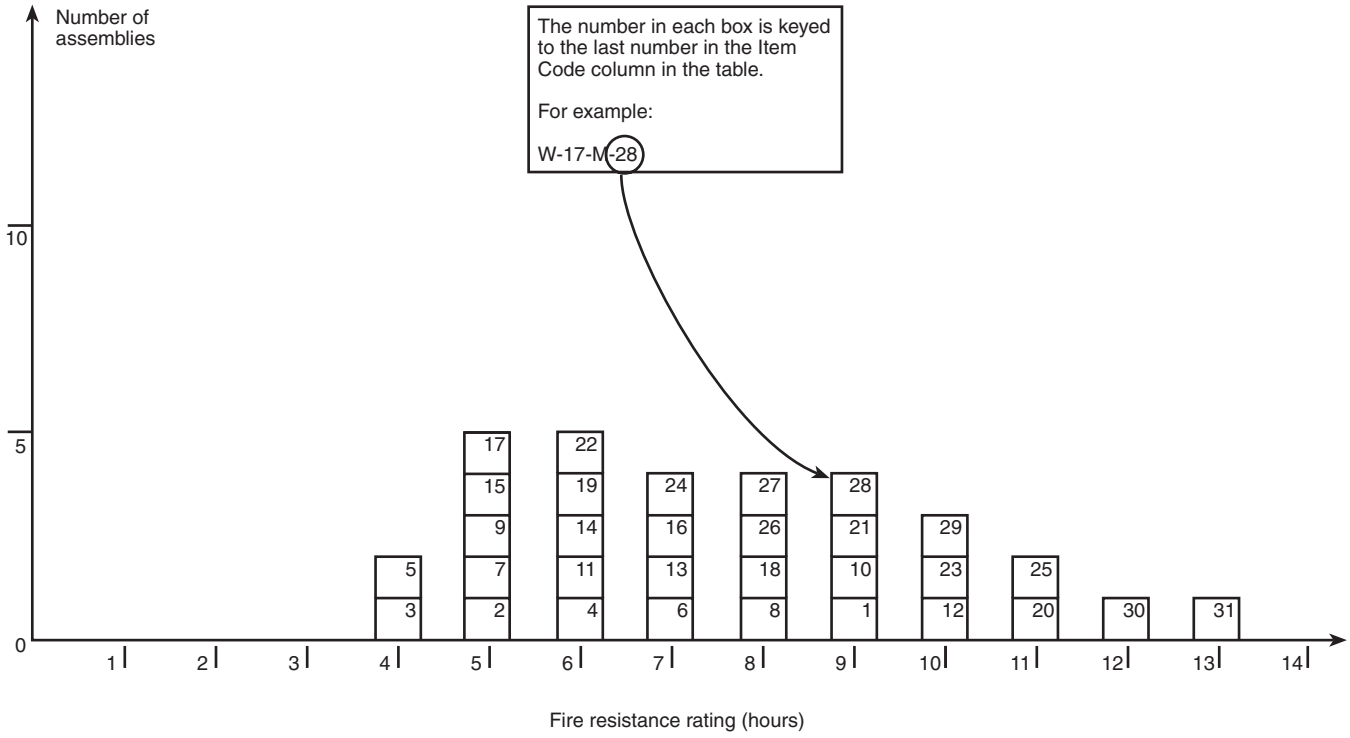

Table O.4.5.7 Masonry Walls 14 in. (350 mm) or More Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-14-M-1	14"	Core: cored concrete masonry; see notes 18, 28, 35, 39, 41; facings: both sides; see note 38	80 psi	9 hr		1		1,20	9
W-16-M-2	16"	Core: clay or shale structural tile; see notes 4, 7, 9, 19; no facings	80 psi	5 hr		1		1,20	5
W-16-M-3	16"	Core: clay or shale structural tile; see notes 4, 7, 9, 19; no facings	80 psi	4 hr		1		1,20	4
W-16-M-4	16"	Core: clay or shale structural tile; see notes 4, 7, 10, 18; no facings	80 psi	6 hr		1		1,20	6
W-16-M-5	16"	Core: clay or shale structural tile; see notes 4, 7, 10, 19; no facings	80 psi	4 hr		1		1,20	4
W-16-M-6	16"	Core: clay or shale structural tile; see notes 4, 7, 11, 18; no facings	80 psi	7 hr		1		1,20	7
W-16-M-7	16"	Core: clay or shale structural tile; see notes 4, 7, 11, 19; no facings	80 psi	5 hr		1		1,20	5
W-16-M-8	16"	Core: clay or shale structural tile; see notes 4, 8, 13, 18; no facings	80 psi	8 hr		1		1,20	8
W-16-M-9	16"	Core: clay or shale structural tile; see notes 4, 8, 13, 19; no facings	80 psi	5 hr		1		1,20	5
W-16-M-10	16"	Clay or shale structural tile core; see notes 4, 8, 15, 18; no facings	80 psi	9 hr		1		1,20	9

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Table O.4.5.7 Masonry Walls 14 in. (350 mm) or More Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-16-M-11	16"	Clay or shale structural tile core; see notes 3, 7, 14, 18; no facings	80 psi	6 hr		1		1,20	6
W-16-M-12	16"	Clay or shale structural tile core; see notes 4, 8, 16, 18; no facings	80 psi	10 hr		1		1,20	10
W-16-M-13	16"	Clay or shale structural tile core; see notes 4, 6, 16, 19; no facings	80 psi	7 hr		1		1,20	7
W-16-M-14	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 7, 9, 18; facings: side 1 see note 17; side 2 none	80 psi	6 hr		1		1,20	6
W-16-M-15	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 7, 9, 19; facings: fire side only; see note 17	80 psi	5 hr		1		1,20	5
W-16-M-16	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 7, 10, 18; facings: side 1 see note 17; side 2 none	80 psi	7 hr		1		1,20	7
W-16-M-17	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 7, 10, 19; facings: fire side only; see note 17	80 psi	5 hr		1		1,20	5
W-16-M-18	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 7, 11, 18; facings: side 1 see note 17; side 2 none	80 psi	8 hr		1		1,20	8
W-16-M-19	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 7, 11, 19; facings: fire side only; see note 17	80 psi	6 hr		1		1,20	6
W-16-M-20	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 8, 13, 18; facings: side 1 and side 2 see note 17;	80 psi	11 hr		1		1,20	11
W-16-M-21	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 8, 13, 18; facings: side 1 see note 17; side 2 none	80 psi	9 hr		1		1,20	9
W-16-M-22	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 8, 13, 19; facings: fire side only; see note 17	80 psi	6 hr		1		1,20	6
W-16-M-23	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 8, 15, 18; facings: side 1 see note 17; side 2 none	80 psi	10 hr		1		1,20	10
W-16-M-24	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 8, 15, 19; facings: fire side only; see note 17	80 psi	7 hr		1		1,20	7
W-16-M-25	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 6, 16, 18; facings: side 1 see note 17; side 2 none	80 psi	11 hr		1		1,20	11
W-16-M-26	$16^{5}/_{8}$"	Clay or shale structural tile core; see notes 4, 6, 16, 19; facings: fire side only; see note 17	80 psi	8 hr		1		1,20	8
W-17-M-27	$17^{1}/_{4}$"	Clay or shale structural tile core; see notes 4, 7, 9, 18; facings: side 1 and side 2 see note 17	80 psi	8 hr		1		1,20	8
W-17-M-28	$17^{1}/_{4}$"	Clay or shale structural tile core; see notes 4, 7, 10, 18; facings: side 1 and side 2 see note 17	80 psi	9 hr		1		1,20	9

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Table O.4.5.7 Masonry Walls 14 in. (350 mm) or More Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-17-M-29	$17^{1}/_{4}$"	Clay or shale structural tile core; see notes 4, 7, 11, 18; facings: side 1 and side 2 see note 17	80 psi	10 hr		1		1,20	10
W-17-M-30	$17^{1}/_{4}$"	Clay or shale structural tile core; see notes 4, 8, 15, 18; facings: side 1 and side 2 see note 17	80 psi	12 hr		1		1,20	12
W-17-M-31	$17^{1}/_{4}$"	Clay or shale structural tile core; see notes 4, 6, 16, 18; facings: side 1 and side 2 see note 17	80 psi	13 hr		1		1,20	13

(Sheet 3 of 3)

Notes:
1. Tested at NBS under ASA A2-1934.
2. One unit in wall thickness.
3. Two units in wall thickness.
4. Two or three units in wall thickness.
5. Two cells in wall thickness.
6. Three or four cells in wall thickness.
7. Four or five cells in wall thickness.
8. Five or six cells in wall thickness.
9. Minimum % of solid materials in units: 40.
10. Minimum % of solid materials in units: 43.
11. Minimum % of solid materials in units: 46.
12. Minimum % of solid materials in units: 48.
13. Minimum % of solid materials in units: 49.
14. Minimum % of solid materials in units: 45.
15. Minimum % of solid materials in units: 51.
16. Minimum % of solid materials in units: 53.
17. Not less than $^{5}/_{8}$ in. thickness of 1:3 sanded gypsum plaster.
18. Noncombustible or no members framed into wall.
19. Combustible members framed into wall.
20. Load: 80 psi for gross area.
21. Portland cement–lime mortar.
22. Failure mode — thermal.
23. British test.
24. Passed all criteria.
25. Failed by sudden collapse with no preceding signs of impending failure.
26. One cell in wall thickness.
27. Two cells in wall thickness.
28. Three cells in wall thickness.
29. Minimum % of solid material in concrete units: 52.
30. Minimum % of solid material in concrete units: 54.
31. Minimum % of solid material in concrete units: 55.
32. Minimum % of solid material in concrete units: 57.
33. Minimum % of solid material in concrete units: 60.
34. Minimum % of solid material in concrete units: 62.
35. Minimum % of solid material in concrete units: 65.
36. Minimum % of solid material in concrete units: 70.
37. Minimum % of solid material in concrete units: 76.
38. Not less than $^{1}/_{2}$ in. of 1:3 sanded gypsum plaster.
39. Three units in wall thickness.
40. Concrete units made with expanded slag or pumice aggregates.
41. Concrete units made with expanded burned clay or shale, crushed limestone, air cooled slag, or cinders.
42. Concrete units made with calcareous sand and gravel. Coarse aggregate, 60% or more calcite and dolomite.
43. Concrete units made with siliceous sand and gravel; 90% or more quartz, chert, or flint.

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FIGURE O.4.5.8 Metal Frame Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick.

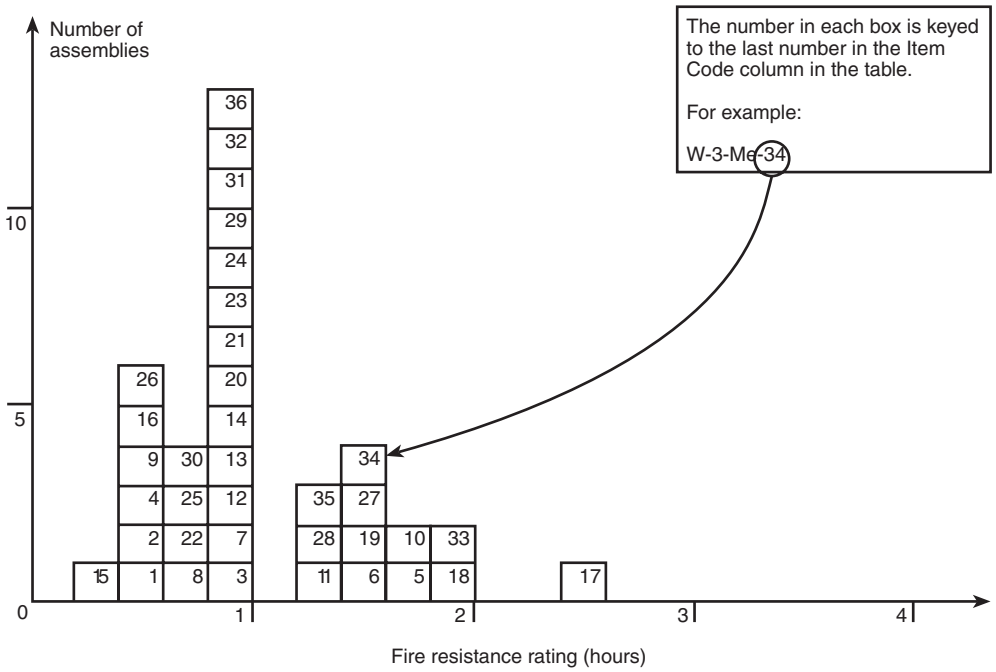

Table O.4.5.8 Metal Frame Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-3-Me-1	3"	Core: steel channels having 3 rows of 4" × 1/8" staggered slots in web; core filled with heat expanded vermiculite weighing 15 lb/ft^2 of wall area; facings: side 1, 18 gauge steel, spot welded to core; side 2, same as side 1	n/a	25 min		1			1/3
W-3-Me-2	3"	Core: steel channels having 3 rows of 4" × 1/8" staggered slots in web; core filled with heat expanded vermiculite weighing 2 lb/ft^2 of wall area; facings: side 1 and side 2, 18 gauge steel, spot welded to core	n/a	30 min		1			1/2
W-2-Me-3	2 1/2"	Solid partition 3/8" tension rods (vertical) 3' O.C. With metal lath; scratch coat, cement/sand/lime plaster; float coats, cement/sand/lime plaster; finish coats, neat gypsum plaster	n/a	1 hr			7	1	1
W-2-Me-4	2"	Solid wall: steel channel per note 1, 2" thickness of 1:2, 1:3 portland cement on metal lath	n/a	30 min		1			1/2
W-2-Me-5	2"	Solid wall: steel channel per note 1, 2" thickness of neat gypsum plaster on metal lath	n/a	1 hr 45 min		1			1 3/4
W-2-Me-6	2"	Solid wall: steel channel per note 1, 2" thickness of 1:1/2, 1:1/2 gypsum plaster on metal lath	n/a	1 hr 30 min		1			1 1/2

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Table O.4.5.8 Metal Frame Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-2-Me-7	2"	Solid wall: steel channel per note 2, 2" thickness of 1:1, 1:1 gypsum plaster on metal lath	n/a	1 hr		1			1
W-2-Me-8	2"	Solid wall: steel channel per note 1, 2" thickness of 1:2, 1:2 gypsum plaster on metal lath	n/a	45 min		1			3/4
W-2-Me-9	2 1/4"	Solid wall: steel channel per note 2, 2 1/4" thickness of 1:2, 1:3 portland cement on metal lath	n/a	30 min		1			1/2
W-2-Me-10	2 1/4"	Solid wall: steel channel per note 2, 2 1/4" thickness of neat gypsum plaster on metal lath	n/a	2 hr		1			2
W-2-Me-11	2 1/4"	Solid wall: steel channel per note 2, 2 1/4" thickness of 1:1 1/2, 1:1 1/2 gypsum plaster on metal lath	n/a	1 hr 45 min		1			1 3/4
W-2-Me-12	2 1/4"	Solid wall: steel channel per note 2, 2 1/4" thickness of 1:1, 1:1 gypsum plaster on metal lath	n/a	1 hr 15 min		1			1 1/4
W-2-Me-13	2 1/4"	Solid wall: steel channel per note 2, 2 1/4" thickness of 1:2, 1:2 gypsum plaster on metal lath	n/a	1 hr		1			1
W-2-Me-14	2 1/2"	Solid wall: steel channel per note 1, 2 1/2" thickness of 4.5:1:7, 4.5:1:7 portland cement, sawdust, and sand sprayed on wire mesh (see note 3 for wire mesh)	n/a	1 hr		1			1
W-2-Me-15	2 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of 1:4, 1:4 portland cement spray on wire mesh (per note 3)	n/a	20 min		1			1/3
W-2-Me-16	2 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of 1:2, 1:3 portland cement on metal lath	n/a	30 min		1			1/2
W-2-Me-17	2 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of neat gypsum plaster on metal lath	n/a	2 hr 30 min		1			2 1/2
W-2-Me-18	2 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of 1:1 1/2, 1:1 1/2 gypsum plaster on metal lath	n/a	2 hr		1			2
W-2-Me-19	2 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of 1:1, 1:1 gypsum plaster on metal lath	n/a	1 hr 30 min		1			1 1/2
W-2-Me-20	2 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of 1:2, 1:2 gypsum plaster on metal lath	n/a	1 hr		1			1
W-2-Me-21	2 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of 1:2, 1:3 gypsum plaster on metal lath	n/a	1 hr		1			1
W-3-Me-22	3"	Core: steel channels per note 2, 1:2, 1:2 gypsum plaster on 3/4" soft asbestos lath, plaster thickness 2"	n/a	45 min		1			3/4
W-3-Me-23	3 1/2"	Solid wall: steel channel per note 2, 2 1/2" thickness of 1:2, 1:2 gypsum plaster on 3/4" asbestos lath	n/a	1 hr		1			1

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Table O.4.5.8 Metal Frame Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick ***(Continued)***

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-3-Me-24	$3^1/_2$"	Solid wall: steel channel per note 2, lath over and 1:2 $^1/_2$, 1:2 $^1/_2$ gypsum plaster on 1" magnesium oxysulfate wood fiberboard, plaster thickness $2^1/_2$"	n/a	1 hr		1			1
W-3-Me-25	$3^1/_2$"	Core: steel studs per note 4; facings: $^3/_4$" thickness of 1:1/30:2, 1:1/30:3 portland cement and asbestos fiber plaster	n/a	45 min		1			$^3/_4$
W-3-Me-26	$3^1/_2$"	Core: steel studs per note 4; facings: both sides $^3/_4$" thickness of 1:2, 1:3 portland cement	n/a	30 min		1			$^1/_2$
W-3-Me-27	$3^1/_2$"	Core: steel studs per note 4; facings: both sides $^3/_4$" thickness of neat gypsum plaster	n/a	1 hr 30 min		1			$1^1/_2$
W-3-Me-28	$3^1/_2$"	Core: steel studs per note 4; facings: both sides $^3/_4$" thickness of 1:$^1/_2$, 1:$^1/_2$ gypsum plaster	n/a	1 hr 15 min		1			$1^1/_4$
W-3-Me-29	$3^1/_2$"	Core: steel studs per note 4; facings: both sides $^3/_4$" thickness of 1:2, 1:2 gypsum plaster	n/a	1 hr		1			1
W-3-Me-30	$3^1/_2$"	Core: steel studs per note 4; facings: both sides $^3/_4$" thickness of 1:2, 1:3 gypsum plaster	n/a	45 min		1			$^3/_4$
W-3-Me-31	$3^3/_4$"	Core: steel studs per note 4; facings: both sides $^7/_8$" thickness of 1:1/30:2, 1:1/30:3 portland cement and asbestos fiber plaster	n/a	1 hr		1			1
W-3-Me-32	$3^3/_4$"	Core: steel studs per note 4; facings: both sides $^7/_8$" thickness of 1:2, 1:3 portland cement	n/a	45 min		1			$^3/_4$
W-3-Me-33	$3^3/_4$"	Core: steel studs per note 4; facings: both sides $^7/_8$" thickness of neat gypsum plaster	n/a	2 hr		1			2
W-3-Me-34	$3^3/_4$"	Core: steel studs per note 4; facings: both sides $^7/_8$" thickness of 1:$^1/_2$, 1:$^1/_2$ gypsum plaster	n/a	1 hr 30 min		1			$1^1/_2$
W-3-Me-35	$3^3/_4$"	Core: steel studs per note 4; facings: both sides $^7/_8$" thickness of 1:2, 1:2 gypsum plaster	n/a	1 hr 15 min		1			$1^1/_4$
W-3-Me-36	$3^3/_4$"	Core: steel studs per note 4; facings: $^7/_8$" thickness of 1:2, 1:3 gypsum plaster on both sides	n/a	1 hr		1			1

(Sheet 3 of 3)

Notes:
1. Failure mode — local temperature rise — back face.
2. Channel framing $^3/_4$ in. or 1 in. — hot-rolled or strip-steel channels.
3. Reinforcement is 4 in.^{2} mesh of No. 6 wire welded at intersections (no channels).
4. Ratings are for any usual type of non-load-bearing metal framing providing 2 in. (or more) of air space.

General Note: The construction details of the wall assemblies are as complete as the source documentation will permit. Data on the method of attachment of facings and the gauge of steel studs was provided when known. The cross-sectional area of the steel stud can be computed, thereby permitting a reasoned estimate of actual loading conditions. For load-bearing assemblies, the maximum allowable stress for the steel studs has been provided in the table "Notes." More often, it is the thermal properties of the facing materials, rather than the specific gauge of the steel, that will determine the degree of fire resistance. This is particularly true for non-load-bearing wall assemblies.

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FIGURE O.4.5.9 Metal Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick.

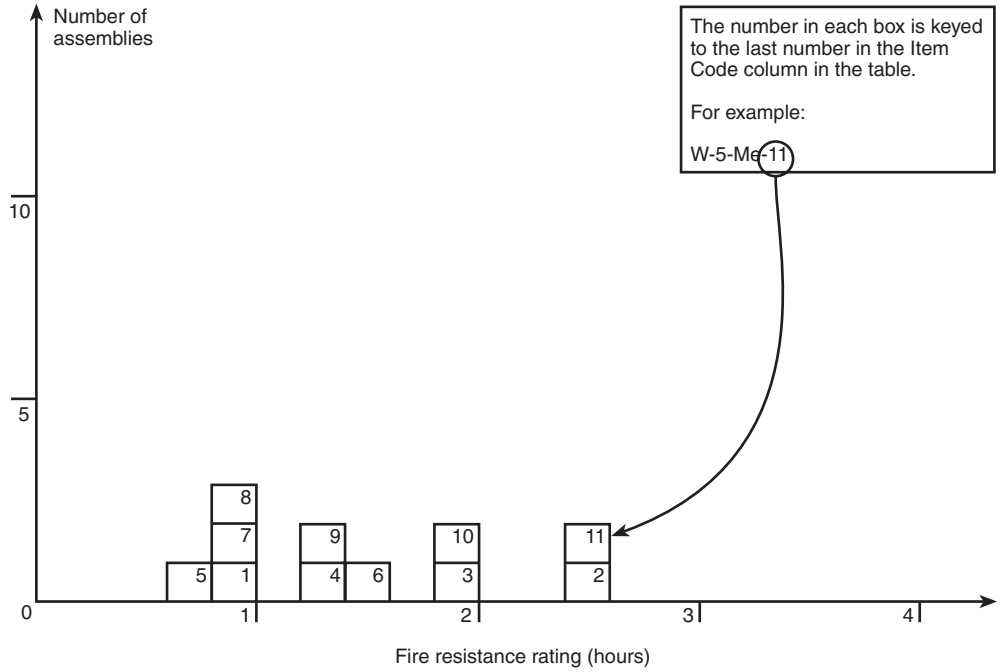

Table O.4.5.9 Metal Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-5-Me-1	$5^1/_2$"	3" cavity with 16 ga. channel studs ($3^1/_2$' O.C.) of $^1/_2$" × $^1/_2$" channel and 3" spacer; metal lath on ribs with plaster (3 coats) $^3/_4$" over face of lath; plaster (each side): scratch coat, cement/lime/sand with hair; float coat, cement/lime/sand; finish coat, neat gypsum	n/a	1 hr 11 min			7	1	1
W-4-Me-2	4"	Core: steel studs per note 2; facings: both sides 1" thickness of neat gypsum plaster	n/a	$2^1/_2$ hr		1			$2^1/_2$
W-4-Me-3	4"	Core: steel studs per note 2; facings: both sides 1" thickness of 1:$^1/_2$, 1:$^1/_2$ gypsum plaster	n/a	2 hr		1			2
W-4-Me-4	4"	Core: steel per note 2; facings: both sides 1" thickness of 1:2, 1:3 gypsum plaster	n/a	$1^1/_4$ hr		1			$1^1/_4$
W-4-Me-5	$4^1/_2$"	Core: lightweight steel stud 3" in depth; facings: both sides $^3/_4$" thick sanded gypsum plaster, 1:2 scratch and 1:3 brown coats applied on metal lath	See note 4	45 min		1		5	$^3/_4$
W-4-Me-6	$4^1/_2$"	Core: lightweight steel studs 3" in depth; facings: both sides $^3/_4$" thick neat gypsum plaster on metal lath	See note 4	1 hr 30 min		1		5	$1^1/_2$

(Sheet 1 of 2)

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Table O.4.5.9 Metal Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-Me-7	$4^1/_2$"	Core: lightweight steel studs 3" in depth; facings: both sides $^3/_4$" thick sanded gypsum plaster, 1:2 scratch and brown coats applied over metal lath	See note 4	1 hr		1		5	1
W-4-Me-8	$4^3/_4$"	Core: lightweight steel studs 3" in depth; facings: both sides $^7/_8$" thick sanded gypsum plaster, 1:2 scratch and 1:3 brown coats applied over metal lath	See note 4	1 hr		1		5	1
W-4-Me-9	$4^3/_4$"	Core: lightweight steel studs 3" in depth; facings: both sides $^7/_8$" thick sanded gypsum plaster, 1:2 scratch and brown coats applied on metal lath	See note 4	1 hr 15 min		1		5	$1^1/_4$
W-5-Me-10	5"	Core: lightweight steel studs 3" in depth; facings: both sides 1" thick neat gypsum plaster on metal lath	See note 4	2 hr		1		5	2
W-5-Me-11	5"	Core: lightweight steel studs 3" in depth; facings: both sides 1" thick neat gypsum plaster on metal lath	See note 4	2 hr 30 min		1		5,6	$2^1/_2$

(Sheet 2 of 2)

Notes:
1. Failure mode — local back face temperature rise.
2. Ratings are for any usual type of non-load-bearing metal framing providing a minimum 2 in. air space.
3. Facing materials secured to lightweight steel studs not less than 3 in. deep.
4. Rating based on loading to develop a maximum stress of 7270 psi for net area of each stud.
5. Spacing of steel studs must be sufficient to develop adequate rigidity in the metal-lath or gypsum-plaster base.
6. As per note 4 but load/stud not to exceed 5120 psi.

General Note: The construction details of the wall assemblies are as complete as the source documentation will permit. Data on the method of attachment of facings and the gauge of steel studs was provided when known. The cross-sectional area of the steel stud can be computed, thereby permitting a reasoned estimate of actual loading conditions. For load-bearing assemblies, the maximum allowable stress for the steel studs has been provided in the table "Notes." More often, it is the thermal properties of the facing materials, rather than the specific gauge of the steel, that will determine the degree of fire resistance. This is particularly true for non-load-bearing wall assemblies.

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Table O.4.5.10 Metal Frame Walls 6 in (150 mm) to Less Than 8 in. (200 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-6-Me-1	$6^5/_8$"	On one side of 1" magnesium oxysulfate wood fiberboard sheathing attached to steel studs (see notes 1 and 2), 1" air space, and 3 $^3/_4$" brick secured with metal ties to steel frame every fifth course; inside facing of $^7/_8$" 1:2 sanded gypsum plaster on metal lath secured directly to studs; plaster side exposed to fire	See note 2	$1^3/_4$ hr		1		1	$1^3/_4$
W-6-Me-2	$6^5/_8$"	On one side of 1" magnesium oxysulfate wood fiberboard sheathing attached to steel studs (see notes 1 and 2), 1" air space, and $3^3/_4$" brick secured with metal ties to steel frame every fifth course; inside facing of $^7/_8$" 1:2 sanded gypsum plaster on metal lath secured directly to studs; brick face exposed to fire	See note 2	4 hr		1		1	4
W-6-Me-3	$6^5/_8$"	On one side of 1" magnesium oxysulfate wood fiberboard sheathing attached to steel studs (see notes 1 and 2), 1" air space, and $3^3/_4$" brick secured with metal ties to steel frame every fifth course; inside facing of $^7/_8$" vermiculite plaster on metal lath secured directly to studs; plaster side exposed to fire	See note 2	2 hr		1		1	2

Notes:
1. Lightweight steel studs (minimum 3 in. deep) used. Stud spacing dependent on loading, but in each case the spacing is to be such that adequate rigidity is provided to the metal-lath plaster base.
2. Load is such that stress developed in studs is not greater than 5120 psi calculated from net stud area.

General Note: The construction details of the wall assemblies are as complete as the source documentation will permit. Data on the method of attachment of facings and the gauge of steel studs was provided when known. The cross-sectional area of the steel stud can be computed, thereby permitting a reasoned estimate of actual loading conditions. For load-bearing assemblies, the maximum allowable stress for the steel studs has been provided in the table "Notes." More often, it is the thermal properties of the facing materials, rather than the specific gauge of the steel, that will determine the degree of fire resistance. This is particularly true for non-load-bearing wall assemblies.

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Table O.4.5.11 Metal Frame Walls 8 in. (200 mm) to Less Than 10 in. (250 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-9-Me-1	$9^1/_{16}$"	On one side of $^1/_2$" wood fiberboard sheathing next to studs, $^3/_4$" air space formed with $^3/_4$" × $1^5/_8$" wood strips placed over the fiberboard and secured to the studs; paper-backed wire lath nailed to strips; $3^3/_4$" brick veneer held in place by filling a $^3/_4$" space between the brick and paper-backed lath with mortar; inside facing of $^3/_4$" neat gypsum plaster on metal lath attached to $^5/_{16}$" plywood strips secured to edges of steel studs; rated as combustible because of the sheathing; see notes 1 and 2; plaster exposed	See note 2	$1^1/_2$ hr		1		1	$1^1/_2$
W-9-Me-2	$9^1/_{16}$"	Same as W-9-Me-1, with brick exposed	See note 2	4 hr		1		1	4
W-8-Me-3	$8^1/_2$"	On one side of paper-backed wire lath attached to studs and $3^3/_4$" brick veneer held in place by filling a 1" space between the brick and lath with mortar; inside facing of 1" paper-enclosed mineral wool blanket weighing 0.6 lb/ft^2 attached to studs, metal lath, or paper-backed wire lath laid over the blanket and attached to the studs, and $^3/_4$" sanded gypsum plaster, 1:2 for scratch and 1:3 for brown coat (see notes 1 and 2); plaster face exposed	See note 2	4 hr		1		1	4
W-8-Me-4	$8^1/_2$"	Same as W-8-Me-3, with brick exposed	See note 2	5 hr		1		1	5

Notes:
1. Lightweight steel studs > 3 in. in depth. Stud spacing is dependent upon loading, but in any case the spacing is to be such that adequate rigidity is provided to the metal-lath plaster base.
2. Load is such that stress developed in the steel studs is < 5120 psi calculated from net area of the stud.

General Note: The construction details of the wall assemblies are as complete as the source documentation will permit. Data on the method of attachment of facings and the gauge of steel studs was provided when known. The cross-sectional area of the steel stud can be computed, thereby permitting a reasoned estimate of actual loading conditions. For load-bearing assemblies, the maximum allowable stress for the steel studs has been provided in the table "Notes." More often, it is the thermal properties of the facing materials, rather than the specific gauge of the steel, that will determine the degree of fire resistance. This is particularly true for non-load-bearing wall assemblies.

Table O.4.5.12 Wood Frame Walls 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-3-W-1	$3^3/_4$"	Solid wall: $2^1/_4$" wood-wool slab core; $^3/_4$" gypsum plaster each side	n/a	2 hr			7	1,6	2
W-3-W-2	$3^7/_8$"	2 in. × 4 in. stud wall, $^3/_{16}$" thick cement asbestos board on both sides of wall	360 psi net area	10 min		1		2–5	$^1/_6$
W-3-W-3	$3^7/_8$"	Same as W-3-W-2 but stud cavities filled with 1 lb/ft^2 mineral wool batts	360 psi net area	40 min		1		2–5	$^2/_3$

Notes:
1. Achieved "Grade C" fire resistance (British).
2. Nominal 2 in. × 4 in. wood studs of No. 1 common or better lumber set edgewise, 2 in. × 4 in. plates at top and bottom and blocking at mid-height of wall.
3. All horizontal joints in facing material backed by 2 in. × 4 in. blocking in wall.
4. Load = 360 psi of net stud cross-sectional area.
5. Facings secured with 6 d casing nails. Nail holes predrilled and 0.02 in.–0.03 in. smaller than nail diameter.
6. The wood-wool core is a pressed excelsior slab that possesses insulating properties similar to cellulosic insulation.

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FIGURE O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick.

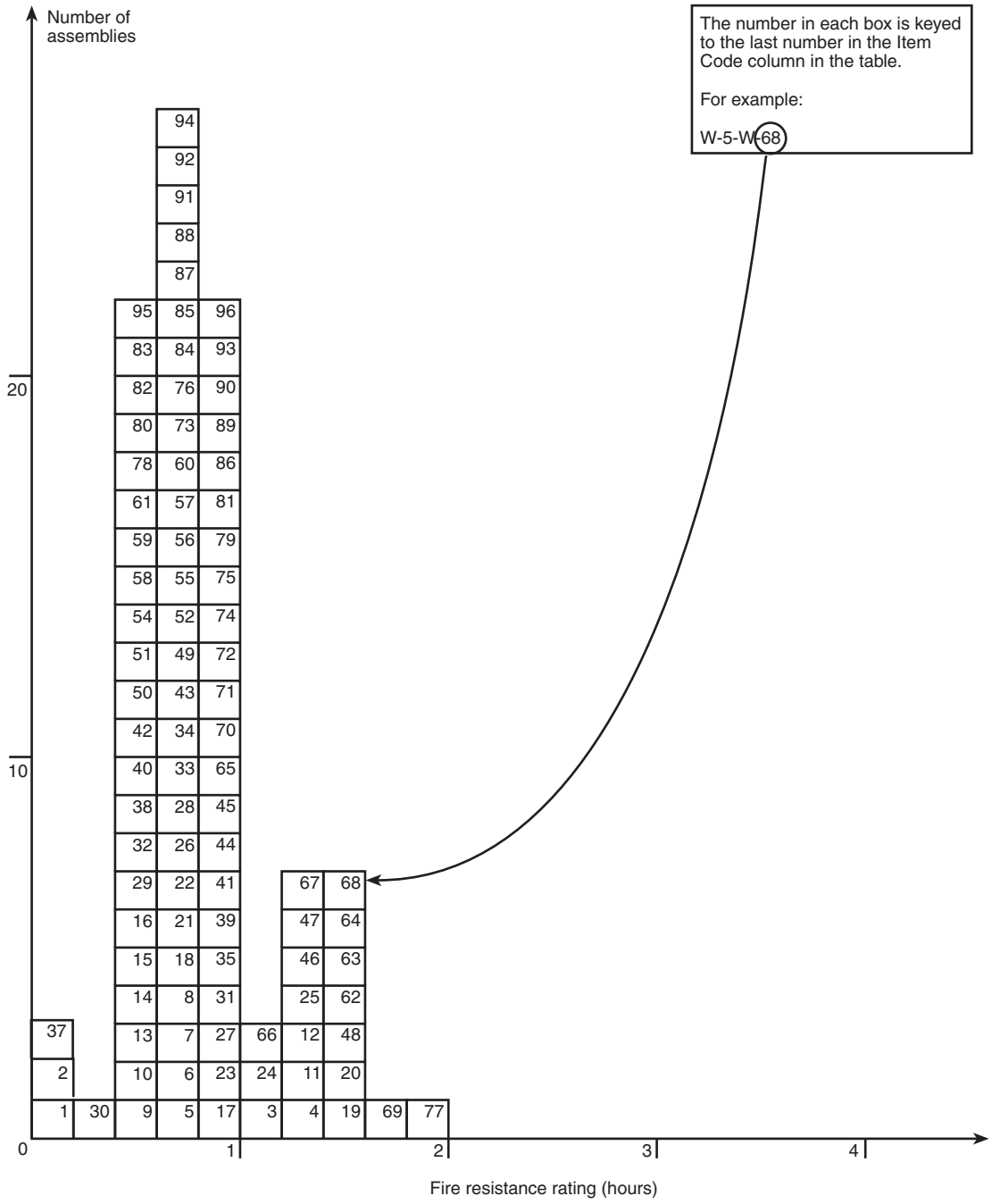

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Table O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-W-1	4"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board; no insulation; design A	35 min	10 min			4	1–10	$^{1}/_{6}$
W-4-W-2	$4^{1}/_{8}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board; no insulation; design A	38 min	9 min			4	1–10	$^{1}/_{6}$
W-4-W-3	$4^{3}/_{4}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board and $^{3}/_{8}$" gypsum board face (both sides); design B	62 min	64 min			4	1–10	1
W-5-W-4	5"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board and $^{1}/_{2}$" gypsum board face (both sides); design B	79 min	Greater than 90 min			4	1–10	1
W-4-W-5	$4^{3}/_{4}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board and $^{3}/_{8}$" gypsum board (both sides); design B	45 min	45 min			4	1–12	–
W-5-W-6	5"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board and $^{1}/_{2}$" gypsum board face (both sides); design B	45 min	45 min			4	1–10, 12-13	–
W-4-W-7	4"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $3^{1}/_{2}$" mineral wool insulation; design C	40 min	42 min			4	1–10	$^{2}/_{3}$
W-4-W-8	4"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $3^{1}/_{2}$" mineral wool insulation; design C	46 min	46 min			4	1–10,43	$^{2}/_{3}$
W-4-W-9	4"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $3^{1}/_{2}$" mineral wool insulation; design C	30 min	30 min			4	1–10, 12-14	
W-4-W-10	$4^{1}/_{8}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $3^{1}/_{2}$" mineral wool insulation; design		30 min			4	1–8,12,14	
W-4-W-11	$4^{3}/_{4}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $^{3}/_{8}$" gypsum strips over studs; $5^{1}/_{2}$" mineral wool insulation; design D	79 min	79 min			4	1–10	1
W-4-W-12	$4^{3}/_{4}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $^{3}/_{8}$" gypsum strips at stud edges; $7^{1}/_{2}$" mineral wool insulation; design D	82 min	82 min			4	1–10	1
W-4-W-13	$4^{3}/_{4}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $^{3}/_{8}$" gypsum board strips over studs; $5^{1}/_{2}$" mineral wool insulation; design D	30 min	30 min			4	1–12	
W-4-W-14	$4^{3}/_{4}$"	2" × 4" stud wall; $^{3}/_{16}$" cement-asbestos board face; $^{3}/_{8}$" gypsum board strips over studs; 7" mineral wool insulation; design D	30 min	30 min			4	1–12	
W-5-W-15	$5^{1}/_{2}$"	2" × 4" stud wall; exposed face: cement-asbestos board shingles over 1" × 6"; unexposed face: $^{1}/_{8}$" cement-asbestos board sheet; $^{7}/_{16}$" fiberboard (wood); design E	34 min	–			4	1–10	$^{1}/_{2}$
W-5-W-16	$5^{1}/_{2}$"	2" × 4" stud wall; exposed face: $^{1}/_{8}$" cement-asbestos board sheet; $^{7}/_{16}$" fiberboard; unexposed face: cement-asbestos board shingles over 1" × 6"; design E	32 min	33 min			4	1–10	$^{1}/_{2}$

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Table O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-5-W-17	$5^1/_2$"	2" × 4" stud wall; exposed face: cement-asbestos board shingles over 1" × 6"; unexposed face: $^1/_8$" cement-asbestos board sheet; gypsum at stud edges; $3^1/_2$" mineral wool insulation; design F	51 min				4	1–10	$^3/_4$
W-5-W-18	$5^1/_2$"	2" × 4" stud wall; exposed face: $^1/_8$" cement-asbestos board sheet, gypsum board at stud edges; unexposed face: cement-asbestos board shingles over 1" × 6"; $3^1/_2$" mineral wool insulation; design F	42 min				4	1–10	$^2/_3$
W-5-W-19	$5^5/_8$"	2" × 4" stud wall; exposed face: cement-asbestos board shingles over 1" × 6"; unexposed face: $^1/_8$" cement-asbestos board sheet, gypsum board at stud edges; $5^1/_2$" mineral wool insulation; design G	74 min	85 min			4	1–10	1
W-5-W-20	$5^5/_8$"	2" × 4" stud wall; unexposed face: cement-asbestos board shingles over 1" × 6"; exposed face: $^1/_8$" cement-asbestos board sheet, gypsum board: $^3/_{16}$" stud edges; $^7/_{16}$" fiberboard; $5^1/_2$" mineral wool insulation; design G	79 min	85 min			4	1–10	$1^1/_4$
W-5-W-21	$5^5/_8$"	2" × 4" stud wall; exposed face: cement-asbestos board shingles 1" × 6" sheathing; unexposed face: cement-asbestos board sheet, gypsum board at stud edges; $5^1/_2$" mineral wool insulation; design G	38 min	38 min			4	1–10, 12–14	–
W-5-W-22	$5^5/_8$"	2" × 4" stud wall; exposed face: cement-asbestos board sheet, gypsum board at stud edges; unexposed face: cement-asbestos board shingles 1" × 6" sheathing; $5^1/_2$" mineral wool insulation; design G	38 min	38 min			4	1–12	–
W-6-W-23	6"	2" × 4" stud wall; 16" O.C.; $^1/_2$" gypsum board each side; $^1/_2$" gypsum plaster each side	n/a	60 min			7	15	1
W-6-W-24	6"	2" × 4" stud wall; 16" O.C.; $^1/_2$" gypsum board each side; $^1/_2$" gypsum plaster each side	n/a	68 min			7	16	1
W-6-W-25	$6^7/_8$"	2" × 4" stud wall; 18" O.C.; $^3/_4$" gypsum plank each side; $^3/_{16}$" gypsum plaster each side	n/a	80 min			7	15	$1^1/_3$
W-5-W-26	$5^1/_8$"	2" × 4" stud wall; 16" O.C.; $^3/_8$" gypsum board each side; $^3/_{16}$" gypsum plaster each side	n/a	37 min			7	15	$^1/_2$
W-5-W-27	$5^3/_4$"	2" × 4" stud wall; 16" O.C.; $^3/_8$" gypsum lath each side; $^1/_2$" gypsum plaster each side	n/a	52 min			7	15	$^3/_4$
W-5-W-28	5"	2" × 4" stud wall; 16" O.C.; $^1/_2$" gypsum board each side	n/a	37 min			7	16	$^1/_2$
W-5-W-29	5"	2" × 4" stud wall; $^1/_2$" fiberboard both sides 14% M.C. with fire-resistant paint at 35 gm/ft^2	n/a	28 min			7	15	$^1/_3$

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Table O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-W-30	$4\frac{3}{4}$"	2" × 4" stud wall; 16" O.C.; fire side: $\frac{1}{4}$" (wood) fiberboard; back face: $\frac{1}{2}$" cement-asbestos board	n/a	17 min			7	15,16	$\frac{1}{4}$
W-5-W-31	$5\frac{1}{8}$"	2" × 4" stud wall; 16" O.C.; $\frac{1}{2}$" fiberboard insulation with $\frac{1}{32}$" asbestos (both sides of each board)	n/a	50 min			7	16	$\frac{3}{4}$
W-4-W-32	$4\frac{1}{4}$"	2" × 4" stud wall; $\frac{3}{8}$" thick gypsum wallboard on both faces; insulated cavities	note 23	25 min		1		17,18,23	$\frac{1}{3}$
W-4-W-33	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick gypsum wallboard on both faces	note 17	40 min		1		17,23	$\frac{2}{3}$
W-4-W-34	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick gypsum wallboard on both faces; insulated cavities	note 17	45 min		1		17,18,23	$\frac{3}{4}$
W-4-W-35	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick gypsum wallboard on both faces; insulated cavities	n/a	1 hr		1		17,18,24	1
W-4-W-36	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick, 1.1 lb/ft^2 wood fiberboard sheathing on both faces	note 23	15 min		1		17,23	$\frac{1}{4}$
W-4-W-37	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick 0.7 lb/ft^2 wood fiberboard sheathing on both faces	note 23	10 min		1		17,23	$\frac{1}{6}$
W-4-W-38	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick "flameproofed" 1.6 lb/ft^2 wood fiberboard sheathing on both faces	note 23	30 min		1		17,23	$\frac{1}{2}$
W-4-W-39	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick gypsum wallboard on both faces; insulated cavities	note 23	1 hr		1		17,18,23	1
W-4-W-40	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick 1:2, 1:3 gypsum plaster on wood lath on both faces	note 23	30 min		1		17,21,23	$\frac{1}{2}$
W-4-W-41	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick 1:2, 1:3 gypsum plaster on wood lath on both faces; insulated cavities	note 23	1 hr		1		17,18, 21,23	1
W-4-W-42	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick 1:5, 1:7.5 lime plaster on wood lath on both wall faces	note 23	30 min		1		17,21,23	$\frac{1}{2}$
W-4-W-43	$4\frac{1}{2}$"	2" × 4" stud wall; $\frac{1}{2}$" thick 1:5, 1:7.5 lime plaster on wood lath on both faces, insulated cavities	note 23	45 min		1		17,18, 21,23	$\frac{3}{4}$
W-4-W-44	$4\frac{5}{8}$"	2" × 4" stud wall; $\frac{3}{16}$" thick cement-asbestos over $\frac{3}{8}$" thick gypsum board on both faces	note 23	1 hr		1		23,25, 26,27	1
W-4-W-45	$4\frac{5}{8}$"	2" × 4" stud wall; studs faced with 4" wide strips of $\frac{3}{8}$" thick gypsum board; $\frac{3}{16}$" thick cement-asbestos board on both faces; insulated cavities	note 23	1 hr		1		23,25, 27,28	1
W-4-W-46	$4\frac{5}{8}$"	Same as W-4-W-45 but non-load-bearing	n/a	$1\frac{1}{4}$ hr		1		24,28	$1\frac{1}{4}$
W-4-W-47	$4\frac{7}{8}$"	2" × 4" stud wall; $\frac{3}{16}$" thick cement-asbestos board over $\frac{1}{2}$" thick gypsum sheathing on both faces	note 23	$1\frac{1}{4}$ hr		1		23,25, 26,27	$1\frac{1}{4}$

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Table O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-W-48	$4\frac{7}{8}$"	Same as W-4-W-47 but non-load-bearing	n/a	$1\frac{1}{2}$ hr		1		24,27	$1\frac{1}{2}$
W-5-W-49	5"	2" × 4" stud wall; exterior face: $\frac{3}{4}$" wood sheathing, asbestos felt 14 lb/100 ft^2, and $\frac{5}{32}$" cement-asbestos shingles; interior face: 4" wide strips of $\frac{3}{8}$" gypsum board over studs; wall faced with $\frac{3}{16}$" thick cement-asbestos board	note 23	40 min		1		18,23, 25,26,29	$\frac{2}{3}$
W-5-W-50	5"	2" × 4" stud wall; exterior face as per W-5-W-49; interior face: $\frac{9}{16}$" composite board consisting of $\frac{7}{16}$" thick wood fiberboard faced with $\frac{1}{8}$" thick cement-asbestos board; exterior side exposed to fire	note 23	30 min		1		23,25, 26,30	$\frac{1}{2}$
W-5-W-51	5"	Same as W-5-W-50 but interior side exposed to fire	note 23	30 min		1		23,25,26	$\frac{1}{2}$
W-5-W-52	5"	Same as W-5-W-49 but exterior side exposed to fire	note 23	45 min		1		18,23, 25,26	$\frac{3}{4}$
W-5-W-53	5"	2" × 4" stud wall; $\frac{3}{4}$" thick T&G wood boards on both sides	note 23	20 min		1		17,23	$\frac{1}{3}$
W-5-W-54	5"	Same as W-5-W-53 but with insulated cavities	note 23	35 min		1		17,18,23	$\frac{1}{2}$
W-5-W-55	5"	2" × 4" stud wall; $\frac{3}{4}$" thick T&G wood boards on both sides with 30 lb/100 ft^2 asbestos, paper between studs and boards	note 23	45 min		1		17,23	$\frac{3}{4}$
W-5-W-56	5"	2" × 4" stud wall; $\frac{1}{2}$" thick 1:2, 1:3 gypsum plaster on metal lath on both sides of wall	note 23	45 min		1		17,21,23	$\frac{3}{4}$
W-5-W-57	5"	2" × 4" stud wall; $\frac{3}{4}$" thick 2:1:8, 2:1:12 lime and Keene's cement plaster on metal lath on both sides of wall	note 23	45 min		1		17,21,23	$\frac{3}{4}$
W-5-W-58	5"	2" × 4" stud wall; $\frac{3}{4}$" thick 2:1:8, 2:1:10 lime-portland cement plaster over metal lath on both sides of wall	note 23	30 min		1		17,21,23	$\frac{1}{2}$
W-5-W-59	5"	2" × 4" stud wall; $\frac{3}{4}$" thick 1:5, 1:7.5 lime plaster on metal lath on both sides of wall	note 23	30 min		1		17,21,23	$\frac{1}{2}$
W-5-W-60	5"	2" × 4" stud wall; $\frac{3}{4}$" thick 1:1/30:2, 1:1/30:3 portland cement, asbestos fiber plaster on metal lath on both sides of wall	note 23	45 min		1		17,21,23	$\frac{3}{4}$
W-5-W-61	5"	2" × 4" stud wall; $\frac{3}{4}$" thick 1:2, 1:3 portland cement plaster on metal lath on both sides of wall	note 23	30 min		1		17,21,23	$\frac{1}{2}$
W-5-W-62	5"	2" × 4" stud wall; $\frac{3}{4}$" thick neat plaster on metal lath on both sides of wall	n/a	1 hr 30 min		1		17,22,24	$1\frac{1}{2}$
W-5-W-63	5"	2" × 4" stud wall; $\frac{3}{4}$" thick neat gypsum plaster on metal lath on both sides of wall	note 23	1 hr 30 min		1		17,21,23	$1\frac{1}{2}$
W-5-W-64	5"	2" × 4" stud wall; $\frac{3}{4}$" thick 1:2, 1:2 gypsum plaster on metal lath on both sides of wall, insulated cavities	note 23	1 hr 30 min		1		17,18, 21,23	$1\frac{1}{2}$

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Table O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-5-W-65	5"	2" × 4" stud wall, same as W-5-W-64 but wall cavities not insulated	note 23	1 hr		1		17,21,23	1
W-5-W-66	5"	2" × 4" stud wall; $^3/_4$" thick 1:2, 1:3 gypsum plaster on metal lath on both sides of wall, insulated cavities	note 23	1 hr 15 min		1		17,18, 21,23	$1^1/_4$
W-5-W-67	$5^1/_{16}$"	Same as W-5-W-49 except cavity insulation of $1^3/_4$ lb/ft^2 mineral wool batts; rating applies when either wall side exposed to fire	note 23	1 hr 15 min		1		23,25,26	$1^1/_4$
W-5-W-68	$5^1/_4$"	2" × 4" stud wall; $^7/_8$" thick 1:2, 1:3 gypsum plaster on metal lath on both sides of wall, insulated cavities	note 23	1 hr 30 min		1		17,18, 21,23	$1^1/_2$
W-5-W-69	$5^1/_4$"	2" × 4" stud wall; $^7/_8$" thick neat gypsum plaster applied on metal lath on both sides of wall	n/a	1 hr 45 min		1		17,22,24	$1^3/_4$
W-5-W-70	$5^1/_4$"	2" × 4" stud wall; $^1/_2$" thick neat gypsum plaster on $^3/_8$" plain gypsum lath, both sides of wall	note 23	1 hr		1		17,22,23	1
W-5-W-71	$5^1/_4$"	2" × 4" stud wall; $^1/_2$" thick 1:2, 1:2 gypsum plaster on $^3/_8$" thick plain gypsum lath with $1^3/_4$" × $1^3/_4$" metal lath pads nailed 8" O.C. vertically, 16" O.C. horizontally, both sides of wall	note 23	1 hr		1		17,21,23	1
W-5-W-72	$5^1/_4$"	2" × 4" stud wall; $^1/_2$" thick 1:2, 1:2 gypsum plaster on $^3/_8$" perforated gypsum lath, one hole $^3/_4$" diam. or larger per 16 in.^{2} of lath surface, both sides of wall	note 23	1 hr		1		17,21,23	1
W-5-W-73	$5^1/_4$"	2" × 4" stud wall; $^1/_2$" thick 1:2, 1:2 gypsum plaster on $^3/_8$" gypsum lath (plain, indented, or perforated), both sides of wall	note 23	45 min		1		17,21,23	$^3/_4$
W-5-W-74	$5^1/_4$"	2" × 4" stud wall; $^7/_8$" thick 1:2, 1:3 gypsum plaster over metal lath on both sides of wall	note 23	1 hr		1		17,21,23	1
W-5-W-75	$5^1/_4$"	2" × 4" stud wall; $^7/_8$" thick 1:1/30:2, 1:1/30:3 portland cement, asbestos plaster applied over metal lath on both sides of wall	note 23	1 hr		1		17,21,23	1
W-5-W-76	$5^1/_4$"	2" × 4" stud wall; $^7/_8$" thick 1:2, 1:3 portland cement plaster over metal lath on both sides of wall	note 23	45 min		1		17,21,23	$^3/_4$
W-5-W-77	$5^1/_2$"	2" × 4" stud wall; 1" thick neat gypsum plaster over metal lath on both sides of wall, non-load-bearing	n/a	2 hr		1		17,22,24	2
W-5-W-78	$5^1/_2$"	2" × 4" stud wall; $^1/_2$" thick 1:2, 1:2 gypsum plaster on $^1/_2$" thick 0.7 lb/ft^2 wood fiberboard, both sides of wall	note 23	35 min		1		17,21,23	$^1/_2$
W-4-W-79	$4^3/_4$"	2" × 4" wood stud wall; $^1/_2$" thick 1:2, 1:2 gypsum plaster over wood lath on both sides of wall; mineral wool insulation	n/a	1 hr			43	21,31, 35,38	1
W-4-W-80	$4^3/_4$"	Same as W-4-W-79 but uninsulated	n/a	35 min			43	21,31,35	$^1/_2$

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Table O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-W-81	$4\frac{3}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 3:1:8, 3:1:12 lime, Keene's cement, and sand plaster over wood lath on both sides of wall; mineral wool insulation	n/a	1 hr			43	21,31, 35,40	1
W-4-W-82	$4\frac{3}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:6 $\frac{1}{4}$, 1:6 $\frac{1}{4}$ lime and Keene's cement plaster over wood lath on both sides of wall; mineral wool insulation	n/a	30 min			43	21,31, 35,40	$\frac{1}{2}$
W-4-W-83	$4\frac{3}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:5, 1:7.5 lime plaster over wood lath on both sides of wall	n/a	30 min			43	21,31,35	$\frac{1}{2}$
W-5-W-84	$5\frac{1}{8}$"	2" × 4" wood stud wall; $\frac{11}{16}$" thick 1:5, 1:7.5 lime plaster over wood lath on both sides of wall; mineral wool insulation	n/a	45 min			43	21,31, 35,39	$\frac{1}{2}$
W-5-W-85	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{3}{4}$" thick 1:5, 1:7 lime plaster over wood lath on both sides of wall; mineral wool insulation	n/a	40 min			43	21,31, 35,40	$\frac{2}{3}$
W-5-W-86	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 2:1:12 lime, Keene's cement, and sand scratch coat, $\frac{1}{2}$" thick 2:1:18 lime, Keene's cement, and sand brown coat over wood lath on both sides of wall; mineral wool insulation	n/a	1 hr			43	21,31, 35,40	1
W-5-W-87	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:2, 1:2 gypsum plaster over $\frac{3}{8}$" thick plaster board on both sides of wall	n/a	45 min			43	21,31	$\frac{3}{4}$
W-5-W-88	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:2, 1:2 gypsum plaster over $\frac{3}{8}$" thick gypsum lath on both sides of wall	n/a	45 min			43	21,31	$\frac{3}{4}$
W-5-W-89	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:2, 1:2 gypsum plaster over $\frac{3}{8}$" gypsum lath on both sides of wall	n/a	1 hr			43	21,31,33	1
W-5-W-90	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick neat plaster over $\frac{3}{8}$" thick gypsum lath on both sides of wall	n/a	1 hr			43	21,22,31	1
W-5-W-91	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:2, 1:2 gypsum plaster over $\frac{3}{8}$" thick indented gypsum lath on both sides of wall	n/a	45 min			43	21,31	$\frac{3}{4}$
W-5-W-92	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:2, 1:2 gypsum plaster over perforated gypsum lath, $\frac{3}{8}$" thick on both sides of wall	n/a	45 min			43	21,31,34	$\frac{3}{4}$
W-5-W-93	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:2, 1:2 gypsum plaster over $\frac{3}{8}$" thick perforated gypsum lath on both sides of wall	n/a	1 hr			43	21,31	1
W-5-W-94	$5\frac{1}{4}$"	2" × 4" wood stud wall; $\frac{1}{2}$" thick 1:2, 1:2 gypsum plaster over perforated gypsum lath $\frac{3}{8}$" thick on both sides of wall	n/a	45 min			43	21,31,34	$\frac{3}{4}$

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Table O.4.5.13 Wood Frame Walls 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick *(Continued)*

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-5-W-95	$5^1/_4$"	2" × 4" wood stud wall; $^1/_2$" thick 1:2, 1:2 gypsum plaster over $^1/_2$" thick wood fiberboard plaster base on both sides of wall	n/a	35 min			43	21,31,36	$^1/_2$
W-5-W-96	$5^3/_4$"	2" × 4" wood stud wall; $^1/_2$" thick 1:2, 1:2 gypsum plaster over $^7/_8$" thick flameproofed wood fiberboard on both sides of wall	n/a	1 hr			43	21,31,37	1

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Notes:
1. All specimens 8 ft or 8 ft 8 in. × 10 ft 4 in. — i.e., one-half of furnace size. See note 42 for design cross section.
2. Specimens tested in tandem (two per exposure).
3. Test per ASA A2-1934 except where unloaded. Also, panels were of "half" size of furnace opening. Time value signifies a thermal failure time.
4. Studs 2 in. × 4 in. 16 in. O.C., where 10 ft 4 in., blocking at 2 ft 4 in. height.
5. Facing — 4 ft × 8 ft cement-asbestos board sheets $^3/_{16}$ in. thick.
6. Sheathing (diagonal) — $^{25}/_{32}$ in. × $5^1/_2$ in., 1 in. × 6 in. pine.
7. Facing shingles — 24 in. × 12 in. × $^5/_{32}$ in. where used.
8. Asbestos felt–asphalt set between sheathing and shingles.
9. Load — 30,500 lb or 360 psi/stud where load was tested.
10. Walls were tested beyond achievement of first test end point. A load-bearing time in excess of performance time indicates that although thermal criteria were exceeded, load-bearing ability continued.
11. Wall was rated for 1-hour combustible use in original source.
12. Hose stream test specimen. See table entry of similar design for recommended rating.
13. Rated $1^1/_4$ hour load-bearing. Rated $1^1/_2$ hour non-load-bearing.
14. Failed hose stream.
15. Test terminated due to flame penetration.
16. Test terminated — local back face temperature rise.
17. Nominal 2 in. × 4 in. wood studs of No. 1 common or better lumber set edgewise; 2 in. × 4 in. plates at top and bottom and blocking at mid-height of wall.
18. Cavity insulation consists of rock wool batts 1.0 lb/ft^2 of filled cavity area.
19. Cavity insulation consists of glass wool batts 0.6 lb/ft^2 of filled cavity area.
20. Cavity insulation consists of blown-in rock wool 2.0 lb/ft^2 of filled cavity area.
21. Mix proportions for plastered walls as follows: first ratio indicates scratch coat mix, weight of dry plaster to dry sand; second ratio indicates brown coat mix.
22. *Neat plaster* is taken to mean unsanded wood-fiber gypsum plaster.
23. Load = 360 psi of net stud cross-sectional area.
24. Rated as non-load-bearing.
25. Nominal 2 in. × 4 in. studs per note 17, spaced at 16 in. O.C.
26. Horizontal joints in facing material supported by 2 in. × 4 in. blocking within wall.
27. Facings secured with 6 d casing nails. Nail holes predrilled and were 0.02–0.03 in. smaller than nail diameter.
28. Cavity insulation consists of mineral wool batts weighing 2 lb/ft^2 of filled cavity area.
29. Interior wall face exposed to fire.
30. Exterior wall face exposed to fire.
31. Nominal 2 in. × 4 in. studs of yellow pine or Douglas fir spaced 16 in. O.C. in a single row.
32. Studs as in note 31 except double row, with studs in rows staggered.
33. Six roofing nails with metal-lath pads around heads to each 16 in. × 48 in. lath.
34. Areas of holes less than $2^3/_4$% of area of lath.
35. Wood laths were nailed with either 3 d or 4 d nails, one nail to each bearing, and the end joining broken every seventh course.
36. Fiberboard plaster base $^1/_2$ in. thick nailed with 3 d or 4 d common wire nails spaced 4–6 in. O.C..
37. Fiberboard plaster base$^7/_8$" thick nailed with 5 d common wire nails spaced 4– 6 in. O.C..
38. Mineral wool batts 1.05–1.25 lb/ft^2 with waterproofed-paper backing.
39. Blown-in mineral wool insulation, 2.2 lb/ft^2.
40. Mineral wool batts, 1.4 lb/ft^2, with waterproofed-paper backing.
41. Mineral wool batts, 0.9 lb/ft^2.
42. See Figure O.4.5.13 of wall design diagram.
43. Duplicate specimen of W-4-W-7, tested simultaneously with W-4-W-7 in 18 ft test furnace.

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FIGURE O.4.5.13 [Diagram of] Wall Design.

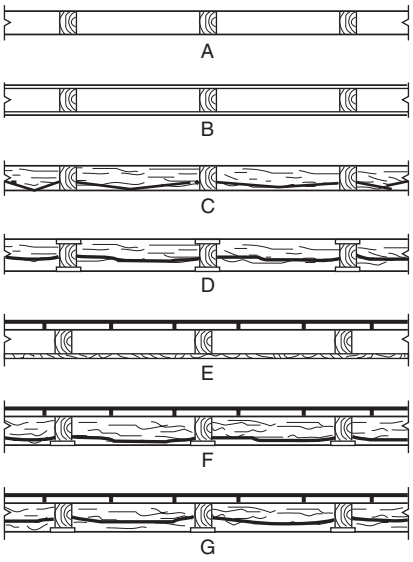

Table O.4.5.14 Wood Frame Walls 6 in. (150 mm) to Less Than 8 in. (200 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-6-W-1	$6^1/_4$"	2" × 4" stud wall, $^1/_2$" thick, 1:2, 1:2 gypsum plaster on $^7/_8$" flameproofed wood fiberboard weighing 2.8 lb/ft^2 on both sides of wall	note 3	1 hr		1		1–3	1
W-6-W-2	$6^1/_2$"	2" × 4" stud wall, $^1/_2$" thick 1:3, 1:3 gypsum plaster on 1" thick magnesium oxysulfate wood fiberboard on both sides of wall	note 3	45 min		1		1–3	$^3/_4$
W-7-W-3	$7^1/_4$"	Double row of 2" × 4" studs, $^1/_2$" thick 1:2, 1:2 gypsum plaster applied over $^3/_8$" thick perforated gypsum lath on both sides of wall; mineral wool insulation	n/a	1 hr			43	2,4,5	1
W-7-W-4	$7^1/_2$"	Double row of 2" × 4" studs, $^5/_8$" thick 1:2, 1:2 gypsum plaster applied over $^3/_8$" thick perforated gypsum lath overlaid with 2" × 2" 16 ga. wire fabric on both sides of wall	n/a	1 hr 15 min			43	2,4	$1^1/_4$

Notes:
1. Nominal 2 in. × 4 in. wood studs of No. 1 common or better lumber set edgewise; 2 in. × 4 in. plates at top and bottom and blocking at mid-height of wall.
2. Mix proportions for plastered walls as follows: first ratio indicates scratch coat mix, weight of dry plaster to dry sand; second ratio indicates brown coat mix.
3. Load — 360 psi of net stud cross-sectional area.
4. Nominal 2 in. × 4 in. studs of yellow pine or Douglas fir spaced 16 in. in a double row, with studs in rows staggered.
5. Mineral wool batts, 0.19 lb/ft^2.

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Table O.4.5.15 Walls — Miscellaneous Materials 0 in. (0 mm) to Less Than 4 in. (100 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-3-Mi-1	$3\frac{7}{8}$"	Glass brick wall (bricks $5\frac{3}{4}" \times 5\frac{3}{4}" \times 3\frac{7}{8}"$): $\frac{1}{4}$" mortar bed cement/lime/sand; mounted in brick (9") wall with mastic and $\frac{1}{2}$" asbestos rope	n/a	1 hr			7	1,2	1
W-3-Mi-2	3"	Core: 2" magnesium oxysulfate wood-fiber blocks laid in portland cement–lime mortar; facings on both sides; see note 3	n/a	1 hr		1		3	1
W-3-Mi-3	$3\frac{7}{8}$"	Core: $8" \times 4\frac{7}{8}$" glass blocks $3\frac{7}{8}$" thick weighing 4 lb each; laid in portland cement–lime mortar, horizontal mortar joints reinforced with metal lath	n/a	$\frac{1}{4}$ hr		1			$\frac{1}{4}$

Notes:
1. No failure reached at 1 hour.
2. These glass blocks are assumed to be solid based on other test data available for similar but hollow units that show significantly reduced fire endurance.
3. Minimum of $\frac{1}{2}$ in. of 1:3 sanded gypsum plaster required to develop this rating.

Table O.4.5.16 Walls — Miscellaneous Materials 4 in. (100 mm) to Less Than 6 in. (150 mm) Thick

Item Code	Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
W-4-Mi-1	4"	Core: 3" magnesium oxysulfate wood-fiber blocks laid in portland cement mortar; facings: both sides per note 1	n/a	2 hr		1			2

Notes:
1. $\frac{1}{2}$ in. sanded gypsum plaster. Voids in hollow blocks to be not more than 30%.

FIGURE O.4.5.17 Finish Ratings — Inorganic Materials.

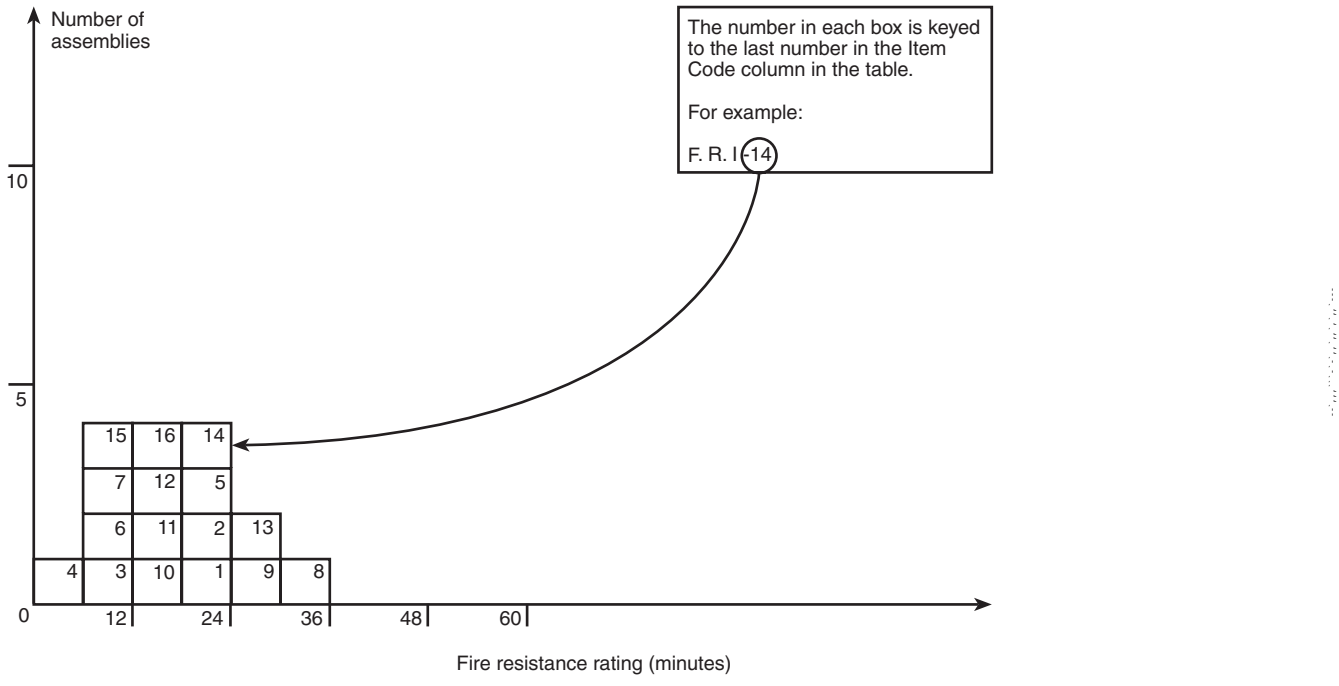

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Table O.4.5.17 Finish Ratings — Inorganic Materials

Item Code	Thickness	Construction Details	Performance	Reference Number			Notes	Rec F.R. (min)
			Finish Rating	Pre-BMS-92	BMS-92	Post-BMS-92		
FR-I-1	9/16"	3/8" gypsum wallboard faced with 3/16" cement-asbestos board	20 min		1		1,2	15
FR-I-2	11/16"	1/2" gypsum sheathing faced with 3/16" cement-asbestos board	20 min		1		1,2	20
FR-I-3	3/16"	3/16" cement-asbestos board over uninsulated cavity	10 min		1		1,2	5
FR-I-4	3/16"	3/16" cement-asbestos board over insulated cavities	5 min		1		1,2	5
FR-I-5	3/4"	3/4" thick 1:2, 1:3 gypsum plaster over paper-backed metal lath	20 min		1		1–3	20
FR-I-6	3/4"	3/4" thick portland cement plaster on metal lath	10 min		1		1,2	10
FR-I-7	3/4"	3/4" thick 1:5, 1:7.5 lime plaster on metal lath	10 min		1		1,2	10
FR-I-8	1"	1" thick neat gypsum plaster on metal lath	35 min		1		1,2,4	35
FR-I-9	3/4"	3/4" thick neat gypsum plaster on metal lath	30 min		1		1,2,4	30
FR-I-10	3/4"	3/4" thick 1:2, 1:2 gypsum plaster on metal lath	15 min		1		1–3	15
FR-I-11	1/2"	Same as F.R.-I-7, except 1/2" thick on wood lath	15 min		1		1–3	15
FR-I-12	1/2"	1/2" thick 1:2, 1:3 gypsum plaster on wood lath	15 min		1		1–3	15
FR-I-13	7/8"	1/2" thick 1:2, 1:2 gypsum plaster on 3/8" perforated gypsum lath	30 min		1		1–3	30
FR-I-14	7/8"	1/2" thick 1:2, 1:2 gypsum plaster on 3/8" thick plain or indented gypsum plaster	20 min		1		1–3	20
FR-I-15	3/8"	3/8" gypsum wallboard	10 min		1		1,2	10
FR-I-16	1/2"	1/2" gypsum wallboard	15 min		1		1,2	15

Notes:
1. The finish rating is the time required to obtain an average temperature rise of 250°F, or a single point rise of 325°F, at the interface between the material being rated and the substrate being protected.
2. Tested in accordance with ASA A2-1934.
3. Mix proportions for plaster as follows: first ratio, dry weight of plaster to dry weight of sand for scratch coat; second ratio, plaster:sand for brown coat.
4. *Neat plaster* means unsanded wood-fiber gypsum plaster.

General Note: The finish rating of modern building materials can be found in the current literature.

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Table O.4.5.18 Finish Rating — Organic Materials

Item Code	Thickness	Construction Details	Performance	Reference Number			Notes	Rec F.R. (min)
			Finish Rating	Pre-BMS-92	BMS-92	Post-BMS-92		
FR-O-1	$^{9}/_{16}$"	$^{7}/_{16}$" wood fiber board faced with $^{1}/_{8}$" cement-asbestos board	15 min		1		1,2	15
FR-O-2	$^{29}/_{32}$"	$^{3}/_{4}$" wood sheathing, asbestos felt weighing 14 lb/100 ft^2 and $^{5}/_{32}$" cement-asbestos shingles	20 min		1		1,2	20
FR-O-3	$1^{1}/_{2}$"	1" thick magnesium oxysulfate wood fiber board faced with 1:3, 1:3 gypsum plaster $^{1}/_{2}$" thick	20 min		1		1–3	20
FR-O-4	$^{1}/_{2}$"	$^{1}/_{2}$" thick wood fiberboard	5 min		1		1,2	5
FR-O-5	$^{1}/_{2}$"	$^{1}/_{2}$" thick flameproofed wood fiberboard	10 min		1		1,2	10
FR-O-6	1"	$^{1}/_{2}$" thick wood fiberboard faced with $^{1}/_{2}$" thick 1:2, 1:2 gypsum plaster	15 min		1		1–3	15
FR-O-7	$1^{3}/_{8}$"	$^{7}/_{8}$" thick flameproofed wood fiberboard faced with $^{1}/_{2}$" thick 1:2, 1:2 gypsum plaster	30 min		1		1–3	30
FR-O-8	$1^{1}/_{4}$"	$1^{1}/_{4}$" thick plywood	30 min			35		30

Notes:
1. The finish rating is the time required to obtain an average temperature rise of 250°F, or a single point rise of 325°F, at the interface between the material being rated and the substrate being protected.
2. Tested in accordance with the ASA A2-1934.
3. Plaster ratios as follows: first ratio, dry weight of plaster to dry weight of sand for scratch coat; second ratio, plaster:sand for brown coat.

General Note: The finish rating of thinner materials, particularly thinner woods, has not been listed because the possible effects of shrinkage, warpage, and aging cannot be predicted.

Table O.4.5.19 Reinforced Concrete Columns Minimum Dimension 0 in. (0 mm) to Less Than 6 in. (150 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-6-RC-1	6"	6" × 6" square columns; gravel aggregate concrete (4030 psi); reinforcement: vertical, four $^{7}/_{8}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; cover 1"	34.7 tons	62 min			7	1,2	1
C-6-RC-2	6"	6" × 6" square columns; gravel aggregate concrete (4200 psi); reinforcement: vertical, four $^{1}/_{2}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; cover 1"	21 tons	69 min			7	1,2	1

Notes:
1. Collapse.
2. British test.

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FIGURE O.4.5.20 Reinforced Concrete Columns with Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm).

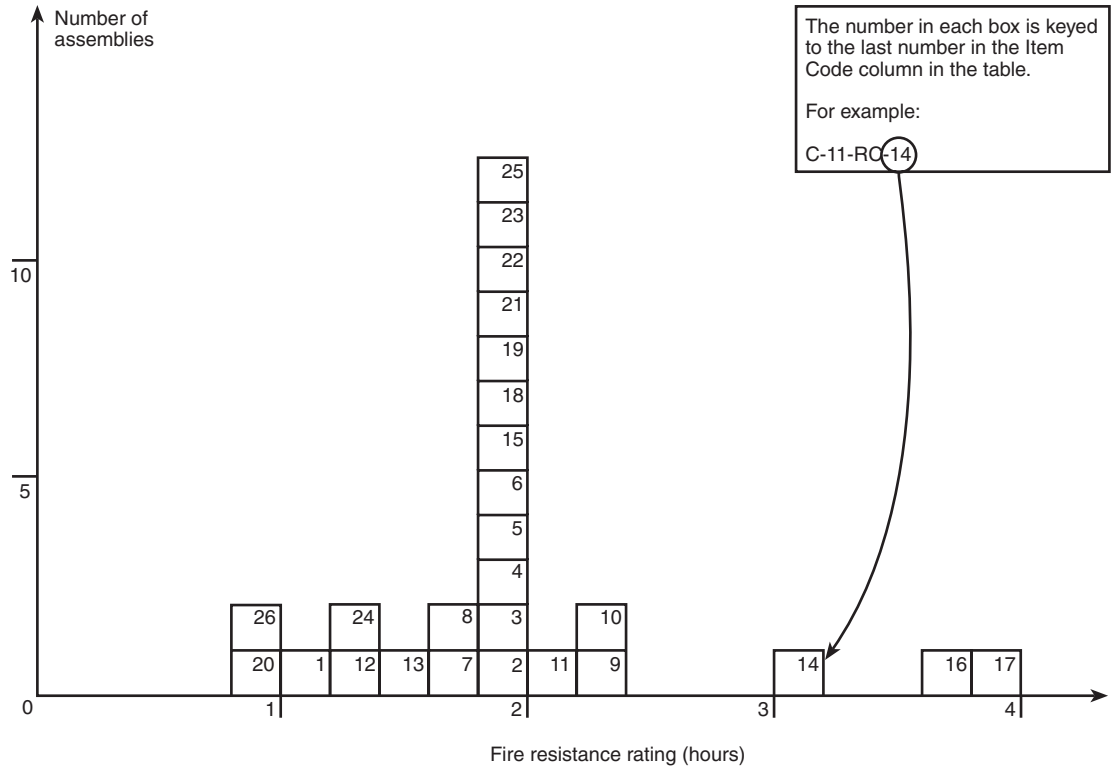

Table O.4.5.20 Reinforced Concrete Columns Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-10-RC-1	10"	10" square columns; aggregate concrete (4260 psi); reinforcement: vertical, four $1^1/_4$" rebars; horizontal, $^3/_8$" ties at 6" pitch; cover $1^1/_4$"	92.2 tons	1 hr 2 min			7	1	1
C-10-RC-2	10"	10" square columns; aggregate concrete (2325 psi); reinforcement: vertical, four $^1/_2$" rebars; horizontal, $^5/_{16}$" ties at 6" pitch; cover 1"	46.7 tons	1 hr 52 min			7	1	$1^3/_4$
C-10-RC-3	10"	10" square columns; aggregate concrete (5370 psi); reinforcement: vertical, four $^1/_2$" rebars; horizontal $^{45}/_{16}$" ties at 6" pitch; cover 1"	46.5 tons	2 hr			7	2,3,11	2
C-10-RC-4	10"	10" square columns; aggregate concrete (5206 psi); reinforcement: vertical, four $^1/_2$" rebars; horizontal, $^5/_{16}$" ties at 6" pitch; cover 1"	46.5 tons	2 hr			7	2,7	2
C-10-RC-5	10"	10" square columns; aggregate concrete (5674 psi); reinforcement: vertical, four $^1/_2$" rebars; horizontal, $^5/_{16}$" ties at 6" pitch; cover 1"	46.7 tons	2 hr			7	1	2
C-10-RC-6	10"	10" square columns; aggregate concrete (5150 psi); reinforcement: vertical, four $1^1/_2$" rebars; horizontal, $^5/_{16}$" ties at 6" pitch; cover 1"	66 tons	1 hr 43 min			7	1	$1^3/_4$

(Sheet 1 of 3)

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Table O.4.5.20 Reinforced Concrete Columns Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-10-RC-7	10"	10" square columns; aggregate concrete (5580 psi); reinforcement: vertical, four $^{1}/_{2}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; 1" cover	62.5 tons	1 hr 38 min			7	1	$1^{1}/_{2}$
C-10-RC-8	10"	10" square columns; aggregate concrete (4080 psi); reinforcement: vertical, four $^{1}/_{8}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; $1^{1}/_{8}$" cover	72.8 tons	1 hr 48 min			7	1	$^{1}/_{4}$
C-10-RC-9	10"	10" square columns; aggregate concrete (2510 psi); reinforcement: vertical, four $^{1}/_{2}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; cover 1"	72.8 tons	1 hr 48 min			7	1	$2^{1}/_{4}$
C-10-RC-10	10"	10" square columns; aggregate concrete (2170 psi); reinforcement: vertical, four $^{1}/_{2}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; cover 1"	45 tons	2 hr 14 min			7	1	$2^{1}/_{4}$
C-10-RC-11	10"	10" square columns; gravel aggregate concrete (4015 psi); reinforcement: vertical, four $^{1}/_{2}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; cover 1"	46.5 tons	2 hr 6 min			7	1	2
C-11-RC-12	11"	11" square columns; gravel aggregate concrete (4150 psi); reinforcement: vertical, four $1^{1}/_{4}$" rebars; horizontal, $^{3}/_{8}$" ties at $7^{1}/_{2}$" pitch; cover $1^{1}/_{2}$"	61 tons	1 hr 23 min			7	1	$1^{1}/_{4}$
C-11-RC-13	11"	11" square columns; gravel aggregate concrete (4380 psi); reinforcement: vertical, four $1^{1}/_{4}$" rebars; horizontal, $^{3}/_{8}$" ties at $7^{1}/_{2}$" pitch; cover $1^{1}/_{2}$"	61 tons	1 hr 26 min			7	1	$1^{1}/_{4}$
C-11-RC-14	11"	11" square columns; gravel aggregate concrete (4140 psi); reinforcement: vertical, four $1^{1}/_{4}$" rebars; horizontal, $^{3}/_{8}$" ties at $7^{1}/_{2}$" pitch; steel mesh around reinforcement; cover $1^{1}/_{2}$"	61 tons	3 hr 9 min			7	1	3
C-11-RC-15	11"	11" square columns; slag aggregate concrete (3690 psi); reinforcement: vertical, four $1^{1}/_{4}$" rebar; horizontal, $^{3}/_{8}$" ties at $7^{1}/_{2}$" pitch; cover $1^{1}/_{2}$"	91 tons	2 hr			7	2–5	2
C-11-RC-16	11"	11" square columns; limestone aggregate concrete (5230 psi); reinforcement: vertical, four $1^{1}/_{4}$" rebars; horizontal, $^{3}/_{8}$" ties at $7^{1}/_{2}$" pitch; cover $1^{1}/_{2}$"	91.5 tons	3 hr 41 min			7	1	$3^{1}/_{2}$
C-11-RC-17	11"	11" square columns; limestone aggregate concrete (5530 psi); reinforcement: vertical, four $1^{1}/_{4}$" rebars; horizontal, $^{3}/_{8}$" ties at $7^{1}/_{2}$" pitch; cover $1^{1}/_{2}$"	91.5 tons	3 hr 47 min			7	1	$3^{1}/_{2}$
C-11-RC-18	11"	11" square columns; limestone aggregate concrete (5280 psi); reinforcement: vertical, four $1^{1}/_{4}$" rebars; horizontal, $^{3}/_{8}$" ties at $7^{1}/_{2}$" pitch; cover $1^{1}/_{2}$"	91.5 tons	2 hr			7	2–4,6	2

(Sheet 2 of 3)

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Table O.4.5.20 Reinforced Concrete Columns Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-11-RC-19	11"	11" square columns; limestone aggregate concrete (4180 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^3/_8$" ties at 7" pitch; cover $1^1/_2$"	71.4 tons	2 hr			7	2,7	2
C-11-RC-20	11"	11" square columns; gravel concrete (4530 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^3/_8$" ties at 7" pitch; cover $1^1/_2$" with $^1/_2$" plaster	58.8 tons	2 hr			7	2,3,9	$1^1/_4$
C-11-RC-21	11"	11" square columns; gravel concrete (3520 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^3/_8$" ties at 7" pitch; cover $1^1/_2$"	variable	1 hr 24 min			7	1,8	2
C-11-RC-22	11"	11" square columns; aggregate concrete (3710 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^3/_8$" ties at 7" pitch; cover $1^1/_2$"	58.8 tons	2 hr			7	2,3,10	2
C-11-RC-23	11"	11" square columns; aggregate concrete (3190 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^3/_8$" ties at 7" pitch; cover $1^1/_2$"	58.8 tons	2 hr			7	2,3,10	2
C-11-RC-24	11"	11" square columns; aggregate concrete (4860 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^3/_8$" ties at 7" pitch; cover $1^1/_2$"	86.1 tons	1 hr 20 min			7	1	$1^1/_3$
C-11-RC-25	11"	11" square columns; aggregate concrete (4850 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^3/_8$" ties at 7" pitch; cover $1^1/_2$"	58.8 tons	1 hr 59 min			7	1	$1^3/_4$
C-11-RC-26	11"	11" square columns; aggregate concrete (3834 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^5/_{16}$" ties at $4^1/_2$" pitch; cover $1^1/_2$"	71.4 tons	53 min			7	1	$^3/_4$

(Sheet 3 of 3)

Notes:
1. Failure mode — collapse.
2. Passed 2-hour fire exposure.
3. Passed hose stream test.
4. Reloaded effectively after 48 hours but collapsed at load in excess of original test load.
5. Failing load was 150 tons.
6. Failing load was 112 tons.
7. Failed during hose stream test.
8. Range of load, 58.8 tons (initial) to 92 tons (92 min) to 60 tons (80 min).
9. Collapsed at 44 tons in reload after 96 hours.
10. Withstood reload after 72 hours.
11. Collapsed on reload after 48 hours.

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Table O.4.5.21 Reinforced Concrete Columns Minimum Dimension 12 in. (300 mm) to Less Than 14 in. (350 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-12-RC-1	12"	12" square columns; gravel aggregate concrete (2647 psi); reinforcement: vertical, four $^5/_8$" rebars; horizontal, $^5/_{16}$" ties at $4^1/_2$" pitch; cover 2"	78.2 tons	38 min		1	7	1	$^1/_2$
C-12-RC-2	12"	Reinforced columns with $1^1/_2$" concrete outside of reinforced steel; gross diameter or side of column 12"; Group I, Column A		6 hr		1		2,3	6
C-12-RC-3	12"	Description as per C-12-RC-2; Group I, Column B		4 hr		1		2,3	4
C-12-RC-4	12"	Description as per C-12-RC-2; Group II, Column A		4 hr		1		2,3	4
C-12-RC-5	12"	Description as per C-12-RC-2; Group II, Column B		2 hr 30 min		1		2,3	$2^1/_2$
C-12-RC-6	12"	Description as per C-12-RC-2; Group III, Column A		6 hr		1		2,3	3
C-12-RC-7	12"	Description as per C-12-RC-2; Group III, Column B		2 hr		1		2,3	2
C-12-RC-8	12"	Description as per C-12-RC-2; Group IV, Column A		2 hr		1		2,3	2
C-12-RC-9	12"	Description as per C-12-RC-2; Group IV, Column B		1 hr 30 min		1		2,3	$1^1/_2$

Notes:
1. Failure mode — unspecified structural.
2. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

3. Groupings of aggregates and ties are the same as for structural steel columns protected solidly with concrete, the ties to be placed over the vertical reinforcing bars and the mesh, where required, to be placed within 1 in. from the surface of the column.

Column A — working loads are assumed as carried by the area of the column inside of the lines circumscribing the reinforcing steel.

Column B — working loads are assumed as carried by the gross area of the column.

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Table O.4.5.22 Reinforced Concrete Columns Minimum Dimension 14 in. (350 mm) to Less Than 16 in. (400 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-14-RC-1	14"	14" square columns; gravel aggregate concrete (4295 psi); reinforcement: vertical, four $^{3}/_{4}$" rebars; horizontal, $^{1}/_{4}$" ties at 9" pitch; cover $1^{1}/_{2}$"	86 tons	1 hr 22 min			7	1	$1^{1}/_{4}$
C-14-RC-2	14"	Reinforced concrete columns with $1^{1}/_{2}$" concrete outside reinforcing steel; gross diameter or side of column: 14"; Group I, Column A		7 hr		1		2,3	7
C-14-RC-3	14"	Description as per C-14-RC-2; Group II, Column B		5 hr		1		2,3	5
C-14-RC-4	14"	Description as per C-14-RC-2; Group III, Column A		5 hr		1		2,3	5
C-14-RC-5	14"	Description as per C-14-RC-2; Group IV, Column B		3 hr 30 min		1		2,3	$3^{1}/_{2}$
C-14-RC-6	14"	Description as per C-14-RC-2; Group III, Column A		4 hr		1		2,3	4
C-14-RC-7	14"	Description as per C-14-RC-2; Group III, Column B		2 hr 30 min		1		2,3	$2^{1}/_{2}$
C-14-RC-8	14"	Description as per C-14-RC-2; Group IV, Column A		2 hr 30 min		1		2,3	$2^{1}/_{2}$
C-14-RC-9	14"	Description as per C-14-RC-2; Group IV, Column B		1 hr 30 min		1		2,3	$1^{1}/_{2}$

Notes:

1. Failure mode — main rebars buckled between links at various points.
2. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

3. Groupings of aggregates and ties are the same as for structural steel columns protected solidly with concrete, the ties to be placed over the vertical reinforcing bars and the mesh, where required, to be placed within 1 in. from the surface of the column.

Column A — working loads are assumed as carried by the area of the column inside of the lines circumscribing the reinforcing steel.

Column B — working loads are assumed as carried by the gross area of the column.

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FIGURE O.4.5.23 Reinforced Concrete Columns with Minimum Dimension 16 in. (400 mm) to Less Than 18 in. (450 mm).

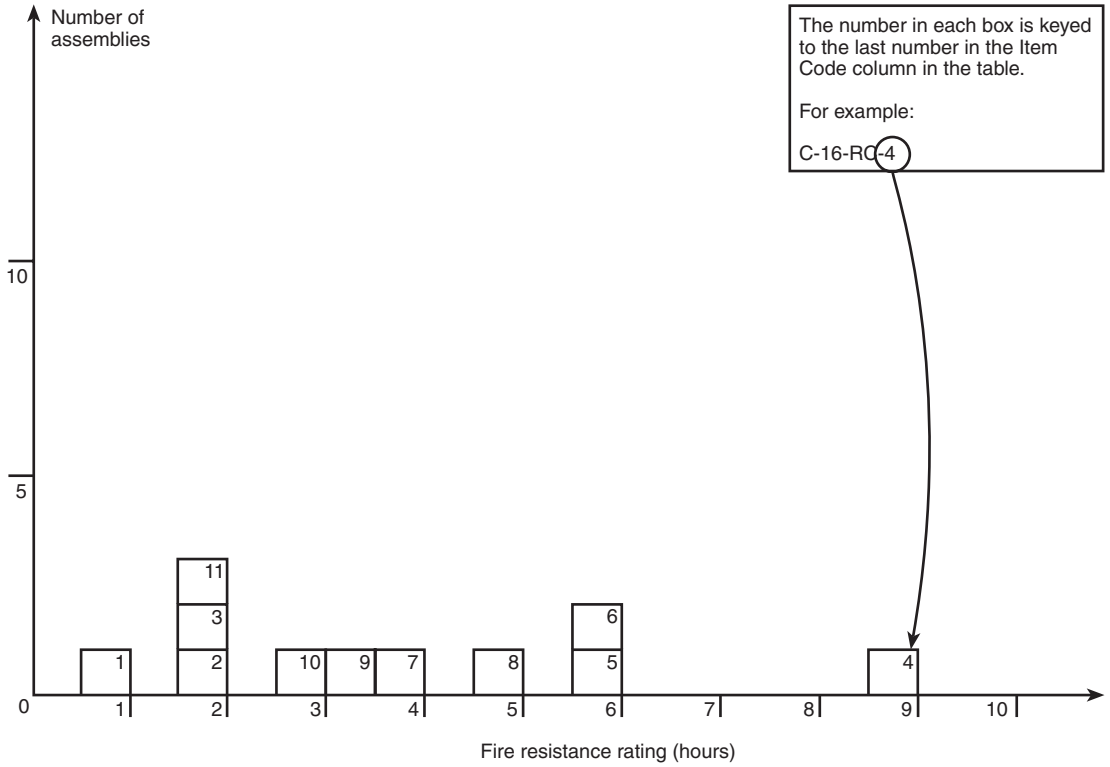

Table O.4.5.23 Reinforced Concrete Columns Minimum Dimension 16 in. (400 mm) to Less Than 18 in. (450 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-16-RC-1	16"	16" square columns; gravel aggregate concrete (4550 psi); reinforcement: vertical, eight $1^{3}/_{8}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch linking center rebars of each face forming a smaller square in column cross section	237 tons	1 hr			7	1–3	1
C-16-RC-2	16"	16" square columns; gravel aggregate concrete (3360 psi); reinforcement: vertical, eight $1^{3}/_{8}$" rebars; horizontal, $^{5}/_{16}$" ties at 6" pitch; cover $1^{3}/_{8}$"	210 tons	2 hr			7	2,4–6	2
C-16-RC-3	16"	16" square columns; gravel aggregate concrete (3980 psi); reinforcement: vertical, four $^{7}/_{8}$" rebars; horizontal, $^{3}/_{8}$" ties at 6" pitch; cover 1"	123.5 tons	2 hr			7	2,4,7	2
C-16-RC-4	16"	Reinforced concrete columns with $1^{1}/_{2}$" concrete outside reinforcing steel; gross diam. or side of column: 16"; Group I, Column A		9 hr		1		8,9	9
C-16-RC-5	16"	Description as per C-16-RC-4; Group I, Column B		6 hr		1		8,9	6
C-16-RC-6	16"	Description as per C-16-RC-4; Group II, Column A		6 hr		1		8,9	6

(Sheet 1 of 2)

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Table O.4.5.23 Reinforced Concrete Columns Minimum Dimension 16 in. (400 mm) to Less Than 18 in. (450 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-16-RC-7	16"	Description as per C-16-RC-4; Group II, Column B		4 hr		1		8,9	4
C-16-RC-8	16"	Description as per C-16-RC-4; Group III, Column A		5 hr		1		8,9	5
C-16-RC-9	16"	Description as per C-16-RC-4; Group III, Column B		3 hr 30 min		1		8,9	$3^1/_2$
C-16-RC-10	16"	Description as per C-16-RC-4; Group IV, Column A		3 hr		1		8,9	3
C-16-RC-11	16"	Description as per C-16-RC-4; Group IV, Column B		2 hr		1		8,9	2

(Sheet 2 of 2)

Notes:
1. Column passed 1-hour fire test.
2. Column passed hose stream test.
3. No reload specified.
4. Column passed 2-hour fire test.
5. Column reloaded successfully after 24 hours.
6. Reinforcing details same as C-16-RC-1.
7. Column passed reload after 72 hours.
8. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

9. Groupings of aggregates and ties are the same as for structural steel columns protected solidly with concrete, the ties to be placed over the vertical reinforcing bars and the mesh, where required, to be placed within 1 in. from the surface of the column.

Column A — working loads are assumed as carried by the area of the column inside of the lines circumscribing the reinforcing steel.

Column B — working loads are assumed as carried by the gross area of the column.

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Table O.4.5.24 Reinforced Concrete Columns Minimum Dimension 18 in. (450 mm) to Less Than 20 in. (500 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-18-RC-1	18"	Reinforced concrete columns with $1^1/_2$" concrete outside reinforcing steel; gross diam. or side of column: 18"; Group I, Column A		11 hr		1		1,2	11
C-18-RC-2	18"	Description as per C-18-RC-1; Group I, Column B		8 hr		1		1,2	8
C-18-RC-3	18"	Description as per C-18-RC-1; Group II, Column A		7 hr		1		1,2	7
C-18-RC-4	18"	Description as per C-18-RC-1; Group II, Column B		5 hr		1		1,2	5
C-18-RC-5	18"	Description as per C-18-RC-1; Group III, Column A		6 hr		1		1,2	6
C-18-RC-6	18"	Description as per C-18-RC-1; Group III, Column B		4 hr		1		1,2	4
C-18-RC-7	18"	Description as per C-18-RC-1; Group IV, Column A		3 hr 30 min		1		1,2	$3^1/_2$
C-18-RC-8	18"	Description as per C-18-RC-1; Group IV, Column B		2 hr 30 min		1		1,2	$2^1/_2$

Notes:

1. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

2. Groupings of aggregates and ties are the same as for structural steel columns protected solidly with concrete, the ties to be placed over the vertical reinforcing bars and the mesh, where required, to be placed within 1 in. from the surface of the column.

Column A — working loads are assumed as carried by the area of the column inside of the lines circumscribing the reinforcing steel.

Column B — working loads are assumed as carried by the gross area of the column.

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FIGURE O.4.5.25 Reinforced Concrete Columns with Minimum Dimension 20 in. (500 mm) to Less Than 22 in. (550 mm).

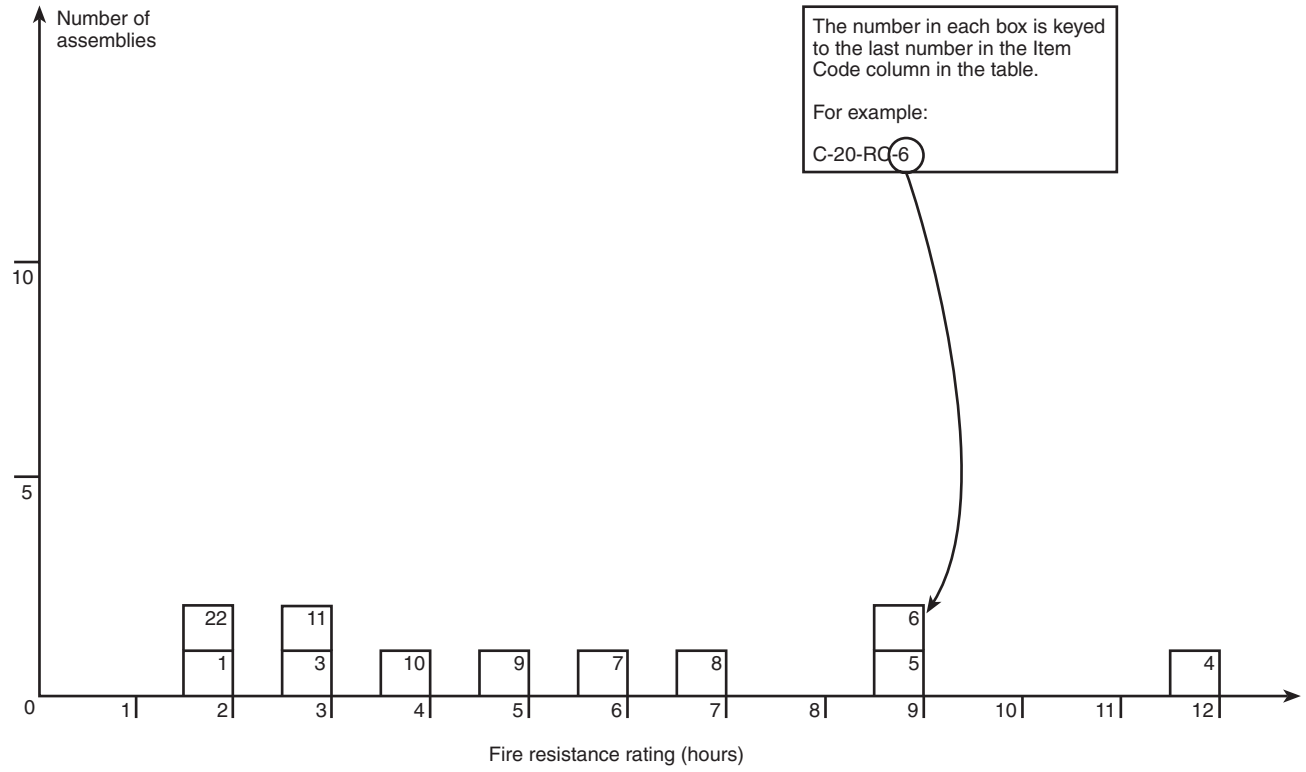

Table O.4.5.25 Reinforced Concrete Columns Minimum Dimension 20 in. (500 mm) to Less Than 22 in. (550 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-20-RC-1	20"	20" square columns; gravel aggregate concrete (6690 psi); reinforcement: vertical, four $1^3/_4$" rebars; horizontal, $^3/_8$" wire at 6" pitch; cover $1^3/_4$"	367 tons	2 hr			7	1–3	2
C-20-RC-2	20"	20" square columns; gravel aggregate concrete (4330 psi); reinforcement: vertical, four $1^3/_4$" rebars; horizontal, $^3/_8$" ties at 6" pitch; cover $1^3/_4$"	327 tons	2 hr			7	1,2,4	2
C-20-RC-3	$20^1/_4$"	$20^1/_4$" square columns; gravel aggregate concrete (4230 psi); reinforcement: vertical, four $1^1/_8$" rebars; horizontal, $^3/_8$" wire at 5" pitch; cover $1^1/_8$"	199 tons	2 hr 56 min			7	5	$2^3/_4$
C-20-RC-4	20"	Reinforced concrete columns with $1^1/_2$" concrete outside of reinforcing steel; gross diameter or side of column: 20"; Group I, Column A		12 hr		1		6,7	12

(Sheet 1 of 2)

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Table O.4.5.25 Reinforced Concrete Columns Minimum Dimension 20 in. (500 mm) to Less Than 22 in. (550 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-20-RC-5	20"	Description as per C-20-RC-4; Group I, Column B		9 hr		1		6,7	9
C-20-RC-6	20"	Description as per C-20-RC-4; Group II, Column A		9 hr		1		6,7	9
C-20-RC-7	20"	Description as per C-20-RC-4; Group II, Column B		6 hr		1		6,7	6
C-20-RC-8	20"	Description as per C-20-RC-4; Group III, Column A		7 hr		1		6,7	7
C-20-RC-9	20"	Description as per C-20-RC-4; Group III, Column B		5 hr		1		6,7	5
C-20-RC-10	20"	Description as per C-20-RC-4; Group IV, Column A		4 hr		1		6,7	4
C-20-RC-11	20"	Description as per C-20-RC-4; Group IV, Column B		3 hr		1		6,7	3

(Sheet 2 of 2)

Notes:
1. Passed 2-hour fire test.
2. Passed hose stream test.
3. Failed during reload at 300 tons.
4. Passed reload after 72 hours.
5. Failure mode — collapse.
6. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

7. Groupings of aggregates and ties are the same as for structural steel columns protected solidly with concrete, the ties to be placed over the vertical reinforcing bars and the mesh, where required, to be placed within 1 in. from the surface of the column.

Column A — working loads are assumed as carried by the area of the column inside of the lines circumscribing the reinforcing steel.

Column B — working loads are assumed as carried by the gross area of the column.

Table O.4.5.26 Hexagonal Reinforced Concrete Columns Minimum Dimension 12 in. (300 mm) to Less Than 14 in. (350 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-12-HRC-1	12"	12" hexagonal columns; gravel aggregate concrete (4420 psi); vertical reinforcement: eight $^1/_2$" rebars; horizontal reinforcement: $^5/_{16}$" helical winding at $1^1/_2$" pitch; cover $^1/_2$"	88 tons	58 min			7	1	$^3/_4$
C-12-HRC-2	12"	12" hexagonal columns; gravel aggregate concrete (3460 psi); vertical reinforcement: eight $^1/_2$" rebars; horizontal reinforcement: $^5/_{16}$" helical winding at $1^1/_2$" pitch; cover $^1/_2$"	78.7 tons	1 hr			7	2	1

Notes:
1. Failure mode — collapse.
2. Test stopped at 1 hour.

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Table O.4.5.27 Hexagonal Reinforced Concrete Columns Minimum Dimension 14 in. (350 mm) to Less Than 16 in. (400 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-14-HRC-1	14"	14" hexagonal columns; gravel aggregate concrete (4970 psi); vertical reinforcement: eight $^1/_2$" rebars; horizontal reinforcement: $^5/_{16}$" helical winding at 2" pitch; cover $^1/_2$"	90 tons	2 hr			7	1–3	2

Notes:
1. Withstood 2-hour fire test.
2. Withstood hose stream test.
3. Withstood reload after 48 hours.

Table O.4.5.28 Hexagonal Reinforced Concrete Columns Diameter 16 in. (400 mm) to Less Than 18 in. (450 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-16-HRC-1	16"	16" hexagonal columns; gravel concrete (6320 psi); vertical reinforcement: eight $^5/_8$" rebars; horizontal reinforcement: $^5/_{16}$" helical winding at $^3/_4$" pitch; cover $^1/_2$"	140 tons	1 hr 55 min			7	1	$1^3/_4$
C-16-HRC-2	16"	16" hexagonal columns; gravel aggregate concrete (5580 psi); vertical reinforcement: eight $^5/_8$" rebars; horizontal reinforcement: $^5/_{16}$" helical winding at $1^3/_4$" pitch; cover $^1/_2$"	124 tons	2 hr			7	2	2

Notes:
1. Failure mode — collapse.
2. Failed on furnace removal.

Table O.4.5.29 Hexagonal Reinforced Concrete Columns Diameter 20 in. (500 mm) to Less Than 22 in. (550 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-20-HRC-1	20"	20" hexagonal columns; gravel concrete (6080 psi); vertical reinforcement: $^3/_4$" rebars; horizontal reinforcement: $^5/_{16}$" helical winding at $1^3/_4$" pitch; cover $^1/_2$"	211 tons	2 hr			7	1	2
C-20-HRC-2	20"	20" hexagonal columns; gravel concrete (5080 psi); vertical reinforcement: $^3/_4$" rebars; horizontal reinforcement: $^5/_{16}$" wire at $1^3/_4$" pitch; cover $^1/_2$"	184 tons	2 hr 15 min			7	2,3,4	$2^1/_4$

Notes:
1. Column collapsed on furnace removal.
2. Passed $2^1/_4$-hour fire test.
3. Passed hose stream test.
4. Withstood reload after 48 hours.

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Table O.4.5.30 Round Cast Iron Columns

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-7-CI-1	7" O.D.	Column: 0.6" minimum metal thickness, unprotected	—	30 min		1			$^1/_2$
C-7-CI-2	7" O.D.	Column: 0.6" metal thickness concrete filled, outside unprotected	—	45 min		1			$^3/_4$
C-11-CI-3	11" O.D.	Column: 0.6" minimum metal thickness; protection: $1^1/_2$" portland cement plaster on high ribbed metal lath, $^1/_2$" broken air space	—	3 hr		1			3
C-11-CI-4	11" O.D.	Column: 0.6" minimum metal thickness; protection: 2" concrete other than siliceous aggregate	—	2 hr 30 min		1			$2^1/_2$
C-12-CI-5	12.5" O.D.	Column: 7" O.D., 0.6" minimum metal thickness; protection: 2" porous hollow tile, $^3/_4$" mortar between tile and column, outside wire ties	—	3 hr		1			3
C-7-CI-6	7.6" O.D.	Column: 7" I.D., $^3/_{10}$" minimum metal thickness, concrete filled, unprotected	—	30 min		1			$^1/_2$
C-8-CI-7	8.6" O.D.	Column: 8" I.D., $^3/_{10}$" minimum metal thickness, concrete filled, reinforced with four $3^1/_2$" × $^3/_8$" angles, in fill; outside unprotected	—	1 hr		1			1

FIGURE O.4.5.31 Steel Columns — Gypsum Encasements.

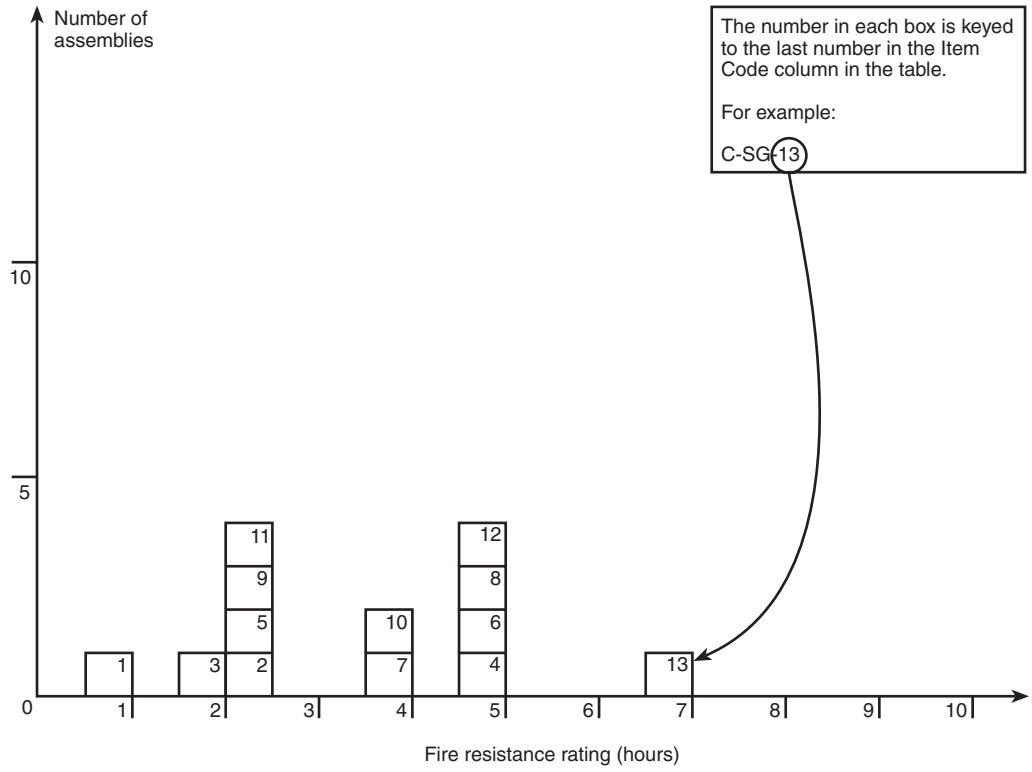

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Table O.4.5.31 Steel Columns — Gypsum Encasements

Item Code	Minimum Area of Solid Material	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-SG-1	—	Steel protected with $^3/_4$" 1:3 sanded gypsum or 1" 1:2$^1/_2$ portland cement plaster on wire or lath; one layer	—	1 hr		1			1
C-SG-2	—	Same as C-SG-1; two layers	—	2 hr 30 min		1			2$^1/_2$
C-SG-3	130 in.^{2}	2" solid blocks with wire mesh in horizontal joints, 1" mortar on flange, re-entrant space filled with block and mortar	—	2 hr		1			2
C-SG-4	150 in.^{2}	Same as C-130-SG-3 with $^1/_2$" sanded gypsum plaster	—	5 hr		1			5
C-SG-5	130 in.^{2}	2" solid blocks with wire mesh in horizontal joints, 1" mortar on flange, re-entrant space filled with gypsum concrete	—	2 hr 30 min		1			2$^1/_2$
C-SG-6	150 in.^{2}	Same as C-130-SG-5 with $^1/_2$" sanded gypsum plaster	—	5 hr		1			5
C-SG-7	300 in.^{2}	4" solid blocks with wire mesh in horizontal joints, 1" mortar on flange, re-entrant space filled with block and mortar	—	4 hr		1			4
C-SG-8	300 in.^{2}	Same as C-300-SG-7 with re-entrant space filled with gypsum concrete	—	5 hr		1			5
C-SG-9	85 in.^{2}	2" solid blocks with cramps at horizontal joints, mortar on flange only at horizontal joints, re-entrant space not filled	—	2 hr 30 min		1			2$^1/_2$
C-SG-10	105 in.^{2}	Same as C-85-SG-9 with $^1/_2$" sanded gypsum plaster	—	4 hr		1			4
C-SG-11	95 in.^{2}	3" hollow blocks with cramps at horizontal joints, mortar on flange only at horizontal joints, re-entrant space not filled	—	2 hr 30 min		1			2$^1/_2$
C-SG-12	120 in.^{2}	Same as C-95-SG-11 with $^1/_2$" sanded gypsum plaster	—	5 hr		1			5
C-SG-13	130 in.^{2}	2" neat fibered gypsum re-entrant space filled, poured solid and reinforced with 4" × 4" wire mesh, $^1/_2$" sanded gypsum plaster	—	7 hr		1			7

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Table O.4.5.32 Timber Columns

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-11-TC-1	11"	With unprotected steel plate cap		30 min		1		1,2	$^1/_2$
C-11-TC-2	11"	With unprotected cast iron cap and pintle		45 min		1		1,2	$^3/_4$
C-11-TC-3	11"	With concrete or protected steel or cast iron cap		1 hr 15 min		1		1,2	$1^1/_4$
C-11-TC-4	11"	With $^3/_8$" gypsum wallboard over column and over cast iron or steel cap		1 hr 15 min		1		1,2	$1^1/_4$
C-11-TC-5	11"	With 1" portland cement plaster on wire lath over column and over cast iron or steel cap; $^3/_4$" air space		2 hr		1		1,2	2

Notes:
1. Minimum area: 120 in.^{2}.
2. Type of wood: Long leaf pine or Douglas fir.

Table O.4.5.33 Steel Columns — Concrete Encasements Minimum Dimension Less Than 6 in. (150 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-5-SC-1	5"	5" × 6" outer dimensions; 4" × 3" × 10 lb H beam; protection: gravel concrete (4900 psi); 6" × 4" mesh 13 SWG	12 tons	1 hr 29 min			7	1	$1^1/_4$

Note:
1. Failure mode — collapse.

Table O.4.5.34 Steel Columns — Concrete Encasements Minimum Dimension 6 in. (150 mm) to Less Than 8 in. (200 mm) Thick

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-7-SC-1	7"	7" × 8" column; 4" × 3" × 10 lb H beam; protection: brick-filled concrete (6220 psi); 6" × 4" mesh 13 SWG, mesh 1" below column surface	12 tons	2 hr 46 min			7	1	3
C-7-SC-2	7"	7" × 8" column; 4" × 3" × 10 lb H beam; protection: gravel concrete (5140 psi); 6" × 4" mesh 13 SWG, 1" below surface	12 tons	3 hr 1 min			7	1	$2^3/_4$
C-7-SC-3	7"	7" × 8" column; 4" × 3" × 10 lb H beam; protection: concrete (4540 psi); 6" × 4" mesh 13 SWG, 1" below column surface	12 tons	3 hr 9 min			7	1	3
C-7-SC-4	7"	7" × 8" column; 4" × 3" × 10 lb H beam; protection: gravel concrete (5520 psi); 4" × 4" mesh 16 SWG	12 tons	2 hr 50 min			7	1	$2^3/_4$

Note:
1. Failure mode — collapse.

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FIGURE O.4.5.35 Steel Columns — Concrete Encasements with Minimum Dimension 8 in. (200 mm) to Less Than 10 in. (250 mm).

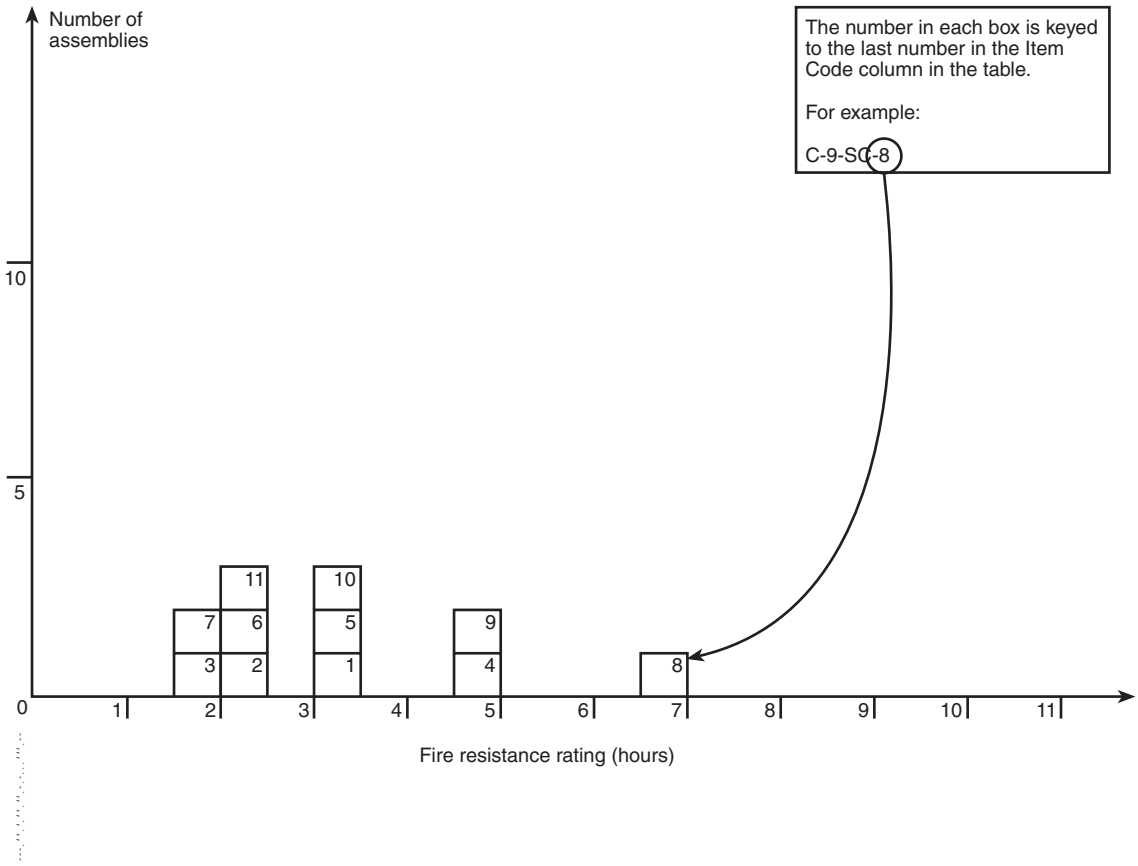

Table O.4.5.35 Steel Columns — Concrete Encasements Minimum Dimension 8 in. (200 mm) to Less Than 10 in. (250 mm)

Item Code	Minimum Dimension	Construction details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-8-SC-1	$8^1/_2$"	$8^1/_2$" × 10" column; 6" × $4^1/_2$" × 20 lb H beam; protection: gravel concrete (5140 psi); 6" × 4" mesh 13 SWG	39 tons	3 hr 8 min			7	1	3
C-8-SC-2	8"	8" × 10" column; 8" × 6" × 35 lb I beam; protection: gravel concrete (4240 psi); 4" × 6" mesh 13 SWG, with $^1/_2$" cover	90 tons	2 hr 1 min			7	1	2
C-8-SC-3	8"	8" × 10" concrete encased column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (3750 psi) with 4" mesh 16 SWG reinforcing $^1/_2$" below column surface	90 tons	1 hr 58 min			7	1	$1^3/_4$
C-8-SC-4	8"	6" × 6" steel column with 2" outside protection; Group I	—	5 hr		1		2	5
C-8-SC-5	8"	6" × 6" steel column with 2" outside protection; Group II	—	3 hr 30 min		1		2	$3^1/_2$
C-8-SC-6	8"	6" × 6" steel column with 2" outside protection; Group III	—	2 hr 30 min		1		2	$2^1/_2$
C-8-SC-7	8"	6" × 6" steel column with 2" outside protection; Group IV	—	1 hr 45 min		1		2	$1^3/_4$

(Sheet 1 of 2)

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Table O.4.5.35 Steel Columns — Concrete Encasements Minimum Dimension 8 in. (200 mm) to Less Than 10 in. (250

Item Code	Minimum Dimension	Construction details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-9-SC-8	9"	6" × 6" steel column with 3" outside protection; Group I	—	7 hr		1		2	7
C-9-SC-9	9"	6" × 6" steel column with 3" outside protection; Group II	—	5 hr		1		2	5
C-9-SC-10	9"	6" × 6" steel column with 3" outside protection; Group III	—	30 hr 30 min		1		2	$3^1/_2$
C-9-SC-11	9"	6" × 6" steel column with 3" outside protection; Group IV	—	2 hr 30 min		1		2	$2^1/_2$

(Sheet 2 of 2)

Notes:
1. Failure mode — collapse.
2. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

FIGURE O.4.5.36 Steel Columns — Concrete Encasements with Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm).

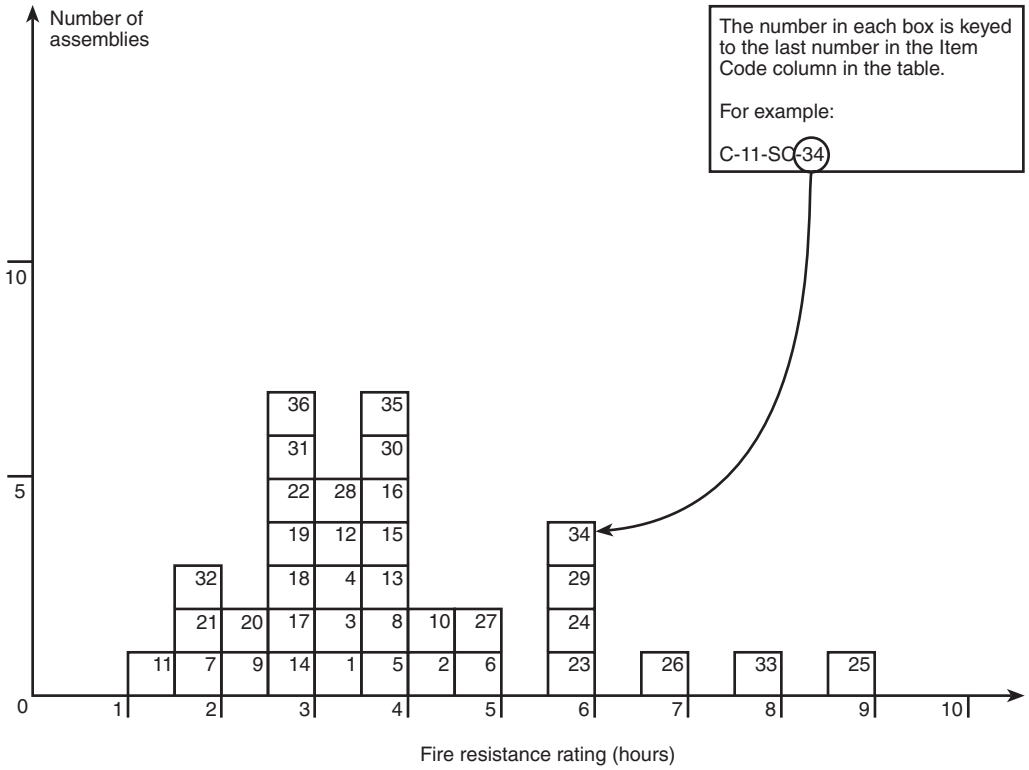

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Table O.4.5.36 Steel Columns — Concrete Encasements Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-10-SC-1	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: gravel aggregate concrete (3640 psi); 6" × 4" mesh; 13 SWG, 1" below column surface	90 tons	3 hr 7 min			7	1,2	3
C-10-SC-2	10"	10" × 16"column; 8" × 6" × 35 lb H beam; protection: clay brick concrete (3630 psi); 6" × 4" mesh; 13 SWG, 1" below column surface	90 tons	4 hr 6 min			7	2	4
C-10-SC-3	10"	10" × 12" column; 8" × 6" × 35 lb H beam; protection: concrete of crushed stone and sand (3930 psi); 6" × 4" mesh; 13 SWG, 1" below column surface	90 tons	3 hr 17 min			7	2	$3^1/_4$
C-10-SC-4	10"	10" × 12"column; 8" × 6" × 35 lb H beam; protection: concrete of crushed basalt and sand (4350 psi); 6" × 4" mesh; 13 SWG, 1" below column surface	90 tons	3 hr 22 min			7	2	$3^1/_3$
C-10-SC-5	10"	10" × 12" column; 8" × 6" × 35 lb H beam; protection: concrete gravel aggregate (5570 psi); 6" × 4" mesh; 13 SWG	90 tons	3 hr 39 min			7	2	$3^1/_2$
C-10-SC-6	10"	10" × 16" column; 8" × 6" × 35 lb I beam; protection: gravel concrete (4950 psi); 6" × 4" mesh; 13 SWG, 1" below column surface	90 tons	4 hr 32 min			7	2	$4^1/_2$
C-10-SC-7	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (1370 psi); 6" × 4" mesh; 13 SWG reinforcing 1" below column surface	90 tons	2 hr			7	3,4	2
C-10-SC-8	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H column; protection: aggregate concrete (4000 psi); 13 SWG iron wire loosely wound around column at 6" pitch, about 2" below column surface	86 tons	3 hr 36 min			7	2	$3^1/_2$
C-10-SC-9	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (3290 psi); 2" cover minimum	86 tons	2 hr 8 min			7	2	2
C-10-SC-10	10"	10" × 14" concrete-encased column; 8" × 6" × 35 lb H column; protection: crushed clay brick–filled concrete (5310 psi); 6" × 4" mesh; 13 SWG reinforcing 1" below column surface	90 tons	4 hr 28 min			7	2	$4^1/_3$
C-10-SC-11	10"	10" × 12" concrete-encased column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (342 psi); 6" × 4" mesh; 13 SWG reinforcing 1" below column surface	90 tons	1 hr 2 min			7	2	1
C-10-SC-12	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (4480 psi); four $^3/_8$" vertical rebars at H beam edges, with $^3/_{16}$" spacers at beam surface at 3' pitch and $^3/_{16}$" binders at 10" pitch; 2" concrete cover	90 tons	3 hr 2 min			7	2	3

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Table O.4.5.36 Steel Columns — Concrete Encasements Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-10-SC-13	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (5070 psi); 6" × 4" mesh; 13 SWG reinforcing at 6", beam sides wrapped and held by wire ties across (open) 8" beam face; reinforcements wrapped in 6" × 4" mesh; 13 SWG throughout, with $^1/_2$" cover to column surface	90 tons	3 hr 59 min			7	2	$3^3/_4$
C-10-SC-14	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H column; protection: aggregate concrete (4410 psi); 6" × 4" mesh; 13 SWG reinforcing $1^1/_4$" below column surface; $^1/_2$" lime-cement plaster with $^3/_8$" gypsum plaster finish	90 tons	2 hr 50 min			7	2	$2^3/_4$
C-10-SC-15	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: crushed clay brick-filled concrete (4260 psi); 6" × 4" mesh; 13 SWG reinforcing 1" below column surface	90 tons	3 hr 54 min			7	2	$3^3/_4$
C-10-SC-16	10"	10" × 12" concrete-encased steel columns; 8" × 6" × 35 lb H beam; protection: limestone aggregate concrete (4350 psi); 6" × 4" mesh; 13 SWG reinforcing 1" below column surface	90 tons	3 hr 54 min			7	2	$3^3/_4$
C-10-SC-17	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: limestone aggregate concrete (5300 psi); 6" × 4" mesh 13 SWG, 1" below column surface	90 tons	3 hr			7	4,5	3
C-10-SC-18	10"	10" × 12" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: limestone aggregate concrete (4800 psi); 6" × 4" mesh; 13 SWG reinforcing 1" below column surface	90 tons	3 hr			7	4,5	3
C-10-SC-19	10"	10" × 14" concrete-encased steel column; 12" × 8" × 65 lb H beam; protection: aggregate concrete (3900 psi); 4" mesh; 16 SWG reinforcing $^1/_2$" below column surface	118 tons	2 hr 42 min			7	2	2
C-10-SC-20	10"	10" × 14" concrete-encased steel column; 12" × 8" × 65 lb H beam; protection: aggregate concrete (4930 psi); 4" mesh; 16 SWG reinforcing $^1/_2$" below column surface	177 tons	2 hr 8 min			7	2	2
C-10-SC-21	$10^3/_8$"	$10^3/_8$" × $12^3/_8$" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (835 psi); 6" × 4" mesh; 13 SWG reinforcing $1^3/_{16}$" below column surface; $^3/_{16}$" gypsum plaster finish	90 tons	2 hr			7	3,4	2
C-11-SC-22	11"	11" × 13" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: "open texture" brick-filled concrete (890 psi); 6" × 4" mesh; 13 SWG reinforcing $1^1/_2$" below column surface; $^3/_8$" lime-cement plaster; $^1/_8$" gypsum plaster finish	90 tons	3 hr			7	6,7	3

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Table O.4.5.36 Steel Columns — Concrete Encasements Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-11-SC-23	11"	11" × 12" column; 4" × 3" × 10 lb H beam; gravel concrete (4550 psi); 6" × 4" mesh; 13 SWG reinforcing 1" below column surface	12 tons	6 hr			7	7,8	6
C-11-SC-24	11"	11" × 12" column; 4" × 3" × 10 lb H beam; protection: gravel aggregate concrete (3830 psi); 4" × 4" mesh; 16 SWG, 1" below column surface	16 tons	5 hr 32 min			7	2	$5^1/_2$
C-10-SC-25	10"	6" × 6" steel column with 4" outside protection; Group I	—	9 hr		1		9	9
C-10-SC-26	10"	Description as per C-10-SC-25; Group II	—	7 hr		1		9	7
C-10-SC-27	10"	Description as per C-10-SC-25; Group III	—	5 hr		1		9	5
C-10-SC-28	10"	Description as per C-10-SC-25; Group IV	—	3 hr 30 min		1		9	$3^1/_2$
C-10-SC-29	10"	8" × 8" steel column with 2" outside protection; Group I	—	6 hr		1		9	6
C-10-SC-30	10"	Description as per C-10-SC-29; Group II	—	4 hr		1		9	4
C-10-SC-31	10"	Description as per C-10-SC-29; Group III	—	3 hr		1		9	3
C-10-SC-32	10"	Description as per C-10-SC-29; Group IV	—	2 hr		1		9	2
C-11-SC-33	11"	8" × 8" steel column with 3" outside protection; Group I	—	8 hr		1		9	8
C-11-SC-34	11"	Description as per C-11-SC-33; Group II	—	6 hr		1		9	6
C-11-SC-35	11"	Description as per C-11-SC-33; Group III	—	4 hr		1		9	4
C-11-SC-36	11"	Description as per C-11-SC-33; Group IV	—	3 hr		1		9	3

(Sheet 3 of 3)

Notes:
1. Tested under total restraint load to prevent expansion — minimum load 90 tons.
2. Failure mode — collapse.
3. Passed 2-hour fire test (Grade "C" — British).
4. Passed hose stream test.
5. Column tested and passed 3-hour grade fire resistance (British).
6. Column passed 3-hour fire test.
7. Column collapsed during hose stream test.
8. Column passed 6-hour fire test.
9. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

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FIGURE O.4.5.37 Steel Columns — Concrete Encasements with Minimum Dimension 12 in. (300 mm) to Less Than 14 in. (350 mm).

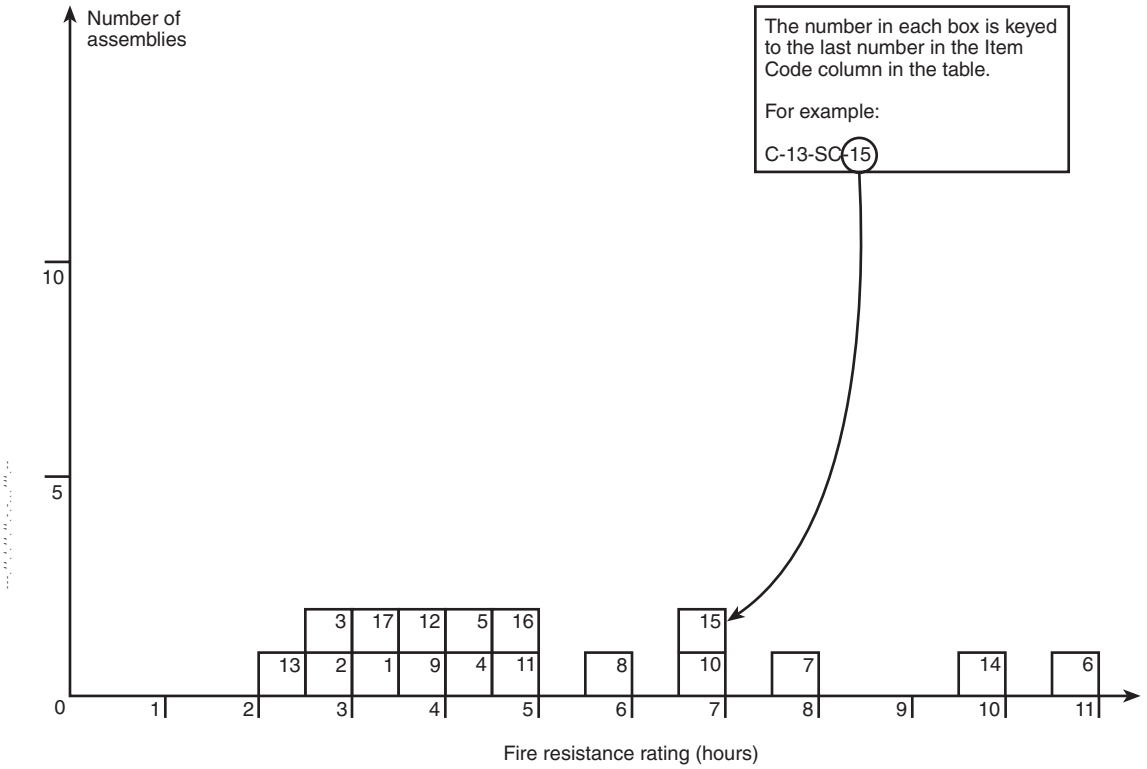

Table O.4.5.37 Steel Columns — Concrete Encasements Minimum Dimension 12 in. (300 mm) to Less Than 14 in. (350 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-12-SC-1	12"	12" × 14" concrete-encased steel column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (4150 psi); 4" mesh; 16 SWG reinforcing 1" below column surface	120 tons	3 hr 24 min			7	1	$3^{1}/_{3}$
C-12-SC-2	12"	12" × 16" concrete-encased column; 8" × 6" × 35 lb H beam; protection: aggregate concrete (4300 psi); 4" mesh; 16 SWG reinforcing 1" below column surface	90 tons	24 hr 52 min			7	1	$2^{3}/_{4}$
C-12-SC-3	12"	12" × 16" concrete-encased steel column; 12" × 8" × 65 lb H column; protection: gravel aggregate concrete (3550 psi); 4" mesh; 16 SWG reinforcement 1" below column surface	177 tons	2 hr 31 min			7	1	$2^{1}/_{2}$

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Table O.4.5.37 Steel Columns — Concrete Encasements Minimum Dimension 12 in. (300 mm) to Less Than 14 in. (350 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-12-SC-4	12"	12" × 16" concrete-encased column; 12" × 8" × 65 lb H beam; protection: aggregate concrete (3450 psi); 4"mesh 16 SWG, reinforcement 1" below column surface	118 tons	4 hr 4 min			7	1	$4^1/_3$
C-12-SC-5	$12^1/_2$"	$12^1/_2$" × 14" column; 6" × $4^1/_2$" × 20 lb H beam; protection: gravel aggregate concrete (3750 psi); 4" × 4" mesh; 16 SWG reinforcing 1" below column surface	52 tons	4 hr 29 min			7	1	$4^1/_3$
C-12-SC-6	12"	8" × 8" steel column; 2" outside protection; Group I	—	11 hr			1	2	11
C-12-SC-7	12"	Description as per C-12-SC-6; Group II	—	8 hr		1		2	8
C-12-SC-8	12"	Description as per C-12-SC-6; Group III	—	6 hr		1		2	6
C-12-SC-9	12"	Description as per C-12-SC-6; Group IV	—	4 hr		1		2	4
C-12-SC-10	12"	10" × 10" steel column with 2" outside protection; Group I	—	7 hr		1		2	7
C-12-SC-11	12"	Description as per C-12-SC-10; Group II	—	5 hr		1		2	5
C-12-SC-12	12"	Description as per C-12-SC-10; Group III	—	4 hr		1		2	4
C-12-SC-13	12"	Description as per C-12-SC-10; Group IV	—	2 hr 30 min		1		2	$2^1/_2$
C-13-SC-14	13"	10" × 10" steel column with 3" outside protection; Group I	—	10 hr		1		2	10
C-13-SC-15	13"	Description as per C-13-SC-14; Group II	—	7 hr		1		2	7
C-13-SC-16	13"	Description as per C-13-SC-14; Group III	—	5 hr		1		2	5
C-13-SC-17	13"	Description as per C-13-SC-14; Group IV	—	3 hr 30 min		1		2	$3^1/_2$

(Sheet 2 of 2)

Notes:
1. Failure mode — collapse.
2. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in., or equivalent ties.

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FIGURE O.4.5.38 Steel Columns — Concrete Encasements with Minimum Dimension 14 in. (350 mm) to Less Than 16 in. (400 mm).

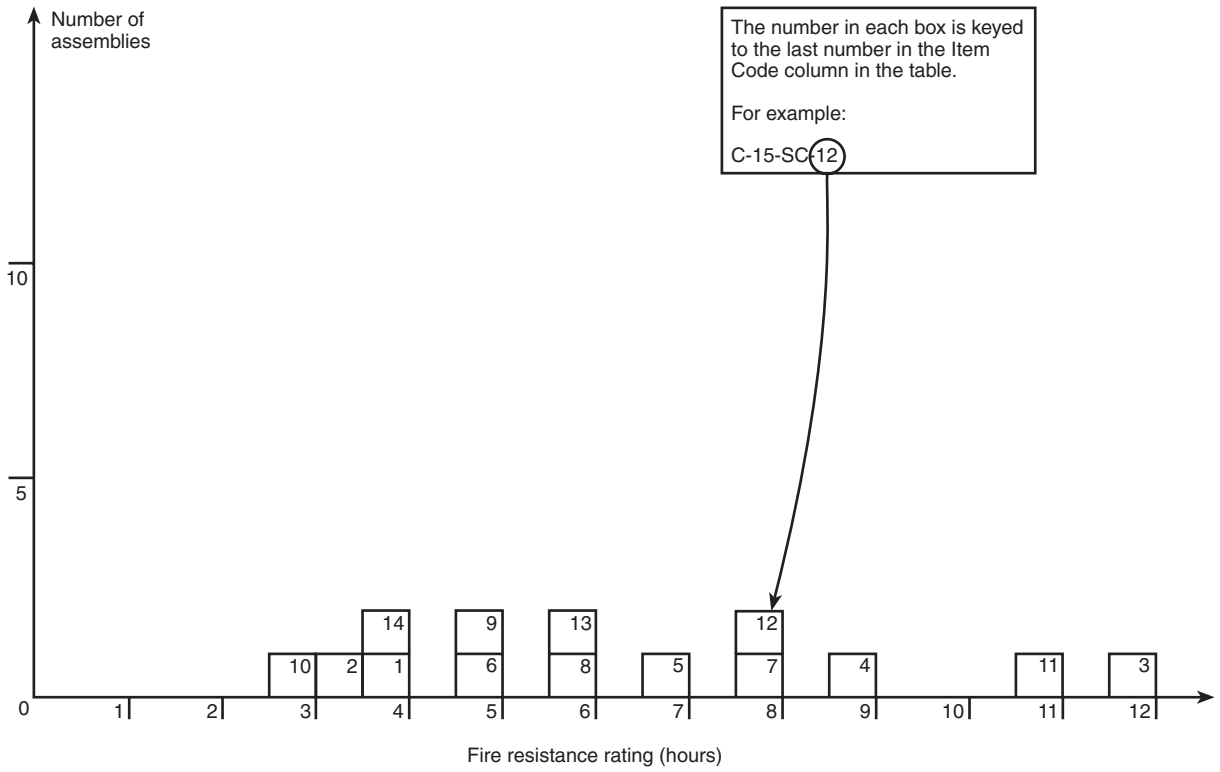

Table O.4.5.38 Steel Columns — Concrete Encasements Minimum Dimension 14 in. (250 mm) to Less Than 16 in. (400 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-14-SC-1	14"	14" × 16" concrete-encased steel column; 8" × 6" × 35 lb H column; protection: aggregate concrete (4240 psi); 4" mesh; 16 SWG reinforcing 1" below column surface	90 tons	3 hr 40 min			7	1	3
C-14-SC-2	14"	14" × 18" concrete-encased steel column; 12" × 8" × 65 lb H beam; protection: gravel aggregate concrete (4000 psi); 4" mesh, 16 SWG reinforcement 1" below column surface	177 tons	3 hr 20 min			7	1	3
C-14-SC-3	14"	10" × 10" steel column with 4" outside protection; Group I	—	12 hr		1		2	12
C-14-SC-4	14"	Description as per C-14-SC-3; Group II	—	9 hr		1		2	9
C-14-SC-5	14"	Description as per C-14-SC-3; Group III	—	7 hr		1		2	7
C-14-SC-6	14"	Description as per C-14-SC-3; Group IV	—	5 hr		1		2	5
C-14-SC-7	14"	12" × 12" steel column with 2" outside protection; Group I	—	8 hr		1		2	8

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Table O.4.5.38 Steel Columns — Concrete Encasements Minimum Dimension 14 in. (250 mm) to Less Than 16 in. (400 mm) ***(Continued)***

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-14-SC-8	14"	Description as per C-14-SC-7; Group II	—	6 hr		1		2	6
C-14-SC-9	14"	Description as per C-14-SC-7; Group III	—	5 hr		1		2	5
C-14-SC-10	14"	Description as per C-14-SC-7; Group IV	—	3 hr		1		2	3
C-15-SC-11	15"	12" × 12" steel column with 3" outside protection; Group I	—	11 hr		1		2	11
C-15-SC-12	15"	Description as per C-15-SC-11; Group II	—	8 hr		1		2	8
C-15-SC-13	15"	Description as per C-15-SC-11; Group III	—	6 hr		1		2	6
C-15-SC-14	15"	Description as per C-15-SC-11; Group IV	—	4 hr		1		2	4

(Sheet 2 of 2)

Notes:
1. Collapse.
2. Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in. or equivalent ties.

Table O.4.5.39 Steel Columns — Concrete Encasements Minimum Dimension 16 in. (400 mm) to Less Than 18 in. (450 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-16-SC-1	16"	12" × 12" steel column with 4" outside protection; Group I	—	14 hr		1		1	14
C-16-SC-2	16"	Description as per C-16-SC-1; Group II	—	10 hr		1		1	10
C-16-SC-3	16"	Description as per C-16-SC-1; Group III	—	8 hr		1		1	8
C-16-SC-4	16"	Description as per C-16-SC-1; Group IV	—	5 hr		1		1	5

Notes:
1. Collapse.

Group I — includes concrete having calcareous aggregate containing a combined total of not more than 10 percent of quartz, chert, and flint for the coarse aggregate.

Group II — includes concrete having traprock aggregate applied without metal ties and also concrete having cinder, sandstone, or granite aggregate, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group III — includes concrete having cinder, sandstone, or granite aggregate tied with No. 5 gauge steel wire, wound spirally over the column section on a pitch of 8 in., or equivalent ties, and concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, if held in place with wire mesh or expanded metal having not larger than 4 in. mesh, weighing not less than 1.7 lb/yd^2, placed not more than 1 in. from the surface of the concrete.

Group IV — includes concrete having siliceous aggregates containing a combined total of 60 percent or more of quartz, chert, and flint, and tied with No. 5 gauge steel wire wound spirally over the column section on a pitch of 8 in. or equivalent ties.

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Table O.4.5.40 Steel Columns — Brick and Block Encasements Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-10-SB-1	$10^1/_2$"	$10^1/_2$" × 13" brick-encased steel columns; 8" × 6" × 35 lb H beam; protection: fill of broken brick and mortar; 2" brick on edge, joints broken in alt. courses; cement-sand grout; 13 SWG wire reinforcement in every third horizontal joint	90 tons	3 hr 6 min			7	1	3
C-10-SB-2	$10^1/_2$"	$10^1/_2$" × 13" brick-encased steel columns; 8" × 6" × 35 lb H beam; protection: 2" brick, joints broken in alt. courses; cement-sand grout; 13 SWG iron wire reinforcement in alt. horizontal joints	90 tons	2 hr			7	2–4	2
C-10-SB-3	10"	10" × 12" block-encased columns; 8" × 6" × 35 lb H beam; protection: 2" foamed slag concrete blocks; 13 SWG wire at each horizontal joint; mortar at each joint	90 tons	2 hr			7	5	2
C-10-SB-4	$10^1/_2$"	$10^1/_2$" × 12" block-encased steel columns; 8" × 6" × 35 lb H beam; protection: gravel aggregate concrete fill (unconsolidated), 2" thick hollow clay tiles with mortar at edges	86 tons	56 min			7	1	$^3/_4$
C-10-SB-5	$10^1/_2$"	$10^1/_2$" × 12" block-encased steel columns; 8" × 6" × 35 lb H beam; protection: 2" hollow clay tiles with mortar at edges	86 tons	22 min			7	1	$^1/_4$

Notes:
1. Failure mode — collapse.
2. Passed 2-hour fire test (Grade "C" — British).
3. Passed hose stream test.
4. Passed reload test.
5. Passed 2-hour fire exposure but collapsed immediately following hose stream test.

Table O.4.5.41 Steel Columns — Brick and Block Encasements Minimum Dimension 12 in. (300 mm) to Less Than 14 in. (350 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-12-SB-1	12"	12" × 15" brick-encased steel columns; 8" × 6" × 35 lb H beam; protection: $2^5/_8$" thick brick; joints broken in alt. courses; cement-sand grout; fill of broken brick and mortar	90 tons	1 hr 49 min			7	1	$1^3/_4$

Note:
1. Failure mode — collapse.

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Table O.4.5.42 Steel Columns — Brick and Block Encasements Minimum Dimension 14 in. (350 mm) to Less Than 16 in. (400 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-15-SB-1	15"	15" × 17" brick-encased steel columns; 8" × 6" × 35 lb H beam; protection: $4^1/_2$" thick brick; joints broken in alt. courses; cement-sand grout; fill of broken brick and mortar	45 tons	6 hr			7	1	6
C-15-SB-2	15"	15" × 17" brick-encased steel columns; 8" × 6" × 35 lb H beam; protection: fill of broken brick and mortar; $4^1/_2$" brick, joints broken in alt. courses; cement-sand grout	86 tons	6 hr			7	2–4	6
C-15-SB-3	15"	15" × 18" brick-encased steel columns; 8" × 6" × 35 lb H beam; protection: $4^1/_2$" brick work; joints alternating; cement-sand grout	90 tons	4 hr			7	5,6	4
C-14-SB-4	14"	14" × 16" block-encased steel columns; 8" × 6" × 35 lb H beam; protection: 4" thick foam slag concrete blocks; 13 SWG wire reinforcement in each horizontal joint; mortar in joints	90 tons	5 hr 52 min			7	7	$4^3/_4$

Notes:
1. Only a nominal load was applied to specimen.
2. Passed 6-hour fire test (Grade "A" — British).
3. Passed (6 minute) hose stream test.
4. Reload not specified.
5. Passed 4-hour fire exposure.
6. Failed by collapse between 1st and 2nd minutes of hose stream exposure.
7. Mode of failure — collapse.

Table O.4.5.43 Steel Columns — Plaster Encasements Minimum Dimension 6 in. (150 mm) to Less Than 8 in. (200 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-7-SP-1	$7^1/_2$"	$7^1/_2$" × $9^1/_2$" plaster-protected steel columns; 8" × 6" × 35 lb H beam; protection: 24 SWG wire metal lath; $1^1/_4$" lime plaster	90 tons	57 min			7	1	$^3/_4$
C-7-SP-2	$7^7/_8$"	$7^7/_8$" × 10" plaster-protected steel columns; 8" × 6" × 35 lb H beam; protection: $^3/_8$" gypsum bal. wire; 16 SWG wire wound helically at 4" pitch; $^1/_2$" gypsum plaster	90 tons	1 hr 13 min			7	1	1
C-7-SP-3	$7^1/_4$"	$7^1/_4$" × $9^3/_8$" plaster-protected steel columns; 8" × 6" × 35 lb H beam; protection: $^3/_8$" gypsum board; 16 SWG wire wound helically at 4" pitch; $^1/_4$" gypsum plaster finish	90 tons	1 hr 14 min			7	1	1

Note:
1. Failure mode — collapse.

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Table O.4.5.44 Steel Columns — Plaster Encasements Minimum Dimension 8 in. (200 mm) to Less Than 10 in. (250 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-8-SP-1	8"	8" × 10" plaster-protected steel columns; 8" × 6" × 35 lb H beam; protection: 24 SWG wire lath with 1" gypsum plaster	86 tons	1 hr 23 min			7	1	$1^1/_4$
C-8-SP-2	$8^1/_2$"	$8^1/_2$" × $10^1/_2$" plaster-protected steel columns; 8" × 6" × 35 lb H beam; protection: 24 SWG metal lath wrap; $1^1/_4$" gypsum plaster	90 tons	1 hr 36 min			7	1	$1^1/_2$
C-9-SP-3	9"	9" × 11" plaster-protected steel columns; 8" × 6" × 35 lb H beam; protection: 24 SWG metal lath wrap; $^1/_8$" M. S. ties at 12" pitch; 22 SWG wire netting at $1^1/_2$" pitch, between 1st and 2nd plaster coats; $1^1/_2$" gypsum plaster	90 tons	1 hr 33 min			7	1	$1^1/_2$
C-8-SP-4	$8^3/_4$"	$8^3/_4$" × $10^3/_4$" plaster-protected steel columns; 8" × 6" × 35 lb H beam; protection: $^3/_4$" gypsum board; 16 SWG wire wound spirally at $1^1/_2$" pitch; $^1/_2$" gypsum plaster	90 tons	2 hr			7	2–4	2

Notes:
1. Failure mode — collapse.
2. Passed 2-hour fire exposure test (Grade "C" — British).
3. Passed hose stream test.
4. Passed reload test.

Table O.4.5.45 Steel Columns — Miscellaneous Encasements Minimum Dimension 6 in. (150 mm) to Less Than 8 in. (200 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-7-SM-1	$7^5/_8$"	$7^5/_8$" × $9^1/_2$" (asbestos plaster) protected steel columns; 8" × 6" × 35 lb H beam; protection: 20 ga. $^1/_2$" metal lath; $^9/_{16}$" asbestos plaster (minimum)	90 tons	1 hr 52 min			7	1	$1^3/_4$

Note:
1. Failure mode — collapse.

Table O.4.5.46 Steel Columns — Miscellaneous Encasements Minimum Dimension 8 in. (200 mm) to Less Than 10 in. (250 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-9-SM-1	$9^5/_8$"	$9^5/_8$" × $11^3/_8$" asbestos slab and cement plaster–protected columns; 8" × 6" × 35 lb H beam; protection: 1" asbestos slabs, wire wound, $^5/_8$" plaster	90 tons	2 hr			7	1,2	2

Notes:
1. Passed 2-hour fire exposure test.
2. Collapsed during hose stream test.

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Table O.4.5.47 Steel Columns — Miscellaneous Encasements Minimum Dimension 10 in. (250 mm) to Less Than 12 in. (300 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-11-SM-1	$11\frac{1}{2}$"	$11\frac{1}{2}$" × $13\frac{1}{2}$" wood-wool and plaster protected–steel columns; 8" × 6" × 35 lb H beam; protection: wood-wool-cement paste as fill and to 2" cover over beam; $\frac{3}{4}$" gypsum plaster finish	90 tons	2 hr			7	1–3	2
C-10-SM-2	10"	10" × 12" asbestos-protected steel columns; 8" × 6" × 35 lb H beam; protection: sprayed-on asbestos paste to 2" cover over column	90 tons	4 hr			7	2–4	4

Notes:
1. Passed 2-hour fire exposure test (Grade "C" — British).
2. Passed hose stream test.
3. Passed reload test.
4. Passed 4-hour fire exposure test.

Table O.4.5.48 Steel Columns — Miscellaneous Encasements Minimum Dimension 12 in. (300 mm) to Less Than 14 in. (350 mm)

Item Code	Minimum Dimension	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
C-12-SM-1	12"	12" × $14\frac{1}{4}$" cement and asbestos protected column; 8" × 6" × 35 lb H beam; protection: fill of asbestos packing pieces 1" thick 1' 3" O.C.; cover of 2" molded asbestos, inner layer; 1" molded asbestos, outer layer; held in position by 16 SWG Nichrome wire ties; wash of refractory cement on outer surface	86 tons	4 hr 43 min			7	1–3	$4\frac{2}{3}$

Notes:
1. Passed 4-hour fire exposure (Grade "B" — British).
2. Passed hose stream test.
3. Passed reload test.

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FIGURE O.4.5.49 Floor/Ceiling Assemblies — Reinforced Concrete.

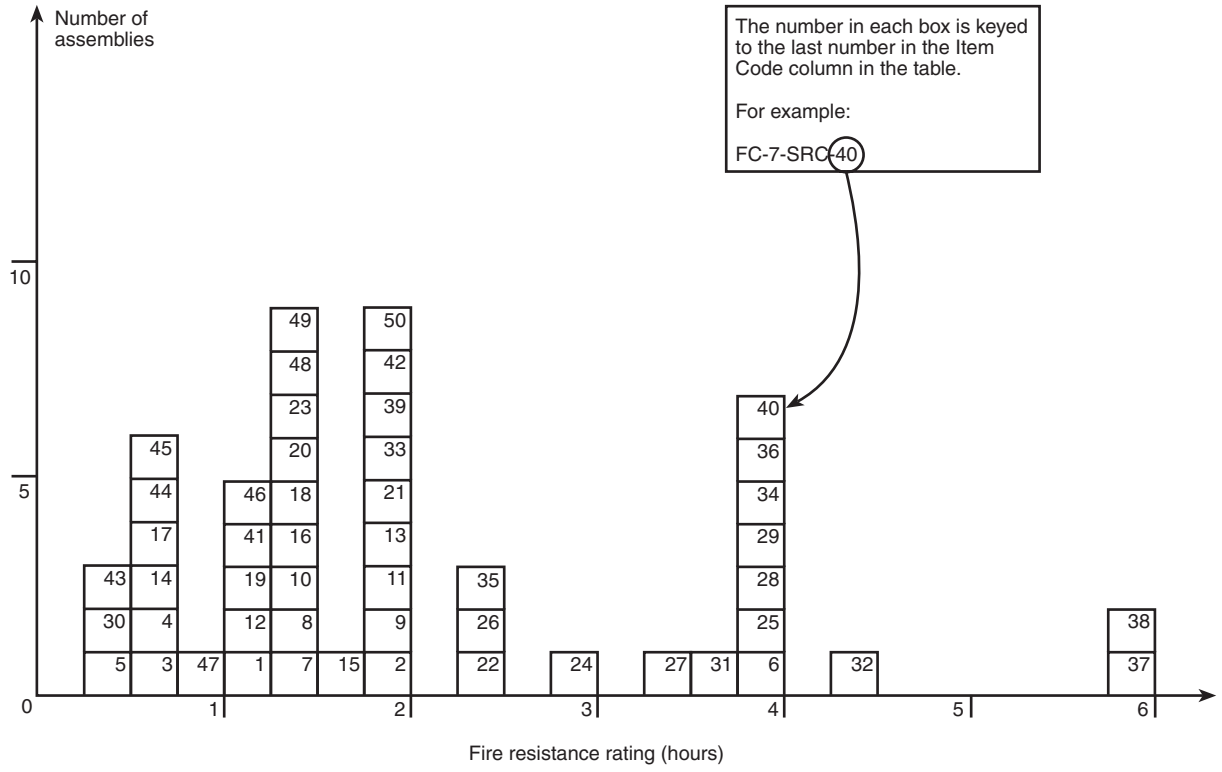

Table O.4.5.49 Floor/Ceiling Assemblies — Reinforced Concrete

Item Code	Assembly Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
FC-3-RC-1	$3\frac{3}{4}$"	$3\frac{3}{4}$" thick floor; $3\frac{1}{4}$" (5475 psi) concrete deck; $\frac{1}{2}$" plaster under deck; $\frac{3}{8}$" main rein. bars at $5\frac{1}{2}$" pitch, with $\frac{7}{8}$" concrete cover; $\frac{3}{8}$" main rein. bars at $4\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" concrete cover; 13' 1" span restrained	195 psf	24 min			7	1,2	1
FC-3-RC-2	$3\frac{1}{4}$"	$3\frac{1}{4}$" deep (3540 psi) concrete deck; $\frac{3}{8}$" main rein. bars at $5\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $4\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	195 psf	2 hr			7	1,3,4	$1\frac{3}{4}$
FC-3-RC-3	$3\frac{1}{4}$"	$3\frac{1}{4}$" deep (4175 psi) concrete deck; $\frac{3}{8}$" main rein. bars at $5\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $4\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	195 psf	31 min			7	1,5	$\frac{1}{2}$
FC-3-RC-4	$3\frac{1}{4}$"	$3\frac{1}{4}$" deep (4355 psi) concrete deck; $\frac{3}{8}$" main rein. bars at $5\frac{1}{2}$" pitch with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $4\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	195 psf	41 min			7	1,5,6	$\frac{1}{2}$

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Table O.4.5.49 Floor/Ceiling Assemblies — Reinforced Concrete *(Continued)*

Item Code	Assembly Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
FC-3-RC-5	$3\frac{1}{4}$"	$3\frac{1}{4}$" thick (3800 psi) concrete deck; $\frac{3}{8}$" main rein. bars at $5\frac{1}{2}$" pitch with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $4\frac{1}{2}$" pitch perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	195 psf	1 hr 5 min			7	1,5	$\frac{1}{4}$
FC-4-RC-6	$4\frac{1}{4}$"	$4\frac{1}{4}$" thick; $3\frac{1}{4}$" (4000 psi) concrete deck; 1" sprayed asbestos lower surface; $\frac{3}{8}$" main rein. bars at $5\frac{7}{8}$" pitch, with $\frac{7}{8}$" concrete cover; $\frac{3}{8}$" main rein. bars at $4\frac{1}{2}$" pitch perpendicular with $\frac{1}{2}$" concrete cover; 13' 1" span restrained	195 psf	4 hr			7	1,7	4
FC-4-RC-7	4"	4"(5025 psi) deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{3}{4}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{3}{4}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	140 psf	1 hr 16 min			7	1,2	$1\frac{1}{4}$
FC-4-RC-8	4"	4" thick (4905 psi) deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{3}{4}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	100 psf	1 hr 23 min			7	1,2	$1\frac{1}{3}$
FC-4-RC-9	4"	4" deep (4370 psi); $\frac{1}{4}$" rein. bars at 6" pitch with $\frac{3}{4}$" cover; $\frac{1}{4}$" main rein. bars at 4" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	150 psf	2 hr			7	1,3	2
FC-4-RC-10	4"	4" thick (5140 psi) deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{3}{4}$" pitch perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	140 psf	1 hr 16 min			7	1,5	$1\frac{1}{4}$
FC-4-RC-11	4"	4" thick (4000 psi) concrete deck; 3" × $1\frac{1}{2}$" × 4 lb R.S.J.; 2' 6" C.R.S.; flush with top surface; 4" × 6" mesh 13 SWG reinforcing 1" from bottom of slab; 6' 6" span restrained	150 psf	2 hr			7	1,3	2
FC-4-RC-12	4"	4" deep (2380 psi) concrete deck; 3" × $1\frac{1}{2}$" × 4 lb R.S.J.; 2' 6" C.R.S.; flush with top surface; 4" × 6" mesh 13 SWG mesh reinforcing 1" from bottom surface; 6' 6" span restrained	150 psf	1 hr 3 min			7	1,2	1
FC-4-RC-13	$4\frac{1}{2}$"	$4\frac{1}{2}$" thick (5200 psi) deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{4}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{3}{4}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	140 psf	2 hr			7	1,3	2
FC-4-RC-14	$4\frac{1}{2}$"	$4\frac{1}{2}$" deep (2525 psi) concrete deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{3}{8}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	150 psf	42 min			7	1,5	$\frac{2}{3}$
FC-4-RC-15	$4\frac{1}{2}$"	$4\frac{1}{2}$" deep (4830 psi) concrete deck; $1\frac{1}{2}$" mesh 15 SWG; $\frac{3}{8}$" rein. bar at 15" pitch, with 1" cover; $\frac{1}{2}$" main rein. bars at 6" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	75 psf	1 hr 32 min			7	1,8	$1\frac{1}{2}$
FC-4-RC-16	$4\frac{1}{2}$"	$4\frac{1}{2}$" deep (4595 psi) concrete deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	75 psf	1 hr 20 min			7	1,8	$1\frac{1}{3}$
FC-4-RC-17	$4\frac{1}{2}$"	$4\frac{1}{2}$" deep (3625 psi) concrete deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	75 psf	35 min			7	1,8	$\frac{1}{2}$

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Table O.4.5.49 Floor/Ceiling Assemblies — Reinforced Concrete ***(Continued)***

Item Code	Assembly Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
FC-4-RC-18	$4\frac{1}{2}$"	$4\frac{1}{2}$" deep (4410 psi) concrete deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	85 psf	1 hr 27 min			7	1,8	$1\frac{1}{3}$
FC-4-RC-19	$4\frac{1}{2}$"	$4\frac{1}{2}$" deep (4850 psi) deck; $\frac{3}{8}$" rein. bars at 15" pitch, with 1" cover; $\frac{1}{2}$" main rein. bars at 6" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	75 psf	2 hr 15 min			7	1,9	$1\frac{1}{4}$
FC-4-RC-20	$4\frac{1}{2}$"	$4\frac{1}{2}$" deep (3610 psi) deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	75 psf	1 hr 22 min			7	1,8	$1\frac{1}{3}$
FC-5-RC-21	5"	5" deep $4\frac{1}{2}$" (5830 psi) concrete deck; $\frac{1}{2}$" plaster finish bottom of slab; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	69 psf	2 hr			7	1,3	2
FC-5-RC-22	5"	$4\frac{1}{2}$" (5290 psi) concrete deck; $\frac{1}{2}$" plaster finish bottom of slab; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 12' span simply supported	No load	2 hr 28 min			7	1,10, 11	$2\frac{1}{4}$
FC-5-RC-23	5"	5" deep (3020 psi) concrete deck; 3" × $1\frac{1}{2}$" × 4 lb R.S.J.; 2' C.R.S. with 1" cover on bottom and top flanges; 8' span restrained	172 psf	1 hr 24 min			7	1,2,12	$1\frac{1}{2}$
FC-5-RC-24	$5\frac{1}{2}$"	5" (5180 psi) concrete deck; $\frac{1}{2}$" retarded plaster underneath slab; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $1\frac{3}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with 1" cover; 12' span simply supported	60 psf	2 hr 48 min			7	1,10	$2\frac{3}{4}$
FC-6-RC-25	6"	6" deep (4800 psi) concrete deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{7}{8}$" cover; 13' 1" span restrained	195 psf	4 hr			7	1,7	4
FC-6-RC-26	6"	6" (4650 psi) concrete deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	195 psf	2 hr 23 min			7	1,2	$2\frac{1}{4}$
FC-6-RC-27	6"	6" deep (6050 psi) concrete deck; $\frac{1}{4}$" rein. bars at $7\frac{1}{2}$" pitch, with $\frac{7}{8}$" cover; $\frac{3}{8}$" main rein. bars at $3\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	195 psf	3 hr 30 min			7	1,10	$3\frac{1}{2}$
FC-6-RC-28	6"	6" deep (5180 psi) concrete deck; $\frac{1}{4}$" bars at 8" pitch, with $\frac{3}{4}$" cover; $\frac{1}{4}$" bars at $5\frac{1}{2}$" pitch, perpendicular with $\frac{1}{2}$" cover; 13' 1" span restrained	150 psf	4 hr			7	1,7	4
FC-6-RC-29	6"	6" thick (4180 psi) concrete deck; 4" × 3" × 10 lb R.S.J.; 2' 6" C.R.S. with 1" cover on both bottom and top flanges; 13' 1" span restrained	160 psf	3 hr 48 min			7	1,10	$3\frac{3}{4}$
FC-6-RC-30	6"	6" thick (3720 psi) concrete deck; 4" × 3" × 10 lb R.S.J.; 2' 6" C.R.S. with 1" cover on both top and bottom flanges; 12" span simply restrained	115 psf	29 min			7	1,5,13	$\frac{1}{4}$
FC-6-RC-31	6"	6" deep (3450 psi) concrete deck; 4" × $1\frac{3}{4}$" × 5 lb R.S.J.; 2' 6" C.R.S. with 1" cover on both top and bottom flanges; 12" span simply supported	25 psf	3 hr 35 min			7	1,2	$3\frac{1}{2}$

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Table O.4.5.49 Floor/Ceiling Assemblies — Reinforced Concrete *(Continued)*

Item Code	Assembly Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
FC-6-RC-32	6"	6" deep (4460 psi) concrete deck; 4" × $1^3/_4$" × 5 lb R.S.J.; 2' C.R.S. with 1" cover on both top and bottom flanges; 12' span simply supported	60 psf	4 hr 30 min			7	1,10	$4^1/_2$
FC-6-RC-33	6"	6" deep (4360 psi) concrete deck; 4" × $1^3/_4$" × 5 lb R.S.J.; 2' C.R.S. with 1" cover on both bottom and top flanges; 13' 1" span restrained	60 psf	2 hr			7	1,3	2
FC-6-RC-34	$6^1/_4$"	$6^1/_4$" thick; $4^3/_4$" (5120 psi) concrete core; 1" T&G board flooring; $^1/_2$" plaster undercoat; 4" × 3" × 10 lb R.S.J.; 3' C.R.S. flush with top surface concrete; 12' span simply supported; 2" × 1' 3" clinker concrete insert	100 psf	4 hr			7	1,7	4
FC-6-RC-35	$6^1/_4$"	$4^3/_4$" (3600 psi) concrete core; 1" T&G board flooring; $^1/_2$" plaster undercoat; 4" × 3" × 10 lb R.S.J.; 3' C.R.S. flush with top surface concrete; 12' span simply supported; 2" × 1' 3" clinker concrete insert	100 psf	2 hr 30 min			7	1,5	$2^1/_2$
FC-6-RC-36	$6^1/_4$"	$4^3/_4$" (2800 psi) concrete core; 1" T&G board flooring; $^1/_2$" plaster undercoat; 4" × 3" × 10 lb R.S.J.; 3' C.R.S. flush with top surface concrete; 12' span simply supported; 2" × 1' 3" clinker concrete insert	80 psf	4 hr			7	1,7	4
FC-7-RC-37	7"	(3640 psi) concrete deck; $^1/_4$" rein. bars at 6" pitch, with $1^1/_2$" cover; $^1/_4$" rein. bars at 5" pitch, perpendicular with $1^1/_2$" cover; 13' 1" span restrained	169 psf	6 hr			7	1,14	6
FC-7-RC-38	7"	(4060 psi) concrete deck; 4" × 3" × 10 lb R.S.J.; 2' 6" C.R.S. with $1^1/_2$" cover on both top and bottom flanges; 4" × 6" mesh 13 SWG reinforcing $1^1/_2$" from bottom of slab; 13' 1" span restrained	175 psf	6 hr			7	1,14	6
FC-7-RC-39	$7^1/_4$"	$5^3/_4$" (4010 psi) concrete core; 1" T&G board flooring; $^1/_2$" plaster undercoat; 4" × 3" × 10 lb R.S.J.; 2' 6" C.R.S. 1" down from top surface of concrete; 12' span simply supported; 2" × 1' 3" clinker concrete insert	95 psf	2 hr			7	1,3	2
FC-7-RC-40	$7^1/_4$"	$5^3/_4$" (3220 psi) concrete core; 1" T&G board flooring; $^1/_2$" plaster undercoat; 4" × 3" × 10 lb R.S.J.; 2' 6" C.R.S. 1" down from top surface of concrete; 12' span simply supported; 2" × 1' 3" clinker concrete insert	95 psf	4 hr			7	1,7	4
FC-7-RC-41	10" ($2^1/_4$" slab)	Ribbed floor: see detail, note 15; slab $2^1/_2$" deep (3020 psi); $^1/_4$" rein. bars at 6" pitch, with $^3/_4$" cover; beams $7^1/_2$" deep × 5" wide; 24" C.R.S; $^5/_8$" rein. bars in 2 rows $^1/_2$" vertically apart, with 1" cover; 13' 1" span restrained	195 psf	1 hr 4 min			7	1,2,15	1
FC-5-RC-42	$5^1/_2$"	Composite ribbed concrete slab assembly; see note 17 for details	See note 16	2 hr			43	16,17	2
FC-3-RC-43	3"	2500 psi concrete; $^5/_8$" cover; fully restrained at test	See note 16	30 min			43	16	$^1/_2$
FC-3-RC-44	3"	2000 psi concrete; $^5/_8$" cover; free or partial restraint at test	See note 16	45 min			43	16	$^3/_4$
FC-4-RC-45	4"	2500 psi concrete; $^5/_8$" cover; fully restrained at test	See note 16	40 min			43	16	$^2/_3$
FC-4-RC-46	4"	2000 psi concrete; $^3/_4$" cover; free or partial restraint at test	See note 16	1 hr 15 min			43	16	$1^1/_4$

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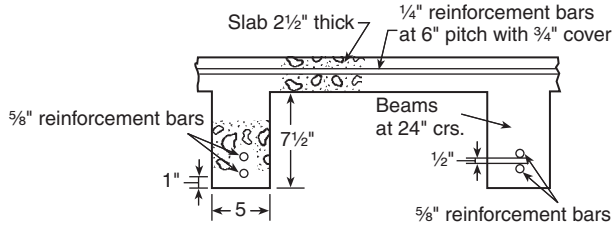
Table O.4.5.49 Floor/Ceiling Assemblies — Reinforced Concrete ***(Continued)***

Item Code	Assembly Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
FC-5-RC-47	5"	2500 psi concrete; $^3/_4$" cover; fully restrained at test	See note 16	1 hr			43	16	1
FC-5-RC-48	5"	2000 psi concrete; $^3/_4$" cover; free or partial restraint at test	See note 16	1 hr 30 min			43	16	$1^1/_2$
FC-6-RC-49	6"	2500 psi concrete; 1" cover; fully restrained at test	See note 16	1 hr 30 min			43	16	$1^1/_2$
FC-6-RC-50	6"	2900 psi concrete; 1" cover; free or partial restraint at test	See note 16	2 hr			43	16	2

(Sheet 5 of 5)

Notes:
1. British test.
2. Failure mode — local back face temperature rise.
3. Tested for Grade "C" (2 hour) fire resistance.
4. Collapse imminent following hose stream.
5. Failure mode — flame-thru.
6. Void formed with explosive force and report.
7. Achieved Grade "B" (4 hour) fire resistance (British).
8. Failure mode — collapse.
9. Test was run to 2 hours, but specimen was partially supported by the furnace at $1^1/_4$ hours.
10. Failure mode — average back face temperature.
11. Recommended endurance is for non-load-bearing performance only.
12. Floor maintained load-bearing ability to 2 hours, at which point test was terminated.
13. Test was run to 3 hours, at which time failure mode 2 (above) was reached in spite of crack formation at 29 minutes.
14. Tested for Grade "A" (6 hours) fire resistance.
15.



16. Load unspecified.
17. Total assembly thickness, $5^1/_2$ in. Blocks of molded excelsior 3 in. thick bonded with portland cement were used as inserts with $2^1/_2$ in. cover (concrete) above blocks and $^3/_4$ in. gypsum plaster below. Ribs 9 in. wide containing reinforcing steel of unspecified size interrupted 20 in. wide segments of slab composite (i.e., plaster, excelsior blocks, concrete cover).

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FIGURE O.4.5.50 Floor/Ceiling Assemblies — Steel Structural Elements.

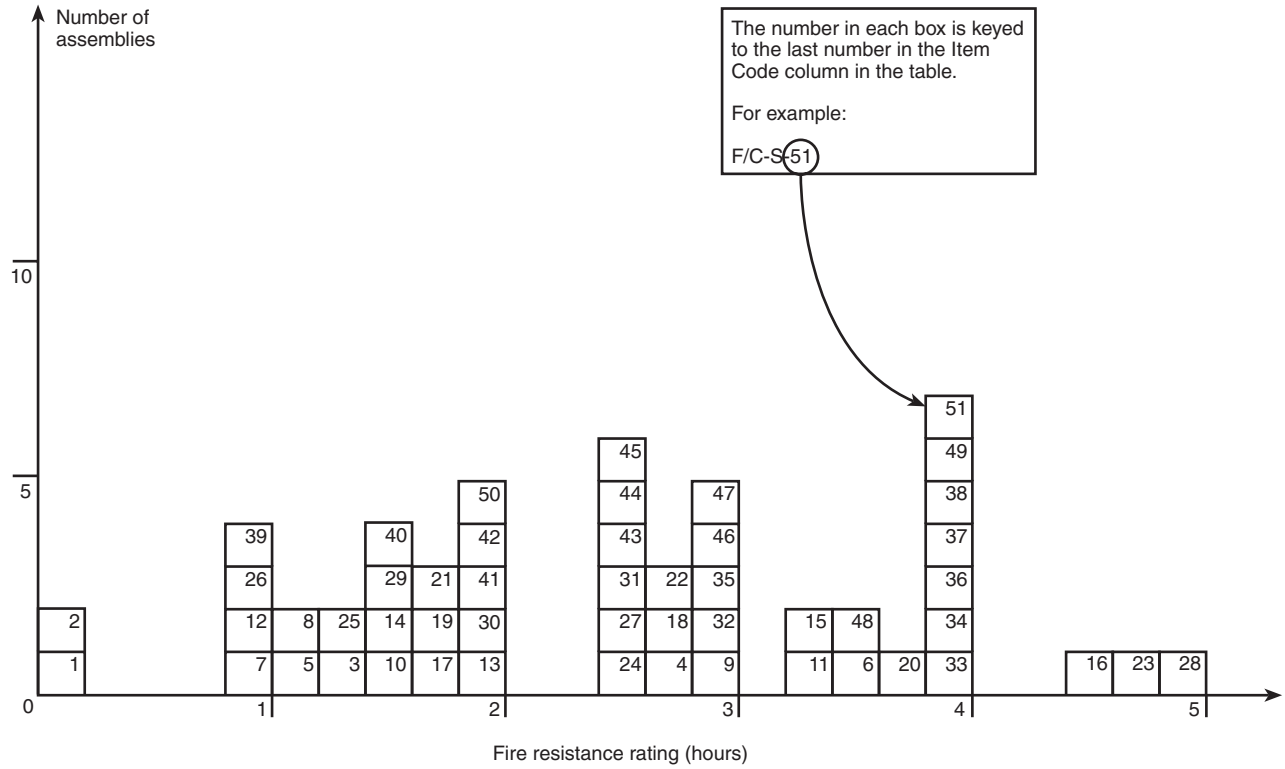

Table O.4.5.50 Floor/Ceiling Assemblies — Steel Structural Elements

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-S-1	0"	10' × 13' 6"; S.J. 103 24" O.C.; deck: 2" concrete; membrane: none	145 psf	7 min			3	1,2,3,8	0
F/C-S-2	0"	10' × 13' 6"; S.J. 103 24" O.C.; deck: 2" concrete; membrane: none	145 psf	7 min			3	1,2,3,8	0
F/C-S-3	$^1/_2$"	10' × 13' 6"; S.J. 103 24" O.C.; deck: 2" concrete 1:2:4; membrane: 12" O.C. furring; clips, A, B, G; no extra reinforcement; $^1/_2$" plaster 1.5:2.5	145 psf	1 hr 15 min			3	2,3,8	$1^1/_4$
F/C-S-4	$^1/_2$"	10' × 13' 6"; S. J. 103 24" O.C.; deck: 2" concrete 1:2:4; membrane: 16" O.C. furring; clips, D. E, F, G; diag. wire reinforcement; $^1/_2$" plaster 1.5:2.5	145 psf	2 hr 46 min			3	3,8	$2^3/_4$
F/C-S-5	$^1/_2$"	10' × 13' 6"; S.J. 103 24" O.C.; deck: 2" concrete 1:2:4; membrane: 16" O.C. furring; clips. A, B, G; no extra reinforcement; $^1/_2$" plaster 1.5:2.5	145 psf	1 hr 4 min			3	2,3,8	1
F/C-S-6	$^1/_2$"	10' × 13' 6"; S.J. 103 24" O.C.; deck: 2" concrete 1:2:4 membrane: 16" O.C., furring; clips, D, E, F, G; hexagonal mesh reinforcement; $^1/_2$" plaster	145 psf	3 hr 28 min			3	2,4,8	$2^1/_3$
F/C-S-7	$^1/_2$"	10' × 13' 6"; S.J. 103 24" O.C.; deck: 4 lb rib lath; 6" × 6" 10 × 10 ga. reinforcement; 2" deck gravel concrete; membrane: furring 16" O.C.; clips, C, E; reinforcement: none; $^1/_2$" plaster 1.5:2.5 mill mix	n/a	55 min			3	5,8	$^3/_4$

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Table O.4.5.50 Floor/Ceiling Assemblies — Steel Structural Elements *(Continued)*

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-S-8	1/2"	Spec. 9' × 4' 4"; S.J. 103 bar joists 18" O.C.; membrane: furring 3/4" C.R.S. 16" O.C.; clips C,E; reinforcement none; 1/2" plaster 1.5:2.5 mill mix; deck: 4 lb rib lath base; 6" × 6", 10 × 10 ga. reinforcement; 2" deck 1:2:4 gravel concrete	300 psf	1 hr 10 min			3	2,3,8	1
F/C-S-9	5/8"	10' × 13' 6" ; S.J. 103 24" O.C.; deck: 2" concrete 1:2:4; membrane: furring 12" O.C.; clips, A, B, G; extra "A" clips reinforcement; 5/8" plaster 1.5:2; 1.5:3	145 psf	3 hr			3	6,8	3
F/C-S-10	5/8"	18' × 13' 6"; 103-24" joists S.J. O.C.; deck: 4 lb rib lath; 6" × 6", 10 × 10 ga. reinforcement; deck: 2": gravel concrete 1:2:3.5; membrane: furring, spacing, 16" O.C.; clips, C,E; reinforcement: none; 5/8" plaster 1.5:2.5 mill mix	145 psf	1 hr 25 min			3	2,3,8	1 1/3
F/C-S-11	5/8"	10' × 13' 6"; S.J. 103 24" O.C.; deck: 2" concrete 1:2:4; membrane: furring 12" O.C.; clips, D, E, F, G; reinforcement: diag. wire; 5/8" plaster 1.5:2; 0.5:3	145 psf	3 hr 15 min			3	2,4,8	3 1/4
F/C-S-12	5/8"	10' × 13' 6"; S.J. 103 joists 24" O.C.; deck: 3.4 lb rib lath; reinforcement: 6" × 6", 10 × 10 ga.; deck: 2" gravel concrete 1:2:4; membrane: furring 16" O.C.; clips D, E, F, G; reinforcement: none; 5/8" plaster 1.5:2.5	145 psf	1 hr			3	7,8	1
F/C-S-13	3/4"	Spec. 9' × 4' 4"; S.J. 103 18" O.C.; deck: 4 lb rib lath; 6" × 6", 10 × 10 ga. reinforcement; deck: 2" gravel concrete 1:2:4; membrane: furring 3/4" CRS 16" O.C.; clips, C, E; reinforcement: none; 3/4" plaster 1.5:2.5 mill mix	300 psf	1 hr 56 min			3	3,8	1 3/4
F/C-S-14	7/8"	Floor finish: 1" concrete; plate cont. weld; 4" 7.7 lb I beams; ceiling: 1/4" rods 12" O.C.; 7/8" gypsum sand plaster	105 psf	1 hr 35 min			6	2,4,9,10	1 1/2
F/C-S-15	1"	Floor finish: 1 1/2" L.W. concrete; 1/2" limestone cement; plate cont. weld; 5" 10 lb I beams; ceiling: 1/4" rods 12" O.C. tack welded to beams, metal lath 1" portland cement plaster	165 psf	3 hr 20 min			6	4,9,11	
F/C-S-16	1"	10' × 13' 6"; S.J. 103 24" O.C; deck: 2" concrete 1:2:4; membrane: furring 12" O.C.; clips, D, E, F, G; plaster: hexagonal mesh reinforcement, 1" thick 1.5:2; 1.5:3	145 psf	4 hr 26 min			3	2,4,8	4 1/3
F/C-S-17	1"	10' × 13' 6"; S.J. 103 joists 24" O.C.; deck: 3.4 lb rib lath; reinforcement: 6" × 6", 10 × 10 ga.; 2" deck 1:2:4 gravel concrete; membrane: furring 16" O.C.; clips, D, E, F, G; 1" plaster	145 psf	1 hr 42 min			3	2,4,8	1 2/3
F/C-S-18	1 1/8"	10" × 13' 6"; S.J. 103 24" O.C.; deck: 2" concrete 1:2:4; membrane: furring 12" O.C.; clips, C, E, F, G; diag. wire reinforcement; 1 1/8" plaster	145 psf	2 hr 44 min			3	2,4,8	2 2/3
F/C-S-19	1 1/8"	10' × 13' 6"; S.J. 103 joists 24" O.C.; deck: 1 1/2" gypsum concrete over 1/2" gypsum board base; membrane: furring 12" O.C.; 1 1/8" plaster 1.5:2; 1.5:3; clips, D, E, F, G	145 psf	1 hr 40 min			3	2,3,8	1 2/3
F/C-S-20	1 1/8"	2 1/2" cinder concrete; 1/2" topping; plate 6" welds 12" O.C.; 5" 18.9 lb H center; 5" 10 lb I ends; 1" channel 18" O.C.; 1 1/8" gypsum sand plaster	150 psf	3 hr 43 min			6	2,4,9,11	3 2/3

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Table O.4.5.50 Floor/Ceiling Assemblies — Steel Structural Elements *(Continued)*

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-S-21	$1^1/_4$"	10' × 13' 6"; S.J. 103 joists 24" O.C.; deck: $1^1/_2$" gypsum concrete over $^1/_2$" gypsum board base; membrane: furring 12" O.C.; clips, D, E, F, G; $1^1/_4$" plaster 1.5:2; 1.5:3	145 psf	1 hr 48 min			3	2,3,8	$1^2/_3$
F/C-S-22	$1^1/_4$"	Floor finish: $1^1/_2$" limestone concrete; $^1/_2$" sand cement topping; plate to beam $3^1/_2$", 12" O.C. welded; 5" 10 lb I beam; 1" channels 18" O.C.; $1^1/_4$" wood fiber gypsum sand plaster on metal lath	292 psf	2 hr 45 min			6	2,4,9,10	$2^3/_4$
F/C-S-23	$1^1/_2$"	$2^1/_2$" L.W. (gas-expanded) concrete; deck: $^1/_2$" topping; plate $6^1/_4$" welds 12" O.C.; beams: 5" 18.9 lb H center; 5" 10 lb I ends; membrane: 1" channel 18" O.C.; $1^1/_2$" gypsum sand plaster	150 psf	4 hr 42 min			6	2,4,9	$4^2/_3$
F/C-S-24	$1^1/_2$"	Floor finish: $1^1/_2$" limestone concrete; $^1/_2$" cement topping; plate $3^1/_2$" 12" O.C. welded; 5" 10 lb I beam; ceiling: 1" channel 18" O.C.; $1^1/_2$" gypsum plaster	292 psf	2 hr 34 min			6	2,4,9,10	$2^1/_2$
F/C-S-25	$1^1/_2$"	Floor finish: $1^1/_2$" gravel concrete on expanded metal; plate cont. weld; 4" 7.7 lb I beams; ceiling: $^1/_4$" rods 12" O.C. welded to beams; $1^1/_2$" fiber gypsum sand plaster	70 psf	1 hr 24 min			6	2,4,9,10	$1^1/_3$
F/C-S-26	$2^1/_2$"	Floor finish: bare plate; $6^1/_4$" welding 12" O.C.; 5"-18.9 lb H girder (inner); 5" 10 lb I girder (2 outer); 1" channel 18" O.C.; 2" reinforced gypsum tile; $^1/_2$" gypsum sand plaster	122 psf	1 hr			6	7,9,11	1
F/C-S-27	$2^1/_2$"	Floor finish: 2" gravel concrete; plate to beam $3^1/_2$–12" O.C. welded; 4" 7.7 lb I beams; 2" gypsum ceiling tiles; $^1/_2$" gypsum sand plaster 1:3	105 psf	2 hr 31 min			6	2,4,9,10	$2^1/_2$
F/C-S-28	$2^1/_2$"	Floor finish: $1^1/_2$" gravel concrete; $^1/_2$" gypsum asphalt; plate cont. weld 4" 7.7 lb I beam; 12" 31.8 lb I beam-girder at 5' from 1 end; 1" channels 18" O.C.; 2" rein. gypsum tile; $^1/_2$" gypsum sand plaster 1:3	200 psf	4 hr 55 min			6	2,4,9,11	$4^2/_3$
F/C-S-29	$^3/_4$"	Floor: 2" rein. concrete or 2" precast rein. gypsum tile; ceiling: $^3/_4$" portland cement sand plaster 1:2 for scratch and 1:3 for brown coat with 15 lb hydrated lime and 3 lb of short asbestos fiber bag per cement, or $^3/_4$" sanded gypsum plaster, 1:2 for scratch and 1:3 for brown coat	See note 12	1 hr 30 min		1		12,13, 14	$1^1/_2$
F/C-S-30	$^3/_4$"	Floor: $2^1/_4$" rein. concrete or 2" rein. gypsum tile, the latter with $^1/_4$" mortar finish; ceiling: $^3/_4$" sanded gypsum plaster 1:2 for scratch and 1:3 for brown coat	See note 12	2 hr		1		12,13, 14	2
F/C-S-31	$^3/_4$"	Floor: $2^1/_2$" rein. concrete or 2" rein. gypsum tile, the latter with $^1/_4$" mortar finish; ceiling: 1" neat gypsum plaster or $^3/_4$" gypsum-vermiculite plaster, ratio of gypsum to fine vermiculite 2:1 to 3:1	See note 12	2 hr 30 min		1		12,13, 14	$2^1/_2$
F/C-S-32	$^3/_4$"	Floor: $2^1/_2$" rein. concrete or 2" rein. gypsum tile, the latter with $^1/_2$" mortar finish; ceiling: 1" neat gypsum plaster or $^3/_4$" gypsum-vermiculite plaster, ratio of gypsum to fine vermiculite 2:1 to 3:1	See note 12	3 hr		1		12,13, 14	3

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Table O.4.5.50 Floor/Ceiling Assemblies — Steel Structural Elements ***(Continued)***

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-S-33	1"	Floor: $2^1/_2$" rein. concrete or 2" rein. gypsum slabs, the latter with $^1/_2$" mortar finish; ceiling: 1" gypsum-vermiculite plaster applied on metal lath, ratio of gypsum to vermiculite 2:1 to 3:1 by weight	See note 12	4 hr		1		12,13, 14	4
F/C-S-34	$2^1/_2$"	Floor: 2" rein. concrete or 2" precast rein. portland cement concrete or gypsum slabs, precast slabs to be finished with $^1/_4$" mortar top coat; ceiling: 2" precast rein. gypsum tile, anchored into beams with metal ties or clips and covered with $^1/_2$" sanded gypsum plaster 1:3	See note 12	4 hr		1		12,13, 14	4
F/C-S-35	1"	Floor: 1:3:6 portland cement, sand, and gravel concrete applied directly to the top of steel units and $1^1/_2$" thick at top of cells, plus $^1/_2$" cement-sand finish 1:2, total thickness at top of cells 2"; ceiling: 1" neat gypsum plaster, back of lath 2" or more from underside of cellular steel	See note 15	3 h		1		15,16, 17,18	3
F/C-S-36	1"	Floor: same as F/C-S-35; ceiling: 1" gypsum-vermiculite plaster (ratio of gypsum to vermiculite 2:1 to 3:1), the back of lath 2" or more from underside of cellular steel	See note 15	4 hr		1		15,16, 17,18	4
F/C-S-37	1"	Floor: same as F/C-S-35; ceiling: 1" neat gypsum plaster, the back of lath 9" or more from underside of cellular steel	See note 15	4 hr		1		15,16, 17,18	4
F/C-S-38	1"	Floor: same as F/C-S-35; ceiling: 1" gypsum-vermiculite plaster (ratio of gypsum to vermiculite 2:1 to 3:1), the back of lath being 9" or more from underside of cellular steel	See note 15	5 hr		1		15,16, 17,18	5
F/C-S-39	$^3/_4$"	Floor: asbestos paper 14 lb/100 ft^2 cemented to steel deck with waterproof linoleum cement, wood screeds, and $^7/_8$" wood floor; ceiling: $^3/_4$" sanded gypsum plaster, 1:2 for scratch and 1:3 for brown coat	See note 19	1 hr		1		19,20, 21,22	1
F/C-S-40	$^3/_4$"	Floor: $1^1/_2$" portland cement concrete 1:2:4; ceiling: $^3/_4$" sanded gypsum plaster, 1:2 for scratch and 1:3 for brown coat	See note 19	1 hr 30 min		1		19,20, 21,22	$1^1/_2$
F/C-S-41	$^3/_4$"	Floor: 2" portland cement concrete 1:2:4; ceiling: $^3/_4$" sanded gypsum plaster, 1:2 for scratch and 1:3 for brown coat	See note 19	2 hr		1		19,20, 21,22	2
F/C-S-42	1"	Floor: 2" portland cement concrete 1:2:4; ceiling: 1" portland cement sand plaster with 10 lb of hydrated lime for a bag of cement, 1:2.5 for brown and 1:2 for scratch coat	See note 19	2 hr		1		19,20, 21,22	2
F/C-S-43	$1^1/_2$"	Floor: 2" portland cement concrete 1:2:4; ceiling: $1^1/_2$" sanded gypsum plaster 1:2, on ribbed metal lath	See note 19	2 hr 30 min		1		19,20, 21,22	$2^1/_2$
F/C-S-44	$1^1/_8$"	Floor: 2" portland cement concrete 1:2:4; ceiling: $1^1/_8$" sanded gypsum plaster 1:1	See note 19	2 hr 30 min		1		19,20, 21,22	$2^1/_2$
F/C-S-45	1"	Floor: $2^1/_2$" portland cement concrete 1:2:4; ceiling: 1" sanded gypsum plaster 1:2	See note 19	2 hr 30 min		1		19,20, 21,22	$2^1/_2$
F/C-S-46	$^3/_4$"	Floor: $2^1/_2$" portland cement concrete 1:2:4; ceiling: 1" neat gypsum plaster or $^3/_4$" gypsum-vermiculite plaster (ratio of gypsum to vermiculite 2:1 to 3:1)	See note 19	3 hr		1		19,20, 21,22	3

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Table O.4.5.50 Floor/Ceiling Assemblies — Steel Structural Elements ***(Continued)***

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-S-47	$1\frac{1}{8}$"	Floor: $2\frac{1}{2}$" portland cement, sand, and cinder concrete 1:2:4, plus $\frac{1}{2}$" cement-sand finish 1:2.5; total thickness 3"; ceiling: $1\frac{1}{8}$" sanded gypsum plaster 1:1	See note 19	3 hr		1		19,20, 21,22	3
F/C-S-48	$1\frac{1}{8}$"	Floor: $2\frac{1}{2}$" gas-expanded portland cement, sand, and concrete, plus $\frac{1}{2}$" cement-sand finish 1:2.5; total thickness 3"; ceiling: $1\frac{1}{8}$" sanded gypsum plaster 1:1	See note 19	3 hr 30 min		1		19,20, 21,22	$3\frac{1}{2}$
F/C-S-49	1"	Floor: $2\frac{1}{2}$" portland cement concrete 1:2:4; ceiling: 1" gypsum-vermiculite plaster (ratio of gypsum to vermiculite 2:1 to 3:1)	See note 19	4 hr		1		19,20, 21,22	4
F/C-S-50	$2\frac{1}{2}$"	Floor: 2" portland cement concrete 1:2:4; ceiling: 2" interlocking gypsum tile supported on upper face of lower beam flange, $\frac{1}{2}$" sanded gypsum plaster 1:3	See note 19	2 hr		1		19,20, 21,22	2
F/C-S-51	$2\frac{1}{2}$"	Floor: 2" portland cement concrete 1:2:4; ceiling: 2" precast metal rein. gypsum tile, $\frac{1}{2}$" sanded gypsum plaster 1:3 (tile clipped to channels that are clipped to lower flange of beams)	See note 19	4 hr		1		19,20, 21,22	4

(Sheet 5 of 5)

Notes:
1. No protective membrane over structural steel.
2. Performance time indicates first end point reached; only several tests were continued to points where other failures occurred.
3. Load failure.
4. Thermal failure.
5. This is an estimated time to load-bearing failure. The same joist and deck specimen was used for a later test with different membrane protection.
6. Test stopped at 3 hours to reuse specimen; no end point reached.
7. Test stopped at 1 hour to reuse specimen; no end point reached.
8. All plaster used was gypsum.
9. Specimen size: 18 ft × $13\frac{1}{2}$ ft. Floor deck: base material $\frac{1}{2}$ in. × 18 ft steel plate welded to I beam.
10. I beams: 24 in. O.C.
11. I beams 4–8 in. O.C.
12. Apply to open web joints, pressed steel joists, or rolled steel beams, which are not stressed beyond 18,000 psi in flexure for open-web pressed or light rolled steel joists, and 20,000 psi for American standard or heavier rolled beams.
13. Ratio of weight of portland cement to fine and coarse aggregates combined for floor slabs shall not be less than 1:6.5.
14. Plaster for ceiling shall be applied on metal lath that shall be tied to supports to give the equivalent of single 18 gauge steel wires 5 in. O.C.
15. Load: maximum fiber stress in steel not to exceed 16,000 psi.
16. Prefabricated units 2 ft wide with length equal to the span, composed of two pieces of 18 gauge formed steel welded together to give four longitudinal cells.
17. Depth not less than 3 in.; and distance between cells not less than 2 in.
18. Ceiling: metal lath tied to furring channels secured to runner channels hung from cellular steel.
19. Load: rolled steel supporting beams and steel plate base shall not be stressed beyond 20,000 psi in flexure.
Formed steel (with wide upper flange) construction shall not be stressed beyond 16,000 psi.
20. Some type of expanded metal or woven wire shall be embedded to prevent cracking in concrete flooring.
21. Ceiling plaster shall be on metal lath wired to rods or channels that are clipped or welded to steel construction. Lath shall be no smaller than 18 gauge steel wire and not more than 7 in. O.C.
22. The securing rods or channels shall be at least as effective as single $\frac{3}{16}$ in. rods, with 1 in. of their length bent over the lower flanges of beams with the rods or channels tied to this clip with 14 gauge iron wire.

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FIGURE O.4.5.51 Floor/Ceiling Assemblies — Wood Joist.

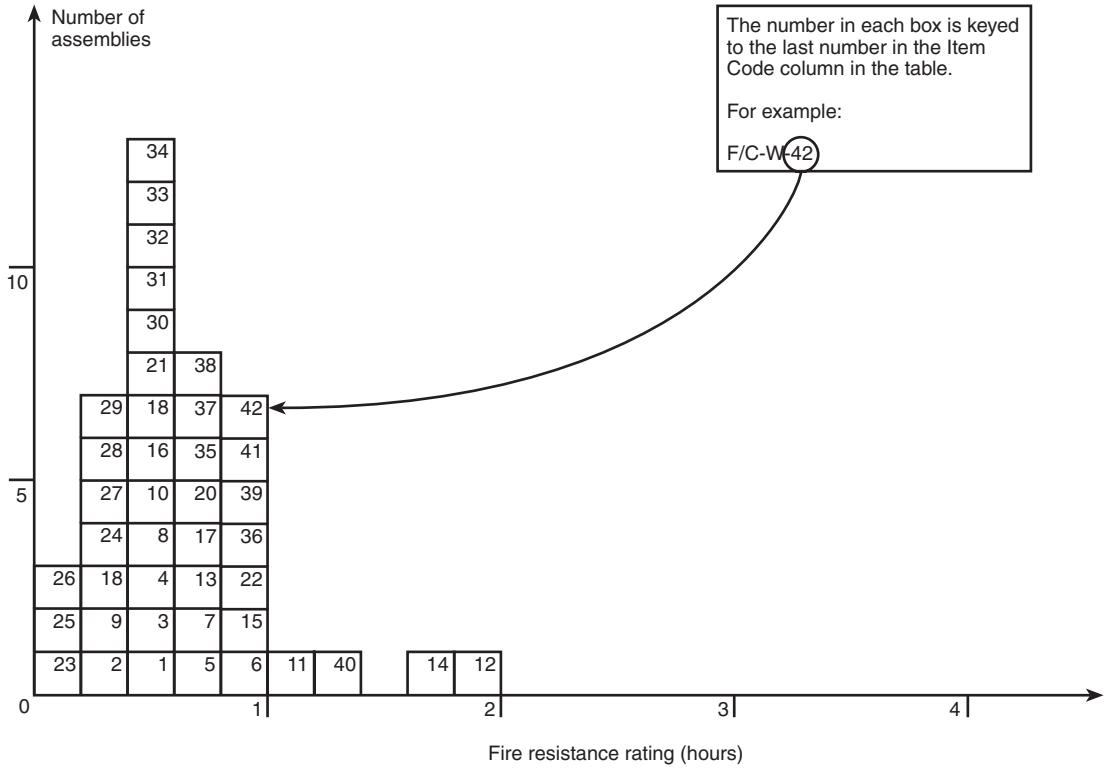

Table O.4.5.51 Floor/Ceiling Assemblies — Wood Joist

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-W-1	$^3/_8$"	12' clear span: 2" × 9" wood joists 18" O.C.; deck: 1" T&G; filler: 3" of ashes on $^1/_2$" boards nailed to joist sides 2" from bottom; 2" air space; membrane: $^3/_8$" gypsum board	60 psf	36 min			7	1,2	$^1/_2$
F/C-W-2	$^1/_2$"	12' clear span: 2" × 7" joists 15" O.C.; deck: 2" × $1^1/_2$" center, bridging at center, 1" nominal lumber; membrane: $^1/_2$" fiberboard	60 psf	22 min			7	1,2,3	$^1/_4$
F/C-W-3	$^1/_2$"	12' clear span: 2" × 7" wood joists 16" O.C., deck: 2" × $1^1/_2$" bridging at center, 1" T&G; membrane: $^1/_2$" fiberboard; 2 coats "distemper" paint	30 psf	28 min			7	1,3,15	$^1/_3$
F/C-W-4	$^3/_{16}$"	12' clear span: 2" × 7" wood joists 16" O.C., deck: 2" × $1^1/_2$" bridging at center span, 1" nominal lumber; membrane: $^1/_2$" fiberboard under $^3/_{16}$" gypsum plaster	30 psf	32 min			7	1,2	$^1/_2$
F/C-W-5	$^5/_8$"	As per F/C-W-4 except membrane is $^5/_8$" lime plaster	70 psf	48 min			7	1,2	$^3/_4$
F/C-W-6	$^5/_8$"	As per F/C-W-5 except membrane is $^5/_8$" gypsum plaster on 22 ga. $^3/_8$" metal lath	70 psf	49 min			7	1,2	$^3/_4$
F/C-W-7	$^1/_2$"	As per F/C-W-6 except membrane is $^1/_2$" fiberboard under $^1/_2$" gypsum plaster	60 psf	43 min			7	1,2,3	$^2/_3$

(Sheet 1 of 4)

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Table O.4.5.51 Floor/Ceiling Assemblies — Wood Joist ***(Continued)***

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-W-8	1/2"	As per F/C-W-7 except membrane is 1/2" gypsum board	60 psf	33 min			7	1,2,3	1/2
F/C-W-9	9/16"	12' clear span: 2" × 7" wood joists 15" O.C., deck: 2" × 1 1/2" center bridging, 1" nominal lumber; membrane: 3/8" gypsum board, 3/8" gypsum plaster	60 psf	24 min			7	1,2,3	1/3
F/C-W-10	5/8"	As per F/C-W-9 except membrane is 5/8" gypsum plaster on wood lath	60 psf	27 min			7	1,2,3	1/3
F/C-W-11	7/8"	12' clear span: 2" × 9" wood joists 15" O.C., 2" × 1 1/2" bridging at center span; deck: 1" T&G; membrane: original ceiling joists have 3/8" plaster on wood lath, 4" metal hangers attached below joists, creating 15" chases filled with mineral wool and closed with 7/8" plaster (gypsum) on 3/8" S.W.M. metal lath to form new ceiling surface	75 psf	1 hr 10 min			7	1,2	1
F/C-W-12	7/8"	12' clear span: 2" × 9" wood joists 15" O.C., 2" × 1 1/2" bridging at center; deck: 1" T&G; membrane: 3" mineral wool below joists; 3" hangers to channel below joists; 7/8" gypsum plaster on metal lath attached to channels	75 psf	2 hr			7	1,4	2
F/C-W-13	7/8"	12' clear span: 2" × 9" wood joists 16" O.C., 2" × 1 1/2" bridging at center span; deck: 1" T&G on 1" bottoms on 3/4" glass wool strips on 3/8" gypsum board nailed to joists; membrane: 3/4" glass wool strips on joists; 3/8" perforated gypsum lath; 1/2" gypsum plaster	60 psf	41 min			7	1,3	2/3
F/C-W-14	7/8"	12' clear span: 2" × 9" wood joists 15" O.C., deck: 1" T&G; membrane: 3" foam concrete in cavity on 1/2" boards nailed to joists; wood lath nailed to 1" × 1 1/4" straps 14" O.C. across joists; 7/8" gypsum plaster	60 psf	1 hr 40 min			7	1,5	1 2/3
F/C-W-15	7/8"	12' clear span: 2" × 9" wood joists 18" O.C., deck: 1" T&G; membrane: 2" foam concrete on 1/2" boards nailed to joist sides 2" from joist bottom; 2" air space; 1" × 1 1/4" wood straps 14" O.C. across joists; 7/8" lime plaster on wood lath	60 psf	53 min			7	1,2	3/4
F/C-W-16	7/8"	12' clear span: 2" × 9" wood joists; deck: 1" T&G; membrane: 3" ashes on 1/2" boards nailed to joist sides 2" from joist bottom; 2" air space; 1" × 1 1/4" (wood) straps 14" O.C.; 7/8" gypsum plaster on wood lath	60 psf	28 min			7	1,2	1/3
F/C-W-17	7/8"	As per F/C-W-16 but with lime plaster mix	60 psf	41 min			7	1,2	2/3
F/C-W-18	7/8"	12' clear span: 2" × 9" wood joists 18" O.C., 2" × 1 1/2" center bridging; deck: 1" T&G; membrane: 7/8" gypsum plaster on wood lath	60 psf	36 min			7	1,2	1/2
F/C-W-19	7/8"	As per F/C-W-18 except membrane uses lime plaster and deck is 1" nominal boards (plain edge)	60 psf	19 min			7	1,2	1/4
F/C-W-20	7/8"	As per F/C-W-19 except deck is 1" T&G boards	60 psf	43 min			7	1,2	2/3
F/C-W-21	1"	12' clear span: 2" × 9" wood joists 16" O.C., 2" × 1 1/2" center bridging; deck: 1" T&G; membrane: 3/8" gypsum base board; 5/8" gypsum plaster	70 psf	29 min			7	1,2	1/3

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Table O.4.5.51 Floor/Ceiling Assemblies — Wood Joist ***(Continued)***

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-W-22	$1\frac{1}{8}$"	12' clear span: 2" × 9" wood joists 16" O.C., bridging: 2" × 2" wood at center; deck: 1" T&G; membrane: hangers, channel with $\frac{3}{8}$" gypsum baseboard affixed under $\frac{3}{4}$" gypsum plaster	60 psf	1 hr			7	1,2,3	1
F/C-W-23	$\frac{3}{8}$"	Deck: 1" nominal lumber; joists: 2" × 7", 15" O.C.; membrane: $\frac{3}{8}$" plasterboard with plaster skim coat	60 psf	$11\frac{1}{2}$ min			12	2,6	$\frac{1}{6}$
F/C-W-24	$\frac{1}{2}$"	Deck: 1" T&G lumber; joists: 2" × 9", 16" O.C.; membrane: $\frac{1}{2}$" plasterboard	60 psf	18 min			12	2,7	$\frac{1}{4}$
F/C-W-25	$\frac{1}{2}$"	Deck: 1" T&G lumber; joists: 2" × 7", 16" O.C.; membrane: $\frac{1}{2}$" fiber insulation board	30 psf	8 min			12	2,8	$\frac{2}{15}$
F/C-W-26	$\frac{1}{2}$"	Deck: 1" nominal lumber; joists: 2" × 7", 15" O.C.; membrane: $\frac{1}{2}$" fiber insulation board	60 psf	8 min			12	2,9	$\frac{2}{15}$
F/C-W-27	$\frac{5}{8}$"	Deck: 1" nominal lumber; joists: 2" × 7", 15" O.C.; membrane: $\frac{5}{8}$" gypsum plaster on wood lath	60 psf	17 min			12	2,10	$\frac{1}{4}$
F/C-W-28	$\frac{5}{8}$"	Deck: 1" T&G lumber; joists: 2" × 9", 16" O.C.; membrane: $\frac{1}{2}$" fiber insulation board: $\frac{1}{2}$" plaster	60 psf	20 min			12	2,11	$\frac{1}{3}$
F/C-W-29	No membrane	Exposed wood joists	See note 13	15 min		1		1,12,13, 14	$\frac{1}{4}$
F/C-W-30	$\frac{3}{8}$"	Gypsum wallboard: $\frac{3}{8}$" or $\frac{1}{2}$" with $1\frac{1}{2}$" No. 15 ga. nails with $\frac{3}{16}$" heads spaced 6" centers, with asbestos paper applied with paperhangers paste and finished with casein paint	See note 13	25 min		1		1,12,13, 14	$\frac{1}{2}$
F/C-W-31	$\frac{1}{2}$"	Gypsum wallboard: $\frac{1}{2}$" with $1\frac{3}{4}$" No. 12 ga. nails with $\frac{1}{2}$" heads, 6" O.C. and finished with casein paint	See note 13	25 min		1		1,12,13, 14	$\frac{1}{2}$
F/C-W-32	$\frac{1}{2}$"	Gypsum wallboard: $\frac{1}{2}$" with $1\frac{1}{2}$" No. 12 ga. nails with $\frac{1}{2}$" heads, 18" O.C., with asbestos paper applied with paperhangers paste and secured with $1\frac{1}{2}$" No. 15 ga. nails with $\frac{3}{16}$" heads and finished with casein paint; combined nail spacing 6" O.C.	See note 13	30 min		1		1,12,13, 14	$\frac{1}{2}$
F/C-W-33	$\frac{3}{8}$"	Gypsum wallboard: 2 layers $\frac{3}{8}$" secured with $1\frac{1}{2}$" No. 15 ga. nails with $\frac{3}{8}$" heads, 6" O.C.	See note 13	30 min		1		1,12,13, 14	$\frac{1}{2}$
F/C-W-34	$\frac{1}{2}$"	$\frac{3}{8}$" perforated gypsum lath — plastered, with $1\frac{1}{8}$" No. 13 ga. nails with $\frac{5}{16}$" heads, 4" O.C.; $\frac{1}{2}$" sanded gypsum plaster	See note 13	30 min		1		1,12,13, 14	$\frac{1}{2}$
F/C-W-35	$\frac{1}{2}$"	Same as F/C-W-34 except with $1\frac{1}{8}$" No. 13 ga. nails with $\frac{3}{8}$" heads, 4" O.C.	See note 13	45 min		1		1,12,13, 14	$\frac{3}{4}$
F/C-W-36	$\frac{1}{2}$"	$\frac{3}{8}$" perforated gypsum lath nailed with $1\frac{1}{8}$" No. 13 ga. nails with $\frac{3}{8}$" heads, 4" O.C.; joints covered with 3" strips of metal lath; with $1\frac{3}{4}$" No. 12 nails with $\frac{1}{2}$" heads, 5" O.C.; $\frac{1}{2}$" sanded gypsum plaster	See note 13	1 hr		1		1,12,13, 14	1
F/C-W-37	$\frac{1}{2}$"	Gypsum lath $\frac{3}{8}$" and lower layer of $\frac{3}{8}$" perforated gypsum lath nailed with $1\frac{3}{4}$" No. 13 ga. nails with $\frac{5}{16}$" heads, 4" O.C.; $\frac{1}{2}$" sanded gypsum plaster or $\frac{1}{2}$" portland cement plaster	See note 13	45 min		1		1,12,13, 14	$\frac{3}{4}$

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Table O.4.5.51 Floor/Ceiling Assemblies — Wood Joist *(Continued)*

Item Code	Membrane Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-W-38	$^3/_4$"	Metal lath nailed with $1^1/_4$" No. 11 ga. nails with $^3/_8$" heads or 6 d common driven 1" and bent over, 6" O.C.; $^3/_4$" sanded gypsum plaster	See note 13	45 min		1		1,12,13, 14	$^3/_4$
F/C-W-39	$^3/_4$"	Same as F/C-W-38 except nailed with $1^1/_2$" No. 11 ga. barbed roof nails with $^7/_{16}$" heads, 6" O.C.	See note 13	1 hr		1		1,12,13, 14	1
F/C-W-40	$^3/_4$"	Same as F/C-W-38 except with lath nailed to joists with additional supports for lath, 27" O.C.; attached to alternate joists and consisting of 2 nails driven $1^1/_4$", 2" above bottom on opposite sides of the joists, one loop of No. 18 wire slipped over each nail; the ends twisted together below lath	See note 13	1 hr 15 min		1		1,12,13, 14	$1^1/_4$
F/C-W-41	$^3/_4$"	Metal lath with $1^1/_2$" No. 11 ga. barbed roof nails with $^7/_{16}$" heads, 6" O.C., with $^3/_4$" portland cement plaster for scratch and 1:3 for brown coat, 3 lb of asbestos fiber and 15 lb of hydrated lime per 94 lb bag of cement	See note 13	1 hr		1		1,12,13, 14	1
F/C-W-42	$^3/_4$"	Metal lath nailed with 8 d 1–$1^1/_2$ ga. barbed box nails $2^1/_2$" driven $1^1/_4$" on slant and bent over, 6" O.C.; $^3/_4$" sanded gypsum plaster, 1:2 for scratch and 1:3 for brown coat	See note 13	1 hr		1		1,12,13, 14	1

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Notes:
1. Thickness indicates thickness of first membrane protection on ceiling surface.
2. Failure mode — flame-thru.
3. Failure mode — collapse.
4. No end point reached at termination of test.
5. Failure imminent — test terminated.
6. Joist failure — 11.5 minutes; flame-thru — 13 minutes; collapse — 24 min.
7. Joist failure — 17 minutes; flame-thru — 18 minutes; collapse — 33 min.
8. Joist failure — 18 minutes; flame-thru — 8 minutes; collapse — 30 min.
9. Joist failure — 12 minutes; flame-thru — 8 minutes; collapse — 22 min.
10. Joist failure — 11 minutes; flame-thru — 17 minutes; collapse — 27 min.
11. Joist failure — 17 minutes; flame-thru — 20 minutes; collapse — 43 min.
12. Joists: 2 in. × 10 in. southern pine or Douglas fir, No. 1 common or better; subfloor: $^3/_4$ in. wood sheathing, diaphragm of asbestos paper, and finish of tongue-and-groove wood flooring.
13. Loadings: not more than 1000 psi maximum fiber stress in joists.
14. Perforations in gypsum lath are to be not less than $^3/_4$ in. diameter, with one perforation for not more than 16 in.^{2} diameter.
15. Distemper is a British term for a water-based paint such as whitewash or calcimine.

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FIGURE O.4.5.52 Floor/Ceiling Assemblies — Hollow Clay Tile with Reinforced Concrete.

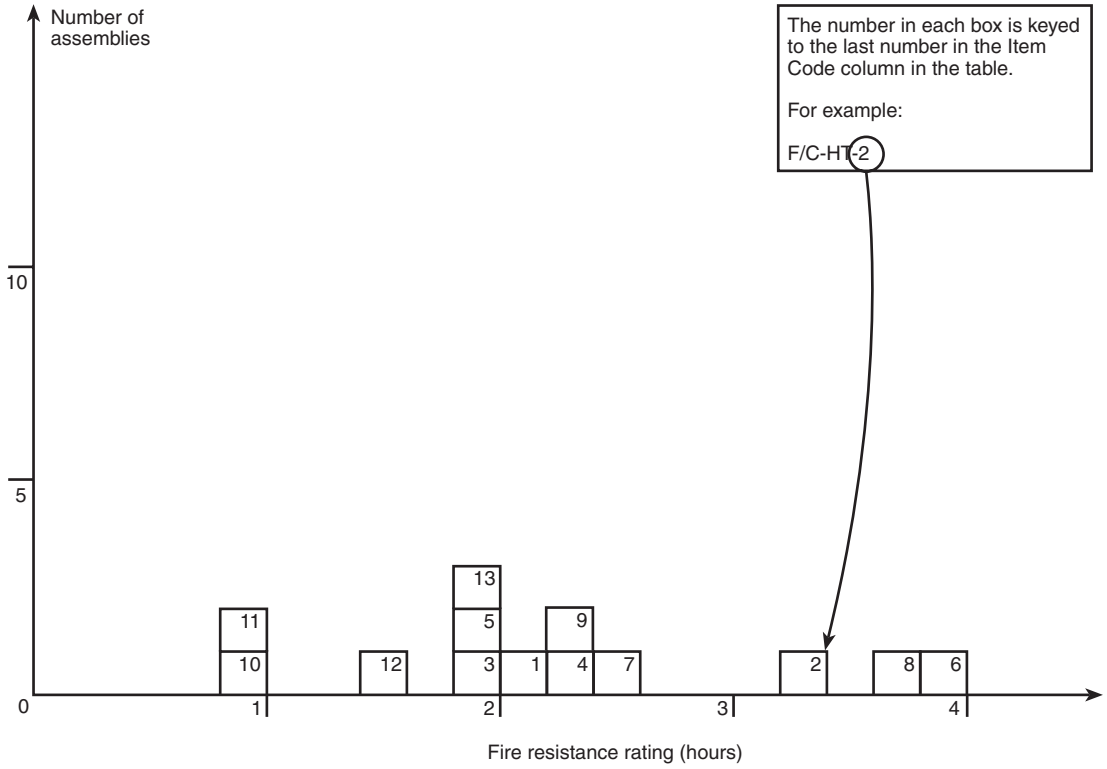

Table O.4.5.52 Floor/Ceiling Assemblies — Hollow Clay Tile with Reinforced Concrete

Item Code	Assembly Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-HT-1	6"	Cover: $1^1/_2$" concrete (6080 psi); 3 cell hollow clay tiles 12" × 12" × 4"; $3^1/_4$" concrete between tiles, including two $^1/_2$" rebars with $^3/_4$" concrete cover; $^1/_2$" plaster cover, lower	75 psf	2 hr 7 min			7	1,2,3	2
F/C-HT-2	6"	Cover: $1^1/_2$" concrete (5840 psi); 3 cell hollow clay tiles 12" × 12" × 4"; $3^1/_4$" concrete between tile, including two $^1/_2$" rebars each with $^1/_2$" concrete cover and $^5/_8$" filler tiles between hollow tiles; $^1/_2$" plaster cover, lower	61 psf	3 hr 23 min			7	3,4,6	$3^1/_3$
F/C-HT-3	6"	Cover: $1^1/_2$" concrete (6280 psi); 3 cell hollow clay tiles 12" × 12" × 4"; $3^1/_4$" concrete between tiles, including two $^1/_2$" rebars with $^1/_2$" cover; $^1/_2$" plaster cover, lower	122 psf	2 hr			7	1,3,5,8	2
F/C-HT-4	6"	Cover: $1^1/_2$" concrete (6280 psi); 3 cell hollow clay tiles 12" × 12" × 4"; $3^1/_4$" concrete between tiles, including two $^1/_2$" rebars with $^3/_4$" concrete cover; $^1/_2$" plaster cover, lower	115 psf	2 hr 23 min			7	1,3,7	$2^1/_3$

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Table O.4.5.52 Floor/Ceiling Assemblies — Hollow Clay Tile with Reinforced Concrete *(Continued)*

Item Code	Assembly Thickness	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
F/C-HT-5	6"	Cover: $1\frac{1}{2}$" concrete (6470 psi); 3 cell hollow clay tiles 12" × 12" × 4"; $3\frac{1}{4}$" concrete between tiles. including two $\frac{1}{2}$" rebars with $\frac{1}{2}$" cover; $\frac{1}{2}$" plaster cover, lower	122 psf	2 hr			7	1,3,5,8	2
F/C-HT-6	8"	Floor cover: $1\frac{1}{2}$" gravel cement (4300 psi); 3 cell tiles 12" × 12" × 6"; $3\frac{1}{2}$" space between tiles including two $\frac{1}{2}$" rebars with 1" cover from concrete bottom; $\frac{1}{2}$" plaster cover, lower	165 psf	4 hr			7	1,3,9, 10	4
F/C-HT-7	9" (nom)	Deck: $\frac{7}{8}$" T&G on 2" × $1\frac{1}{2}$" bottoms (18" O.C.), $1\frac{1}{2}$" concrete cover (4600 psi); 3 cell hollow clay tiles 12" × 12" × 4"; 3" concrete between tiles, including one $\frac{3}{4}$" rebar $\frac{3}{4}$" from tile bottom; $\frac{1}{2}$" plaster cover	95 psf	2 hr 26 min			7	4,11, 12,13	$2\frac{1}{3}$
F/C-HT-8	9" (nom)	Deck: $\frac{7}{8}$" T&G on 2" × $1\frac{1}{2}$" bottoms (18" O.C.), $1\frac{1}{2}$" concrete cover (3850 psi); 3 cell hollow clay tiles 12" × 12" × 4"; 3" concrete between tiles, including one $\frac{3}{4}$" rebar $\frac{3}{4}$" from tile bottoms; $\frac{1}{2}$" plaster cover	95 psf	3 hr 28 min			7	4,11, 12,13	
F/C-HT-9	9" (nom)	Deck: $\frac{7}{8}$" T&G on 2" × $1\frac{1}{2}$" bottoms (18" O.C.), $1\frac{1}{2}$" concrete cover (4200 psi); 3 cell hollow clay tiles 12" × 12" × 4"; 3" concrete between tiles including one $\frac{3}{4}$" rebar $\frac{3}{4}$" from tile bottoms; $\frac{1}{2}$" plaster cover	95 psf	2 hr 14 min			7	3,5,8, 11	
F/C-HT-10	$5\frac{1}{2}$"	Fire clay tile (4" thick); $1\frac{1}{2}$" concrete cover; for general details see note 15	See note 14	1 hr			43	15	1
F/C-HT-11	8"	Fire clay tile (6" thick); 2" cover	See note 14	1 hr			43	15	1
F/C-HT-12	$5\frac{1}{2}$"	Fire clay tile (4" thick); $1\frac{1}{2}$" cover; $\frac{5}{8}$" gypsum plaster, lower	See note 14	$1\frac{1}{2}$ hr			43	15	$1\frac{1}{2}$
F/C-HT-13	8"	Fire clay tile (6" thick); 2" cover; $\frac{5}{8}$" gypsum plaster, lower	See note 14	2 hr			43	15	$1\frac{1}{2}$

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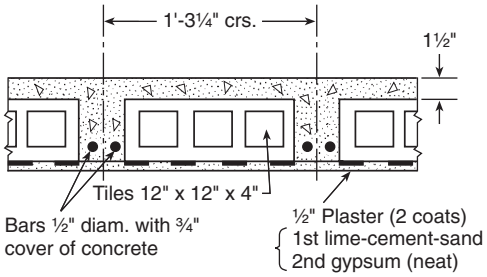
Notes:
1. A generalized cross-section of this floor type follows.



2. Failure mode — structural.
3. Plaster: base coat, lime-cement-sand; top coat, neat gypsum.
4. Failure mode — collapse.
5. Test stopped before any end points were reached.

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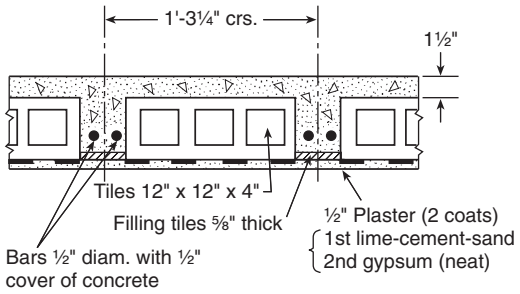
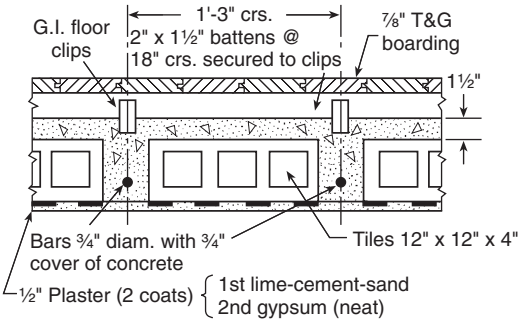
6. A generalized cross-section of this floor type follows.



7. Failure mode — thermal, back face temperature rise.
8. Passed hose stream test.
9. Failed hose stream test.
10. Test stopped at 4 hours before any end points were reached.
11. A generalized cross-section of this floor type follows.



12. Plaster: base coat, retarded hemihydrate gypsum-sand; second coat, neat gypsum.
13. Concrete in item 7 is portland cement–based but with crushed brick aggregates, while in item; river sand and river gravels are used with the portland cement.
14. Load — unspecified.
15. The 12 in. × 12 in. fire clay tiles were laid end to end in rows spaced $2^1/_2$ in. or 4 in. apart. The reinforcing steel was placed between these rows, and the concrete cast around them and over the tile to form the structural floor.

Table O.4.5.53 Reinforced Concrete Beams Depth 10 in. (250 mm) to Less Than 12 in. (300 mm)

Item Code	Depth	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
B-11-RC-1	11"	24" wide × 11" deep reinforced concrete T beam (3290 psi); details: see figure, note 5	8.8 tons	4 hr 2 min			7	1,2,14	4
B-10-RC-2	10"	24" wide × 10" deep reinforced concrete T beam (4370 psi); details: see figure, note 6	8.8 tons	1 hr 53 min			7	1,3	$1^3/_4$
B-10-RC-3	$10^1/_2$"	24" wide × $10^1/_2$" deep reinforced concrete T beam (4450 psi) concrete; details: see figure, note 7	8.8 tons	2 hr 40 min			7	1,3	$2^2/_3$
B-11-RC-4	11"	24" wide × 11" deep reinforced concrete T beam (2400 psi); details: see figure, note 8	8.8 tons	3 hr 32 min			7	1,3,14	$3^1/_2$

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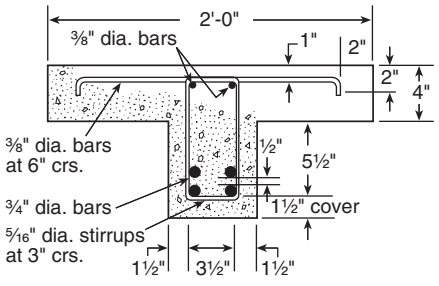
Table O.4.5.53 Reinforced Concrete Beams Depth 10 in. (250 mm) to Less Than 12 in. (300 mm) *(Continued)*

Item Code	Depth	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
B-11-RC-5	11"	24" wide × 11" deep reinforced concrete T beam (4250 psi); details: see figure, note 9	8.8 tons	3 hr 3 min			7	1,3,14	3
B-11-RC-6	11"	Concrete flange: 4" deep × 2' wide (4895 psi) concrete; 7" deep × $6^1/_2$" wide beam; I beam reinforcement: 10" × $4^1/_2$" × 25 lb R.S.J.; 1" cover on flanges; reinforcement: $^3/_8$" diam. bars at 6" pitch parallel to T; $^1/_4$" diam. bars perpendicular to T; 4" × 6" wire mesh 13 SWG; span: 11' restrained; details: see figure, note 10	10 tons	6 hr			7	1,4	6
B-11-RC-7	11"	Concrete flange: 6' deep × 1' $6^1/_2$" wide (3525 psi) concrete; 5" deep × 8" wide precast concrete blocks $8^3/_4$" long; I beam reinforcement: 7" × 4" × 16 lb R.S.J.; 2" cover on bottom; $1^1/_2$" cover on top; 2 rows $^1/_2$" diam. rods parallel to T; $^1/_8$" wire mesh perpendicular to 1" span 1'3" simply supported; details: see figure, note 11	3.9 tons	4 hr			7	1,2	4
B-11-RC-8	11"	Concrete flange: 4" × 2" (3525 psi) concrete; 7" × $4^1/_2$" (scaled from drawing); I beam reinforcement: 10" × $4^1/_2$" × 25 lb R.S.J.; no concrete cover on bottom; reinforcement: $^3/_8$" diam. bars at 6" pitch parallel to T; $^1/_4$" bars perpendicular to T; span: 11' restricted	10 tons	4 hr			7	1,2,12	4
B-11-RC-9	$11^1/_2$"	24" wide × $11^1/_2$" deep reinforced concrete T beam (4390 psi); details: see figure, note 12	8.8 tons	3 hr 24 min			7	1,3	$3^1/_3$

(Sheet 2 of 2)

Notes:
1. Load concentrated at mid-span.
2. Achieved 4-hour performance (Class "B" — British).
3. Failure mode — collapse.
4. Achieved 6-hour performance (Class "A" — British).
5.



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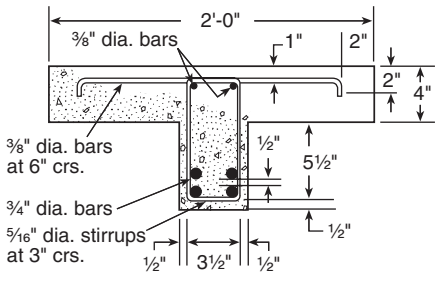

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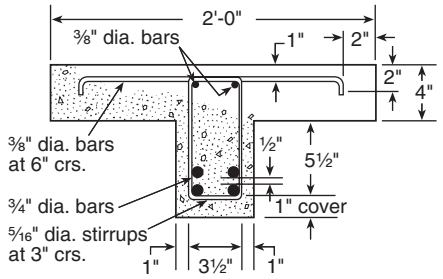

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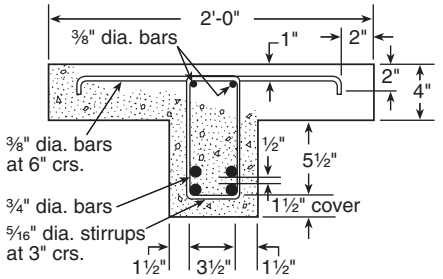

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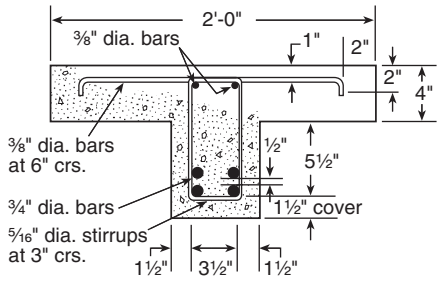

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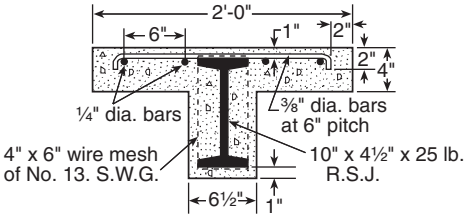
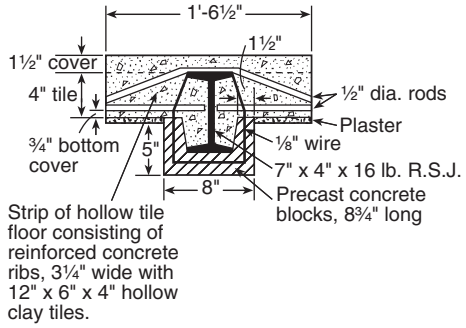


11. Span and end conditions: 10 ft 3 in. (clear), simply supported.



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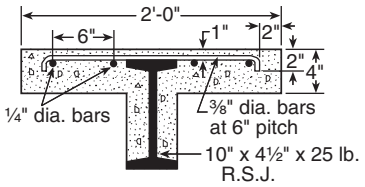

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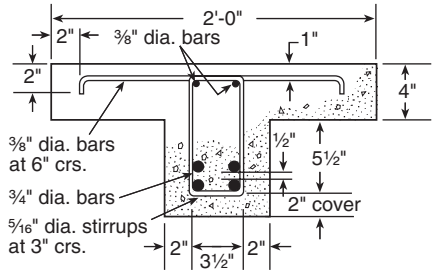

14. The different performances achieved by B-11-RC-1, B-11-RC-4, and B-11-RC-5 are attributable to differences in concrete aggregate compositions reported in the source document but unreported in this table. This demonstrates the significance of material composition in addition to other details.

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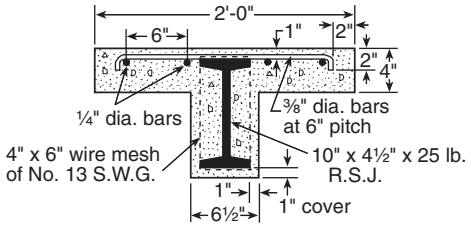
Table O.4.5.54 Reinforced Concrete Beams Depth 12 in. (300 mm) to Less Than 14 in. (350 mm)

Item Code	Depth	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
B-12-RC-1	12"	12" × 8" section: aggregate concrete (4160 psi); reinforcing four $^{7}/_{8}$" rebars at corners; 1" below each surface; $^{1}/_{4}$" stirrups 10" O.C.	5.5 tons	2 hr			7	1	2
B-12-RC-2	12"	Concrete flange: 4" deep × 2" wide (3045 psi) at 35 days; concrete beam: 8" deep; I beam reinforcement: 10" × $4^{1}/_{2}$" × 25 lb R.S.J.; 1" cover on flanges; reinforcement: flange $^{3}/_{8}$" diam. bars at 6" pitch, parallel to T; flange $^{1}/_{4}$" diam. bars perpendicular to T; beam 4" × 6" wire mesh 13 SWG; span: 10'3" simply supported	10 tons	4 hr			7	2,3,5	4
B-13-RC-3	13"	Concrete flange: 4" deep × 2" wide (3825 psi) at 46 days; concrete beam: 9" deep × $8^{1}/_{2}$" wide (scaled from drawing); I beam reinforcement: 10" × $4^{1}/_{2}$" × 25 lb R.S.J.; 3" cover on bottom flange, 1" cover on top flange; reinforcement: flange $^{3}/_{8}$" diam. bars at 6" pitch, parallel to T; $^{1}/_{4}$" diam. bars perpendicular to T; beam 4" × 6" wire mesh 13 SWG; span: 11' restrained	10 tons	6 hr			7	2,3,6,8,9	4
B-12-RC-4	12"	Concrete flange: 4" deep × 2" wide (3720 psi) at 42 days; concrete beam: 8" deep × $8^{1}/_{2}$" wide (scaled from drawing); I beam reinforcement: 10" × $4^{1}/_{2}$" × 25 lb R.S.J.; 2" cover bottom flange; 1" cover top flange; reinforcement: flange $^{3}/_{8}$" diam. bars at 6" pitch, parallel to T; $^{1}/_{4}$" diam. bars perpendicular to T; beam 4" × 6" wire mesh 13 SWG; span: 11' restrained	10 tons	6 hr			7	2–4,7–9	4

Notes:
1. Qualified for 2-hour use. (Grade "C" — British) test included hose stream and reload at 48 hours.
2. Load concentrated at mid-span.
3. British test.
4. British test — qualified for 6-hour use (Grade A).
5.



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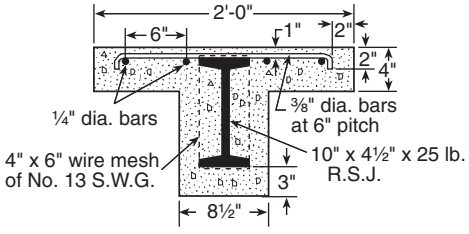

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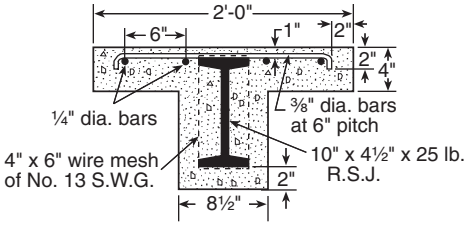

8. See Table L.4.5.55, note 5.
9. Hourly rating based upon B-12-RC-2.

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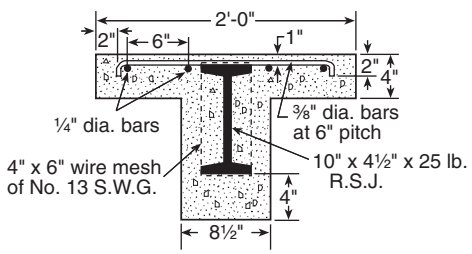
Table O.4.5.55 Reinforced Concrete Beams Depth 14 in. (350 mm) to Less Than 16 in. (400 mm)

Item Code	Depth	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
B-15-RC-1	15"	Concrete flange: 4" deep × 2' wide (3290 psi) concrete; concrete beam: 10" deep × $8^1/_2$" wide; I beam reinforcement: 10" × $4^1/_2$" × 25 lb R.S.J.; 4" cover on bottom flange; 1" cover on top flange; reinforcement: flange; $^3/_8$" diam. bars at 6" pitch, parallel to T; $^1/_4$" diam. bars perpendicular to T; beam 4" × 6" wire mesh 13 SWG; span: 11' restrained	10 tons	6 hr			7	1,2,3,5,6	4
B-15-RC-2	15"	Concrete flange: 4" deep × 2' wide (4820 psi) concrete; concrete beams: 10" deep × $8^1/_2$" wide; I beam reinforcement: 10" × $4^1/_2$" × 25 lb R.S.J.; 1" cover on top flange; 1" cover over wire mesh on bottom; reinforcement: flange $^3/_8$" diam. bars at 6" pitch, parallel to T; $^1/_4$" diam. bars perpendicular to T; beam 4" × 6" wire mesh 13 SWG; span: 11' restrained	10 tons	6 hr			7	1,2,4,5,6	4

Notes:
1. Load concentrated at mid-span.
2. Achieved 6-hour fire rating (Class "A" — British).
3.



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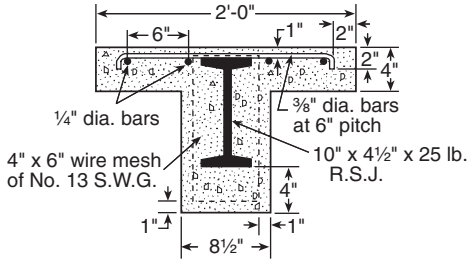

5. Section 43.147 of the 1979 edition of the *Uniform Building Code* standards provides:
"A restrained condition in fire tests, as used in this standard, is one in which expansion at the supports of a load-carrying element resulting from the effects of the fire is resisted by forces external to the element. An unrestrained condition is one in which the load-carrying element is free to expand and rotate at its support.

"[R]estraint in buildings is defined as follows: Floor and roof assemblies and individual beams in buildings shall be considered restrained when the surrounding or supporting structure is capable of resisting the thermal expansion throughout the range of anticipated elevated temperatures. Construction not complying . . . is assumed to be free to rotate and expand and shall be considered as unrestrained.

"Restraint may be provided by the lateral stiffness of supports for floor and roof assemblies and intermediate beams forming part of the assembly. In order to develop restraint, connections must adequately transfer thermal thrusts to such supports. The rigidity of adjoining panels or structures shall be considered in assessing the capability of a structure to resist thermal expansion."
Because it is difficult to determine whether an existing building's structural system is capable of providing the required restraint, the lower hourly ratings of a similar, but unrestrained, assembly have been recommended.
6. Hourly rating based upon Table O.4.5.54, Item B-12-RC-2.

Table O.4.5.56 Reinforced Concrete Beams Unprotected Depth 10 in. (250 mm) to Less Than 12 in. (300 mm)

Item Code	Depth	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
B-SU-1	10"	10" × $4^1/_2$" × 25 lb I beam	10 tons	39 min			7	1	$^1/_3$

Note:
1. Concentrated at mid-span.

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Table O.4.5.57 Steel Beams — Concrete Protection Depth 10 in. (250 mm) to Less Than 12 in. (300 mm)

Item Code	Depth	Construction Details	Performance		Reference Number			Notes	Rec Hours
			Load	Time	Pre-BMS-92	BMS-92	Post-BMS-92		
B-SC-1	10"	10" × 8" rectangle; aggregate concrete (4170 psi) with 1" cover top and 2" cover bottom; 13 SWG iron wire loosely wrapped at approx. 6" pitch about 7" × 4" × 16 lb I beam	3.9 tons	3 hr 46 min			7	1,2,3	$3^3/_4$
B-SC-2	10"	10" × 8" rectangle; aggregate concrete (3630 psi) with 1" cover top and 2" cover bottom; No. 13 SWG iron wire loosely wrapped at approx. 6" pitch about 7" × 4" × 16 lb I beam	5.5 tons	5 hr 26 min			7	1,4,5,6,7	$3^3/_4$

Notes:
1. Load concentrated at mid-span.
2. Specimen: 10 ft 3 in. clear span, simply supported.
3. Passed Grade "C" fire resistance (British), including hose stream and reload.
4. Specimen: 11 ft clear span, restrained.
5. Passed Grade "B" fire resistance (British), including hose stream and reload.
6. See Table O.4.5.55, note 5.
7. Hourly rating based upon B-SC-1.

FIGURE O.4.5.58 Resistance of Doors to Fire Exposure.

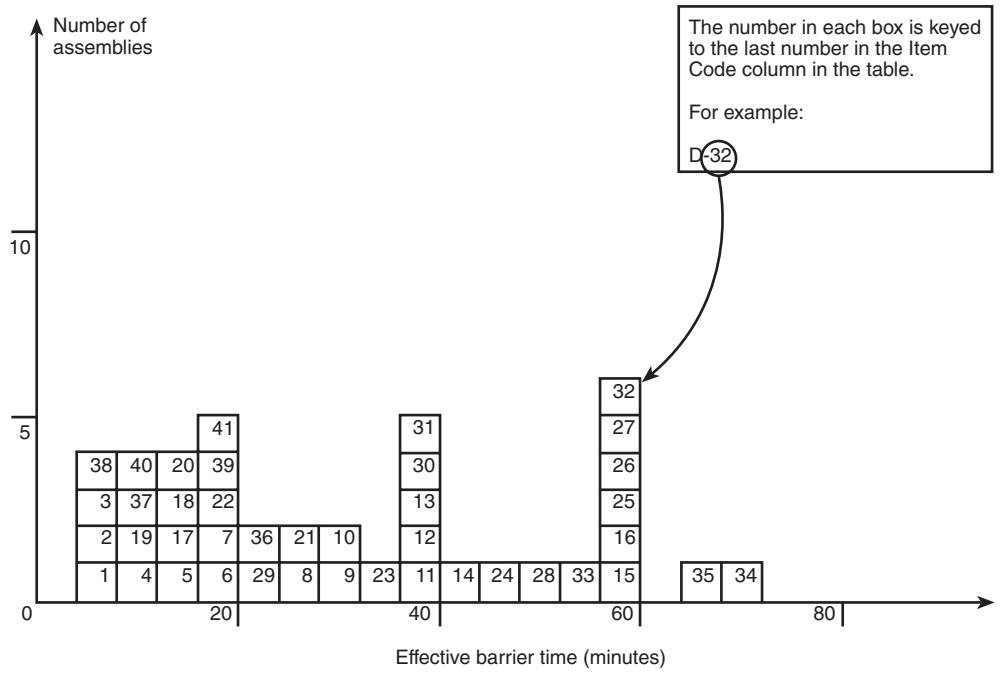

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Table O.4.5.58 Resistance of Doors to Fire Exposure

Item Code	Door Minimum Thickness	Construction Details	Performance		Reference Number			Notes	Rec (Min)
			Effective Barriers	Edge Flaming	Pre-BMS-92	BMS-92	Post-BMS-92		
D-1	3/8"	Panel door, pine perimeter (1 3/8"); painted (enamel)	5 min 10 sec	n/a			90	1,2	5
D-2	3/8"	As D.I, with 2 coats UL-listed intumescent coating	5 min 30 sec	5 min			90	1,2,7	5
D-3	3/8"	As D-1 with standard primer and flat interior paint	5 min 55 sec	n/a			90	1,3,4	5
D-4	2 5/8"	As D-1 with panels covered each side with 1/2" plywood, edge grouted with sawdust-filled plaster; door faced with 1/8" hardboard each side; paint, see note 5	11 min 15 sec	3 min 45 sec			90	1,2,5,7	10
D-5	3/8"	As D-1 but surface protected with glass fiber-reinforced intumescent fire-retardant coating	16 min	n/a			90	1,3,4,7	15
D-6	1 5/8"	Door detail as D-4 but with 1/8" cement asbestos board facings with aluminum foil; door edges protected by sheet metal	17 min	10 min 5 sec			90	1,3,4	15
D-7	1 5/8"	Door detail with 1/8" hardboard cover each side as facings; glass fiber-reinforced intumescent coating applied	20 min	n/a			90	1,3,4,7	20
D-8	1 5/8"	Door detail as D-4; panel was glass reinforced epoxy, intumescent	26 min	24 min 45 sec			90	1,3,4,6,7	25
D-9	1 5/8"	Door detail as D-4 with facings of 5/8" cement asbestos board	29 min	3 min 15 sec			90	1,2	5
D-10	1 5/8"	As per D-9	31 min 30 sec	7 min 20 sec			90	1,3,4	6
D-11	1 5/8"	As per D-7 painted with epoxy intumescent coating including glass-fiber roving	36 min 25 sec	n/a			90	1,3,4	35
D-12	1 5/8"	As per D-4 with intumescent fire-retardant paint	37 min 30 sec	24 min 40 sec			90	1,3,4	30
D-13	1 1/2" (nom)	As per D-4 but with 24 ga. galv. sheet metal facings	39 min	39 min			90	1,3,4	39
D-14	1 5/8"	As per D-9	41 min 30 sec	17 min 20 sec			90	1,3,4,6	20
D-15		Class C steel fire door	60 min	58 min			90	7,8	60
D-16		Class B steel fire door	60 min	57 min			90	7,8	60
D-17	1 3/4"	Solid core flush door; core staves laminated to facings but not each other; birch plywood facings 1/2" rebate in door frame for door; 3/32" clearance between door and wood frame	15 min	13 min			37	11	13
D-18	1 3/4"	As per D-17	14 min	13 min			37	11	13
D-19	1 3/4"	Door as per D-17 but with 16 ga. steel; 3/32" door frame clearance	12 min				37	9,11	10
D-20	1 3/4"	As per D-19	16 min				37	10,11	10
D-21	1 3/4"	Door as per D-17, with intumescent paint applied to top and side edges	26 min				37	11	25

(Sheet 1 of 2)

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Table O.4.5.58 Resistance of Doors to Fire Exposure ***(Continued)***

Item Code	Door Minimum Thickness	Construction Details	Performance		Reference Number			Notes	Rec (Min)
			Effective Barriers	Edge Flaming	Pre-BMS-92	BMS-92	Post-BMS-92		
D-22	$1^3/_4$"	Door as per D-17 but with $^1/_2$" × $^1/_8$" steel strip set into edges of door at top and side facing stops; matching strip on stop	18 min	6 min			37	11	18
D-23	$1^3/_4$"	Solid oak door	36 min	22 min			15	13	25
D-24	$1^7/_8$"	Solid oak door	45 min	35 min			15	13	35
D-25	$1^7/_8$"	Solid teak door	58 min	34 min			15	13	35
D-26	$1^7/_8$"	Solid (pitch) pine door	57 min	36 min			15	13	35
D-27	$1^7/_8$"	Solid deal (pine) door	57 min	30 min			15	13	30
D-28	$1^7/_8$"	Solid mahogany door	49 min	40 min			15	13	45
D-29	$1^7/_8$"	Solid poplar door	24 min	3 min			15	13,14	5
D-30	$1^7/_8$"	Solid oak door	40 min	33 min			15	13	35
D-31	$1^7/_8$"	Solid walnut door	40 min	15 min			15	13	20
D-32	$2^5/_8$"	Solid Quebec pine door	60 min	60 min			15	13	60
D-33	$2^5/_8$"	Solid pine door	55 min	39 min			15	13	40
D-34	$2^5/_8$"	Solid oak door	69 min	60 min			15	13	60
D-35	$2^5/_8$"	Solid teak door	65 min	17 min			15	13	60
D-36	$1^1/_2$"	Solid softwood door	23 min	$8^1/_2$ min			15	13	10
D-37	$^3/_4$"	Panel door	8 min	$7^1/_2$ min			15	13	5
D-38	$^5/_{16}$"	Panel door	5 min	5 min			15	13	5
D-39	$^3/_4$"	Panel door, fire retardant treated	$17^1/_2$ min	13 min			15	13	8
D-40	$^3/_4$"	Panel door, fire retardant treated	$8^1/_2$ min	$8^1/_2$ min			15	13	8
D-41	$^3/_4$"	Panel door, fire retardant treated	$16^3/_4$ min	$11^1/_2$ min			15	13	8

(Sheet 2 of 2)

Notes:
1. All door frames were of standard lumber construction.
2. Wood doorstop protected by asbestos millboard.
3. Wood doorstop protected by sheet metal.
4. Door frame protected with sheet metal and weather strip.
5. Surface painted with intumescent coating.
6. Door edge protected by sheet metal.
7. Door edge protected by intumescent paint.
8. Formal steel frame and doorstop.
9. Door opened into furnace at 12 ft.
10. Similar door opened into furnace at 12 ft.
11. The doors reported in these tests represent the type contemporaries used as 20-minute solid core wood doors. The test results demonstrate the necessity of having wall-anchored metal frames, minimum cleaners possible between door, frame, and stops. They also indicate the utility of long throw latches and the possible use of intumescent paints to seal doors to frames in event of a fire.
12. Minimum working clearance and good latch closure are absolute necessities for effective containment for all such working door assemblies.
13. Based on British tests.
14. Failure at door–frame interface.

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