Designation: E2280 – 13

An American National Standard

Standard Guide for Fire Hazard Assessment of the Effect of Upholstered Seating Furniture Within Patient Rooms of Health Care Facilities[1]

INTRODUCTION

The traditional approach to codes and standards is the specification of individual fire-test-response requirements for each material, component or product placed in a certain environment and deemed important to ensure fire safety. This practice has been in place for so long that it gives a significant level of comfort: a manufacturers knows what is required to comply with the specifications and specifiers apply the requirements. Implicit assumptions, not stated, are that the use of the prescribed requirements ensures an adequate level of safety. There is no need to impose any change on those manufacturers who supply safe systems meeting existing prescriptive requirements. However, as new materials and products are developed, manufacturers, designers, and specifiers often desire the flexibility to choose how the overall safety requirements are to be met. Thus, it is the responsibility of the developer of an alternative approach to state explicitly the assumptions being made to produce the output. The way to generate explicit and valid assumptions is to provide a performance-based approach, based on test methods providing data in engineering units, suitable for use in fire safety engineering calculations, as this guide provides. The resulting fire hazard assessment focuses on upholstered seating furniture items within patient rooms in health care occupancies. This requires developing the fire scenarios to be considered and the effect of all contents and design considerations within the patient room which are potentially able to affect the resulting fire hazard. This offers opportunities for innovation, and ingenuity, without compromising safety.

1. Scope

1.1 This is a guide to developing fire hazard assessments for upholstered seating furniture, within patient rooms of health care occupancies. As such, it provides methods and contemporary fire safety engineering techniques to develop a fire hazard assessment for use in specifications for upholstered seating furniture in such occupancies.

1.2 Hazard assessment is an estimation of the potential severity of the fires that can develop with certain products in defined scenarios, once the incidents have occurred. Hazard assessment does not address the likelihood of a fire occurring, but is based on the premise that an ignition has occurred.

1.3 Because it is a guide, this document cannot be used for regulation, nor does it give definitive instructions on how to conduct a fire hazard assessment.

1.4 This guide is intended to provide assistance to those interested in mitigating the potential damage from fires associated with upholstered furniture in patient rooms in health care occupancies.

1.5 Thus, this guide can be used to help assess the fire hazard of materials, assemblies, or systems intended for use in upholstered furniture, by providing a standard basis for studying the level of fire safety associated with certain design choices. It can also aid those interested in designing features appropriate to health care occupancies. Finally, it may be useful to safety personnel in health care occupancies.

1.6 This guide is a focused application of Guide E1546, which offers help in reference to fire scenarios that are specific to upholstered furniture in health care occupancies, and includes an extensive bibliography. It differs from Guide E1546

[1] This guide is under the jurisdiction of ASTM Committee E05 on Fire Standards and is the direct responsibility of Subcommittee E05.33 on Fire Safety Engineering.

Current edition approved Oct. 1, 2013. Published October 2013. Originally approved in 2003. Last previous edition approved in 2009 as E2280-09 DOI: 10.1520/E2280-13.

in that it offers guidance that is specific to the issue of upholstered furniture in patient rooms of health care facilities, rather than general guidance. Appendix X11 includes some statistics on the magnitude of the potential problem in the U.S.

1.7 A fire hazard assessment conducted in accordance with this guide is strongly dependent on the limitations in the factors described in 1.7.1 – 1.7.4.

1.7.1 Input data (including their precision or accuracy).

1.7.2 Appropriate test procedures.

1.7.3 Fire models or calculation procedures that are simultaneously relevant, accurate and appropriate.

1.7.4 Advancement of scientific knowledge.

1.8 This guide addresses specific fire scenarios which begin inside or outside of the patient room. However, the upholstered furniture under consideration is inside the patient room.

1.9 The fire scenarios used for this hazard assessment guide are described in 9.2. They involve the upholstered furniture item within the patient room as the first or second item ignited, in terms of the room of fire origin. Additionally, consideration should be given to the effect of the patient room upholstered furniture item on the tenability of occupants of rooms other than the room of fire origin, and on that of potential rescuers.

1.10 This guide does not claim to address all fires that can occur in patient rooms in health care occupancies. In particular, fires with more severe initiating conditions than those assumed in the analysis may pose more severe fire hazard than that calculated using this guide (see also 9.5).

1.11 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.12 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.13 This fire standard cannot be used to provide quantitative measures.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles
E176 Terminology of Fire Standards
E603 Guide for Room Fire Experiments
E648 Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source
E662 Test Method for Specific Optical Density of Smoke Generated by Solid Materials
E906 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using a Thermopile Method
E1321 Test Method for Determining Material Ignition and Flame Spread Properties
E1352 Test Method for Cigarette Ignition Resistance of Mock-Up Upholstered Furniture Assemblies
E1353 Test Methods for Cigarette Ignition Resistance of Components of Upholstered Furniture
E1354 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter
E1355 Guide for Evaluating the Predictive Capability of Deterministic Fire Models
E1472 Guide for Documenting Computer Software for Fire Models (Withdrawn 2011)[3]
E1474 Test Method for Determining the Heat Release Rate of Upholstered Furniture and Mattress Components or Composites Using a Bench Scale Oxygen Consumption Calorimeter
E1537 Test Method for Fire Testing of Upholstered Furniture
E1546 Guide for Development of Fire-Hazard-Assessment Standards
E1590 Test Method for Fire Testing of Mattresses
E1591 Guide for Obtaining Data for Fire Growth Models
E1740 Test Method for Determining the Heat Release Rate and Other Fire-Test-Response Characteristics of Wall Covering or Ceiling Covering Composites Using a Cone Calorimeter
E2061 Guide for Fire Hazard Assessment of Rail Transportation Vehicles
E2067 Practice for Full-Scale Oxygen Consumption Calorimetry Fire Tests
E2257 Test Method for Room Fire Test of Wall and Ceiling Materials and Assemblies
F1534 Test Method for Determining Changes in Fire-Test-Response Characteristics of Cushioning Materials After Water Leaching

2.2 *CA Standards:*[4]

CA Technical Bulletin 116, "Requirements, Test Procedure and Apparatus for Testing the Flame Retardance of Upholstered Furniture," January 1980
CA Technical Bulletin 117, "Requirements, Test Procedures, and Apparatus for Testing the Flame Retardance of Resilient Filling Materials Used in Upholstery Furniture," January 1980

2.3 *NFPA Codes and Standards:*[5]

NFPA 101 Code to Safety to Life from Fire in Buildings and Structures
NFPA 265 Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile Wall Coverings
NFPA 286 Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Wall and Ceiling Interior Finish
NFPA 555 Guide on Methods for Decreasing the Probability of Flashover

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from California Bureau of Home Furnishings and Thermal Insulation, State of California, Department of Consumer Affairs, 3485 Orange Grove Avenue, North Highlands, CA, 95660-5595.

[5] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02269-9101.

NFPA 901 Uniform Coding for Fire Protection

2.4 *International Organization for Standardization (ISO) Standards:*[6]

ISO 4880 Burning Behaviour of Textiles and Textile Products—Vocabulary

ISO 9705 Full Scale Room Fire Test for Surface Products

ISO 13943 Fire Safety—Vocabulary

2.5 *Federal Standards:*[7]

Americans with Disabilities Act

FED STD 191A Textile Test Method 5830

2.6 *Underwriters Laboratories Standard:*[8]

UL 1975 Standard Fire Tests for Foamed Plastics Used for Decorative Purposes

2.7 *International Code Council Codes:*[9]

IBC International Building Code, 2001 Supplement to 2000 Edition

IFC International Fire Code, 2001 Supplement to 2000 Edition

2.8 *AATCC Standards:*[10]

AATCC Test Method 86 - 2005 Drycleaning: Durability of Applied Designs and Finishes

AATCC Test Method 124 - 2006 Appearance of Fabrics after Repeated Home Laundering

3. Terminology

3.1 For definitions of terms used in this guide and associated with fire issues refer to the terminology contained in Terminology E176 and ISO 13943. In case of conflict, the definitions given in Terminology E176 shall prevail. For definitions of terms used in this guide and associated with textile issues refer to the terminology contained in Terminology D123 and ISO 4880. In case of conflict, the definitions given in Terminology D123 shall prevail.

3.2 *Definitions:* Definitions contained in Terminology E176 deemed essential for use with this guide:

3.2.1 *fire hazard, n*—the potential for harm associated with fire.

3.2.1.1 *Discussion*—A fire may pose one or more types of hazard to people, animals, or property. These hazards are associated with the environment and with a number of fire-test-response characteristics of materials, products, or assemblies including but not limited to ease of ignition, flame spread, rate of heat release, smoke generation and obscuration, toxicity of combustion products and ease of extinguishment.

3.2.2 *fire performance, n*—response of a material, product, or assembly in a specific fire, other than in a fire test involving controlled conditions (different from *fire-test-response characteristic*, q.v.).

3.2.2.1 *Discussion*—The ASTM Policy on Fire Standards distinguishes between the response of materials, products or assemblies to heat and flame "under controlled conditions," which is fire-test-response characteristic, and "under actual fire conditions," which is fire performance. Fire performance depends on the occasion or environment and may not be measurable. In view of the limited availability of fire-performance data, the response to one or more fire tests, appropriately recognized as representing end-use conditions, is generally used as a predictor of the fire performance of a material, product, or assembly.

3.2.3 *fire scenario, n*—a detailed description of conditions, including environmental, of one or more of the steps from before ignition to the completion of combustion in an actual fire, or in a full-scale simulation.

3.2.3.1 *Discussion*—The conditions describing a fire scenario, or a group of fire scenarios, are those required for the testing, analysis, or assessment that is of interest. Typically they are those conditions that can create significant variation in the results. The degree of detail necessary will depend upon the intended use of the fire scenario. Environmental conditions may be included in a scenario definition but are not required in all cases. Fire scenarios often define conditions in the early steps of a fire while allowing analysis to calculate conditions in later steps.

3.2.4 *flashover, n*—the rapid transition to a state of total surface involvement in a fire of combustible materials within an enclosure.

3.2.4.1 *Discussion*—Flashover occurs when the surface temperatures of an enclosure and its contents rise, producing combustible gases and vapors, and the enclosure heat flux becomes sufficient to heat these gases and vapors to their ignition temperatures. This commonly occurs when the upper layer temperature reaches 600°C or when the radiant heat flux at the floor reaches 20 kW/m^2.

3.2.5 *heat release rate, n*—the heat evolved from the specimen, per unit of time.

3.2.6 *smoke, n*—the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion.

3.2.7 *upholstered, adj*—covered with material (as fabric or padding) to provide a soft surface.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *tenability (of humans to fire-generated conditions), n*—the capability of humans to occupy a room without becoming incapacitated or being killed as a result of a fire.

3.3.2 *tenability limit (of humans to fire-generated conditions) , n*—limit at which a human being is rendered physically incapacitated or dies as a consequence of exposure to one or more factors (such as toxic gases, temperature, heat flux, or smoke obscuration) generated by a fire.

3.3.3 *upholstered seating furniture, n*— a unit of interior furnishing that (*1*) contains any surface that is covered, in

[6] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland or from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[7] Available from General Services Administration, Specifications Activity, Printed Materials Supply Division, Building 197, Naval Weapons Plant, Washington, DC, 20407.

[8] Available from Underwriters Laboratories (UL), Corporate Progress, 333 Pfingsten Rd., Northbrook, IL 60062.

[9] Available from International Code Council (ICC), 5203 Leesburg Pike, Suite 600, Falls Church, VA 22041.

[10] Available from American Association of Textile Chemists and Colorists (AATCC), One Davis Dr., P.O. Box 12215, Research Triangle Park, NC 27709-2215.

whole or in part, with a fabric or related upholstery cover material, (*2*) contains upholstery material, and (*3*) is intended or promoted for sitting upon.

3.3.3.1 *Discussion*—For the purpose of this guide, mattresses, bedding and other sleep products are excluded from the definition of upholstered seating furniture.

3.3.4 *upholstery cover material, n*—the outermost layer of fabric or related material used to enclose the main support system or upholstery materials, or both, used in the furniture item.

3.3.5 *upholstery material, n*—the padding, stuffing, or filling material used in a furniture item, which may be either loose or attached, enclosed by an upholstery cover material, or located between the upholstery cover material and support system, if present.

3.3.5.1 *Discussion*—This includes, but is not limited to, material, such as foams, cotton batting, polyester fiberfill, bonded cellulose, or down.

4. Significance and Use

4.1 This guide is intended for use by those undertaking the development of fire hazard assessments for upholstered seating furniture in health care occupancies.

4.2 As a guide this document provides information on an approach to development of a fire hazard assessment, but fixed procedures are not established. Section 1.7 describes some cautions to be taken into account.

4.3 A fire hazard assessment developed following this guide should specify all steps required to determine fire hazard measures for which safety thresholds or pass/fail criteria can be meaningfully set by responsible officials using the standard.

4.4 A fire hazard assessment developed as a result of using this guide should be able to assess a new item of upholstered seating furniture being considered for use in a certain health care facility, and reach one of the conclusions in 4.4.1 – 4.4.4.

4.4.1 The new upholstered seating furniture item is safer, in terms of predicted fire performance, than the one in established use. Then, the new product would be desirable, from the point of view of fire safety.

4.4.2 There is no difference between the predicted fire safety of the new item and the one in established use. Then, there would be neither advantage nor disadvantage in using the new product, from the point of view of fire safety.

4.4.3 The new upholstered seating furniture item is predicted to be less safe, in terms of fire performance, than the one in established use. Then, the new item would be less desirable, from the point of view of fire safety than the one in established use.

4.4.3.1 If the new upholstered furniture item is predicted to be less safe, in terms of fire performance, than the one in established use, a direct substitution of the products would provide a lower level of safety and the new product should not be used, without other compensatory changes being made. A new upholstered furniture product can, however, be made acceptable if, and only if, it is part of a complete, comprehensive, fire safety design for the patient room. Such a patient room redesign should include one or more of the following features: use of an alternative layout (albeit one that cannot be altered by the patient room users) or increased use of automatic fire protection systems or changes in other furnishings or contents. In such cases, a more in-depth fire hazard assessment should be conducted to ensure that all of the changes together have demonstrated a predicted level of fire safety for the new design which is at least equal to that for the design in established use, in order to permit the use of the new upholstered seating furniture item.

4.4.3.2 Alternatively, the new design may still be acceptable if the predicted level of fire safety is commensurate with new stated fire safety objectives developed in advance.

4.4.4 The new upholstered seating furniture item offers some safety advantages and some safety disadvantages over the item in established use. An example of this outcome could be increased smoke obscuration with decreased heat release. Then, a more in depth fire hazard assessment would have to be conducted to balance the advantages and disadvantages.

4.5 If the patient room does not contain an upholstered seating furniture item, then the fire hazard assessment implications of the introduction of an upholstered seating furniture item should be analyzed in the same way as in 4.4. The fire safety should then be compared with that achieved in the room in established use (which has no upholstered seating furniture). The same analysis would also apply if an additional upholstered furniture item is being considered for introduction in a patient room: the fire hazard assessment should compare the fire safety implications of the addition.

4.5.1 An additional upholstered furniture item adds to the fuel load of a room. Thus, an analysis such as that in 4.4 would offer options 4.4.2 through 4.4.4 only.

4.6 Following the analysis described in 4.4, a fire hazard assessment developed following the procedures in this guide would reach a conclusion regarding the desirability of the furniture product studied.

4.7 An alternative to the analysis based on the anticipated fire performance of the materials or products contained in the patient room is the use of active fire protection measures, such as fire suppression sprinklers. Active fire protection involves measures such as automatic sprinklers and alarm systems, while passive fire protection involves using materials that are difficult to burn and give off low heat and smoke if they do burn. Traditional prescriptive requirements are based exclusively on passive fire protection, with the common approach being to describe the fire tests to be met for every property. The opposite extreme is based entirely on active fire protection, which assumes that active fire protection measures (mostly sprinklers) ensure fire safety. The fire safety record of sprinklers is excellent, but not flawless. Moreover, neither approach gives the type of flexibility that is the inherent advantage of fire hazard and fire risk assessments.

4.7.1 Note that the activation of automatic fire suppression sprinklers does not ensure a safe level of smoke obscuration.

4.8 This guide provides information on a different type of fire hazard assessment than Guide E2061. While Guide E2061 considers an entire occupancy, namely a rail transportation vehicle, this guide addresses a specific product, namely upholstered furniture.

5. Procedure

5.1 The procedure for conducting a fire hazard assessment on upholstered seating furniture in patient rooms of health care occupancies is given in Section 7, for the fire safety objectives in Section 6. This requires applying the design considerations in Section 8, for the scenarios considered in Section 9, and under the assumptions on patient rooms and patient room occupancy given in Section 10. The test methods to be used should be chosen from among those listed in Appendix X1 and some calculation methods are listed in Appendix X5.

6. Fire Safety Objectives

6.1 The primary fire safety objective is to ensure the safe (unharmed) evacuation or removal of all patients threatened by fire to an area of refuge in the event of a fire.

6.1.1 This is achieved if the time required, in the event of a fire, to evacuate the threatened area is less than the time for the fire to create untenable conditions (preferably for the fire not to create conditions that cause harm to people, whenever possible) in the patient room or along the evacuation path. The evacuation time includes the time required for the occupants to reach, or be transported to, a safe location and notification time.

6.1.1.1 As noted in 6.5, this fire safety objective does not address individuals intimate with the ignition.

6.1.2 The time to untenability is the shortest time until untenable conditions are created for any occupant starting at any location within the threatened area or along the evacuation path.

6.1.3 As this guide addresses the consequences of the fire-related properties of the upholstered furniture used, the upholstered furniture used should not decrease tenability.

6.1.4 The time required for evacuation or removal of patients to an area of refuge will be a function of the time required for safety personnel to arrive at the scene of the fire, which will depend, in turn, on the fire detection and fire suppression devices present in the patient room or its vicinity and on the proximity of the safety personnel, including whether they are present in the health care facility or whether they are fire fighters coming from outside the facility.

6.1.5 In some health care facilities, the approach to patient fire safety involves protection in place. In such cases, the time for safe evacuation should be considered to be zero. The effect of this approach is that untenable conditions cannot be allowed to develop in the patient room.

6.2 A potential secondary fire safety objective, considered supportive of the primary objective (but less comprehensive) and more readily measurable, is to prevent flashover inside the fire room. This may require drastic reductions in the total room fuel load (see also NFPA Guide 555).

NOTE 1—Flashover is a crucial phenomenon (**1**).[11] In this guide the onset of flashover is considered to occur when the upper layer temperature reaches 600°C or when the radiant heat flux at the floor reaches 20 kW/m^2 (see 3.2.4).

6.2.1 Analyses of fire statistics show that the vast majority of fire fatalities in the United States occur in fires that have gone to flashover (**2**). In fact, fire statistics are tabulated in the United States, by NFPA, according to a concept roughly equivalent to flashover, namely according to whether there has been "flame damage beyond the room," which does not occur if the fire does not progress beyond the pre-flashover stage, but does if flashover is reached and burning continues (**2**). Thus, in this analysis, if a fire spreads beyond of the room of origin it is considered to have reached flashover.

6.2.1.1 If analysis shows that the flame damage outside of the room of origin has been caused by a factor, such as a flying brand, without flashover having occurred, the hazard assessment should take this into account.

6.3 In the primary fire safety objective, tenability (see 3.3.1 and 3.3.2) is assessed on the basis of fire effects on the occupants, including both direct effects, such as heat, toxic gases or oxygen deprivation, and indirect effects, such as reduced visibility due to smoke obscuration. A tenable environment will therefore prevent loss of life and reduce the likelihood of harm, including non-fatal injury to individuals.

6.3.1 Levels of tenability need to be set to develop a fire hazard assessment.

6.3.2 The default tenability criteria should be the values specified in Table X10.1. Appendix X10 also contains additional discussion on tenability criteria, and should be consulted. If the developer of the fire hazard assessment or the specifier require it, one or more of the default tenability criteria from Table X10.1 can be amended to satisfy the corresponding needs. In such case, an explanation should be given as to why the default criteria have been modified.

6.3.3 In health care occupancies, the health care staff should be aware of specific requirements for certain patients, which must be taken into account for the appropriate areas.

6.3.4 Temperature and heat: Investigations of the tenability in a fire scenario have shown the maximum temperatures which human beings can withstand (**3-5**), the maximum convected heat humans can tolerate (**6**), and the heat flux required to blister or burn skin (**7-9**).

6.3.5 Smoke toxicity: Investigations conducted of the toxicity of smoke of individual gases and of materials have resulted in knowledge about the effects of the primary toxic gases (**10-15**), and the overall effects of smoke toxicity (**16-19**). Such work has shown that results of standard toxicity tests on materials are less helpful for fire hazard assessment than either analyses of emissions of individual gases over time or calculations based on the overall amount of smoke emitted (**6,17, 18**). Furthermore, 2001 bioassay work on rodents over various exposure periods has indicated that the effects of smoke on incapacitation and lethality from smoke toxicity can be assigned to smoke concentration levels of 17 to 27 g/m^3 and 21

[11] The boldface numbers in parentheses refer to the list of references at the end of this standard.

to 37 g/m^3 respectively (**20**), which is consistent with the results of the survey conducted on all previous bioassay work: 15 g/m^3 and 30 g/m^3 respectively (**21**). Various ways have been presented on how to combine one or more of these tenability effects, in documentation for the NIST program HAZARD I and in a review by Purser, (**6**,**22**,**23**).

6.3.6 Smoke obscuration: Smoke obscuration (also known as smoke opacity) does not cause harm in and of itself. However, it seriously hinders ease of escape and ease of rescue of trapped fire victims. Investigations have been able to quantify the restrictions to escape imposed by smoke obscuration (**24-26**) and to propose reasonable visibility limits. A value of Total Smoke Released of 1,000 m^2 in a "standard room" is a criterion used in codes based on this concept (**27**,**28**). (See Appendix X7).

6.4 When conducting this fire hazard assessment the welfare and evacuation of individuals with disabilities (Americans with Disabilities Act) must be considered with particular care.

6.5 A fire safety objective of this guide is to protect the occupants not intimate with the initial fire development from loss of life and to improve the survivability of those who are intimate with the fire development (see NFPA 101). The fire safety of those individuals intimate with the fire development cannot be guaranteed through decisions based on the design of the upholstered furniture product.

6.5.1 An individual is deemed to be intimate with the fire development if that individual is located in the immediate vicinity of the ignition source, typically in contact with it.

6.5.2 The concept of an individual being intimate with the fire development is much more restrictive than being in the room of fire origin. If a compartment has more than one occupant, each occupying their own bed, for example, if one of them is intimate with the fire development, the other one would probably not be considered to be.

6.6 The user needs to consider the inclusion of a final fire safety objective, which is to prevent fire fatalities or serious injuries due to fire effects to the fire fighters responding to an incident.

6.7 The user also needs to consider that evacuation efforts may be affected by ongoing health care emergencies, unrelated to the fire, which may affect the availability of rescue personnel.

6.8 The user also needs to consider the potential effect of the fire (and the smoke) on the life-sustaining and health-care equipment used in the health care facility, to assess whether particular measures need to be taken to prevent the hazard to patients from increasing due to specific damage to certain equipment.

7. Steps in Conducting a Fire Hazard Assessment

7.1 Fire hazard assessment begins by choosing fire safety objective(s) to be achieved. This step is described in Section 6.

7.2 Fire hazard assessment requires specification of the design to be assessed, in a form that permits the fire safety performance of the design to be tested and modeled. This step is described in Section 8.

7.3 Fire hazard assessment requires specification of the fire scenarios for which the design will be required to meet the objectives. This step is described in Section 9.

7.4 Fire hazard assessment requires specification of any additional assumptions, such as conditions of the environment and characteristics of the anticipated occupants, in the assessment. This step is described in Section 10.

7.5 Fire hazard assessment requires the use of testing and calculation methods to determine whether the objectives are expected to be met by a specified design for a specified fire scenario, under the specified assumptions. The calculations to be performed are described in Section 11, and the selection and qualifying of calculation methods for the assessment are described in Section 12.

7.6 For the fire hazard assessment procedure to be valid, it is necessary that the calculation methods and the fire-test-response characteristics used produce valid estimates of success or failure in achievement of the fire safety objectives, given the specified fire scenario(s).

7.7 Fire hazard assessment finds a specified design to be acceptable if, under the specified assumptions, each of the objectives will be met when a health care facility patient room is involved in a fire, for each of the specified fire scenarios.

7.7.1 It is advisable for the validity of the fire hazard assessment procedure to be confirmed by peer review.

8. Use of Design Specifications in Calculations for Estimates of Fire Hazard

8.1 The issue of design of products, or of health care patient rooms as a whole, can have significant impact on fire safety. Design specifications can be used as input into the calculation methods of a fire hazard assessment. However, for design specifications to be useful, they cannot be expressed in vague terms but must be expressed as either numerical values or as other instructions, for example equations, compatible with the fire hazard assessment calculation method used.

8.1.1 Once expressed as numerical or other specific values, design specifications are a source for input variables for fire hazard assessment. For example, design specifications will include specification of the materials to be used in the room linings, including ceilings, walls, and floors. The calculations required to assess whether flashover will be prevented in the patient room (an objective specified in 6.2) will require heat absorption parameters for the room linings. These heat absorption parameters will not be identical to the design specifications for the room lining materials but will be derivable from these specifications by reference to data from established test methods. Because this guide does not specify the models or calculation methods to be used, it follows that it cannot list the input variables that will be required or the appropriate procedures to use in deriving those input variables from design specifications.

8.1.2 A fire hazard assessment is an evaluation of a complete design which addresses certain fire safety objectives. Therefore, the design specifications used must address and include all relevant products and design features used, including those specified by conventional prescriptive practices.

Thus, a fire hazard assessment of a remodeling or redesign cannot be limited to the parts of the design being changed. Rather, a fire hazard assessment of a redesign carried out according to the practices presented in this guide must address the patient room, including contents, and its surroundings, in its entirety.

8.2 In connection with this guide, the term "design" refers both to the general arrangement of the patient room (for example, size, location of openings, number and configuration of furnishings, as well as to whether furnishings are fixed in place) and to the materials, products, and components used to build the patient room. The development of such designs often involves decisions which include tradeoffs and ad hoc benefit analyses, and is a traditional approach.

8.2.1 The design should also consider items which are brought into the patient room for occasional use. This includes medical equipment such as an oxygen tank or breathing apparatus. Other examples are mattress overlays (such as decubitus pads) or wheelchairs. In some cases, such temporary furnishings can provide a fire scenario of greater severity than is usually considered for this occupancy (see also 9.5).

8.3 Design specifications for products, components, and materials should include fire-test-response characteristics. The test methods from Appendix X1 should be used to develop these fire-test-response characteristics. Alternatively, other test methods may also be used, provided the tests chosen comply with the criteria of 8.3.1 and 8.3.2.

8.3.1 This guide does not provide a required test method to assess any fire-test-response characteristic. The developer of a fire hazard assessment will need to provide evidence of the validity of any test method chosen for use in testing of components or composites.

8.3.2 The test methods referenced in Appendix X1: (*a*) have been designed to yield results in fire safety engineering units, which are appropriate for fire hazard assessment and (*b*) measure heat release rate, which has been demonstrated to be an essential component of fire hazard assessment (**25,26,29, 30**). The concept of restricting fuel load is described in Appendix X2.

8.3.2.1 The choice of any test method is non-mandatory and the developer of a fire hazard assessment will need to provide evidence of its validity for use in testing of materials or products for use patient rooms of health care occupancies (see also 7.7.1). Design and quality control of component materials critically affects the precision of composite fire test results. Therefore, emphasis should be placed on ensuring consistency in the actual fire performance of components which have been assessed as part of a composite system.

8.3.3 It is likely that design specifications of any finished product with different component materials will not normally be available (from the suppliers of the individual materials or components that go into them) in a form suitable for application of fire hazard assessment. Manufacturers of such products cannot normally be expected to have developed data on characteristics that are not part of existing sets of requirements or recommendations for their products. Similarly, suppliers of individual materials cannot be expected to identify or provide products, components, or materials, based exclusively on the kinds of design specifications required for fire hazard assessment. Therefore, suppliers of such products may require the translation of the performance specifications into conventional specifications for the individual materials.

8.3.3.1 Thus, an alternative approach should exist whereby fire safety objectives are permitted to be achieved by meeting certain sets of fire-test-response characteristics of individual materials or products, if fire loss experience has shown that such sets of requirements have led to suitable fire safety. However, selective use of parts of the methodology in this guide and of individual fire-test-response characteristics does not satisfy the fire safety objectives of this guide. This guide is not suitable for use in developing a fire hazard assessment except in its entirety.

8.3.4 Aesthetic design, as well as geometric and spatial configuration of the individual furnishing items, can have significant influence on the ignition and burning properties of all items used for room furnishings and contents.

8.4 A particular choice of material and material combinations (for fabric, padding, and interliner, if present) in upholstered furniture can have the effect of delaying fire development or even of preventing a fire from becoming self propagating. Furthermore, the concept used to increase fire safety (such as improved fire performance of the materials, incorporation of upholstery barriers, redesign of furniture construction features, or prevention of transport of furniture items as part of variations in room layout) can affect the resulting fire hazard. Several preliminary fire research projects have investigated the role of materials and product design characteristics on the fire properties of the room contents and furnishings (**31-52**).

8.5 The construction features which are a part of the furniture item design can be critical. Important factors for consideration include the presence or absence of armrests, gaps between various cushion areas, internal cavities, dust covers, crevice or entrapment areas, and skirts. Other factors include the shape and construction of the back, the size of the gap between back and seat, the type of threads used, and the relative dimensions of the various materials used at each location.

9. Fire Scenarios of Concern

9.1 The fire scenarios in 9.2 are designed to represent the spectrum of most likely fires involving upholstered seating furniture in the patient rooms of health care occupancies.

9.1.1 When prevention of flashover is one of the objectives (see 6.2), the performance of upholstered furniture that becomes involved in the fire only at the time of or after flashover, either in the room of fire origin or in a second room, need not be assessed in terms of the room of fire origin (see 9.2.6).

9.2 Specific fire scenarios considered in this guide.

9.2.1 Upholstered furniture item is first ignited, as an eventual consequence of smoldering ignition by cigarettes.

9.2.2 Upholstered furniture item is first item ignited, by direct ignition from a small open flame source, such as a match, lighter or candle.

9.2.3 Upholstered furniture item is first item ignited, by direct ignition from a large source, such as a radiant heater.

9.2.4 Upholstered furniture item is first item ignited, by direct ignition (from either of the type of sources in 9.2.1 and 9.2.2), accentuated by an accelerant, such as a spilled flammable liquid (or some intentional action, such as vandalism) (see also Appendix X3).

9.2.5 The upholstered furniture item is the second item ignited, prior to flashover, as a result of heat released by the first item ignited. The source of heat is likely to be another furnishing or content item. This scenario is included since the concept of secondary ignition of products allows the treatment of such fires. Note that, for the purposes of this guide to fire hazard assessment, the upholstered furniture item is assumed to be either the first or the second item ignited only.

9.2.6 If the upholstered furniture item is not ignited until flashover, by other ignition sources within the room, the effect of the upholstered furniture item need not be assessed further in terms of the room of fire origin.

9.2.6.1 The rationale for 9.2.6 is that, if the product is not burning until flashover, or until flashover is inevitable, it can be assumed that the product is likely to have little effect on whether the room will get to flashover. Moreover, in practice, there is little, if any, statistical information available on fires where the item is neither (*a*) the first or second item ignited nor (*b*) burning before flashover occurs.

9.2.6.2 After flashover, the room of fire origin has ceased to be tenable. However, the fire may still impact the survival of occupants of other rooms. Thus, the impact of the fire on occupants of other rooms, after flashover in the room of origin, would still need to be addressed. Flashover in the room of origin can also impact the evacuation of patients from rooms other than the room of origin.

9.2.6.3 Thus, once flashover has occurred, consideration may need to be given to the effect of the patient room upholstered furniture, on an increased heat, smoke obscuration and toxic load on occupants of rooms other than the room of fire origin, and on potential rescuers.

9.2.6.4 If the fire starts in a room other than the patient room and spreads into the patient room, that fire will already be a flashover fire before the upholstered furniture item in the patient room is involved (see 6.2.1), and it will be an example of a fire scenario of the type addressed in 9.2.6.

9.2.7 A specialized fire scenario, other than those listed in 9.2.1 through 9.2.6, resulting from an unusual design, room occupancy or special circumstances, can also be addressed, but a detailed description of it must be provided before undertaking the fire hazard assessment.

9.3 NFPA develops statistics of fires in facilities that care for the sick, for example in **(53)**.

9.4 The application of this guide to a fire hazard assessment of upholstered furniture items in rooms other than patient rooms, for example lounges or cafeterias, would require additional considerations and is beyond the scope of the present document. If the fire starts in a room outside of the patient room, and spreads into it, that fire must be considered to have already become fully developed before it involves the product to be assessed, namely the upholstered furniture within the patient room (see 6.2.1 and 9.2.6.4).

9.5 The enumeration of fire scenarios in 9.2 assumes that other fire scenarios either are less severe, and therefore will lead to achievement of the fire safety objectives, with respect to upholstered furniture, if the design achieves the objectives for the specified fire scenarios, or are less likely and therefore need not be considered as part of the fire hazard assessment (see also 8.2.1).

10. Assumptions Regarding Patient Room

10.1 *Patient Room Design and Layout:*

10.1.1 The specific patient room layout must be defined to conduct this fire hazard assessment.

10.1.2 An example patient room involves a room 9 m long, 3.8 m wide and 2.4 m high, with a single door 2 m high and 1 m wide, which is assumed to be open. The walls are estimated to be covered by ca. 16 mm (nominal 0.63 in.) gypsum-board type X, itself covered by wallpaper (thermal conductivity: 0.14 W/(m·K); density: 770 kg/m^3; specific heat: 900 J/(kg·K)) and the ceiling by ca. 15 mm (0.59 in.) acoustic tile (thermal conductivity: 0.058 W/(m·K); density: 290 kg/m^3 ; specific heat: 1340 J/(kg·K)), with concrete flooring (ca. 12 mm (0.47 in.), thermal conductivity: 1.6 W/(m·K); density: 2400 kg/m^3; specific heat: 800 J/(kg·K). The ceiling is assumed to be horizontal (not beamed or sloping), and to have a smoke detector, but no fire suppression sprinklers. This room contains two beds, two bedside tables, each one adjacent to one bed and two chairs, each located just past the bedside table from the bed, as well as some floor covering system (See Appendix X4 for some tentative heat release data).

10.1.3 The closing (or the partial closing) of the patient room door would each constitute a different fire scenario. The use of either of these scenarios should be justified by the user.

10.1.4 A fire hazard assessment requires the definition of a patient room design and layout. If an analysis is conducted without specifying a different patient room, the default patient room to be used should be the one in 10.1.2.

10.2 *Patient Room Occupancy:*

10.2.1 The occupants of patient rooms can include both patients, visitors and staff. The maximum patient occupancy will be occupancy to room capacity. Furthermore, there is likely to be a mix of patient occupants with different abilities, including a significant proportion who will have disabilities because of age, or physical or mental impairment and even some occupants who may be impaired for other reasons, for example as a result of the use of prescription drugs, or other substances.

10.2.2 Occupancy of the patient room (room of fire origin), and any occupiable spaces nearby to which the fire can spread, could be set for analysis purposes, for example, so as to pose the greatest challenge to the fire safety objectives. Typically, this would involve occupancy to capacity, with all occupants disabled, for whatever reason.

10.2.3 Assumptions regarding numbers and abilities of disabled persons need to incorporate any appropriate relevant provisions of the Americans with Disabilities Act.

10.2.4 Assumptions regarding age distributions of the occupants need to reflect data on age patterns among health care facility patients. Assumptions regarding the capabilities of older or younger occupants (including visitors and staff) need to reflect patterns in the general population and need to be documented as to sources of data.

10.2.5 Assumptions regarding impairment due to prescription drugs or other substances among occupants need to be documented as to source data. If data are unavailable, alternative methods of developing the assumptions need to be sought. One example is to use the patterns in the general population, weighted to reflect the age of health care facility patients. Another example is to conservatively assume that all patients are impaired by drugs. A third example is to choose an arbitrary fraction of patients who are impaired, for example 10 %.

10.2.6 In view of the type of facility under consideration, assume that fire occurs when the maximum number of people will be sleeping. If there are no data available to determine the maximum fraction of people sleeping, assume all patients are sleeping.

10.2.6.1 One example of patient room occupancy, which could be used for the default patient room scenario described in 10.1.2, involves two patients, one in each bed, asleep at the time of ignition. One patient is able to walk, at an average speed of 0.5 m/s, while the other one cannot walk unassisted. Time periods must be estimated for assistance to arrive and for the patient who cannot walk unassisted to be removed from the room. Minimum times for this to occur are likely to be 30 s and 4 min after the smoke detector alarm goes off (if one is present), but the times should be based on the actual facility investigated.

10.2.6.2 A fire hazard assessment requires the definition of a patient room occupancy. If an analysis is conducted without specifying a different patient room occupancy, the patient room occupancy to be used should be the one in 10.2.6.1.

11. Required Calculations

11.1 The fire hazard assessment conducted following the procedures in this guide involves using calculation procedures to determine whether the fire safety objectives in Section 7 will be met if the design specified in Section 8 experiences each of the fires of the scenarios specified in Section 9, and given the additional assumptions specified in Section 10.

11.1.1 Use Guide E1546 when developing the procedure.

11.1.2 Use NFPA 901 if needed for overall coding of materials or products.

11.2 Because the fire safety objectives are all stated in terms of specified fire effects by location and time, the fire hazard assessment calculation procedures must support the calculations in 11.2.1 through 11.2.5.

11.2.1 Translate the fire scenario specifications into a description of the fire in its initial stages, as a function of time in the initially involved space. Among the fire-test-response characteristics of the materials or products initially involved that may be required for such a description are rate of heat release, rate of mass loss, total heat release (if burned to completion, or cumulative heat release to end of burning otherwise), flame spread, cumulative full-scale smoke obscuration and toxic potency of the products of combustion released.

11.2.2 Translate the design specifications into characteristics of the fuel load environment near the initial fire. Use these and the time-based description of the initial fire as a function of time to calculate the spread of fire to secondary items and the ignition of those secondary items.

11.2.3 Calculate the timing of major fire events for each space, including the onset of flashover and fire spread from one space to an adjacent space. The calculation of fire spread from one space to another will require measurement of barrier fire resistance characteristics.

11.2.4 If the calculations in 11.2.3 show that other items in the room are likely to ignite prior to the upholstered furniture item, release enough heat and at a large enough rate, and are used in sufficient quantities to cause flashover, the upholstered furniture item need not be assessed further for the room of fire origin, as its fire performance would not alter the probability of flashover.

11.2.5 For each potentially exposed occupant, the fire hazard assessment must calculate whether the fire safety objective has been met or has not been met. Thus, for each potentially exposed occupant, calculate the time to reach, or be transported to, safe refuge and comparing that time to the calculated time until exposure to an unacceptable hazard. The former requires calculation of occupant alerting, response, travel speed, and other behavior. For occupants requiring rescue, calculations will need to estimate the size, capabilities, and arrival time of fire department or other rescue personnel. The latter can be calculated as the time to exposure to an untenable cumulative dose of fire effects or conservatively calculated as time to first exposure to unacceptably hazardous fire conditions. Calculations will be required for the area of fire origin, any occupied spaces, and any spaces that are part of escape routes.

11.2.6 When making the calculations described in 11.2.3 and 11.2.4, note that the fire hazard may be decreased by the presence, and activation, of fire protection systems, including automatic or manual fire suppression, detection, and smoke control systems. Calculations should take into account whether such systems are in proper functioning order and the times at which activation occurs.

11.3 For the fire safety objective of preventing flashover, the onset of flashover is considered to occur when the upper layer temperature reaches 600°C or when the radiant heat flux at the floor reaches 20 kW/m^2 (see 3.2.4), and either of these can be used to assess achievement of the objective.

11.4 The issue of smoke obscuration often needs to be dealt with specifically, to avoid lack of visibility, even in a relatively small fire, from preventing escape or rescue (see Appendix X7).

12. Selection and Qualification of Fire Hazard Calculation Methods

12.1 The choice of calculation method is not provided in this guide. However, the calculation method, or methods, chosen by the developer of a fire hazard assessment based on it must be accompanied by written evidence of the validity of the method for this purpose. Use Guide E1355 in order to evaluate the predictive capability of the fire model used. Guide E1591 provides guidelines on how to obtain the appropriate input data, in particular material properties, that are needed for fire modeling. Guide E1472 illustrates the type of documentation that the fire model used should provide.

12.2 The user must provide guidance on safety factors needed to offset the uncertainties and biases associated with the method or with the data used by the method. Any valid calculation method is valid only for certain applications and within the limits of its own uncertainties and biases and the uncertainties of its source data. Therefore, the evidence of validity required in 12.1 will provide the basis for specifying safety factors.

12.3 See Appendix X5 and Appendix X6 for candidate calculation methods for heat release, Appendix X7 for consideration of smoke obscuration, and Appendix X8 for an example application of the data from Appendix X4.

13. Keywords

13.1 fire; fire hazar heat release; ignition; smoke obscuration; smoke toxicity; upholstered furniture

APPENDIXES

(Nonmandatory Information)

X1. RECOMMENDED METHODS FOR GENERATING APPROPRIATE DATA FOR CALCULATION METHODS

X1.1 Expose composites of upholstered furniture to radiant heat according to Test Method E1474, at an incident heat flux of 35 kW/m^2.

X1.2 The fire-test-response characteristics of an upholstered furniture component material should be demonstrated to be permanent after laundering, for example as shown in Appendix X9.[12]

X1.3 The combination of cover fabric, barrier and padding used in the upholstered furniture should be shown to be resistant to cigarette ignition.

X1.3.1 The most adequate way of ensuring such cigarette ignition resistance is by conducting full scale tests on the actual item of upholstered furniture, for example by using California Technical Bulletin 116.

X1.3.2 A small-scale method of demonstrating resistance to cigarette ignition would be for the combination of components to show no ignition when tested in accordance with Test Method E1352.

X1.3.3 An alternative method often used for demonstrating resistance to cigarette ignition is that each one of the component materials meets Class I requirements in the appropriate one of Test Methods E1353. However, since this method does not involve testing the combinations actually used, there is less certainty that the combination will be resistant to cigarette ignition. Moreover, it has been found that, for certain combinations of materials, the overall item of upholstered furniture may meet full scale cigarette ignition requirements without each individual component material meeting the requirements.

X1.4 Expose all individual materials in component products other than upholstered furniture to radiant heat according to Test Method E1354, at an incident heat flux of 35 kW/m^2.

X1.5 Expose any wall covering systems, in a construction representative of that in which they are installed in the room, to radiant heat according to Test Method E1740, at an incident heat flux of 35 kW/m^2.

X1.6 Expose the floor covering materials, in a manner representative of the way they are installed in a health care occupancy, to radiant heat according to Test Method E1354, at an incident heat flux of 25 kW/m^2. This heat flux has been chosen on the basis of its suitability to test floor covering materials (**54-57**).

X1.7 Calculate the heat released by each material and by each composite of materials.

X1.8 Compare the results obtained with the estimations in Appendix X2, to ensure that no material, and no composite of materials, is used in quantities large enough that its potential for heat release is such that it is capable of yielding flashover conditions on its own.

X1.8.1 The requirement in X1.8 neglects the effect of combining products in the fire scenario. However, it is closer to the traditional prescriptive approach and permits material manufacturers to have a simple measurable goal.

X1.9 Other test methods exist for assessing various fire-test-response characteristics of materials or of specific products. An example of such test methods is Test Method E662, for smoke obscuration. These methods are not mentioned in this Appendix since their output is not directly suitable for use in fire hazard assessment, usually because it is not expressed in the appropriate engineering units. However, such information may be needed to ensure appropriate safety, in some cases.

[12] FED STD 191-A Textile Test Method 5830 has long been used as a laundering method. Unfortunately, the detergent it references is no longer in use. The American Association of Textile Chemists and Colorists (AATCC, PO Box 12215, Research Triangle Park, NC, 27709) has issued the Standard Laboratory Practice for Home Laundering Fabrics prior to Flammability Testing, to Differentiate Between Durable and Non-durable Finishes (May 1, 1991) and AATCC Test Method 124-1996: Appearance of Fabrics after Repeated Home Laundering. No equivalent standard to FED STD 191-A Textile Test Method 5830 exists, but the AATCC practice mentioned may be used as a replacement for it. More recently, another method has been proposed laundering for laundering, and is described in Appendix X9.

X1.9.1 A test which should be discussed specifically is Test Method E648, for the critical radiant flux of floor covering systems. It yields a measurement of the heat flux level required to sustain flame spread over a floor covering in a wind-opposed fire scenario, such as a fire in a corridor spreading away from the room of fire origin with air flowing towards the fire. It can also provide information on flame spread rate of the floor covering and on the required heat flux for the hot layer to cause the floor covering to contribute added heat and smoke to the fire. This information may be useful in modeling the flame spread along the floor covering outside the room of fire origin.

X1.10 The issue of smoke obscuration often needs to be dealt with specifically, to avoid lack of visibility, even in a relatively small fire, from preventing escape or rescue. This should be done, however, with a test method that yields results in proper engineering units, to permit use in calculation models. The results from Test Method E1354 include smoke obscuration information in the correct units, and may be appropriate for many fire scenarios. Other tests or calculations may be required in specific cases (see Appendix X7).

X1.11 *Full Scale Test Methods:*

X1.11.1 It is likely that properly validated tests of composites and components will be sufficient to carry out this fire hazard assessment. However, it may be desirable to carry out full scale tests of individual products, or of specially designed compartments, for confirmation or other purposes.

X1.11.2 Test Method E1537 is suitable for testing individual examples of upholstered furniture. Test Method E1537 may not, however, be suitable to address the fire hazard resulting from accelerated ignition (such as is discussed in 9.2.4), in which case it may need to be replaced by a non standardized test method.

X1.11.3 Test Method E1590 has been deemed adequate for testing individual mattresses.

X1.11.4 The use of alternative ignition sources (at a different location, of a different intensity or for a different duration) for Test Method E1537 or Test Method E1590 may be a means of addressing some very high challenge fire scenarios, if they are proven relevant.

X1.11.4.1 The use of bedding products (such as bed linens, blankets, or pillows) should be considered only if they affect the fire performance of the mattress on which they are used. Another product that should be considered are mattress decubitus pads, frequently used in health care occupancy beds.

X1.11.5 NFPA 265 and NFPA 286 are means of testing wall, ceiling, or wall and ceiling linings in a standardized room for their contribution to compartment fire development. This can be used to test room surface finishes. NFPA 265 is suitable for textile wall coverings only, and uses an ignition source at 40 kW (for 5 min) and then 150 kW (for 10 min). NFPA 286 is suitable for all interior wall and ceiling finish, other than textile wall coverings, and uses an ignition source at 40 kW (for 5 min) and then 160 kW (for 10 min). Both NFPA 265 and NFPA 286 contain provisions for assessing smoke obscuration (X1.11.11).

X1.11.5.1 Another means of testing wall or ceiling linings is with ISO 9705 or with Test Method E2257. However, it must be noted that most combustible wall linings are likely to reach flashover when tested according to ISO 9705 or according to Test Method E2257. Test results, in terms of time to flashover and heat release rate, are still likely to produce useful information.

X1.11.6 UL 1975 is an example of a full scale furniture calorimeter test of an individual product, in this case foam displays. The exact same technology could be used for full scale tests of several other individual products, if they are not specifically covered by other test methods. The products covered by other test methods, namely upholstered furniture, mattresses and wall linings, have been addressed in X1.11.2, X1.11.3, and X1.11.5.

X1.11.7 If non standardized full scale tests are being designed, use Guide E603 and Practice E2067 to develop a realistic representation of the fire room under consideration, and to obtain guidance on full scale testing and conduct measurements of heat release and associated parameters. The test method or test methods to be used should address the expected fire performance of all surfaces potentially affected by the fire scenario being considered.

X1.11.8 Use an ignition source realistic for the fire scenario investigated, and applicable to as large as possible a variety of potential fire scenarios, to ignite the upholstered furniture item. The applicability of the ignition source must be explicitly addressed. When designing the ignition source to be used, the fuel load and items brought by the patients and visitors must also be considered.

X1.11.9 When conducting full scale test methods, carry out measurements of heat release, by oxygen consumption calorimetry, of smoke obscuration, of mass loss, and of emission of carbon oxides, during the test. Carbon monoxide concentrations are indicative both of toxic fire hazard and of completeness of combustion. If the hazard estimation procedure requires measurements of other gaseous combustion products, such as hydrogen chloride or hydrogen cyanide, measure those products as well.

X1.11.10 Compare the results obtained with the estimations in Appendix X6 of the minimum heat release for flashover, to ensure that no product, or combination of products, is used in such a way that its potential for heat release is such that it is capable of yielding flashover conditions, or creating an untenable environment, on its own.

X1.11.11 The reduction in visibility due to smoke hinders escape capabilities. Tenability considerations have resulted in a variety of proposals on the visibility distance limits reasonable to permit escape or rescue in a fire situation. Such data can be presented in terms of distance, or in terms of test results in a full-scale test, such as optical density or rate of smoke release. Some full scale tests, such as Test Method E1537, Test Method E1590, NFPA 265 and NFPA 286, include requirements for measurement of smoke obscuration information.

X1.11.11.1 Several codes in the United States (International Building Code, International Fire Code, NFPA 101) have used research on room-corner testing (**27**) to adopt a maximum total smoke released in the NFPA 286 room corner test as a criterion for interior wall and ceiling finish, other than textile wall coverings (**28**).

X1.11.12 Compare too the results obtained with estimation for tenability values for smoke toxicity (see 6.3).

X2. FUEL LOAD RESTRICTIONS AS A STRATEGY FOR ACHIEVING FIRE SAFETY OBJECTIVES

X2.1 Any of the approaches listed in Appendix X6 can be used to provide a maximum value on the potential heat from the fuel load of a fire room. In order to keep the total fuel load below this maximum, the potential heat released by each item must also fall below the maximum. In other words, the combination of effective heat of combustion and total mass for each individual component material contained in the fire room must be kept low enough that it cannot, on its own, be responsible for a flashover. This provides the basis for achieving the fire safety objectives through restrictions on the fuel load.

X2.2 To estimate the fuel load, measure the interior volume and floor area of the fire room and measure the mass and exposed surface area of all major combustible items in the room, and then determine the fuel loading, per unit area and per unit volume.

X3. PHYSICAL CHANGES OCCURRING IN PRODUCTS AFTER MANUFACTURE

X3.1 Products may be exposed to the effects of accidental or intentional disfiguration, so that the exposed surface is different from the one intended to be exposed when it was offered for sale.

X3.2 The exposure to a flame source of inner layers of various products (including upholstered furniture) has been shown, in some cases, to result in different fire performance.

X3.3 The standard test methods referenced in this Guide do not address changes to protective layers due to wear, tear, or abuse, which potentially affect the fire-test-response characteristics of the item.

X3.4 If the user of a particular test method chooses to expose one or more of the inner layers during testing, the mode in which the inner layer was exposed should be described in detail.

X4. TENTATIVE DATA FOR HOSPITAL ROOM FIRE SCENARIO

X4.1 Table X4.1 contains tentative heat release rate and effective heat of combustion data for the major furniture items contained in the hospital room recommended. The use of Eq X6.2 (X6.5) for the patient room considered here (with no opening other than the door specified in 10.1.1, suggests that flashover would be obtained at a heat release rate of 2.25 MW, with door losses 1.16 MW and wall losses of 1.09 MW. The chair is a composite of three chairs (**58**). The mattresses are (*a*) a composite of 3 hospital mattresses and (*b*) an existing hospital mattress (**59**). The bed table has been tested in a furniture calorimeter, with a small open flame ignition, with the type of guidance provided by Guide E603 and Practice E2067 (**25,26**). Fig. X8.1 shows the heat release curves of all four products, each tested individually.

X4.2 The chair used is a combination of the results of three hospital room chairs: a vinyl covered armless chair weighing 16.0 kg, chair 2 had bent wooden arms and weighed 18.2 kg and chair 3 was the left-facing arm of a modular group, with a treated heavy nylon fabric, weighing 18.5 kg (tested by using Test Method E1537) (**58**). Mattress 1 is a combination of (*a*) a treated vinyl-covered inner spring mattress with a decubitus pad directly under the cover and on top of a 18 mm (0.75 in.) conventional foam insulator pad hog-ringed to the inner spring followed by a polyester shoddy insulator sheet, the inner spring unit and another polyester shoddy sheet and another 18 mm (0.75 in.) pad of foam, before the fabric, weighing 17.6 kg, (*b*) a mattress identical to the earlier one, but with a 25 mm (1 in.) thickness of conventional polyurethane foam, weighing 18.3 kg, and (*c*) a mattress like (*a*) but where the foam was designed to meet certain fire test requirements (represented by California Technical Bulletin 117) (**59**). Mattress 2 is an inner spring hospital mattress with a 25 mm (1 in.) conventional polyurethane foam pad and shredded polyester fiber insulator pad and an impervious reinforced vinyl cover (**59**). The mattresses were tested by using Test Method E1590.

TABLE X4.1 Estimate of Heat Release Rate of Hospital Furnishing Items (24,57,58)

	Chair	Bed Table	Mattress A	Mattress B
Ht Comb (MJ/kg)[A]	15	15	15	15
Time/s	HRR/kW	HRR/kW	HRR/kW	HRR/kW
0	0	0	0	0
20	12	14	20	8
40	20	16	105	10
60	65	36	200	12
80	120	64	320	17
100	270	100	455	22
110	295	150	510	24
120	310	200	465	25
140	400	500	435	29
160	390	500	500	32
180	340	400	745	35
200	250	350	695	38
220	220	300	520	40
240	160	250	430	35
260	100	200	300	50
280	50	150	125	60
300	20	100	30	80
320	20	50	6	120
340		30		180
360		20		290
370				325
380				280
390				250
450				140
510				290
540				335
570				180
720				30
900				5

[A] The heat of combustion indicated is a median value, for the purpose of an example calculation, from Ref (24).

NOTE 1— HRR: rate of heat release.

X5. CALCULATION METHODS FOR ESTIMATING TIME TO UNTENABILITY

X5.1 Use a room fire growth model to estimate the development of potentially incapacitating conditions in the fire room, as a function of time.

X5.1.1 In one survey (60), 36 actively supported models were identified. Of these models, 20 predict the fire generated environment (mainly temperature), 19 predict smoke movement in some way, 6 calculate fire growth rate, 9 predict fire endurance, 4 address detector or sprinkler response, and 2 calculate evacuation times. Available computer models vary considerably in scope, complexity, and purpose.

X5.1.2 Some models, such as the Available Safe Egress Time (ASET) model (61), can be used on many personal computers, and provide adequate estimates of a few parameters of interest for a fire in a single compartment.

X5.1.3 Special purpose models can provide a single function. For example, COMPF2 (62) calculates post-flashover room temperatures and LAVENT (63) includes the interaction of ceiling jets with fusible links in a room containing ceiling vents and draft curtains. Very detailed models like the HARVARD 5 code (64) or FIRST (65) predict the burning behavior of multiple items in a room, along with the time-dependent conditions therein.

X5.1.4 In addition to the single-room models mentioned above, some multi-room models have also been developed. These include the BRI transport model (66), the HARVARD 6 code (67) (which is a multi-room version of HARVARD 5) (68), FAST (68,69), CCFM (70) and the CFAST model discussed in X5.1.5 (71). These are of interest in tracking smoke leaving the room of fire origin.

X5.1.5 As part of the preparation of written evidence of validity, required for any calculation methods selected for use, the user may find some existing detailed reviews useful.

X5.1.6 Reports by Mitler (72), Jones (73) and Janssens (74) have reviewed the underlying physical concepts in several of the fire models in detail.

X5.1.6.1 Fire models fall into two categories: (*1*) those that start with the principles of conservation of mass, momentum, and energy; and (*2*) curve fits to particular experiments or series of experiments, used in order to develop the relationship among some parameters. In both cases, errors arise in those instances where a mathematical short cut was taken, a simplifying assumption was made, or something important was not well enough understood to include.

X5.2 To operate any room fire growth model, it will be necessary to estimate the time to secondary ignition of each of the major combustible items in the compartment (**75**).

X5.3 To obtain the time required for safe evacuation of the fire room, measure the maximum time between consecutive points of safe evacuation and, from drills, estimate the time required for evacuation once evacuation begins.

X6. CALCULATION METHODS FOR ESTIMATING HEAT RELEASE AND WHETHER FLASHOVER WILL OCCUR

X6.1 A secondary objective is to prevent flashover. This objective can be achieved by the use of a room fire model, such as the ones described in Appendix X5. Alternatively, it is possible to estimate whether flashover will occur by means of a calculation approach.

X6.2 A variety of models have been developed to predict the minimum rate of heat release required to achieve flashover in a certain compartment. Some of these models or calculation methods may apply to specific scenarios that do not involve furniture, and they would then be inappropriate for use.

X6.3 Direct estimations, by simple calculations have been proposed by Thomas (**1**), Babrauskas and Krasny (**76**), and Quintiere (**77**), based simply on geometrical characteristics of the compartment. These expressions are a first approximation, but they will vary depending on the materials used for construction and for lining the various surfaces.

X6.4 The first two of these approaches permit the calculation of a range of values of heat release rate sufficient to cause flashover in a compartment with a floor area not to exceed 500 m^2. The equations are optimized for surfaces made from gypsum board, wallboard, concrete, or thermally similar materials, on walls, floors and ceilings, preferably with the same type of material on all surfaces. These equations have been validated for heat release rates in the range of 0.5 to 1.0 MW. The approach by Quintiere (**76**) is less limited in the choice of interior surface materials, but is more complex, because it includes thermal properties of the compartment surfaces. The most commonly used one (for example in NFPA 555) is that by Thomas, Eq X6.1:

$$Q = 7.8 \cdot 10^{-3} \cdot A_T + 0.758 \cdot \dot{m} \quad (X6.1)$$

where:

A_T = total compartment area: walls, floor and ceiling, m^2.

X6.5 The air flow rate in Eq X6.1 is estimated by Eq X6.2:

$$\dot{m} = 0.5\, A \sqrt{H} \quad (X6.2)$$

where:

A = area of the ventilation opening, m^2, and
H = height of the ventilation opening, m.

X6.6 Two empirical relative approaches have also been proposed, by Ostman and Nussbaum (**78**) and Hirschler (**54, 79**). The Ostman-Nussbaum (**78**) relationship was designed to predict time to flashover from room wall lining materials in the ISO 9705 test, at 100 and 300 kW input, and materials lining three walls and the ceiling. It uses input data from Test Method E1354, at incident heat fluxes of 25 and 50 kW/m^2, and has been validated with test data on wall lining materials (**80**). The Hirschler empirical approach (**52,79**) is a first order approximation for relative time to flashover in a room-corner fire scenario and uses input data from Test Method E1354, at an incident heat flux which is relevant to the fire scenario in question. Recent work has shown the simultaneous successful application of this method to a room-corner and an aircraft interior (**45**).

X6.7 Several additional approaches should be mentioned, all fire models where heat release rates in a room are estimated from wall lining test result data in a small scale test.

X6.8 The OSU model (Smith and Satija (**81**)) predicts fire growth of materials or products tested as wall linings on the basis of ignition, flame spread, heat and smoke release data obtained from the OSU small scale heat release calorimeter (Test Method E906). The model has been validated with wood materials, but not with some other wall linings. No work on its development has been conducted since 1990.

X6.9 The EUREFIC method (Wickstrom and Goransson (**80,82**)), predicts time to flashover of linings in the ISO 9705 test method (with lining material on three walls and ceiling and an ignition source at 100 kW followed by 300 kW), as a function of time using results obtained with the cone calorimeter (Test Method E1354). The model is a reasonably simple empirical approach, based on 3 major assumptions: (*a*) there is no direct relationship between the burning area growth rate and the heat release rate, (*b*) the burning area growth rate is directly proportional to the ease of ignition (in other words it is inversely proportional to the time to ignition in the cone calorimeter) and (*c*) the history of the heat release rate per unit area at each location is the same in full scale as in small scale (cone calorimeter).

X6.10 The Lund model (Karlsson and Magnusson (**83-86**)), represents a fire scenario similar to that in the EUREFIC model, except that the walls only are lined with the material being investigated in ISO 9705, instead of walls and ceiling. Furthermore, it requires input from the lateral ignition and spread of flame test (LIFT) apparatus (Test Method E1321) as well as from the cone calorimeter (Test Method E1354). Third, it predicts a large number of room fire test variables, rather than simply heat release rate and time to flashover. Finally, this model is based on a more fundamental approach, rather than on an empirical one. The model assumes that the total heat release rate comes from five sources: (*a*) the gas burner, (*b*) the vertical wall area behind the burner flame, (*c*) a horizontal strip of material at the ceiling/wall intersection corresponding to the vertical height of the ceiling jet, (*d*) the wall material in the upper layer, after flame spread has started and the wall linings burning below the hot gas layer. The ISO 9705 test is rarely run under the conditions this model requires; however, the fire scenario modeled in this approach can be changed. This model can also be used to simply estimate whether a self propagating fire is obtained using the Karlsson inequality (**85**) (based on the cone calorimeter heat release curve) and whether the flashover is achieved during the 100 kW exposure (**86**).

X6.11 Another compartment fire model was developed by Quintiere (**87**) and improved by Dillon (**88**), and Janssens (**89**) and later used by Janssens et al. (**89,90**) for ISO 9705 predictions. This model, which is generic enough for a wide range of materials and room-corner test scenarios, assumes that the ignition burner flame heats a rectangular area of the back and side walls of the room, in contact with the burner. The width of these areas is that of the burner and the height related to burner height. Once the initially heated area is ignited, upward and lateral flame spread occurs.

X6.12 Semi-empirical correlations by Dillon et al. (**91**) have been shown to do an excellent job of predicting not only room flashover but also heat release rates in the North American room-corner tests (NFPA 265 and NFPA 286) from cone calorimeter (Test Method E1354) data at 50 kW/m^2 incident flux. The calculation involves assessing an exponential decay coefficient from the cone calorimeter data, similar to that used by Karlsson (**85**) earlier.

X6.13 An approach developed for European regulation, namely the assessment of FIGRA, is potentially useful for predicting whether flashover will occur, in the ISO 9705 test. FIGRA (fire growth rate) is the ratio of the peak rate of heat release and the time at which this maximum occurs (**92**). Data exist on the European classification system results using both ISO 9705 and the cone calorimeter.

X6.14 Any one of these approaches can be used to estimate (at least on a relative basis) the energy required for flashover of a health occupancy room. This total should be compared with the sum of the heat release rates measured or estimated for all items proposed as room contents. If the former exceeds the latter, the analysis indicates that flashover is not likely to occur. Report the method used.

X7. SMOKE OBSCURATION

X7.1 It is well known that, generally, heat release rate is a key indicator of smoke emission (**93**).

X7.2 However, it has recently been shown that a small but significant fraction of materials can generate low heat release but high enough smoke, in full-scale fires, that hazardous situations may develop (**27,28**). Therefore, measurements of smoke obscuration should be made to ensure that smoke release is not excessive.

X7.3 The semi-empirical correlation by Dillon (**91**) that can be used for assessing heat release, is also applicable to smoke release predictions, by ascribing to the total smoke release in the room a direct relationship with an empirical smoke area of 4 m^2 and cone calorimeter data on total heat release, specific extinction area and effective heat of combustion. Many other approaches, most of them empirical, also exist.

X7.4 A parameter for smoke obscuration named SMOGRA also exists, which is parallel to the FIGRA parameter for heat release, but based on the rate of smoke release (**92**).

X7.5 Any one of these approaches can be used to estimate (at least on a relative basis) the smoke released in the health occupancy room. The smoke released should be compared with the tenability criterion for smoke obscuration. If the former exceeds the latter, the analysis indicates that changes are required for the fire safety objectives to be met. The method used should be reported.

X8. EXAMPLE CALCULATION

X8.1 One of the methods that can be employed to calculate upper layer room temperatures is the fire model contained in the FPETOOL software (**94**). In that fire model, a moderate fire is defined as one where the growth is governed by a constant $\alpha = 11.72 \times 10^{-3}$ kJ/s^3 and a fast fire is defined as one where the growth is governed by a constant $\alpha = 46.88 \times 10^{-3}$ kJ/s^3. Results obtained using fast and moderate fire curves are shown in Table X8.1. The analyses were conducted using concrete flooring. In order to see the sensitivity of the analysis, alternative analyses were conducted under the exact same ventilation conditions and fire growth rates, but using wood flooring and resilient flooring of similar thickness (Tables X8.2 and X8.3). Different results were obtained for the various flooring types, representing the thermal response characteristics of the flooring material.

X8.2 Application of a different fire model within the same FPETOOL software can be made using specially-constructed fire curves. Four curves were constructed, as shown in Fig. X8.2. They contain the summed heat release rates of one chair, one table and one mattress (each mattress from Table X4.1), in two ways. In the first assumption all three items ignite simultaneously and in the second assumption the chair ignites first, followed by the table at 30 s and then by the mattress at

TABLE X8.1 Effect of Standard Fast and Moderate Fire Curves on Patient Room Recommended for Use in Fire Hazard Assessment (Concrete Floor)

	Fast Fire	Fast Fire	Moderate Fire	Moderate Fire
Time	HRR	Upp. Temp	HRR	Upp. Temp
s	kW	°C	kW	°C
0	0	20	0	20
40	75	57	19	35
80	298	134	75	65
120	671	219	160	99
160	1193	316	284	138
200	1864	423	444	180
240	2684	538	639	226
280	1337[A]	725[A]	870	274
320	1377	747	1137	334
360	1379	748	1439	387
400	1390	755	1776	447
440	1390	755	2149	504
480	1390	755	2558	564
520	1390	755	1390[A]	755[A]
560	1390	755	1390	755
600	1390	755	1390	755
Flashover, s	261	261	504	504

[A] The burning rate and resulting upper layer temperature is limited by the ventilation capacity of the room opening (door). From this point on the program assumes there is more than enough fuel to continue for the full fire duration of 600 s.

NOTE 1—The calculations have been conducted using the Upper Layer Temperature module of the FPETOOL fire model, with the standard FAST FIRE and MODERATE FIRE curves contained in it (**93**).

NOTE 2—Abbreviations: HRR: rate of heat release; Upp. Temp: temperature in the upper layer.

60 s. The results are shown in Table X8.4, where side-by side comparisons indicate the effect of having the products ignite simultaneously or staggered at 30 s intervals. The assumptions made involve the same wall (gypsum board type X) and ceiling (acoustic tile) surface linings as in the base case, and concrete flooring. Once more, it was found that the type of flooring surface would have an effect, but the data are not presented.

TABLE X8.2 Effect of Standard Fast and Moderate Fire Curves on Patient Room Recommended for Use in Fire Hazard Assessment (Wood Flooring)

	Fast Fire	Fast Fire	Moderate Fire	Moderate Fire
Time	HRR	Upp. Temp	HRR	Upp. Temp
s	kW	°C	kW	°C
0	0	20	0	20
40	75	69	19	39
80	298	158	75	75
120	671	273	168	121
160	1193	410	300	175
200	1864	565	468	237
240	1813[A]	990[A]	674	305
280	1859	1015	917	379
320	2062	1128	1198	498
360	2090	1143	1516	587
400	2179	1193	2179[A]	1193[A]
440	2418	1325	2418	1325
480	2418	1325	2418	1325
520	2418	1325	2418	1325
560	2418	1325	2418	1325
600	2418	1325	2418	1325
Flashover, s	209	209	366	366

[A] The burning rate and resulting upper layer temperature is limited by the ventilation capacity of the room opening (door). From this point on the program assumes there is more than enough fuel to continue for the full fire duration of 600 s.

NOTE 1—The calculations have been conducted using the Upper Layer Temperature module of the FPETOOL fire model, with the standard FAST FIRE and MODERATE FIRE curves contained in it (**93**).

NOTE 2—Abbreviations: HRR: rate of heat release; Upp. Temp: temperature in the upper layer.

TABLE X8.3 Effect of Standard Fast and Moderate Fire Curves on Patient Room Recommended for Use in Fire Hazard Assessment (Resilient Flooring)

Time	Fast Fire	Fast Fire	Moderate Fire	Moderate Fire
	HRR	Upp. Temp	HRR	Upp. Temp
s	kW	°C	kW	°C
0	0	20	0	20
40	75	67	19	39
80	298	153	75	73
120	671	264	168	117
160	1193	396	300	170
200	1864	545	468	229
240	1752[A]	956[A]	674	295
280	1796	980	917	366
320	1973	1078	1198	476
360	2226	1219	2226[A]	1219[A]
400	2317	1270	2317	1270
440	2317	1270	2317	1270
480	2317	1270	2317	1270
520	2317	1270	2317	1270
560	2317	1270	2317	1270
600	2317	1270	2317	1270
Flashover, s	214	214	354	354

[A] The burning rate and resulting upper layer temperature is limited by the ventilation capacity of the room opening (door). From this point on the program assumes there is more than enough fuel to continue for the full fire duration of 600 s.

NOTE 1—The calculations have been conducted using the Upper Layer Temperature module of the FPETOOL fire model, with the standard FAST FIRE and MODERATE FIRE curves contained in it (**93**).

NOTE 2—Abbreviations: HRR: rate of heat release; Upp. Temp: temperature in the upper layer.

TABLE X8.4 Effect of Fire Curves with Chair, Table and Mattress on Patient Room Recommended for Use in Fire Hazard Assessment

Time	Mattress 1, Simultaneous	Mattress 1, Staggered	Mattress 2, Simultaneous	Mattress 2, Staggered
	Upper Temp.	Upper Temp.	Upper Temp.	Upper Temp.
s	°C	°C	°C	°C
0	20	20	20	20
20	45	30	40	30
40	77	40	47	40
60	132	66	79	66
80	181	98	107	93
100	246	165	158	143
120	275	203	191	162
140	338	259	270	200
160	348	317	269	239
180	365	336	244	261
200	336	309	217	235
220	294	303	201	216
240	259	328	177	194
260	211	302	155	170
280	147	251	129	144
300	96	217	112	121
320	70	181	112	113
340	47	115	118	93
360	41	67	147	88
380		48	140	98
400		20	134	110
420		39	116	143
500		85	136	103
540		123	155	122
600		187	88	155

NOTE 1—The calculations have been conducted using the Upper Layer Temperature module of the FPETOOL fire model (**93**), with the curves from Fig. X8.1.

NOTE 2—Abbreviations: HRR: rate of heat release; Upp. Temp: temperature in the upper layer.

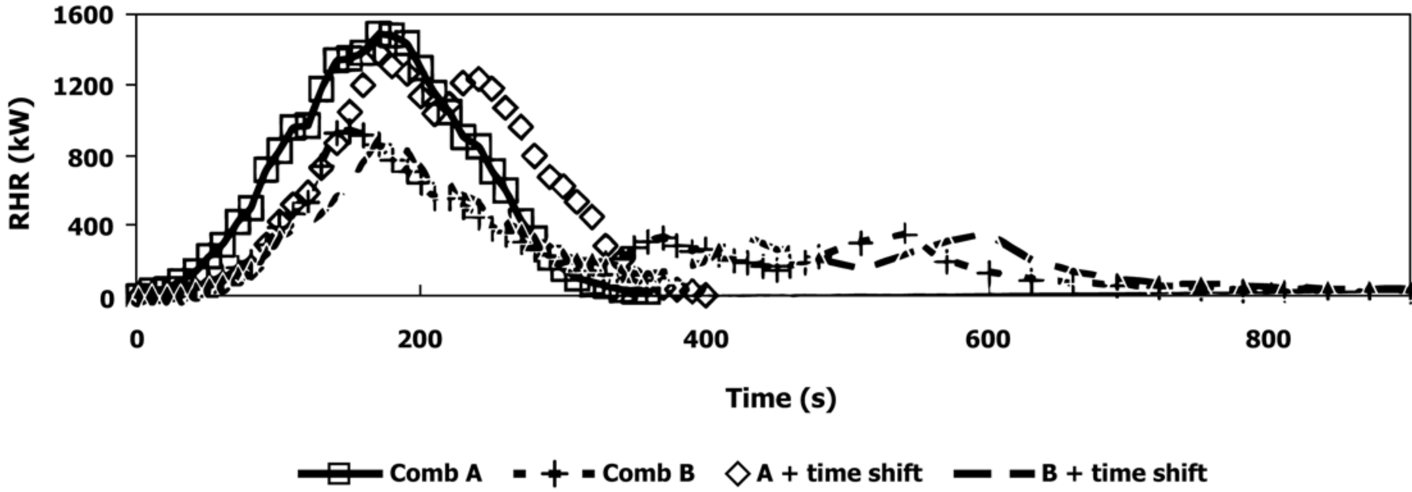

FIG. X8.1 Hospital Items Burning Separately

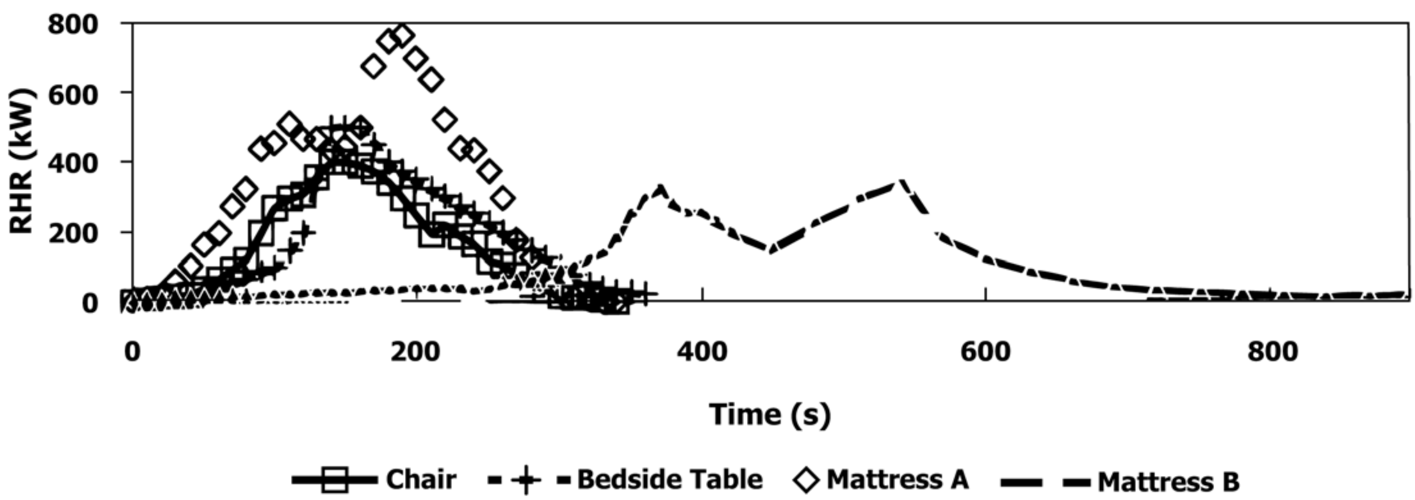

FIG. X8.2 Hospital Items Burning In Combination

X9. EXAMPLE LAUNDERING AND DRY-CLEANING PROCEDURE FOR ASSESSING PERMANENCE OF FIRE-TEST-RESPONSE CHARACTERISTICS OF TEXTILE FABRICS

X9.1 If the fabric manufacturer does not specifically recommend machine washing, the laundering should be conducted as indicated in X9.2. If the fabric manufacturer specifically recommends machine washing, the laundering should be conducted as indicated in X9.3.

X9.2 *Hand Washing Procedure:*

X9.2.1 Cut the number of test specimens to the dimensions required by the fire test to be conducted.

X9.2.2 Vacuum the cut specimens or shake them vigorously to remove any loose fibers, dust or possible accumulated debris.

X9.2.3 Place individual specimen face down in a shallow pan, which has been filled to a depth of 50 mm (2 in.) with a wash solution of 1.5 g per litre of AATCC (American Association of Textile Chemists and Colorists) Standard Detergent as specified in AATCC Test Method 124 (or equivalent), with the water preheated to 41 ± 1°C (105 ± 2°F). Knead the back of the specimen with hand for 1 min. Maintain the water level and the temperature separately for each specimen.

X9.2.4 Rinse specimen thoroughly, face down, with warm water, at 40 ± 5°C (105 ± 9°F), for 1 min, under a faucet with strong water pressure.

X9.2.5 Remove excess liquor by using a wringer, hydro-extractor or by gentle hand squeezing. Then dry in a circulating air oven at 95 ± 5°C (200 ± 9°F) until dry.

X9.2.6 Repeat the above procedure 10 times, each time using fresh detergent and fresh water, for each set of specimens being laundered.

X9.2.7 Subject the laundered dry specimens to the required fire test methods.

X9.3 *Machine Washing Procedure:*

X9.3.1 A fabric sample, or oversized specimens selected for the fire testing procedure, should be washed 10 times, prior to the preparation of test specimens, by the washing and drying procedure prescribed in AATCC Test Method 124.

X9.3.2 Prepare the test specimens from the laundered fabrics and subject the laundered dry test specimens to the required fire test methods.

X9.4 *Special Alternate Washing Procedure:*

X9.4.1 Alternatively, the selected fabric sample, or oversized specimens, should be permitted to be washed or shampooed 10 times, prior to the preparation of test specimens, in a manner that the manufacturer, or other interested party, has previously established to be suitable for assessing the permanence of the fire-test-response characteristics to the satisfaction of the intended specifier, for the intended use.

X9.4.2 One example of a potentially suitable procedure is Test Method F1534, developed for assessing the permanence of the fire-test-response characteristics of cushioning materials in detention and correctional facilities when tested to Test Method E162 and Test Method E662. In Test Method F1534, no detergent is used, and each specimen is immersed in softened water (a volume at least 20 times as large as that of the specimen) at 20 ± 5°C (68 ± 9°F) for 6 h, with continuous water flow at a rate of at least between two and three water changes per hour.

X9.4.3 The laundering procedure used should be clearly described in a report.

X9.4.4 The test specimens should be prepared from the laundered fabrics and the laundered dry test specimens should be subjected to the required fire test methods.

X9.5 *Dry-cleaning Procedure:*

X9.5.1 If the fabric requires a dry-cleaning procedure, the test method in AATCC 86 should be used.

X9.5.2 The dry-cleaning procedure used should be clearly described in the report.

X10. TENABILITY CRITERIA SELECTION

X10.1 Table X10.1 contains the default tenability criteria that should be specified if a user does not have additional information to develop specific criteria for the hazard assessment being conducted.

X10.2 The selection of tenability criteria is critical in that it could increase or decrease the time available for egress depending on the fire scenario. Unfortunately, guidelines often provide multiple choices for acceptable tenability criteria or "factors to consider" when deciding what tenability limit to utilize. As a consequence, the designer has a lot of leeway in this matter. Table X10.2 shows how various authors have chosen tenability criteria quite diverse from one another (**95**).

TABLE X10.1 Default Tenability Criteria Recommended, Based on Various Sources

Hazard	Incapacitation Criterion	Lethality Criterion	Reference
Smoke Toxicity Ct (g min/m^3)^A	450	900	(**23-25**)
Smoke Toxicity Concentration (g/m^3)	15	30	(**23-25**)
Smoke Toxicity FED	0.5	1	(**23-25**)
Smoke Toxicity Concentration (g/m^3)	22	29	(**26**)
Convected Heat/ Temperature (°C)	65	100 (intolerable burn)	(**6**,**23**, **25**)
Radiated Heat/Heat Flux (kW min/m^2)	1.0	2.5 (intolerable burn)	(**6**)
Smoke Obscuration	Visibility Distance = 4 m or 13 m^B		(**10 and 11**)

^{A} Toxicity work was conducted at various exposure periods, and is presented averaged, for a 30 min exposure period, to generate a "Ct" value. Concentration data are shown too, without a time period.
^{B} Lack of visibility has no direct health effects, but inhibits, or even prevents, safe escape or rescue. The following equation, from NIST, has been used as a tenability criterion for visibility: Extinction Coefficient (in m^{-1}) × Visibility Distance (in m) = 2 (**25**). There is generally, a difference in the tenability criteria associated with visibility as a function of the familiarity between occupants and their surrounding. Jin (**10**,**11**) recommends 4 m visibility (0.15 1/m extinction coefficient) for people in familiar environments and 13 m (0.5 1/m extinction coefficient) for people in unfamiliar environments. A value of Total Smoke Released of 1,000 m^2 in a "standard room" is a criterion used in codes based on these concepts (**27**,**28**).

X10.3 One decision that should be made by the developer of a hazard assessment is what "untenable conditions" mean. For example, untenable conditions could mean "conditions along the egress route to prevent occupant evacuation" or "conditions that are life threatening to the occupants." In practice, the time to untenability is reached when either set of untenable conditions occurs, but the way in which it is reached (or the criterion that is dominant) could be different.

X10.4 Visibility will never result, on its own, in "life threatening conditions," but should still be a required tenability criterion because its lack will prevent egress or rescue. Fig. X10.1 shows the relationship between visibility and optical density, based on the work by Jin (**24**,**25**).

X10.5 With these concepts in mind, it is useful to consider the selection of tenability criteria, as based on the work of Fleming (**95**).

X10.5.1 If the occupants will be exposed to untenable conditions for survival unless they leave the scene, then the tenability criteria should allow for safe egress and movement to a safe location.

X10.5.2 If the occupants are assured never to be exposed to untenable conditions for survival, then the tenability criteria simply need to ensure that they remain safe, but need not allow for safe egress and movement to a safe location.

X10.5.3 If the occupants need to leave the scene in order to survive, then tenability criteria must allow for safe egress and

TABLE X10.2 Tenability Limits from Several Case Studies

	A	B	C	D
Temperature	150°C upper layer (2 min)	Time < (10 700 exp-T(°C)/36.6)	200°F at 6 ft	100°C and smoke layer < 1.9 m above floor
Radiant Heat	2.5 kW/m^2	Time < 90/$q^{4/3}$ For q > 2.4 kW/m^2	NA	2.5 kW/m^2
CO	0.2 % (5 min)	NA	3000 ppm (15 min)	1500 ppm
CO_2	5 %	NA	6 %	NA
O_2	10 %	NA	< 12 %	NA
Visibility	0.5 OD/m	0.1 – 0.2 OD/m (large rooms – small rooms)	< 30 ft (approximately 0.1 OD/m)	< 20 m at < 1.9 m above floor (approximately < 0.05 OD/m)

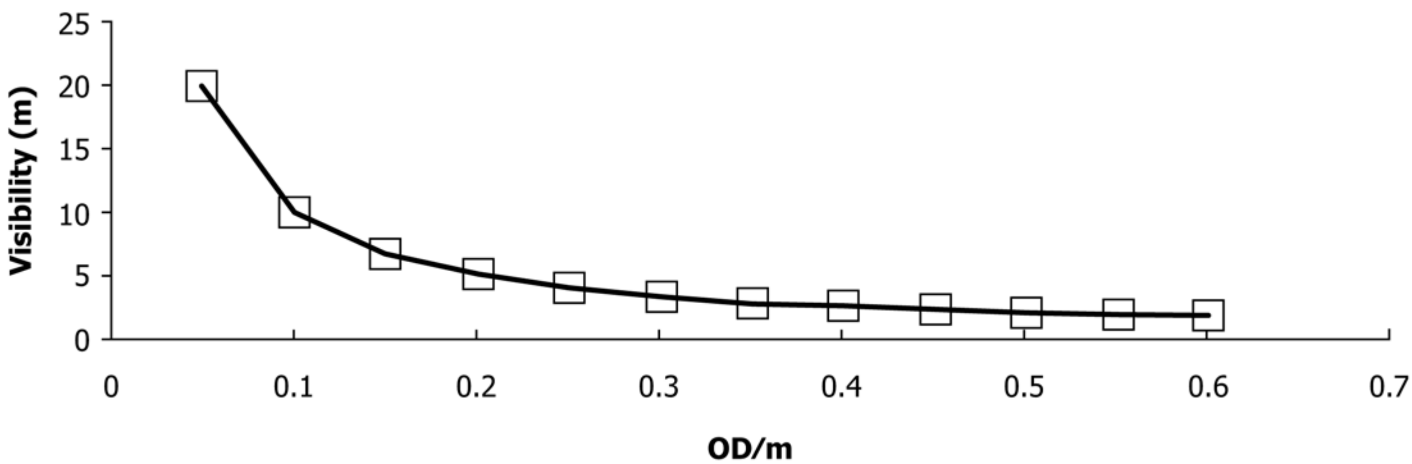

FIG. X10.1 Visual Obscuration From Smoke

movement to a safe location and should take into account smoke toxicity and heat effects, as well as visibility along their path.

X10.5.4 Visibility along an egress path should assume that the upper layer is within 1.2 m through 1.8 m of the floor. Although some people are shorter than 1.8 m and others may crawl, an approach should consider the height at which the smoke layer becomes a visibility obstacle, and levels of 1.2 m through 1.8 m have been proposed, where the latter represents a tall adult in a standing position.

X10.5.5 The reference source that is used to justify the selection for tenability criteria should be placed in the proper context.

X11. STATISTICS OF HEALTH CARE FACILITY FIRES

X11.1 During the 1994-1998 period, there were a yearly average of 2,600 fires, 5 fire fatalities, 107 fire injuries and $9.2 million dollars in fire losses in "hospitals, clinics or other facilities that care for the sick" (96). That corresponds to 0.5 % of all structure fires, 0.1 % of structure fire fatalities and 0.5 % of all structure fire injuries.

X11.2 Of those fires, the second leading area of origin (after kitchens) was bedrooms (11.7 %). However, fires starting in bedrooms were by far the leading cause of fire fatalities: 72 %.

X11.3 When investigating causes of fires leading to fire fatalities, 35.0 % were caused by matches, 20.0 % by lighters, 5.3 % by other smoking materials, 14.2 % were incendiary or suspicious and 24.6 % by other equipment (half of it biomedical).

REFERENCES

(1) Thomas, P. H., "Testing Products and Materials for their Contribution to Flashover in Rooms," *Fire and Materials*, 5, 1981, pp. 103-111.

(2) Gann, R. G., Babrauskas, V., Peacock, R. D., and Hall, J. R., "Fire Conditions for Smoke Toxicity Measurement," *Fire and Materials*, 18, 1994, pp. 193-199.

(3) Blockley, W. V. and Taylor, C. L., "Human Tolerance Limits for Extreme Heat," *Heating, Piping & Air Conditioning*, 21, 1949, pp. 111-116.

(4) Crane, C. R., "Human Tolerance Limit to Elevated Temperature: An Empirical Approach to the Dynamics of Acute Thermal Collapse," Federal Aviation Administration, Aviation Toxicology Lab., Oklahoma City, OK, Memorandum Report, AAC-114-78-2, 1978.

(5) Kosunen, K. J., et al., "Plasma Renin Activity, Angiotensin II, Alldosterone During Intense Heat Stress," *Journal of Applied Physiology*, 41, 1976, pp. 323-327.

(6) Purser, D. A., "Toxicity Assessment of Combustion Products," *SFPE Handbook of Fire Protection Engineering, 2nd Ed*, Eds. P. J. DiNenno, C. L. Beyler, R. L. P. Custer, W. D. Walton, J. M. Watts, D. Drysdale, and J. R. Hall, Natl Fire Prot. Assoc., Quincy, MA, 1995, pp. 2-85 to 2-146.

(7) Stoll, A. M. and Greene, L. C., "Relationship Between Pain and Tissue Damage Due to Thermal Radiation," *Journal of Applied Physiology*, 14, 1959, pp. 373-382.

(8) Stoll, A. M. and Chianta, M. A., "Method and Rating System for Evaluation of Thermal Protection," *Aerospace Medicine*, 40, 1969, pp. 1232-1238.

(9) Derksen, W. L., Monahan, T. I., and deLhery, G. P., "The Temperature Associated with Radiant Skin Energy Burns," *Temperature—Its Measurement and Control in Science and Industry*, 3(3), 1963, pp. 171-175.

(10) Levin, B. C., Paabo, M., Gurman, J. L., Harris, S. E., and Braun, E., "Toxicological Interactions Between Carbon Monoxide and Carbon Dioxide," *Toxicology*, 47, 1987, pp. 135-164.

(11) Hartzell, G. E., Priest, D. N., and Switzer, W. G., "Modeling of Toxicological Effects of Fire Gases: II. Mathematical Modeling of Intoxication of Rats by Carbon Monoxide and Hydrogen Cyanide," *J. Fire Sciences*, 3, 1985, pp. 115-128.

(12) Kaplan, H. L., Grand, A. F., and Hartzell, G. E., "Combustion Toxicology: Principles and Test Methods," Technomic, Lancaster, PA, 1983.

(13) Hinderer, R. K. and Hirschler, M. M., "The Toxicity of Hydrogen Chloride and of the Smoke Generated by Poly(Vinyl Chloride), Including Effects on Various Animal Species, and the Implications for Fire Safety," *ASTM E-5 Symposium on Smoke*, Dec. 3, 1988, Phoenix, AZ, "Characterization and Toxicity of Smoke," *ASTM STP 1082*, Amer. Soc. Testing and Materials, Philadelphia, PA, Ed. H. J. Hasegawa, 1990, pp. 1-22.

(14) Babrauskas, V., Harris, R. H., Jr., Braun, E., Levin, B. C., Paabo, M., and Gann, R. G., "Large-scale Validation of Bench-scale Fire Toxicity Tests," *J. Fire Sciences*, 9, 1991, pp. 125-149.

(15) Sakurai, T., "Toxic Gas Tests With Several Pure and Mixed Gases Using Mice," *J. Fire Sciences*, 7, 1989, pp. 22-77.

(16) Babrauskas, V., Harris, R. H., Jr., Braun, E., Levin, B. C., Paabo, M., and Gann, R. G., "Large-scale Validation of Bench-scale Fire Toxicity Tests," *INTERFLAM '90: Fifth Intl. Fire Conf. Proc.*, London, UK, 1990, pp. 3-12.

(17) Babrauskas, V., Levin, B. C., and Gann, R. G., "New Approach to Fire Toxicity Data for Hazard Evaluation," *Fire J.*, 81, March/April 1987, pp. 22-23+.

(18) Babrauskas, V., Harris, R. H., Braun, E., Levin, B., Paabo, M., and Gann, R. G., "The Role of Bench-Scale Test Data in Assessing Real-Scale Fire Toxicity," Tech. Note 1284, Natl. Inst. Stand. Technol., Gaithersburg, MD, 1991.

(19) Hirschler, M. M., "Fire Retardance, Smoke Toxicity and Fire Hazard," *Proc. Flame Retardants '94*, British Plastics Federation Editor, Interscience Communications, London, UK, Jan. 26-27, 1994, pp. 225-237.

(20) Sainrat, A. and Le Tallec, Y., "The Toxicity of Combustion Gases Produced by Upholstered Furniture," *Proc. Fire and Materials 2001, 7th. Int. Conf.*, Interscience Communications, London, UK, 2001, pp. 419-432.

(21) Gann, R. G., "Update: International Study of Sublethal Effects of Fire Smoke on Survivability and Health (SEFS)," *Proc. FPRF Fire Risk and Hazard Assessment Research Application Symp.*, NFPA Fire Protection Research Foundation, Baltimore, MD, June 20-22, 2001, Quincy, MA, 2002, pp. 74-111.

(22) Peacock, R. D., Jones, W. W., Bukowski, R. W., and Forney, C. L., "Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method, Version 1.1," *NIST Handbook 146*, Vol II, Natl. Inst. Stand. Technol., Gaithersburg, MD, 1991.

(23) Peacock, R. D., Jones, W. W., Forney, G. P., Portier, R. W., Reneke, P. A., Bukowski, R. W., and Klote, J. H., "An Update Guide for HAZARD I, Version 1.2," NISTIR 5410, Natl. Inst. Stand. Technol., Gaithersburg, MD, 1994.

(24) Jin, T., "Visibility Through Fire Smoke," *Report of the Fire Research Institute of Japan*, 2(33), 1971, pp. 12-18.

(25) Jin, T., "Studies of Emotional Instability in Smoke from Fires," *J. Fire Flammability*, 12, 1981, pp. 130-142.

(26) Malhotra, H. L., "Movement of Smoke on Escape Routes, Part 1—Instrumentation and Effect of Smoke on Visibility," Joint Fire Research Organization, Fire Research Station, Note 651, January, Borehamwood, Herts., UK, 1967, p. 21.

(27) Hirschler, M. M., and Janssens, M. L., "Smoke Obscuration Measurements in the NFPA 265 Room-Corner Test," *Fire and Materials Conf.*, San Antonio, TX, Feb. 22-23, 1999, Interscience Communications, London, UK, pp. 179-198.

(28) Hirschler, M. M., "Fire Performance of Organic Polymers, Thermal Decomposition, and Chemical Composition," American Chemical Society Preprints, August 2000 National Meeting, Symposium on Fire and Polymers, Symp. Chair: G. L. Nelson and C. Wilkie, Washington, DC.

(29) Thomas, P. H., "How Heat Release Influences Fire Hazard," *Int. Conf. Fire: Control the Heat ... Reduce the Hazard*, London, UK, 24-25 Oct. 1988, paper 1.

(30) Babrauskas, V. and Peacock, R. D., "Heat Release Rate: The Single Most Important Variable in Fire Hazard," *Fire Safety J.*, 18, 1992, pp. 255-272.

(31) Babrauskas, V., "Will the Second Item Ignite?," *Fire Safety J.*, 4, 1981/82, pp. 281-292.

(32) Babrauskas, V., "Upholstered Furniture Heat Release Rates: Measurements and Estimation," *J. Fire Sci.*, 1, 1983, pp. 9-32.

(33) Lawson, J. R., Walton, W. D., and Twilley, W. H., "Fire Performance of Furnishings as Measured in the NBS Furniture Calorimeter, Part 1," NBSIR 83-2787, Natl Bur. Stands, Gaithersburg, MD, 1984.

(34) Babrauskas, V. and Walton, W. D., "Simplified Characterization of Upholstered Furniture Heat Release Rates," *Fire Safety J.*, 11, 1986, pp. 181-192.

(35) Damant, G. H., McCormack, J. A., Mikami, J. F., and Wortman, P. S., "The California Technical Bulletin 133 Test: Some Background and Experience," *Proc. 14th Intern. Conf. Fire Safety*, Millbrae, CA, Jan. 9-13, 1989, Millbrae, CA, Hilado, C.J. Ed., Product Safety Corp., Sunnyvale, CA, 1989, pp. 1-12.

(36) Smiecinski, T. M., Grace, O. M., and Wujcik, S. E., "Performance of Foam & Fabric Composites in Large-Scale Furniture Flammability Tests," *Proc. 14th Intern. Conf. Fire Safety*, Jan. 9-13, 1989, Millbrae, CA, C.J. Hilado, Ed., Product Safety Corp., Sunnyvale, CA, 1989, pp. 35-40.

(37) Schuhmann, J. G. and Hartzell, G. E., "Flaming Combustion Characteristics of Upholstered Furniture," *J. Fire Sci*., 7, 1989, pp. 368-402.

(38) Hirschler, M. M., and Smith, G. F., "Flammability of Sets of Fabric/Foam Combinations for Use in Upholstered Furniture," *Fire Safety J*. 16, 1990, pp. 13-31.

(39) Parker, W. J., Tu, K.-M., Nurbakhsh, S., and Damant, G. H., "Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test. Part III: Full Scale Chair Burns," NISTIR 90-4375, Natl Inst. Stands Technology, Gaithersburg, MD, 1990.

(40) Damant, G. H. and Nurbakhsh, S., "Heat Release Rates of Seating Furniture Using California Technical Bulletin 133," *Heat Release & Fire Hazard, 1st U.S. Symposium*, Abstracts, December 1991, San Diego, CA, Interscience Communications, London, UK, 1991, pp. 15-17.

(41) Hirschler, M. M. and Shakir, S., "Comparison of the Fire Performance of Various Upholstered Furniture Composite Combinations (Fabric/Foam) in Two Rate of Heat Release Calorimeters: Cone and Ohio State University Instruments," *J. Fire Sci*., 9, 1991, pp. 222-248.

(42) Villa, K. M. and Babrauskas, V., "Cone Calorimeter Rate of Heat Release Measurements for Upholstered Composites of Polyurethane Foam," Natl Inst. Stands Technol., Gaithersburg, MD, NISTIR 4652, August, 1991.

(43) Gallagher, J. A., "Minimum Flux for Fire Propagation: A New Parameter for Classification of Foam/Fabric Composites," *J. Fire Sci*., 10, 1992, pp. 40-57.

(44) Barile, P., "A Systematic Approach for Predicting Compliance with Technical Bulletin 133 for a Vast Combination of Chair Styles & Fabrics," *Proc. 18th Intern. Conf. Fire Safety*, Millbrae, CA, Jan. 11-15, 1993, Millbrae, CA, Hilado, C.J. Ed., Product Safety Corp., Sunnyvale, CA, 1993, pp. 20-31.

(45) Grand, A. F., Priest, D. N., and Stansberry, H. W., "Burning Characteristics of Upholstered Chairs," *Fire and Flammability of Furnishings and Contents of Buildings, ASTM STP 1233*, Fowell, A. J., Ed., Amer. Soc. Testing Mater., Philadelphia, PA, 1994, pp. 63-82.

(46) Forsten, H. H., "Prediction of CAL TB133 Test Results from Cone Calorimeter," *Proc. 20th Intern. Conf. Fire Safety*, Jan. 9-13 1995, Millbrae, CA, Hilado, C.J. Ed., 1995, pp. 53-66.

(47) Hirschler, M. M. "Predictive Tools for Fire Hazard and Furnishings and Contents," *Fire and Polymers II*, Ed. Nelson, G. L., ACS Symposium Series 599, Amer. Chem. Soc., Washington, DC, 1995, pp. 593-608.

(48) Ohlemiller, T. and Shields, J., "Behavior of Mock-ups in the California TB133 Test Protocol: Fabric & Barrier Effects," NISTIR 5653, Natl Inst. Stands Technol., Gaithersburg, MD, May, 1995.

(49) Sundstrom, B., Ed., CBUF Report, "Fire Safety of Upholstered Furniture—The Final Report on the CBUF Research Programme," *EUR 16477 EN*, European Commission, Measurements and Testing Report, Contract No. 3478/1/0/196/11-BCR-DK(30), 1995, Interscience Communications, London, UK.

(50) Forsten, H. H., "Use of Small Scale Testing to Predict Cal 133 Performance," *Proc. 21st Intern. Conf. Fire Safety*, Jan. 8-12 1996, Millbrae, CA, Hilado, C.J. Ed., 1996, pp. 75-87.

(51) Damant, G. H., "Flammability Studies of Upholstered Furniture Using California Technical Bulletin 133 and the Cone Calorimeter," *Proc. 21st Intern. Conf. Fire Safety*, Jan. 8-12 1996, Millbrae, CA, Hilado, C.J. Ed., 1996, pp. 1-15.

(52) Hirschler, M. M., "Analysis of Cone Calorimeter and Room-Scale Data on Fire Performance of Upholstered Furniture," *Proc. 23rd Intern. Conf. Fire Safety*, Jan. 13-16 1997, Millbrae, CA, Hilado, C.J. Ed., 1997.

(53) Hall, J. R., "Report on Leading Items First Ignited in Fire," Report to NFPA Technical Committee on Contents and Furnishings, Aug. 17, 1992.

(54) Hirschler, M. M., "Smoke and Heat Release and Ignitability as Measures of Fire Hazard from Burning Of Carpet Tiles," *Fire Safety J*. 18, 1992, pp. 305-324.

(55) Briggs, P. J., Harris, S. R., Ollerenshaw, M., Van Hees, P., and Van Wesemael, E., "Full Scale Fire Testing of Carpets in Room/Corridor Scenarios and Comparisons with Small Scale Test Procedures," *Flame Retardants 1992*, (Ed. The Plastics and Rubber Institute), Elsevier, London, UK, 1992, pp. 297-307.

(56) Ames, S. A., Rogers, S., and Murray, C., "Small and Full Scale Studies of Heat Release from Building Contents," *Proc Interflam 1993*, (Ed. C. A. Franks), Interscience Communications, London, UK, 1993, pp. 213-231.

(57) Tomann, J., "Comparison of Nordtest Fire 007, CEN Draft Proposal (Radiant Panel) and Cone Calorimeter Methods in the Fire Testing of Floor Coverings," *Fire and Materials*, 17, 1993, pp. 185-190.

(58) Talley, H., private communication.

(59) Damant, G., private communication.

(60) Friedman, R., "An International Survey of Computer Models for Fire and Smoke," *J Fire Prot. Engr*. 4, 1992, pp. 81-92.

(61) Cooper, L. Y., "A Mathematical Model for Estimating Available Safe Egress Time in Fires," *Fire and Materials*, 6, No. 4, 1982, pp. 135-144.

(62) Babrauskas, V., "COMPF2—A Program for Calculating Post-flashover Fire Temperatures," National Bureau of Standards (U.S.) Technical Note 991, 1979.

(63) Davis, W. D. and Cooper, L. Y., "Computer Model for Estimating the Response of Sprinkler Links to Compartment Fires With Draft Curtains and Fusible Link-actuated Ceiling Vents," *Fire Technology*, 27, No. 2, 1991, pp. 113-127.

(64) Mitler, H. E. and Emmons, H. W., Documentation for "CFCV, the Fifth Harvard Computer Fire Code," National Bureau of Standards (U.S.), NBSGCR 81-344, Gaithersburg, MD, 1981.

(65) Mitler, H. E. and Rockett, J., "A User's Guide for FIRST, a Comprehensive Single-room Fire Model," National Bureau of Standards (U.S.), NBSIR 87-3595, Gaithersburg, MD, 1987.

(66) Tanaka, T., "A Model of Multiroom Fire Spread," National Bureau of Standards (U.S.), NBSIR 83-2718, Gaithersburg, MD, 1983.

(67) Gahm, J. B., "Computer Fire Code VI, Volume I," National Bureau of Standards (U.S.), NBS GCR 83-451, Gaithersburg, MD, 1983.

(68) Jones, W. W., "A Multicompartment Model for the Spread of Fire, Smoke and Toxic Gases," *Fire Safety Journal*, 9, No. 55, 1985.

(69) Jones, W. W. and Peacock, R. D., "Refinement and Experimental Verification of a Model for Fire Growth and Smoke Transport," *Fire Safety Science, Proc. 2nd International Symposium on Fire Safety Science*, Tokyo, Japan, 13-17 June, 1988, Eds. T. Wakamatsu, Y. Hasemi, A. Sekizawa, P. G. Seeger, P. J. Pagni, and C. E. Grant, Hemisphere, Washington, DC, 1989, pp. 897-906.

(70) Forney, G. P. and Cooper, L. Y., "The Consolidated Compartment Fire Model (CCFM) Computer Application CCFM.VENTS—Part II: Software Reference Guide," National Institute of Standards and Technology, NISTIR 90-4343, 1990.

(71) Jones, W. W. and Forney, G. P., "A Programmer's Reference Manual for CFAST, the Unified Model of Fire Growth and Smoke Transport," National Institute of Standards and Technology, Technical Note 1283, 1990.

(72) Mitler, H. E., "Comparison of Several Compartment Fire Models: An Interim Report," National Bureau of Standards (U.S.), NBSIR 85-3233, 1985.

(73) Jones, W. W., "A Review of Compartment Fire Models," National Bureau of Standards (U.S.), NBSIR 83-2684, 1983.

(74) Janssens, M., "Room Fire Models, General," Chapter 6a, *Heat Release in Fires*, Elsevier, London, UK, Eds, V. Babrauskas and S .J. Grayson, 1992, pp. 113-158.

(75) Babrauskas, V., "Will the Second Item Ignite?" *Fire Safety J*., 4, 1981/82, pp. 281-292.

(76) Babrauskas, V. and Krasny, J., "Fire Behavior of Upholstered Furniture," *NBS Monograph 173*, Natl. Bur. Stds, (U.S.), Gaithersburg, MD, 1985.

(77) Quintiere, J. G., *Fire and Materials*, 6, 1982, p. 145.

(78) Ostman, B. A.-L. and Nussbaum, R. M., "Correlation Between Small Scale Rate of Heat Release and Full Scale Room Flashover for Surface Linings," *Fire Safety Science, Proc. 2nd. Int. Symp*., Tokyo, Japan, 13-17 June, 1988, Eds. T. Wakamatsu, Y. Hasemi, A. Sekizawa, P. G. Seeger, P. J. Pagni, and C. E. Grant, Hemisphere, Washington, DC, 1989, pp. 823-32.

(79) Hirschler, M. M., "Heat Release from Plastic Materials," Chapter 12 a, *Heat Release in Fires*, Elsevier, London, UK, Eds. V. Babrauskas and S. J. Grayson, 1992. pp. 375-422.

(80) Wickström, U. and Göransson, U., "Full-scale/Bench-scale Correlations of Wall and Ceiling Linings," *Heat Release in Fires*, Eds. V. Babrauskas and S. J. Grayson, Chapter 13, Elsevier, London, 1992, pp. 461-477.

(81) Smith, E. E. and Satija, S., "Release Rate Model for Developing Fires," *J. Heat Transfer*, 105, 1983, pp. 282-287.

(82) Wickström, U., and Göransson, U., "Prediction of Heat Release Rates of Large Scale Room Fire Tests Based on Cone Calorimeter Results," *J. Testing and Evaluation*, 15, 1987, pp. 364-370.

(83) Karlsson, B. and Magnusson, S. E., "Combustible Wall Lining Materials: Numerical Simulation of Room Fire Growth and the Outline of a Reliability Based Classification Procedure," *Fire Safety Science, Proc. Third Int. Symp*., G. Cox and B. Langford, Eds., Elsevier, London, UK, 1991, pp. 667-676.

(84) Karlsson, B. and Magnusson, S. E., "An Example Room Fire Model," Chapter 6b, *Heat Release in Fires*, Elsevier, London, UK, Eds, V. Babrauskas and S. J. Grayson, 1992, pp. 159-172.

(85) Karlsson, B., "Models for Calculating Flame Spread on Wall Lining Materials and the Resulting Heat Release Rate in a Room," *Fire Safety J*., 23, 1994, pp. 365-386.

(86) Hirschler, M. M.,"How to Assess the Effect of an Individual Product on the Fire Hazard in a Real Occupancy, Based on Heat Release Rate," *Flame Retardants '98*, Interscience Communications, London, UK, February 3-4, 1998, pp. 225-240.

(87) Quintiere, J. G., "A Simulation Model for Fire Growth on Materials Subject to a Room-Corner Test," *Fire Safety J*., 20, 1993, pp. 313-339.

(88) Dillon, S. E., "Analysis of the ISO 9705 Room/Corner Test: Simulations, Correlations and Heat Flux Measurements," NIST GCR-98-756, National Institute of Standards and Technology, Gaithersburg, MD, 1998.

(89) Janssens, M. L. Grexa, O., Dietenberger, M., and White, R. H., "Predictions of ISO 9705 Room/Corner Test Using a Simple Model," *Proc. Fire and Materials 1995, 4th. Int. Conf*., Interscience Communications, London, UK, 1995, pp. 73-83.

(90) Grenier, A. T., Janssens, M. L., and Dillon, S. E., *Proc. Fire and Materials 2001, 7th. Int. Conf*., Interscience Communications, London, UK, 2001, pp. 351-362.

(91) Dillon, S. E., Janssens, M. L., and Hirschler, M. M., "Using the Cone Calorimeter as Screening Tool for the NFPA 265 and NFPA 286 Room Test Procedures," *Proc. Fire and Materials 2001, 7th. Int. Conf*., Interscience Communications, London, UK, 2001, pp. 527-539.

(92) Sundstrom, B., van Hees, P., and Thureson, P., "Results and Analysis from Fire Tests of Building Products in ISO 9705, the Room/Corner Test. The SBI Research Programme," SP Report 1998:11, Swedish National Testing and Research Institute, Boras, Sweden, 1998.

(93) Hirschler, M. M.,"How to Measure Smoke Obscuration in a Manner Relevant to Fire Hazard Assessment: Use of Heat Release Calorimetry Test Equipment," *J. Fire Sciences*, 9, 1991, pp. 183-222.

(94) Nelson, H. E., "FPETOOL: Fire Protection Engineering Tools for Hazard Estimation," National Institute of Standards and Technology, NISTIR 90-4380, Gaithersburg, MD, 1990.

(95) Fleming, J., "Visibility as Egress Criteria: A Review of the Literature," *Proc. FPRF Fire Risk and Hazard Assessment Research Application Symp*., NFPA Fire Protection Research Foundation, Baltimore, MD, June 20-22, 2001, Quincy, MA, 2002, pp. 199-210.

(96) Ahrens, M., "The US Fire Problem Overview Report: Leading Causes and Other Patterns and Trends," NFPA Fire Analysis and Research Division, Natl Fire Protection Assoc., Quincy, MA, June 2001.