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FIRE RISK ASSESSMENT METHOD: CASE STUDY 4, INTERIOR FINISH IN RESTAURANTS

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1. Introduction

1.1 Purpose of this Report

This report describes results from the application of a recently developed, generally applicable method for the assessment of life safety fire risk associated with new and existing products. As part of this effort, the method was applied to several test cases, resulting in modifications to the method followed by limited reapplication to the cases. The methodology report [1] should be read prior to reading this and other case studies, both for a full rendition of the method and a clear understanding of terms.

To describe fire risk and the fire risk assessment process, it is necessary to define some terms [2].

- *Fire hazard* is the fire's potential for inflicting harm to some person(s) or thing(s); the magnitude of the fire hazard is the amount of harm that might result, including the seriousness and the number of people exposed.

- *Fire risk* combines the fire hazard with the probability that potential harm or undesirable consequences will be realized. The result includes the predicted outcome of all fires under consideration.

- *Fire risk assessment* is the process of characterizing the potential impact on risk of changes in any factor which affects the expected outcome. It includes estimates of the risk and uncertainties in measurements, analytical techniques and interpretive models which affect those estimates.

- *Occupancy* is a use category of a building established by a code organization. In this project, occupancy refers to the property classifications used in the 1976 edition of the National Fire Protection Association NFPA 901 Standard, *Uniform Coding for Fire Protection*. Examples include public assembly, educational, institutional, residential, store/office, and manufacturing. The classifications may be further narrowed to buildings with specific activities because NFPA 901 includes subclassifications within each major occupancy.

- *Fire Scenario* is the detailed description of a specific fire incident. This description includes the building (room sizes, connections, and materials of construction), fire (items, their fire properties, and sequence of burning), and occupants (number, initial location, and characteristics).

- *Occupant Set* is a group of occupants of specific characteristics present in a fire scenario.

Described in this report are the procedures used to exercise the fire risk assessment method for the fourth developmental case: fires involving interior finish in restaurants. Numerical results are also provided. This case study provided a "test bed" for application of the method using available and expert judgment in place of in-depth studies. Therefore, the descriptions and results presented should not be viewed as definitive, but rather as demonstrating the technique.

1.1.1 Uses and Limitations

The methodology discussed herein is a first attempt to apply deterministic models to the assessment of product risk. To do so requires that we predict, at least in aggregate form, the outcome of every fire incident which can possibly involve the target product in the target occupancy. To make this herculean task even somewhat tractable, numerous compromises must be made. Further, we find that many required details of actual incidents are not collected and many important phenomena are not sufficiently understood, such that approximations and estimates must be employed to fill in the gaps.

What has emerged is an analytical method which has extremely powerful potential which may or may not be realizable at the present time, depending on the specific case (product/occupancy pair) of interest. As is so clearly demonstrated in the four case studies conducted, we were able to do a fairly complete and competent job with Upholstered Furniture in Residences (Case 1) and were unable to perform a risk assessment at all (although the method was able to provide some valuable insight into product performance and hazard) for Interior Finish in Restaurants (Case 4). The state-of-the-art of both the fire science and data requires the method to rely extensively on the expert judgement of the analyst, to accept substantial bounds of uncertainty on the results of many cases, and to rely on the skills of the user to adapt the method for best results in any given case.

Regardless of where a case of interest might fall in the continuum of capability, the method can be of substantial benefit. Its detailed structure provides a procedure by which the important fire involvements (including for the first time, secondary ignitions) of a specified product can be determined with an estimable degree of confidence - a "scenario generator". In most (but not all) cases, the method's results can be calibrated against actual incident data, giving an estimate of accuracy. But this is not a standardized, self-contained method that will be executed the same by all users and produce comparative statistics of high precision. However it should improve the decision making process of any user group, not the least by identifying unstated assumptions in the less formal and explicit procedures now used to combine and synthesize information relevant to product risk.

In the remainder of this and the case study reports, details of the compromises, assumptions and limitations, uncertainty estimates, and confidence in the results will be presented. It is crucial that these be kept in mind whenever these risk analyses are examined for conclusions. And, as the technology continues to develop, the method will eventually realize its full potential.

1.2 The NFPRF Risk Assessment Method Approach

Briefly, fire risk is measured in terms of both the probability of an event (fire) and the consequence of that event (e.g., deaths resulting from a fire). The challenge is to predict how a change in the fire properties of a product (ignitability, heat release rate, toxic potency, etc.) will change the life safety risk in a given occupancy. This new method for calculating risk combines the likelihood of a fire, based upon fire incident data, with the expected consequences or severity of a fire, predicted by a computer based simulation (HAZARD I) [3]. The method provides an organized structure for a large series of fire scenarios constructed to represent all the possible ways that a fire might involve the product being studied. As a consequence of the current state-of-the-art of fire science, the fire risk assessment methodology is constrained to predicting death and not injury to exposed occupants, nor does it consider property damage.

While a more complete explanation of this process can be found in the documentation of the methodology, the step-by-step approach employed in each of the case studies, follows. The first five steps establish the structure and set-up the method for the life safety risk assessment performed in the last three steps.

1. Select the product and occupancy pair.
2. Identify and specify the physical characteristics of the building(s) representing the occupancy.
3. Develop a scenario structure with associated probabilities which uses a set of scenario classes drawn from the universe of all possible fires.
4. Adapt the fire model to fit the needs of the product and occupancy pair.
5. Specify occupant sets (groupings of people) at risk, their associated probabilities and relevant tenability criteria to judge survivability to toxic and thermal hazard.
6. Perform the risk calculation for the base case (status quo) and compare the results (deaths/fire and predicted deaths) by scenario with the expected results derived from the national fire database.
7. Perform the risk calculation for a "new" product case and compare the results with the results for the base case to obtain the impact on life safety risk.
8. Interpret the outcome.

However, this case is distinct from the prior three, in that the project team encountered a lack of the data required to apply the method to assess fully the risk of this product. Specifically, the team was unable to ascertain:

- the distribution of finish materials used in restaurants, or even on classes of such materials,

- the burning behavior of any but a small set of interior finish materials as measured in the apparatus required by the fire model,

- the physical size or construction characteristics of restaurants,

- physical and mental characteristics of restaurant patrons, and

- only limited information on ignition sources.

Therefore, a very different approach was required. Since this lack of data impairs the ability to make an overall risk prediction, the risk method was adapted to estimation of product risk through an examination of *hazard* in key scenarios identified from the incident data. In fact, it is likely that many of the initial attempts to apply this risk method to product occupancy pairs will encounter such limits in the data available. Thus, the lessons learned from this case study will serve as an example of how to proceed in these cases.

To summarize the approach followed in this case, we:

1. Identified the properties of interior finish materials which can serve as a *benchmark* rather than representing the performance of the products in current use.

2. Specified the physical characteristics of two restaurants which are considered typical, but where we cannot necessarily quantify their relation to the distribution of properties in use.

3. Specified a generic set of adult occupants for which an egress time can be computed. By examining the difference between this value and the time-to-untenable-conditions in the occupied spaces, the potential impact of variations from the generic occupant set can be determined.

What results is not a true risk analysis since the data do not exist to weigh the results by the degree to which the product properties, occupancy characteristics, or occupants represent their counterparts in the real world. Instead, what can be done is a range of hazard analyses, which serve to bound the result that could be obtained if probabilities were available to combine them. Various measures on this range can be used as benchmarks against which the performance of other products, buildings, or occupants can be judged in terms of whether they are safer or less safe than the benchmark.

1.3 Scope of this Case

Interior finish in restaurants was selected as the fourth and final product occupancy pair for several reasons. First, combustible interior finish materials have long been considered (justifiably or not) as critical contributors to fire disasters. Of particular note in this area are low density fiberboard (cellulosic) ceilings which were implicated in a number of fires ignited by overheated fluorescent ballasts, and very thin plywood paneling which has a tendency to delaminate and burn vigorously when exposed to fire. The flammability of interior finish materials used in selected areas (e.g., exit access) of high risk occupancies (e.g., assembly and health care) has long been regulated.

Second, modeling a fire involving flames spreading over vertical surfaces required developing an additional computational procedure to supplement the HAZARD I fire model FAST. The flame spread process has been studied extensively at both small- and full-scale [e.g., 4], and a standard test method is available which measures important properties of materials and assemblies relative to how they spread flame [5].

A number of flame spread or burning rate models and subroutines appropriate to walls are currently under development. But significant effort would be required to incorporate these into the FAST model on which the risk software depends. A model (called HEMFAST) which predicts fire development on upholstered furniture [6] has been under development by a CFR grantee for some years, and operates in conjunction with FAST. Since the walls of a room can be thought of as a scale-up of the back and arms of a sofa, we felt that HEMFAST could be utilized to estimate the involvement of the interior finish as a function of time. Also important is the fact that HEMFAST is designed to require only data from the Cone Calorimeter [7] and the LIFT apparatus (ASTM E1321) [5] to characterize a material's fire performance.

The third reason for selecting this product/occupancy combination was that it allowed the expansion of the occupancies addressed by the method to Assembly Occupancies. While Assembly Occupancies do not offer any substantial differences in evacuation simulation over offices or the function areas of hotels, a number of the most famous major fires have occurred in assembly properties. Examples range from the Iroquois Theater fire of 1903 (602 dead) to the Coconut Grove fire of 1942 (492 dead) and the Beverly Hills Supper Club fire of 1977 (165 dead) - with each having at least some involvement of interior finish.

It was these considerations, and the particularly strong interest on the part of many of the project sponsors to see a demonstration of the capabilities of the risk method as applied to interior finish, which resulted in the selection of this product-occupancy pair as the fourth case study.

2. Description of Method Implementation - Set Up for Interior Finish in Restaurants

2.1 Selection of Interior Finish Characteristics

In the first step, we define interior finish in restaurants in terms of the NFPA 901 Standard and characterize the population of finish materials now in use in terms of fire properties, type and location. We will specify a set of fire properties for finish materials in restaurants. Since interior finish is a broad descriptor applied to wall, floor, and ceiling materials, we also decided to limit the present case to wall coverings.

Examining the relevant incident data, a review of the national fire data for *Eating and Drinking Establishments* [1] (which includes restaurants and bars) for the years 1980-1986 revealed total annual rates of 19 deaths in 20,700 fires. Of these, fires starting in the kitchen account for 9500 fires (4 deaths) and fires beginning in the dining room account for 1100 fires (2 death). Bathrooms and cloakrooms ranked second with 1200 fires but had no deaths. If larger function rooms and bar/lounge areas, which are like dining rooms are included with them, the resulting group clearly ranks second, well ahead of bathrooms and cloakrooms. Unfortunately, fire locations other than kitchens are quite diverse, so it is not possible to select just a few areas that capture most fire deaths.

Next we decide on the context of use for the product in the target occupancy and specify the fire scenarios to be examined. Health and safety codes normally prohibit kitchens from having combustible interior finish materials. Thus, it is appropriate to assume the product is always in the dining room, and the fire can either start there or start in the kitchen and spread there at flashover (to be consistent with previous assumptions about fire spread to another room). The incident data identifies the item most frequently ignited (62%) first in the kitchen as food so the model uses this as the first item ignited for the kitchen fires. Interior finish is involved only secondarily if at all.

In dining rooms, a key first item ignited associated with deaths was "gas or liquid in or from a pipe or container." In order to focus on the risk of death (and remembering that this case could be set up as a small series of hazard analyses), the lone dining room scenario used was one in which a propane fed cooking unit is wheeled to a table and starts a fire that moves so quickly to the interior finish that the finish can be treated as the first item ignited. Thus, the team decided that the dining room fires will begin on or near a table or booth adjacent to the wall, implying a separation distance of zero between the ignition source and the wall surface.

Unlike the previous cases, industry associations were unable to supply data on the distribution of types of wallcovering materials used in restaurants. Also, since this occupancy often involves a theme (ethnic or other unique decor) it is unlikely that the market share across all buildings would be appropriate. Thus, it was not possible to develop a weighting for the current mix of product in use.

In the first case study, we needed three sets of properties (with associated market shares) to describe the current product. For carpet, the burning behavior was largely described by the levels of external radiant flux necessary for it to ignite and spread flame, and the rate at which that flame spreads. Because of current regulations applied to all carpet sold in the US, the range of variation in these properties is relatively small. Thus, a single set of benchmark properties were used for the current product. In Case 3, we limited the concealed combustibles under consideration to typical NMSC power (branch circuit) cable. This had the effect of giving us a single product with one set of properties.

For this fourth case, the (HEMFAST) model which provided the mechanism for predicting flame spread on walls requires as input, data from both the Cone Calorimeter and the LIFT Apparatus to model the burning behavior of the wall material. Data from older, more established test methods such as ASTM E 84 could not be utilized even to estimate the required material properties, and the base of data on the same finish materials tested in both apparatus is small. But a recent paper by Harkleroad [8] presents just such a data base for a selection of textile wall coverings selected by the American Textile Manufacturers Institute (ATMI) as representative of the class. These materials also had the advantage that they had been tested in a full-scale room 8 by 12 by 8 ft. high (the U.C. Berkeley room test), giving us data on real-scale burning rates against which to compare our model predictions. In fact, the stated purpose of the study was to provide a data base on textile wall coverings for use in predictive methods.

The thirteen materials included in this report represent a broad range of materials (natural, synthetic, and blends) and constructions (woven, non-woven, knit, tufted, and needle punched), which covered the range of low, medium, and high heat release rates in the room test. The materials exhibited a range of critical flux for spread values of 2.4 to 16.7 kW/m^2 (LIFT Apparatus) and peak heat release rates of 73 to 288 kW/m^2 (Cone Calorimeter).

Unfortunately, similar data bases do not exist for vinyl or paper wall coverings or for paneling (other than aircraft panels which are certainly not appropriate for restaurants), so our analysis was limited to the materials available. Even if they did exist, the method specifies that these data be used with the associated market shares to establish the burning characteristics representative of current product. Since such data were not available, we are forced to apply the data we have to a different analytical approach in order to estimate the performance of wallcoverings.

As noted earlier, it was not considered possible to produce probabilities to support weighted averages or probability distributions to represent the mix of product present in the real world. Rather, we began by examining the performance of a material in the middle of the group as ranked by the full-scale rate of heat release values - material AA. When data for this material was input to HEMFAST for a room like the Berkeley room, it burned only in the vicinity of the ignition source and then self-extinguished. The total mass consumed was small, as was the energy and mass released into the room. Thus, there would be no hazard to occupants of that room, for this product or any of the better performing ones.

Next, we examined the two worst-performing materials (highest peak rates of heat release) from the viewpoint of the full-scale test data. These materials are described in Tables 1a and 1b below.

Table 1a - Base Case Restaurant Wallcovering Materials

ATMI Code	Material Type	Weight Oz/Yd^2 (kg/m^2)	Construction	E84 Index	Full-scale Peak RHR (kW)
AA	70% Acrylic 30% Wool	38.0 (1.29)	Tufted	25	684
PP-PF	100% Polypropylene	18.0 (0.61)	non-woven	N/A	1166
Q	100% Polyester	12.8 (0.43)	Knit plush	15	5771

Table 1b - Combustion Properties of Selected Wallcoverings [8]

Property	Material AA	Material PP-PF	Material Q
Critical Flux for Ign. (kW/m^2)	18.1	16	24
Ign. Temp. (°C)	414	386	473
Thermal Inertia (kW/m^{2}K)^{2}s	0.98	0.85	0.84
Critical Flux for Spread (kW/m^2)	7.8	7.2	6.6
Flame Heating Parameter (kW^2/m^3)	20.9	27.9	25.3
Ignition Parameter (s$^{-½}$)	0.053	0.053	0.065
Peak RHR (kW/m^2) at 30 [50] kW flux	233 [252]	209 [262]	140 [225]
Heat of Comb. at peak RHR (mJ/kg) at 30 [50] kW flux	29 [31]	24 [35]	12 [14]

In the full-scale tests, material PP-PF ignited and spread flame part way across the wall before self-extinguishing, and material Q burned to the end of the wall, possibly representing a life safety hazard in some building and occupant combinations. These materials therefore served well to establish the range of performance, and other materials could have their fire hazards assessed by comparison of their test burning properties to these base case references.

In summarizing this first step in the method, we have:

- examined the leading areas and items ignited in restaurant fires using national fire incident data,
- detailed test fire properties for selected textile wall coverings,
- linked these test properties to a major indicator of fire hazard (peak rate of heat release), and
- made assumptions regarding the separation distance between the wall and the igniting source.

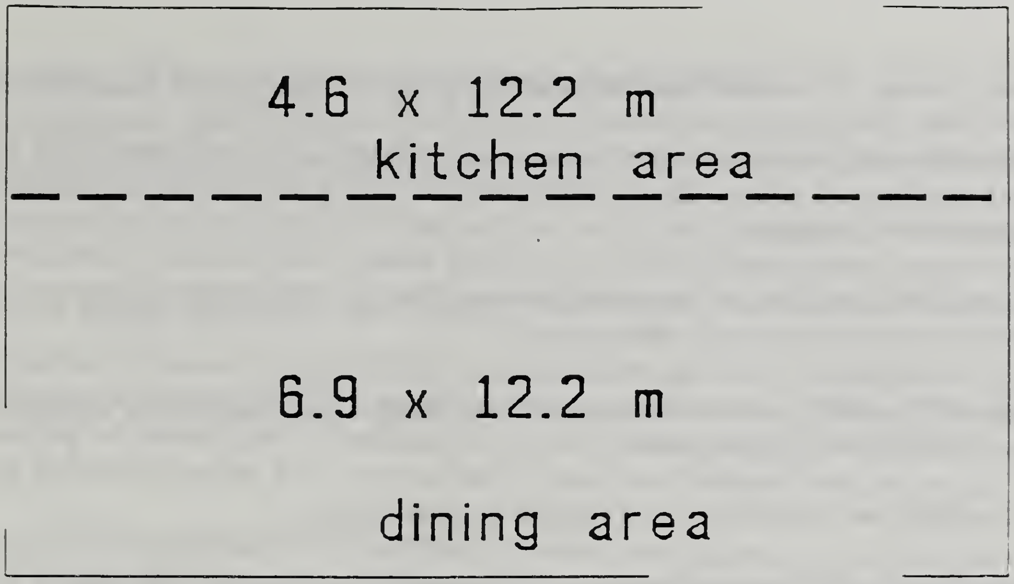
But we have also determined that fire performance data do not exist on other types of wallcoverings nor on the distribution of product in use from which we could determine the properties of interior finish representative of the current mix of products or to weight those products if the performance data were available. Therefore we departed from the risk method and the output will be closer to an unweighted range of fire hazard analyses.

2.2 Identify and Specify the Physical Characteristics of the Restaurant

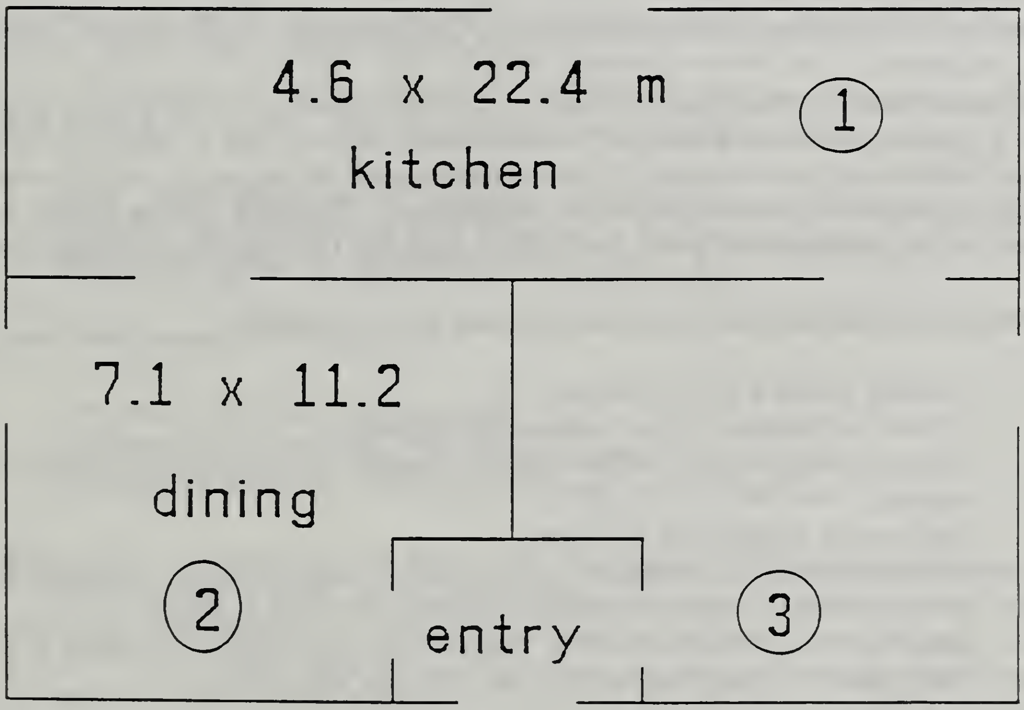
Unlike the other cases, there was little information available on typical restaurants. The industry seems to classify them into "fast food" and "the rest," with the former being smaller (we estimate about 1500 ft^2 as compared to 2800 ft^2). Other common differences involve the fact that fast food cooking areas generally open to a single dining area where in other restaurants the kitchen is a separate room or rooms. In this step, we must describe one or more representative buildings in the terms necessary to run the hazard model. This consists of a geometric configuration, physical arrangement of the rooms, and the materials of construction needed to run the hazard model. We must also specify for the building the "areas of origin" - rooms where fires start, and any fire safety features provided in the design.

Missing in this step is data on the distribution of restaurant sizes from which the representativeness weightings for the selected buildings would be made. These data are apparently not kept by the restaurant industry in the same way that they are by the hotel or commercial building owners. Thus, like the wallcovering properties we will be unable to determine the representativeness of the selected geometries or their associated weightings.

Faced with the lack of uniformity and the lack of data, the team used the limited available information to "construct" a small number of typical restaurant arrangements. This is important since the rate of development of the fire depends on the size of the room in which the fire starts, the thermal properties of the walls and ceilings, the fire load in the room, connections to and total volume of other rooms, and openings to the outside. Evacuation times are also strongly dependent on the number and location of exits. Code requirements [e.g., 9] uniformly require two, separate exits in the dining area, neither of which may egress through the kitchen or serving areas. All of this led the team to decide on two restaurant configurations, as shown in figure 1. With the two rooms of origin, this results in four fire scenarios which will be addressed in the case.



"FAST FOOD RESTAURANT"



"TRADITIONAL RESTAURANT"

Figure 1 - Floorplan drawings for the selected restaurants

The walls and ceilings of both buildings are assumed to be 1/2 inch gypsum board and the floors, 6 inch concrete slabs. The dining room walls are covered with the textile wall coverings of interest, but they are sufficiently thin that they do not impact the thermophysical properties of the walls.

Summarizing step two, we have:

- specified two sizes of restaurants which will be treated as typical but whose true representativeness cannot be determined,
- specified number, size, and construction of each room arrangement with two exits as required in the codes, and
- identified two potential areas of origin in each building.

As in step one, the inability to establish the distribution of, and thus weightings for, the building geometries further contributes to the necessity of limiting this analysis to hazard rather than risk. But again, the structure of the method with appropriate modifications can provide a reference against which to compare product and occupancy variations and derive a qualitative estimate of risk impact.

2.3 Development of the Scenario Structure and Calculation of Scenario Probabilities

In the third step we develop the organizational structure for reducing the universe of all possible fire scenarios to a representative set, which the risk assessment method uses to assess life safety impact. However, the limited data do not support the determination of the degree to which the scenarios we select are representative of current product or occupancies. Therefore we can specify scenarios of interest based on key incident categories, but cannot compute the associated probabilities.

For the scenarios, the calculational procedures require that we specify:

1. building where a fire originates,
2. rooms for "Area of Origin" where fire initiates,
3. burning characteristics of the item first ignited (growth rate and peak rate of heat release),
4. heat source igniting the first item,
5. final size of the fire, measured as the extent of flame damage (confined to the object, area or room of origin or extended beyond the room of origin), and
6. extent of fire growth at the time when the interior finish contributes to the fire, for those fires initiating with items other than the wall finish.

These descriptors are tied to data elements in the NFPA 901 Standard and are associated with a set of physical parameters which we use in the modeling to assess the development of fire hazard.

The first five items on the list are derived directly from data elements in the national fire database, collected using the NFPA 901 code. For the sixth item, secondary ignition, we will use a special procedure which accounts for fire spread from the kitchen to the wall of the dining room. So in step 2, we have selected two representative restaurants and two "areas of origin." Our treatment of the last four scenario descriptors is explained in the remainder of this Section.

2.3.1 Burning Characteristics of the Item First Ignited

To compute risk for any product it is necessary to account both for fires originating with the product and fires originating with everything else, which could eventually involve the product. In the present case this requires that we be able to describe both the rate of fire development of a wall covered with the textile material of interest when ignited directly by a small flaming source, and the ignition time and subsequent rate of spread when the wall is ignited by flames from a flashover fire in the kitchen.

For direct ignition of the wall, the HEMFAST model *predicts* the rate of development by dividing the wall into elements and predicting the state of each as a function of time. The possible states are: not burning, burning, or burned out. If burning, the model further predicts the release rates of energy and mass, as influenced by the flux to the element from other elements and the room.

For scenarios involving spread to the wall from a flashed over kitchen, the initiating fire needs only be sufficient to flash over the room. Here we used one of the generic fire growth curves employed by the risk method to describe general combustibles. The risk method assigns all combustible items identified in the incident data to one of nine burning characteristic classes. The classes are described by their rate of rise in rate of heat release (fast, medium, or slow) and by their peak rate of heat release (low, medium, or high). These growth rate curves are identical to the assignments made of the burning rates of unspecified items by the NFPA Committees on Detection Devices and Automatic Sprinklers [10]. These fire growth rate (of heat release) curves are represented as a curve proportional to time squared, where the curve is defined by the time required for it to reach a particular heat release rate value. The three growth rate curves used are:

- slow - which grows to 1055 kilowatts (1000 Btu/sec) in 600 seconds,
- medium - which grows to 1055 kilowatts in 300 seconds, and
- fast - which grows to 1055 kilowatts in 150 seconds.

The three peak heat release rate values are:

- low energy emitters - 250 kilowatts,
- medium energy emitters - 500 kilowatts, and
- high energy emitters - 1000 kilowatts (not used in this case).

As an example, Table 2 indicates the item classes for dwellings with the items in each class identified using their NFPA 901 standard code. Since three classes had no items identified, the original nine classes reduce to six. The bases for the assignments made to the growth rate and peak heat release rate burning classification in the Table were either full-scale tests of an item of the same general description or small scale test (Cone Calorimeter) data on a sample of material of a type from which the item might be made (see Tables 3 and 4).

Looking at Table 2, we see that there is only one NFIRS "first item ignited" code which seems appropriate for a kitchen fire. This is fast/medium, which describes flammable liquid fires, such as a grease fire. In all cases, the peak heat release rate is limited by the model to be consistent with the available oxygen which entered through the two exit doors at either end of the dining room.

The last material property required by the hazard model is the production rate of smoke. This parameter results in the optical density which affects the occupants' speed of movement and potentially whether their egress path is blocked requiring them to select an alternate path. Here, a review of unpublished data from the Cone Calorimeter shows that there is a distinct clustering of yield fractions for natural materials (cotton and wool) and synthetics (nylons and polyesters) about values of 0.003 and 0.03 respectively [11].

Table 2 - Burning-Characteristic Item Classes for Dwellings

Growth Rate	Peak Heat Release Rate	Classes of Items First Ignited Included[*]
Slow	Low	18, 43, 44 Thermal insulation; books, magazines, paper
Slow	Medium	None identified
Slow	High	None identified
Medium	Low	22, 33-38, 45, 61 Non-upholstered chairs; soft goods other than mattresses, pillows, bedding; toys and games; wire or cable insulation
Medium	Medium	21 Upholstered furniture
Medium	High	15, 17, 23, 24, 29 Interior wall coverings; structural members; cabinetry, including tables; ironing boards; unclassified furniture
Fast	Low	14, 16, 42, 46-48, 51-57, 71-78, 85, 87 Floor or ceiling coverings; decorations; awnings; tents; supplies and stock except cleaning supplies; pelletized or rolled materials
Fast	Medium	25, 31-32, 41, 58, 62-68, 81-84, 86, 88 Appliance housings; mattresses, pillows and bedding; cleaning supplies; power transformer equipment; fuels and other combustible or flammable liquids or gases, dust or lint; explosives; adhesives
Fast	High	None identified

[*] Numbers refer to NFPA 901 codes (1976 edition) for form of material first ignited. Exterior forms of material first ignited (11-13) are excluded from analysis of indoor products. Unspecified and unknown type items, except where shown above, are proportionally allocated over the classes they belong to.

Table 3 - Tests of Actual Items

ITEM DESCRIPTION	NFPA 901	REFERENCE
WOOD CABINETRY (plywood)	[23]	NBSIR 83-2787 (Fig 112,113)
WOOD CABINETRY (purchased)	[23]	NBSIR 83-2787 (Fig 126) and NBSIR 82-2469 (Fig 7)
PLASTIC APPLIANCE HOUSING		
(calculator)	[25]	unpublished data
(TV cabinet)	[25]	unpublished data
WOOD APPLIANCE HOUSING	[25]	unpublished data
MATTRESS (purchased, residential type	[31]	NBSIR 83-2789 (Fig 79)
PILLOW (purchased)	[31]	NBS MONOGRAPH 173 (Fig 20)
WEARING APPAREL (clothes on hangers)	[34]	NBSIR 82-2469 (Fig 8,9)
(metal wardrobe contents)	[34]	NBSIR 83-2787 (Fig 84)
BOOKS and MAGAZINES (box of files)	[43,44]	NBSIR 82-2469 (Fig 7)
BOX (container of paper trash)	[51]	NBSIR 85-3195 (Fig 8)
PACKAGING (trash fire)	[55]	NBSIR 85-3195 (Fig 12)
ELECTRIC CABLES (cables in a tray)	[61]	NBSIR 85-3195 (Fig 4,5,6)
FLAMMABLE LIQUID SPILL (fuel oil spill)	[62]	NBSIR 85-3195 (Fig 19)
COOKING MATERIAL (12" pan of cook. oil)	[67]	NBSIR 87-3604 (CKG001)
CURTAINS (cotton)	[36]	NBSIR 87-3604 (CUR001)

NOTE: Unpublished data are USFA tests of fuel pkgs. for QRS performance tests.

Table 4 - Small Scale Test Data

PLASTIC NON-UPH. FURNITURE	[22]	RIGID POLYURETHANE (RPU001)
WOOD NON-UPH. FURNITURE	[22]	PINE BOARD (PIN002)
PLASTIC CABINETRY	[23]	RIGID POLYURETHANE (RPU001)
IRONING BOARD	[24]	PINE BOARD (PIN002)
FABRIC AND YARDGOODS (synthetic)	[37]	RAYON (RYN001)
(natural)	[37]	COTTON (CTN002)
LUGGAGE	[38]	RIGID POLYURETHANE (RPU001)
DECORATIONS (synthetic)	[42]	ACRYLIC (MMA001)
(natural)	[42]	PINE (PIN002)

NOTE: All of these data are taken in the cone calorimeter and reported in NBSIR 87-3604. Small-scale data are reported on a per-unit-area (burning) basis. Thus, to arrive at a slope, a maximum rate of spread across the surface must be assumed. Likewise, a peak burning rate requires the assumption of a maximum surface area involved. The assumed mass of he item would relate to the total burn time.

2.3.2 Heat Source Igniting the first Item

Another factor in the development of scenarios relates to the heat source igniting the first item. A combination of item and source resulting in an initial smoldering phase produces some toxic smoke before producing an appreciable amount of heat. For upholstered furniture, we assumed that all ignitions by cigarettes and other tobacco products which are listed in NFPA 901 were smoldering ignitions which were discovered and extinguished by staff or patrons prior to any significant exposure of the wall. All other ignition sources were assumed to produce flaming ignition of the wall. Thus, for this case study only flaming fire scenarios were modeled.

2.3.3 Final Extent of Fire Growth

The characterization of fire growth (final size of the flame spread) as coded in NFPA 901 based data uses the following classes:

1. Confined to object of origin
2. Confined to area of origin but beyond object
3. Confined to room of origin but beyond area
4. Extended beyond room of origin (assumed to mean flashover)

While these classes are *subjectively* assessed by the fire officers collecting the data, we assigned to each of the classes a *specific* measure of peak severity to be used in the physical modeling. The measure is peak upper level temperature.

Extent of Flame Damage	Peak Upper Level Temperature
Confined to object of origin	100 °C
Confined to area of origin	200 °C
Confined to room of origin	450 °C
Extended beyond room of origin	>600 °C

These values were subjectively assigned without any direct scientific basis. They are, however, consistent with the concept that fire spread on or to an object is driven by radiant energy from its surroundings (flames and hot gases and room surfaces) which heat the surface and increase the volatilization rate. The higher the upper layer temperature, the higher the imposed flux and the more objects ignite and burn, thereby spreading the fire. Note that a way of considering the potential impact of fixed suppression systems would be to assume that nearly (weight by the reliability of a sprinkler system, ca. 98%) all ignitions would be "confined to object."

2.3.4 Secondary Ignition of the Wallcovering

All scenarios initiating in the dining rooms were assumed to be primary ignitions of the product, and all scenarios initiating in the kitchen were assumed to be secondary ignitions of the product by a large ignition source. A lack of data made it impossible to include other possible scenarios such as secondary ignition of the wall from a fire originating in fixed wiring within the wall.

2.3.5. Calculation of Scenario Probabilities

The inability to establish the representativeness of either the product (properties) or the occupancy (building characteristics) relative to the current distribution of materials and restaurants which exist makes the calculation of scenario probabilities impossible. In lieu of the steps called for in the risk method, we have substituted a reference hazard calculation which can be used for comparing product or occupancy characteristics once obtained. This process has involved:

- developing a fire scenario structure for modeling fires on walls of restaurants, based on two assumed restaurant arrangements,

- limiting the areas of origin to the kitchens or adjoining dining areas,

- defining the categories of first items ignited as the wall itself or food in the kitchen, based on incident data for restaurant fires,

- limiting heats of ignition to a single flaming class, which is applicable to the particular characteristics of the product, and

- describing the procedure for determining the secondary involvement of the wallcovering in fires initiating in the kitchen.

2.4 Adapting the Fire Model for Flame Spread on Walls and Constructing Heat Release Rate Curves for Fire Scenarios

2.4.1 Adapting the Fire Model

In the previous cases, technical enhancements were made directly to the FAST model, which serves as the core of the hazard (and thus the risk) prediction. In the present case, we took advantage of the significant, long term investment of CFR in supporting the development of a fire development model called HEMFAST [6].

HEMFAST is a model designed to make highly detailed predictions of the rate of spread and fire development on items of upholstered furniture. It was developed to operate as the combustion module of FAST, eliminating the need for a user-specified fire by predicting the fire development from first principles. Further, it was designed to operate solely on material property data obtained in the Cone Calorimeter and the LIFT apparatus.

Two other wall flame spread models or algorithms were considered, including an algorithm for burning on a vertical surface, currently under development by Mitler [12], and the OSU model [13] which includes a wall burning routine. The former was rejected because it does not predict the crucial process of spread rate, and the latter because it requires OSU Calorimeter data which we did not have for materials of interest.

While HEMFAST was not specifically designed for flame spread on walls, the physics is the same for a fire spreading along the back and arms of a sofa and a fire spreading along three walls of a room, except for the physical size of the assemblies. Thus, we felt that such a scale-up was feasible. Since we had both bench- and full-scale room fire data on the wallcovering materials being used, we had the ability to validate the results obtained from HEMFAST.

The other model "modification" (which did not require any actual change to the model) dealt with our need to spread the fire from one room to the next, a feature which FAST does not directly support. This was accomplished by using the RESTART feature, which was used to reduce the computation time in Case 1 by running one smoldering furniture run, and RESTARTing the flaming growth curves onto the result. This feature essentially allows multiple runs of FAST to be connected (appended) end-to-end, to form a single composite run.

In the present case, RESTART was used to simulate fire spread from one room to another by first running the FAST case for the fire in the first room and determining from it, the time of spread to the second room (in this case the time of flashover), and then RESTARTing the FAST run for the dining room fire using HEMFAST. This procedure has the effect of initializing the dining room fire with the temperature, layer heights, and smoke and gas concentrations existing at the time of ignition of the wallcovering by the kitchen fire. What it does not do is to allow the kitchen fire to continue beyond that point of transition, since FAST cannot account for a fire burning in two rooms *simultaneously*.

2.4.2 Constructing the Heat Release Rate Curves for Fire Scenarios

Appendix C of the Methodology Report [1] provides the rules which specify how to compute the heat release rate curve needed to run FAST from ignition until all the fuel is pyrolyzed in the room of origin. For the kitchen fires (not involving the wallcovering) these procedures were followed. For the combustion of the wallcovering, however, they were not needed since HEMFAST *predicts* the growth and release rates from the small-scale properties.

All fires follow one of the paths depicted in the event tree in Figure 2. Each path includes four fire scenarios by extent of spread. The method stipulates a maximum upper layer temperature corresponding to each extent of spread (section 2.3.3). We model the set of fire scenarios initiating with a specific item as follows:

1. Use FAST to model the fire scenario for extent of spread beyond room of origin (flashover). This scenario extends through each of the upper layer temperatures for the less severe fire scenarios and pyrolyses the entire contents of the room.

2. Use the risk software to derive the hazardous conditions which apply to the three fire scenarios with extent of spread less than flashover.

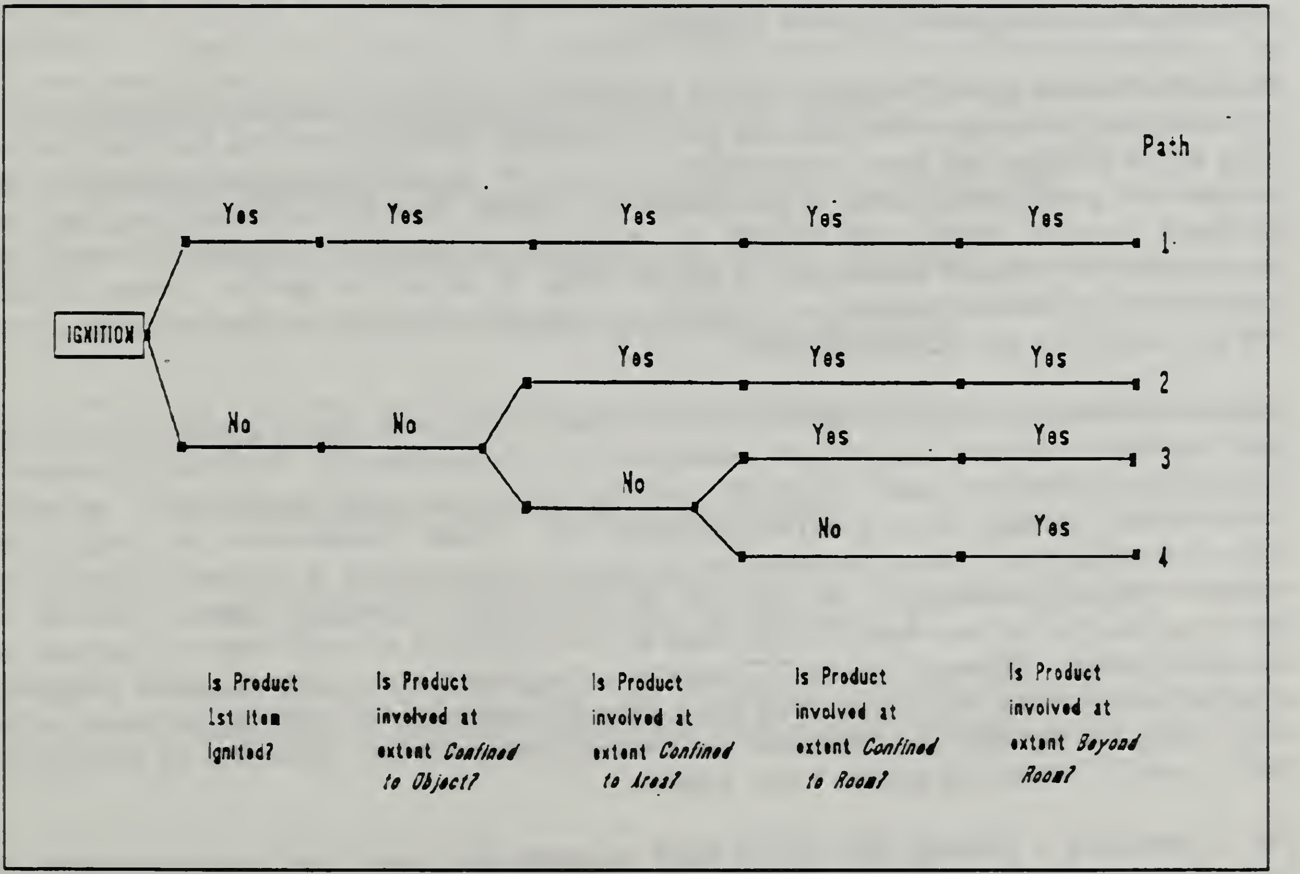


Figure 2 - Event tree indicating at what *Extent of Spread* the product becomes involved.

The risk software has been designed to use one run of FAST for each growth curve, picking the three peak limits from that single curve to derive the hazardous conditions which apply to a specific scenario when the extent of spread is less than "beyond the room of origin" (flashover). The software uses the upper layer temperature criterion for each extent of spread, previously described, as the trigger for cutting off the fire. This significantly reduces the computational burden of making FAST runs, but does so by neglecting the die out portion of fires which do not reach flashover. However, an assessment was made that the die out portion of the fire of less severity than flashover is not significant, especially since these fires are not the major contributors to death totals. Also, fires which are interrupted prior to flashover are most likely discovered and extinguished, which assures a strong possibility of assistance to any persons still in the building.

In summary, the fire model was modified to predict the particular burning characteristics of wallcoverings as a function of the small-scale properties measured. We have developed the heat release rate input curves for the fire scenarios associated with secondary ignition of wallcoverings by kitchen fires, and a mechanism to approximate fire spread to a second room.

2.5 Specification of Occupant Sets, Associated Probabilities, and Tenability Limits

As was the case for the product and building, the restaurant industry was unable to provide detailed demographic data on restaurant patrons. Thus, the team was again forced to make assumptions concerning occupant characteristics, such that the calculation represented a reference against which other assumed characteristics could be compared.

In general, for each type of building and each fire scenario, there are potentially different groups of people exposed to the fire's heat and toxic gases. Specifying these occupant sets, their likelihood of being in the building and their susceptibility to the fire is the fifth step in the procedure. An occupant set is defined in terms of the number of persons, their characteristics (e.g., age, sex, handicap), location (within and outside the building) and condition (asleep or awake and incapacitation by physical impairment or due to drugs or alcohol) at ignition. Some of these characteristics, particularly location and condition, are strongly dependent on the time of day, and is how the time of the fire affects the result.

Exposure evaluation involves placing the occupants appropriately at the time of ignition and modeling their response to the cues (e.g., detector alarm and smoke) from the fire. HAZARD I contains a deterministic evacuation model (EXITT) with decision rules which depend upon occupant characteristics, building layout and fire conditions [14]. These characteristics are used in the evacuation model to set evacuation speed and to simulate behavior such as alerting and/or assisting others or requiring assistance. We then use the HAZARD I tenability program (TENAB) to determine whether or not occupants succumb to the conditions to which they are exposed or successfully escape. However, the EXITT model is not appropriate to model restaurants containing large groups of persons who are expected to be delayed in egress by the formation of queues at the exits. Thus, for this case, we employed the same simpler procedure developed by Nelson and MacLennan [15] which was used in Cases 2 and 3.

This is essentially a hydraulic flow model which estimates the escape time required in terms of horizontal or vertical movement, travel speeds, and building features such as corridors, doors, landings, and stairways, which may constrict occupant flow. These specific factors are related to constants applied in several equations to give an evacuation time. These equations use the *effective width* concept of Pauls [16], and model the queuing and congestion that occurs at doors and stairs when a large building is evacuated. Thus, this model is more appropriate to restaurants than EXITT.

Like the occupants of offices and function rooms in hotels, restaurant patrons are a much more homogeneous group. We assumed all occupants are awake and able to evacuate without assistance, and we restricted our analysis to fire scenarios with maximum occupant exposure. To do otherwise would have required unfounded assumptions as to how many persons were present at various times of day. In any case, assuming awake, adult occupants in the room of origin negates any possible role of detectors in alerting occupants.

With regard to occupancy load, an absence of hard data required an assumption by the project team, based on the floor area of the dining room and a typical occupant density of about .03 persons/ft^2. This led to an estimated 44 patrons and 8 staff for the fast food restaurant and 62 patrons with 20 staff for the traditional restaurant.

2.5.1 Specification of Occupant Sets and Associated Probabilities

The risk calculation requires an estimate of the probability of each occupant set for each fire scenario. The national fire data provide no information on building occupants unless they are injured or killed. In this case, there is only one occupant set for each building configuration, and their probability is simply equal to that of the geometric arrangement. That is, the probability of the occupant set is 100% for that physical arrangement. There was no attempt to address time-of-day through assumed variations in occupant load associated with mealtimes.

The following assumptions were made with respect to the evacuation calculation:

- At the time of the fire, all occupants are able to escape without assistance.
- Occupant behavior is not affected by the fire conditions.
- All occupants encounter the same fire and smoke conditions and, once out the exit, they are safe.
- The occupants will evenly distribute to both exits.
- All occupants begin evacuation at the same time, with that time retained as a variable so that the effect of delayed discovery can be evaluated.
- Initial movement speed is 235 feet per minute [15] for all occupants (none are handicapped or impaired) although the effect of slower speeds is easy to determine.

2.5.2 Tenability Limits

The tenability program (TENAB) is used to determine the impact of exposure of the occupants to the heat, and gases produced by the fire, and ultimately whether or not the occupants successfully escape [17]. If they do not, TENAB decides upon a *limiting condition* (toxicity or heat), when this occurred, and how far the occupant got before being overcome. The TENAB program compares the conditions in the building over time as predicted by FAST and the occupant location over time as predicted by EXITT (or in this case, the alternate evacuation calculation) with tenability criteria (toxicity and heat tolerance) based on the work of researchers in fire toxicity. A detailed discussion of the criteria and the literature on which they are based is contained in the HAZARD I documentation [18]. For each type of criterion, two or more independent parameters are computed as a means of addressing the high degree of variability inherent in such physiological predictions. The toxicity measure used in this analysis was limited to the concentration-time product (Ct). This parameter represents a time-integrated exposure to the toxic products produced by the burning contents items relative to a small-scale combustion toxicity screening test. On this basis, a reference value of 900 mg-min/ℓ is typical for common materials. Ct is calculated in the FAST model by taking the cumulative mass of fuel lost and distributing it into the upper layers in each room. Unlike the more detailed fractional effective dose (FED) parameter also computed by TENAB the Ct measure does not require a knowledge of the specific materials of construction and their associated release rates of gases. Using the Ct parameter, a generic fuel can be characterized with an appropriate level of specificity. New products can be tested to determine their toxicity and the input to FAST (Ct) will reflect these results.

In a revision to TENAB included in the general release of HAZARD I oxygen deprivation was included as lethality condition in addition to the Ct parameter. TENAB includes a formulation which accounts for oxygen deprivation as a time-integrated function, and allows for an occupant moving from a room depleted of oxygen into a room where oxygen is plentiful in a physiologically proper manner. This provides a more appropriate evaluation for larger fires which deplete the ambient oxygen.

Heat is assessed as an incapacitation measure in the analysis. Purser [19] has derived from various literature sources, a mathematical expression for tolerance time to convected heat. This expression was slightly modified to allow for a threshold temperature below which no impact occurs. This relationship produces a more realistic response prediction than simply a limiting temperature as was originally used, since it allows for the time-dependent nature of the heat transfer to the subject. While heat is an incapacitation measure in the simulation, it is not differentiated from lethality. When convected heat is predicted to be the cause of death, it may ultimately be from toxicity or oxygen deprivation, but only because the victims were prevented from escape by convected heat.

In the fifth step we have assumed an occupant set to be exposed to the reference scenarios. We have discussed the evacuation calculation used to replace the EXITT model for non-residential occupancies. And we have selected the criteria for judging occupant survivability to exposure to the heat and gases produced by the fire.

3. Description of Method Implementation - The "Base" Case Risk Computation for Interior Finish in Restaurants

3.1 Sequence of Calculation

In Section 2, we described how we implemented a significantly modified approach to the risk method as was applied to the prior three case studies. Faced with a lack of the detailed data required to specify the characteristics of wallcoverings representative of that currently in use in restaurants, the physical arrangements and construction representative of this class of properties, or demographics on the patrons of such businesses, the analysis was limited to that of product hazard in key scenarios related to fire incident data records.

The calculation employed a sequence similar to the previous cases, but with very different steps:

1. Each of the four fire scenarios and two products were run in the HEMFAST model to obtain a prediction of the rate of involvement of each wallcovering material and the conditions produced in the dining areas of the restaurants.

2. The evacuation calculation was performed for each of the two sets of building arrangement and occupant load to obtain the required evacuation time.

3. TENAB was used to judge survivability over the time required for all occupants to evacuate.

We then compared these predicted results with actual losses obtained from the national fire database. These comparisons in the earlier case studies led to adjustments in the method. Here the limited calculation would not support such modifications, although the results obtained did not seem to warrant any. For clarity, the procedures used in this case are summarized in the following sections.

3.1.1 Thermal Tenability Limit

The evaluation of human susceptibility to convected heat was performed using a relation developed by Purser [19]. This equation accounts for both the temperature and time of exposure, unlike an earlier limit based on a simple limiting temperature.

3.1.2 Updated Version of FAST

In the initial case studies, the version of FAST available did not account for oxygen availability and its effect on burning rate. This was not considered a major shortcoming for the carpet case, but was crucial to the concealed combustible case due to the fact that there, the burning takes place in a very restricted volume. Thus, the newer version of FAST was used for Cases 3 and 4, but not for Cases 1 or 2. The modification of primary importance was the utilization of the HEMFAST model for the prediction of fire spread and burning rate of the wallcovering materials.

3.1.3 Modifying the Upper Level Temperature Criteria

The upper level temperatures associated with a given extent of flame spread class were arbitrarily established by the technical team. These were discussed at a meeting of the Advisory Committee, at which some modifications were suggested by that committee. In the absence of data and since the suggested new values were reasonable, these were adopted as a part of the risk method and were used in Cases 2, 3, and 4. These are the values presented in section 2.3.3.

3.2 Example Output

In this section we will present the performance of the wall materials predicted by HEMFAST. Simulations were run for only three minutes because this was enough time for complete evacuation, and since HEMFAST requires significant computer time. Figures 3 to 5 show burn patterns predicted by HEMFAST. The contours show the predicted flame front at regular intervals. Thus, closely spaced lines represent slow flame spread rates and widely spaced lines indicate rapid spread.

3.2.1 Fire Performance of Textile Wallcoverings

The two materials selected for examination were a polypropylene (ATMI code PP-PF) and a polyester (ATMI code Q). These were the two worst performing materials in the full-scale tests, but material Q was substantially worse than PP-PF. Material Q burned completely and flashed over the test room. Material PP-PF burned vigorously, but self-extinguished near the corners of the room and did not flash over the room.

The HEMFAST model predicted behavior in the restaurant dining rooms in this case study, similar to that observed in the full-scale tests despite the difference in room size. Material PP-PF ignited and spread flame partially along the long wall of the dining room. It did not spread around the corners to the side wall but rather self-extinguished before reaching the corners of the room. Remember that the burning behavior and resulting burn pattern **were *not* user specified, but rather were predicted by the model from the small-scale data on the materials.** For this wallcovering material, no lethal or incapacitating conditions were predicted in either restaurant within the first three minutes (the maximum time that we ran the calculations) of the time that the wall first becomes involved.

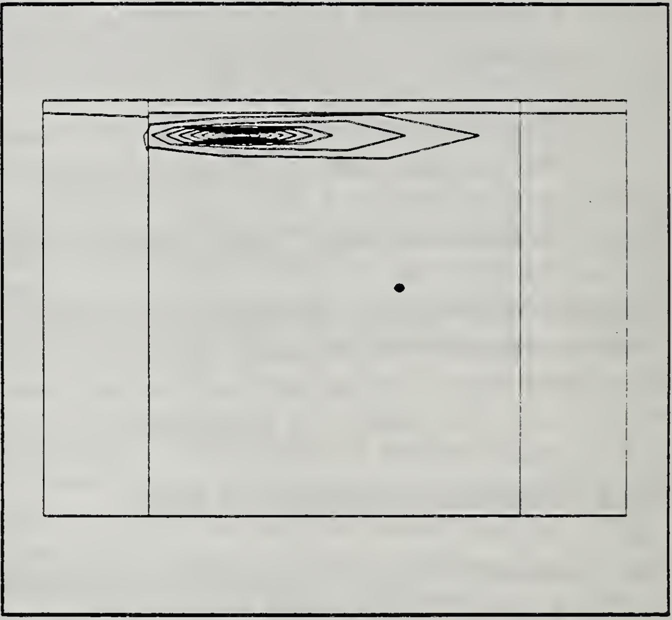


Figure 3 - Predicted burn pattern for material PP-PF.

Material Q was predicted to perform similarly to PP-PF, but burned more vigorously releasing more energy and mass. It spread flame just into the corners of the room and stopped with minor involvement of the side walls. Its burning was sufficiently intense to create untenable conditions in the dining room from temperature just at three minutes, allowing sufficient time for egress of the fully-capable patrons assumed to be present. Flashover of the dining room was predicted not to occur.

The flame spread behavior of these materials is driven by the radiant flux to the wall. The restaurant dining rooms are larger than the room in which the full-scale tests were conducted, and the flux will decrease as the room size increases, for the same fire size. Thus, we examined the sensitivity of this result to room size. These results are reported in section 3.4.

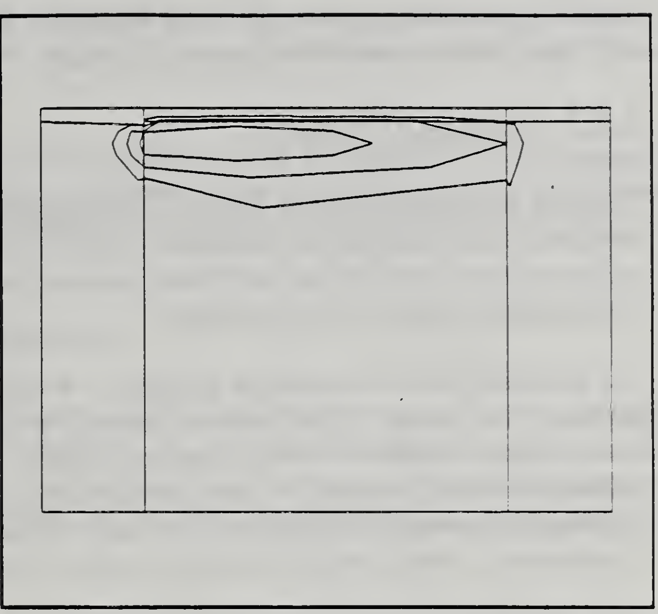


Figure 4 - Predicted burn pattern for material Q

Since all other textile materials reported in reference [8] performed better than PP-PF, they would be predicted to perform no worse when used in the prototype restaurants and would result in no predicted fatalities.

3.2.2 Required Evacuation Time

Using the evacuation model of Nelson and MacLennan [15], the following evacuation times were calculated for the two restaurants.

In both restaurants, all occupants are in a single room with direct exits to the outside. When the fire initiates in the dining room, the alerting time is zero because the occupants can see the fire start. When the fire initiates in the kitchen the alerting time is no longer than the time at which the fire products enter the dining room. For all cases, a reaction time of 6 seconds (the value applied to awake adults in Case 3) was used.

At the same (horizontal) travel speed as was used for adults in Case 3, the travel speed within the dining room is insignificant compared to the queue time at the doors. Based on the maximum flow through the two available exit doors, we find that 9.6 people can exit every 5 seconds. Thus, including an engineering safety factor of 2 as recommended in reference [15], it will take 54 seconds to evacuate the 52 occupants of the Fast Food restaurant, and 86 seconds to evacuate the 82 occupants of the larger restaurant. Adding the 6 second reaction time produces the final values of 60 seconds and 92 seconds, respectively.

These values reflect an adult population fully capable of unassisted evacuation. The impact of handicapped people, a fire start which rapidly blocks one of the exits, or even furniture being knocked over and partially blocking the route are simple to evaluate since we know the maximum safe time in the room (see following section).

3.2.3 Occupant Safety

For fires involving material PP-PF in the dining room we find that all occupants evacuate well in advance of any dangerous conditions. Since no lethal or incapacitating conditions were predicted in either restaurant within the first three minutes, there was sufficient egress time for all occupants even if some short delays were introduced.

For material Q, the situation is marginal. While all of the patrons in the benchmark occupant set escaped, the dining rooms become dangerous (incapacitation due to temperature) just before the three minute terminus for fires initiating in the dining room of either restaurant and at about two minutes for fires initiating in the kitchen, due primarily to the much larger source igniting the wall. Particularly for the kitchen fires in the large restaurant with the larger occupant load, any extenuating circumstance which delays evacuation could result in fatalities.

3.3 Base Case Comparison with Statistics

Since we do not have data on which to quantify the representativeness of the wallcoverings, buildings, or occupants, we are unable to establish the appropriate weightings and thus the weighted fatality rate. This means that we can only make qualitative comparisons to the fire statistics. These statistics show that there is a very low fatality rate for restaurant fires which may involve interior finish in the dining rooms. While this analysis predicted no fatalities, the results for material Q were marginal and with materials only slightly worse, or when there are other extenuating circumstances as discussed above, the result will be different.

This means that the fire performance properties of material Q provide a reference against which other wallcovering materials can be compared. As measurements are made on other materials and assemblies in the LIFT Apparatus and Cone Calorimeter, those whose performance is worse (higher release rates or faster spread) should result in fatalities in these scenarios, and those whose performance is better should not.

3.3.1 Judging the Quality of Agreement

What is considered "good agreement" is often subject to argument or at least individual interpretation. As the risk method is applied, comparisons to incident data are made in developing and calibrating the "base case." The "new product case" involves comparisons to both the incident data and the base case. In each area, these comparisons can involve both absolute numbers (of deaths) and distributions (smoldering vs flaming or death from heat vs toxicity). This quality of agreement is a function both of the ability of the science to address properly the physics of the scenario, and the ability of the data to describe fully what occurs in the real world. Thus, some criteria are needed for judging the quality of the comparisons made, which are tailored *for the individual case under consideration.*

In terms of the intended use of the model, the degree of agreement should be sufficient that modeling errors are considerably less than the likely differences between the true base case risk and the true risk associated with a significantly better new product. This criterion may require better agreement than the "factor of two" criterion that is applied to several of the key models used in the risk method.

For the present case, the lack of data on several key factors prevents the completion of a risk analysis and limits us to a hazard analysis on key scenarios identified from the statistics, with qualitative comparisons to those statistics. In the absence of quantitative comparisons, statements on quality of agreement are not possible.

3.3.2 Judging the Significance of the Results

It should be clear that the method will permit the calculation of differences in risk for a selected product/occupancy pair (e.g., new product vs. baseline), but not all differences can be safely interpreted as indicating real product differences. The accuracy and precision of the method will be functions of the quality of the input data, the adequacy of the many simplifying assumptions, and the coarseness of the scenario structure.

One way to assess the accuracy of the method is to calibrate the "base case", which will be based on real fire probabilities for a certain period, against actual fire death rates for the same period. The degree of correspondence between the predicted and actual fire death rates is a measure of the accuracy of the method. It has limitations, however. On one hand, high accuracy in predicting totals need not mean high accuracy in the underlying structure of the method. If an accurate tool is generated for the wrong reasons, that could mean an inaccurate answer for the new product. On the other hand, poor accuracy in predicting totals may be due to systematic errors that would have the same effect in other calculations. Therefore, one could do a poor job of predicting the total fire death rate in the baseline and still do an excellent job of estimating the relative change in fire risk between the baseline and new product.

Too little is known at present to do a truly satisfactory job of quantifying the degree on uncertainty in the method, overall or for a particular case. Instead, the authors have attempted for each case, to provide guidelines on how to judge the significance of differences in risk in that case. Sensitivity analyses and expert judgement play a large role in checking the confidence of these results.

Because the absence of key data prevented completion of the test risk analysis for this case, the authors suggest that the method be used only to define a series of hazard analyses, with statistical significance judged qualitatively on the basis of uniformity of results, i.e., whether or not one product is better in all scenarios and under all sensitivity analyses.

3.4 Sensitivity Analysis

Earlier we observed that the two textile wallcoverings examined were predicted to spread flame to a point and self-extinguish, and that material Q did so at the side walls in our restaurant, where it spread to the ends in the full-scale experiment. Noting that the restaurant room was larger, we examined the sensitivity of this result by reducing the size of the restaurant room to that of the room in which the full-scale tests were done.

When we did this the flame was predicted to spread around the corner and burn down the two side walls to the end, matching the performance observed in the full-scale experiment. Flames also spread downward, involving much more surface area before the end of the computer run. This qualitative agreement with experimental observation lends credence to the HEMFAST predictions for the larger room where there were no experimental results against which to validate the model prediction.

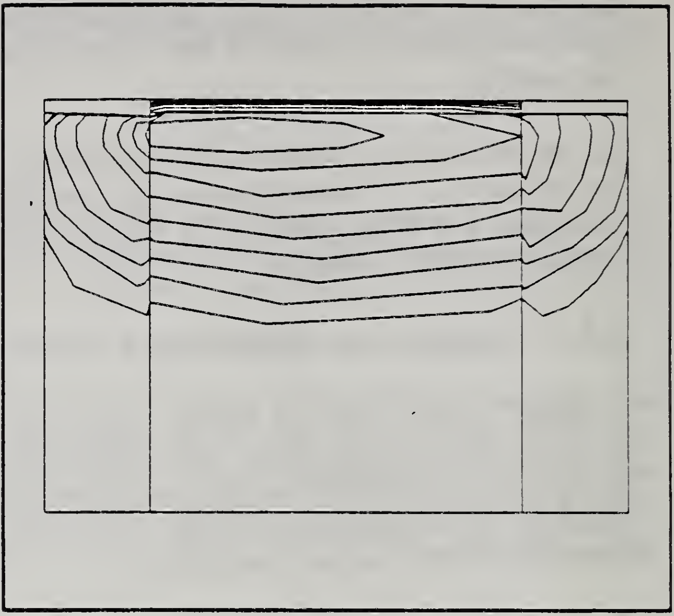


Figure 5 - Predicted burn pattern for material Q in the Berkeley room.

3.5 Key "Base" Case Assumptions

The conduct of the case required many more assumptions to be made than the prior cases. These were based largely on the expert judgement of the project team, and resulted in a significant departure from the risk method as applied to the prior three cases. These assumptions are:

- Interior finish materials' performance in the Cone Calorimeter and LIFT Apparatus is representative of their full-scale performance in physical configurations similar to restaurants.
- All interior finish materials' fire behavior is similar to that exhibited by these textile wallcoverings.
- The two restaurant buildings specified are typical of the class and the observed losses do not typically involve contributory code violations.
- The majority of restaurant patrons can be represented as normal adults and do not exhibit unusual behavior when faced with a fire.
- The risk associated with interior finish in restaurants is dominated by the high incidence scenarios represented in this analysis and changes in the product will not affect this.

4. Description of Method Implementation - The "New" Product Risk Computation for Interior Finish in Restaurants

4.1 Sequence of Tasks to Calculate Risk for the "New" Product

The "base case", once completed and calibrated against the fire statistics (which we cannot do for this case), becomes the mechanism by which the risk impact of changes in the product can be evaluated. In this context, the "new" product is any product item which incorporated one or more changed performance properties (e.g., ignitability, burning rate, toxic potency, smoke production) It is also important to remember that the "new" product must be assumed to **totally replace the existing product.** However, in this case the lack of required data prevented the completion of a risk analysis and limited our ability to examine fully the impact of any changes in the properties of the product to a comparison with the results obtained for the "benchmark" product.

To calculate the risk for the "new" product requires 1) measuring its fire properties (ignitability and burning characteristics); 2) running the previously described calculation procedure using the building(s) occupant sets and the scenarios from the base case with the fire properties of the "new" product; and (3) comparing the predicted hazard with that obtained in the base case. It is assumed that the "new" wallcovering is completely substitutable for the finish material in use and that changes in the product do not affect who will buy it or what kind of restaurant it will be in, etc.

4.2 Modeling Changes in the Fire Properties

Changes in the product's fire properties can result in changes to the fire hazard and risk results. Changes in ignition resistance (in terms of critical radiant flux for ignition) for the "new" wallcovering could change the scenarios of interest. Ignitability influences both the propensity for primary ignition from the various possible heat sources as well as when the wallcovering begins to contribute when other items are first ignited.

Similarly, changes in the assumed (or measured) burning properties of the product once ignited can influence the occurrence of fatalities among staff or patrons, and thus the hazard assessment for the product. In particular, since our assumed occupants were just able to escape safely, any diminution in the combustion properties of the finish material will likely result in the onset of fatalities, at least for fires originating in the kitchen of the large restaurant.

4.3 Comparison of "New" Wallcovering's Results with "Base" Case Results

For this case the project team decided to examine the impact of just such a diminution in properties, in terms of both the rate and quantity of energy and mass released by the wallcovering. Since there is a significant amount of input data required to run the HEMFAST simulation, and since data files for upholstered furniture assemblies were available (HEMFAST is an upholstered furniture model) we decided to use them. This is might be similar to a restaurant where several layers of wallcoverings had been applied one over another.

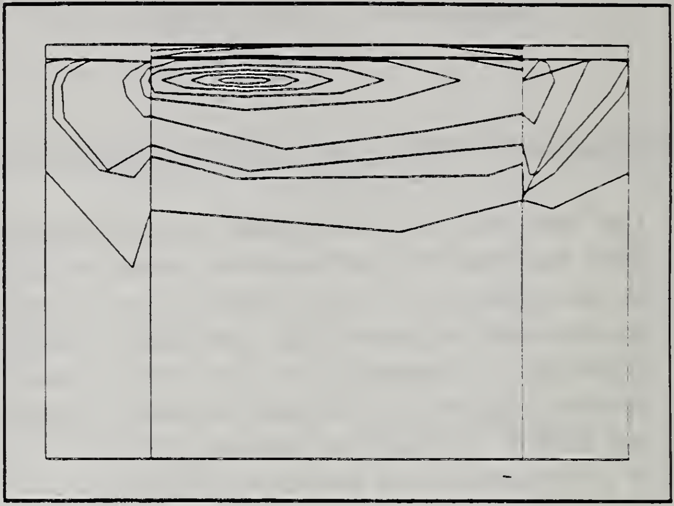


Figure 6 - Predicted burn pattern for foam wall

The HEMFAST model predicted very rapid flame spread and vigorous burning until all of the wall materials were consumed. Maximum tenability times were of the order of only 20 seconds. With a 6 second reaction time this leaves 14 seconds for safe evacuation. For fires originating in the kitchen most patrons of either restaurant were killed as they queued at the doors. For fires originating in the dining rooms more patrons successfully escaped because the fire was smaller when evacuation began, but most patrons died in all scenarios; the number depending on the assumed properties of the material.

5. Conclusions and Observations

In this report, we have described a fourth and very different application of a quantitative method for the estimation of the fire risk associated with a specified product class in a specified occupancy. This case study tested the limits of the method with respect to addressing cases where data on representative products, buildings, or occupants are not available. With all of this lacking, the method collapses to a benchmark hazard analysis against which product changes can be compared.

Like Case 2 (carpet), this case demonstrated how the method can be used to evaluate a product which at present does not contribute significantly to life loss. The calculation provided a means to examine a product whose involvement is largely secondary; as secondary product involvements have never before been addressable in risk analysis of any type. Through enhancements to the fire model, we succeeded in providing a prediction of flame spread and fire development on a wall, which was qualitatively the same as was observed in full-scale experiments conducted with these materials.

Because of the lack of required data, any risk assessment for interior finish in restaurants must be made in the traditional way from the fire incidence data. What we can derive from the hazard results obtained on the textile wallcoverings examined is a quantification of the flammability properties that represent the margin at which life safety is threatened in the restaurant arrangements and patron characteristics considered. While there were no fatalities predicted in the restaurant scenarios examined, fairly small additional delays in exiting, faster fire development, or increased occupant susceptibility could result in a much different outcome. The interrelationship of the product, building, and occupant demonstrated in this analysis is something that cannot be derived from the incident data and has a value of its own in better understanding fires of these types.

This case pointed out the crucial role of demographic and product use data in the success of the method. In some cases special studies may be necessary to attempt to capture the needed information. In still others, we may never be able to satisfy the needs of the system. But the identification of needs coupled with the potential value of the method should provide incentive for advances in these areas.

Taken as a whole, we feel that this series of case studies has demonstrated a significant potential for the risk method to provide highly detailed analyses of the risk (and cost) impact of regulation and of the fire performance of products in our society. The potential benefits to both the provision of public safety and the costs of such safety are enormous. But further investments, particularly in the area of data collection will be required. We hope that these reports are sufficiently convincing to influence this investment.

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Traditional methods of assessing fire risk are based on probabilistic treatment of fire incident data. Recent advances in the ability to make deterministic predictions of the consequences of specific fire scenarios, presents an opportunity to reduce this dependency on incident data and greatly improve the ability to assess the risk associated with new products for which such data do not exist. This paper presents a trial application of a risk assessment method developed for such a purpose. A separate report provides the essential documentation for the methodology to be understood and applied by others. There are three other associated reports detailing trial applications of the methodology to other selected products and occupancies.

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computer models; fire statistics; hazard assessment; ignitability; probability; risk assessment

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