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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 NFPA 901, *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 second developmental case: fires involving carpet in offices. 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 phenonema 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 databases, 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.

1.3 Scope of this Case

Carpet in offices was selected as the second product occupancy pair for several reasons. First, unlike the initial case study on upholstered furniture in residences, carpet in offices does not play a major role in fatalities as a first item ignited. In fact, a review of national fire experience for the period 1980 to 1984 revealed an average of only 6 fatalities per year reported for offices, none involving carpet as a first item ignited. However, its prevalence in offices means that carpet could be a contributor to the fire hazard if ignited by other items.

Second, modeling a fire involving carpet required developing an additional computational procedure to supplement the HAZARD I fire model FAST. The burning characteristics of carpet have been studied extensively at both small- and full-scale [e.g., 4], and a standard test method is available which measures the critical radiant flux needed for carpet to spread flame [5]. The fire model [6] which is an integral part of the fire risk assessment methodology computes the flux to the floor, and could be easily modified to estimate the area of involvement of the carpet as a function of time.

The third reason for selecting this product involved the challenge to the method offered by office buildings which require an evacuation model capable of simulating as many as several hundred persons evacuating a large building. The EXITT model which is part of HAZARD I was designed for a family evacuating a residence. Thus, we were challenged to develop an alternate evacuation calculation which is more appropriate for non-residential occupancies where there are larger number of occupants and where behavioral interactions are not reported in actual fire incidents.

This combination of national fire experience data showing no fatalities, available laboratory studies and relevant data, and the opportunity to make an appropriate modification to the fire and evacuation models, made carpet in offices a good choice to extend the fire risk assessment methodology relative to the first case.

2. Description of Method Implementation - Set Up for Carpet in Offices

2.1 Selection of Carpet Characteristics

In the first step, we define carpet in offices in terms of the NFPA 901 categories and characterize the population of carpet now in use in terms of fire properties, type and location. We establish in this step the coding link between the national fire experience data and the carpet as it is coded in NFPA 901 under form of material first ignited. We will use statistics derived for carpet using this coding to determine the frequency of fire scenarios involving carpet and to validate the method's fire severity predictions in terms of deaths per fire. We will also specify a set of fire properties representing current carpet in offices.

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 is 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.

After discussions with industry experts, the fire properties of current office carpet were judged to be more resistant to ignition than typical home carpet but less resistant than that found in code regulated occupancies (where minimum critical radiant flux values are required for carpet, usually in exit access corridors). To represent the installed base of office carpet currently in place, a value of critical radiant flux (a measure of the energy imposed on the carpet surface) to ignite of 1.5 W/cm^2 was selected for a benchmark value. For comparison, carpet installed in critical areas of regulated occupancies will have a higher critical flux of 2.5 W/cm^2. All carpet sold in the US is required to pass a federal standard [7] (known as the Pill Test). Such carpet will have a minimum critical radiant flux for ignition of at least 0.5 W/cm^2. Thus the benchmark value selected to represent current carpet falls between these two values. Other selected properties assumed[1] for the carpet are given in Table 1. Note that typical values for nylon are generally used except for toxicity, where the higher toxicity of wool is accounted for by use of a conservative figure. We will also examine the sensitivity of the result to the assumed critical radiant flux value as part of the analysis (see section 3.4).

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[1] In applying the risk method to a case, the user must make many assumptions for specific inputs required. Wherever possible these assumptions should be based on data, but often there are none. In the case study reports whenever an assumption is stated without a literature reference, that assumption was made on the best judgement of the technical team, often with input from the Advisory Committee.

Table 1. Flammability Properties of Existing ("Base Case") Office Carpet

Property	Value Assigned	Justification Source
Carpet Weight	1.1 kg/cm^2 (35 oz/sq yd)	Industry recommendation
Critical Radiant Flux for Ignition $\dot{q}_i''$	1.5 W/cm^2	Median value between home and institutional carpet
Critical Radiant Flux for Spread $\dot{q}_e''$	0.2 W/cm^2	Typical for nylon
Heat of Combustion	20 MJ/kg	Typical for nylon
Smoke Toxic Potency	900 mg-min/ℓ	Typical for most materials
Mass Optical Density of Smoke	250 m^2/kg	Typical for nylon
Flame Spread Velocity	1.5 mm/s	Typical for nylon

Since carpet is rarely the first item ignited, fire incident data do not help us determine the likelihood that carpet is in rooms where fires initiate. Instead, we used marketing surveys provided by the Carpet and Rug Institute (CRI). Their survey of new U.S. office construction indicated that slightly over one-half of the floor space was covered with carpet (51 percent in 1973 and 56 percent in 1978). A second CRI survey projected that carpet would reach 75 percent of non-industrial commercial floor space by 1985. These data are used to weight the risk results to account for fires in non-carpeted offices.

Next, we addressed the separation distance between the product and items which are first ignited. This (with the assumed flux for ignition) determines secondary ignition of the product by other items. This is particularly important for carpet since this is its only means of ignition. In case 1, we followed a complex procedure with an expert panel estimating typical (horizontal) distances between the product (furniture) and all other "items first ignited." Since carpet is evenly distributed over the floor and any items first ignited are located *on top of it*, we have used a single value (0.5 meters, vertically) as the separation distance, as shown in figure 1. This distance then represents an assumption that most fires will start above the floor, such as on the seat of a chair or the top of a desk.

Finally, we need to consider the possible role of carpet in spreading fire from one object to another. This might occur directly if the carpet spreads flame between objects, or indirectly if the carpet constitutes a significant fuel source. These will be addressed through the calculation of maximum area of involvement (see section 3.2.1).

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

- examined the role of carpet in office fires through national fire experience,
- estimated typical fire properties for office carpet, and
- estimated the separation distance between carpet and other items.

2.2 Identify and Specify the Physical Characteristics of the Office

In the second step, we will 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 also specify for the building the "areas of origin" - rooms where fires start, and any fire safety features provided in the design. To do this, we used data from the U.S. Census [8] and from the Building Owners and Managers Association (BOMA) [9] - a trade association of owners and managers of commercial properties. We also made use of surveys by the Department of Energy [10] on characteristics of office space and number of workers and by NIST on fire loads in office buildings [11].

We must match the building specification with the level of detail required by the hazard model, HAZARD I. 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. U.S. Department of Energy data shown in Table 2 indicates that buildings with three or fewer floors average approximately 5000 square feet per floor, while buildings with more than three floors are not as easily characterized because the data are lumped together.

Table 2. Office Building Characteristics
Source: *Characteristics of Commercial Buildings, 1983*

	Building Height				
	1 Floor	2 Floors	3 Floors	>3 Floors	Total
Total Area (M sq ft)	1368	1458	1295	4333	8454
Buildings (thous.)	289	153	81	52	575
Area per floor (sq ft)	4700	4800	5300	<21,000*	15,000

* Figure assumes that building is four floors; more floors means lower average area per floor.

We have chosen to maximize the floor area by assuming all buildings over three floors are four floors. Therefore, the area per floor is obtained by dividing the total floor area (4.33 billion square feet) by the number of buildings (52 thousand) by four floors per building. This yields an estimate of approximately 21,000 square feet per floor. We will use a value of 20,000 square feet per floor. If we assumed more floors the area per floor would be less, closer to the value used for the smaller building. The effect of this assumption, and the assumption of open architecture in larger buildings as cited below, is to give fires a large potential area free of barriers in which they can spread. If, on the other hand, floor areas in larger buildings were assumed to be nearly the same as shorter buildings, fire behavior might be much the same in both, and the true variation in practice would be lost.

The population of workers appears to be evenly divided between buildings with three or fewer floors and buildings with more than three floors [10]. For this demonstration, we have selected two buildings to model. The first building has three floors with each floor having 5000 square feet. The fire floor has a central hall with exits at each end and four offices entering on to the hall. The second building has four floors with each floor having 20,000 square feet. The fire floor is assumed to be a large single room without significant barriers to smoke movement and in accordance with fire protection practice exits are provided for occupants at opposite sides of the floor.

The walls and ceilings of both buildings are assumed to be 1/2 inch gypsum board and the floors are 6 inch concrete slabs. Based on survey data [11], a typical office fuel load of seven pounds per square foot was assumed for post-flashover fires.

We made use of the NFPA 901 area of origin categories to identify rooms or spaces in the building where fires are coded as originating. Since carpet plays such a minor role as a first item ignited in office fires, we address our attention to the total fire picture in offices. We can classify areas of origin in terms of areas where carpet is expected, areas where carpet is unusual, connecting spaces where carpet is expected (such as corridors), and service areas where carpets are unlikely. The fire experience data showed the distribution of all fires to be: carpeted areas, 40 percent; uncarpeted areas, 14 percent; carpeted connecting spaces 8 percent; service areas, 14 percent; and 24 percent originate in concealed spaces or other areas excluded from consideration in this case. This distribution is needed to weight the (area of origin) scenarios which will be calculated as to their representativeness in actual fire incidents.

Summarizing step two, we have:

- specified two sizes of representative office buildings,
- specified number, size, and construction of each room arrangement with two exits at opposite ends of the floor, and
- identified a total room fuel load, and four potential areas of origin for fires involving carpet in these buildings.

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. We define a fire scenario in terms of a set of descriptors for the:

1. building where a fire originates,
2. rooms for area of origin where fire originates,
3. burning characteristics of the item first ignited (growth rate and peak rate of heat release),
4. heat source igniting the first item (open flame or smoldering),
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 carpet contributes to the fire, for those fires initiating with items other than carpet.

These descriptors are tied into the NFPA 901 categories, so that we can estimate the probability of occurrence for each scenario using the national fire data base. The descriptors are also associated with a set of physical parameters, which we use in the modeling to assess the development of fire hazard within the building.

The first five items on the scenario structure list are data elements in the national fire database, collected using the NFPA 901 categories. For the sixth item, secondary ignition, we devised a special procedure which accounts for carpet's fire properties and its involvement in fire both prior to and after flashover.

In step 2, we selected two representative office buildings and four "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 for both fires originating with the product and fires originating with everything else, which could eventually involve the product. In the case of office carpet, the incident data show that fires very rarely originate in it and fatal fires never do. Therefore, we chose to set up this case for only the "secondary ignition" cases.

The fire incident data specify only which items were first ignited. Since office carpet was never the first item ignited, we need to model the burning behavior of what was first ignited in order to determine the role (if any) the carpet plays in the eventual fire size. The risk method does this by assigning 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). As an example, Table 3 indicates the item classes for dwellings with the items in each class identified using their NFPA 901 form of material first ignited codes. 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 4 and 5).

Looking at Table 3, we see that there are four "first item ignited" codes which correspond to items normally found in offices. These are slow/low (books and paper), medium/medium (upholstered furniture), fast/low (interior finish), and fast/medium (appliance housings - representing business equipment). While some differences would be expected between residential and commercial items in these classes, the class assignments are broad enough that we felt they were appropriate. Also remember that these are burning rate properties only and do not reflect differences in ignitability. These fire growth rate (of heat release) curves are identical to the assignments made of the burning rates of unspecified items by the NFPA Technical Committees on Detection Devices and Automatic Sprinklers [12]. These fire growth rate 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 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.

Table 3 - 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 4 - Tests of Actual Items

ITEM DESCRIPTION	NFPA 901	REFERENCE
WOOD CABINETRY (plywood-made NBS)	[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 (TV cabinet)	[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 5 - Small Scale Test Data

PLASTIC NON-UPHOLSTERED FURNITURE	[22]	RIGID POLYURETHANE (RPU001)
WOOD NON-UPHOLSTERED 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.

The numbers in brackets refer to the 901 codes for <u>form of material ignited</u>. Where wood (or natural) and plastic (or synthetic) are differentiated, these would be apportioned on the basis of the <u>type of material ignited</u> category.

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).

In all cases, the peak energy release rate was limited to be consistent with the available ventilation, all of which entered through the two exit doors at either end of the floor. After an item has reached its peak heat release rate it is assumed that the rate of heat release declines according to a *linear* curve that requires the same time to decline to zero as was required to reach the peak rate from zero. This approach was selected for simplicity in using HAZARD I. Based on the actual rate of heat release curves in reference [13], the assignment of general burning rate curves to generic items is not expected to represent a significant source of error in the hazard calculation.

The last material property required by the hazard model is the production rate of smoke. This parameter determines the optical density which affects the occupants' speed of movement and potentially whether their egress path is blocked, requiring an alternate path selection. 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 [14].

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. In the case of furniture, we assumed that all ignitions by cigarettes and other tobacco products, which are listed in NFPA 901, were smoldering ignitions. All other ignitions were assumed to produce flaming ignitions. For carpet, cigarettes will not ignite the product directly and smoldering ignitions of other products (like furniture) were assumed to be discovered and extinguished by occupants prior to any significant exposure. Thus, for this case only flaming fire scenarios were modeled.

2.3.3 Final Extent of Fire Growth

The characterization of the fire growth (final size of the flame spread) as coded in NFPA 901 data used 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 (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 or area."

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 for this case and made a part of the risk method. These are the values presented.

2.3.4 Secondary Ignition of Carpet

When carpet is not the first item ignited, the fire experience data do not tell us if or when carpet became involved. Therefore, the method supplies a procedure for deducing furniture's secondary involvement.

The carpet (along with other combustibles in the room) is assumed to become involved in all fires spreading beyond the room of origin (because we assume that these all go to flashover). Further, for the class "confined to object," the carpet never ignites (by definition). For the remaining classes (fires confined to the area or room of origin), the secondary ignition of carpet depends on the ignition characteristics of the carpet, the assumed separation distance between the first item and the carpet, and the heat release rate of the first item ignited in terms of the resulting flux to the floor. (See section 2.4)

2.3.5. Calculation of Scenario Probabilities

Baseline probabilities were derived directly from the national fire incident database. Since the scenario classes are defined using NFPA 901, the base case probability for each scenario can be calculated as the probability that the item was "first ignited," given the extent of flame damage and the area of origin. Of course since carpet is never first ignited, the scenarios are for office fires in general and the presence or absence of carpet has no effect on the probabilities. The following briefly describes the procedure used to calculate the scenario probabilities.

1. We created a matrix using the NFPA 901 categories whose dimensions are:
    (a) Area of Fire Origin,
    (b) Form of Material First Ignited,
    (c) Final Extent of Flame Damage, and
    (d) Form of Heat of Ignition

2. We filled the matrix with NFIRS (National Fire Incident Reporting System) national estimates for 1980-1984 fires in offices, scaled to include a proportional allocation of unknown area of origin.

3. We allocated the set of fires with unknown form of material first ignited proportionally over the knowns.

4. We similarly allocated the fires with partially known forms of material first ignited.

5. We proportionally allocated fires with unknown final extent of flame damage, with unknown form of heat of ignition, and with unknown time of day.

6. With the matrix now complete, we constructed groupings such as groupings of first burning items (forms of material first ignited) on the basis of common reference values for rate of rise in rate of heat release and peak rate of heat release.

The total of all matrix entries remained the same, from step #2 to step #6, and was the denominator for calculating probabilities.

We have now developed the fire scenario structure for modeling fires in offices. This structure is based on the two assumed office arrangements and limiting the areas of origin to the office spaces or adjoining storage areas. We have defined the categories of first items ignited as office furniture based on their burning characteristics. The heats of ignition have been limited to a flaming class, which is applicable to all first items ignited. We have described the procedure for determining the secondary involvement of carpet in fires initiating with other items. Finally we have calculated the probabilities associated with each fire scenario.

2.4 Adapting the Fire Model for Carpet in Offices and Constructing Heat Release Rate Curves for Fire Scenarios

2.4.1 Adapting the Fire Model

All carpeting sold in the US is subject to a Federal Standard for ignition resistance from small flames [7]. In addition, standard test methods like the Flooring Radiant Panel (ASTM E648) [5] are available to measure the flame spread characteristics of carpet. The result is that modern carpets require a certain, minimum external irradiance to ignite (critical radiant flux for ignition) and a somewhat lower irradiance to spread flame over its surface once ignited (critical radiant flux for spread). Thus, modern carpet materials are rarely the "First Item Ignited" in the way that the other products examined with the risk method can be.

The ignition or failure to ignite of a carpet and its eventual degree of involvement are directly linked to these two critical flux values, along with a surface flame spread rate (as a function of external irradiance) as measured in an apparatus like the Lateral Ignition and Flamespread Test [15]. The FAST model already predicts the (uniform) external irradiance to the carpet from the upper layer and upper room surfaces (see figure 1) in the variable "ON-TARGET." To address the specific burning behavior of carpet, we used an expression for the flux from the flame over the first burning item as a function of distance from the flame axis added to "ON-TARGET" to give us the total flux at any location on the carpet.

$$\dot{q}'' = \frac{X_r Q_f}{4\pi r^2} + \text{ON TARGET} \qquad (1)$$

where: $\dot{q}''$ is the total flux to the carpet

X_r is the radiative fraction of the fuel (=.30)

Q_f is the heat release rate of the fuel (input to FAST)

r is the radial distance from the plume axis to an element on the carpet

ON TARGET is the flux to the floor from the upper layer and room surfaces (from FAST)

The criteria for carpet combustion were applied as follows:

- Any part of the carpet which was exposed to flux above the critical flux for ignition was assumed to burn, and spread flame at the flame spread velocity.

- If an area is exposed to a flux greater than the critical flux for spread but less than the critical flux for ignition, that element will burn when the flame front reaches it.

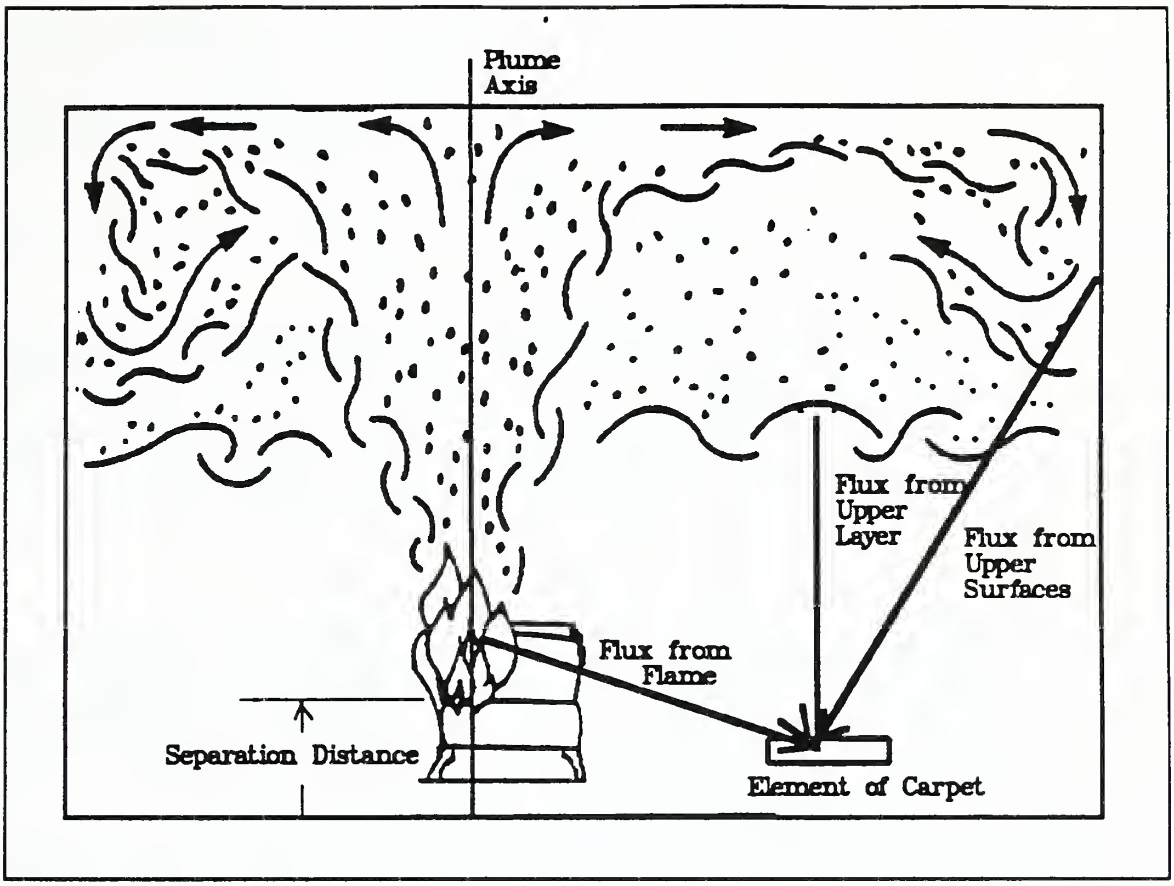

Figure 1 : Schematic of factors affecting carpet flammability

- If the area is exposed to a flux level below the critical flux for spread, it will not burn.

As each scenario progressed, the maximum size of the burned area was recorded. Additionally, the assumed flame spread rate was examined for any section of carpet that was burning to determine whether occupants would be overtaken by the spreading flames. (We did not allow flame spreading on the carpet to ignite other items.) This was only possible for assumed flame spread rates many times higher than those observed for real carpet (see section 4.2).

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. The carpet's contribution was evaluated for those fires which start with each of the five classes (see section 2.3.1) of first item ignited which eventually involve the carpet.

All fires must follow one of the paths depicted in the event tree in Figure 2. Each path includes four fire scenarios which differ only by extent of spread. The method stipulates a maximum upper layer

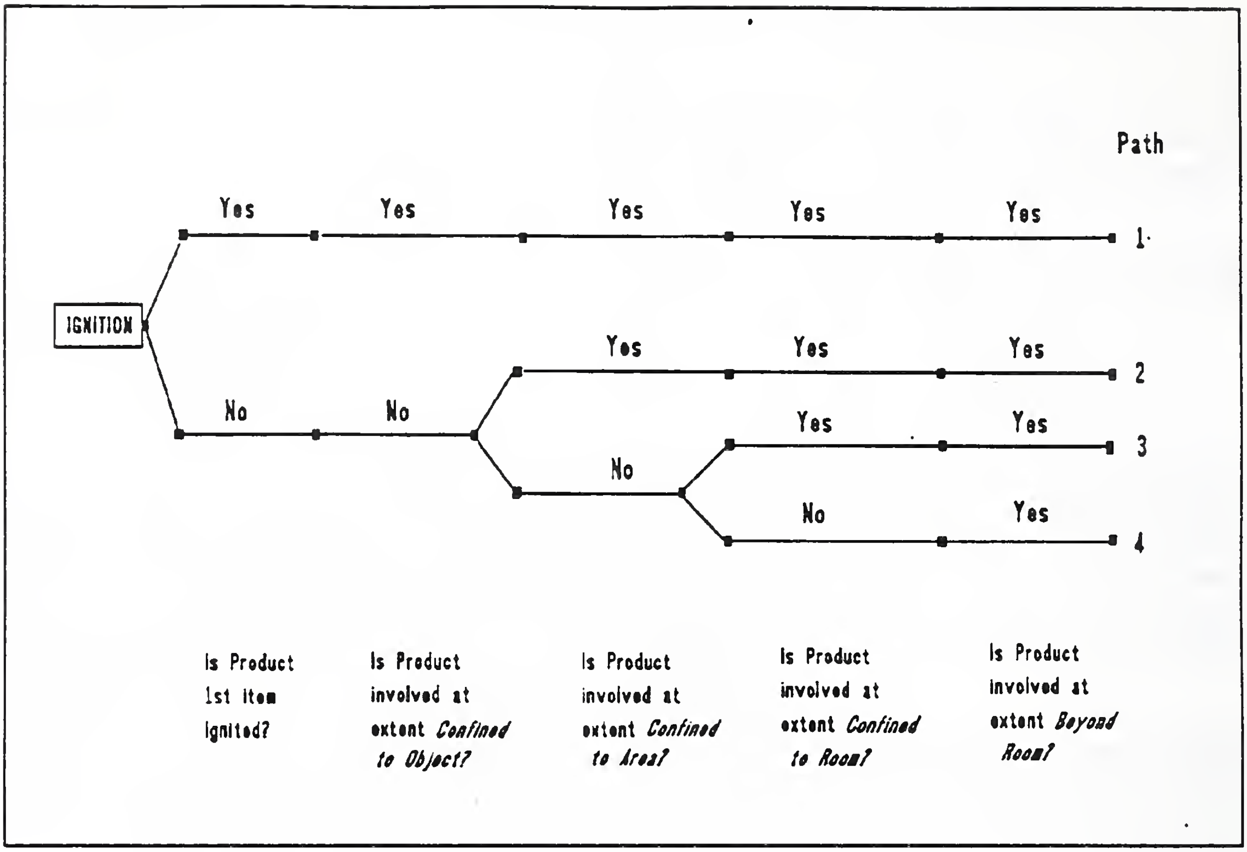

Figure 2 - Event tree indicating at what *Extent of Spread* the product becomes involved.

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 produces upper layer temperatures that extend through each of the upper layer temperatures for the less severe fire scenarios and pyrolyzes 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.

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 FAST model was modified to predict the particular burning characteristics of carpet as a function of the combustion property usually measured. We have developed the heat release rate input curves for the fire scenarios associated with carpet secondarily ignited in offices. Moreover, we have applied a protocol in which FAST runs are carried out for flashover fires, and the three less severe fire results are obtained from truncations of these runs.

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

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 house) 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 [16]. 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 office buildings containing large groups of persons who are expected to behave largely independently. Thus, for this case, we employed a simpler procedure developed by Nelson and MacLennan [17].

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 [18], 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 the office occupancy than EXITT.

In contrast to homes, office occupants are a much more homogeneous group. We assumed all occupants are awake and able to evacuate without assistance, and we restricted our analysis to daytime fire scenarios with maximum occupant exposure. To do otherwise would have required unfounded assumptions as to how many persons were present and where they were during non-business hours. It should be noted, however, that fires in offices with second or third shifts would experience the same result as those modeled. In any case, assuming awake, adult occupants in the room of origin negates any possible role of detectors in alerting those occupants.

With regard to occupancy load, data in reference 10 indicated that buildings under 5,000 sq ft average only 15 workers per floor, while the larger buildings of 20,000 sq ft were assumed to have 100 persons per floor.

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 office building configuration, and its probability is simply equal to that of the geometric arrangement. That is, the probability of the occupant set is 100% for that physical arrangement.

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

- At the time of the fire, all occupants are awake and able to escape without assistance.
- Occupant behavior is not affected by the fire conditions.
- All occupants on a floor encounter the same fire and smoke conditions and, once off the fire floor, 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.
- In multi-story buildings, phased evacuation (as defined in the high-rise sections of the model codes) is used. This means that evacuation is initially limited to the fire floor, two floors above, and one below.
- Initial movement speed is 235 feet per minute [17] for all occupants (none are handicapped or impaired) although the effect of slower speeds is easy to determine.
- The height of a story is 12 feet.
- The two exits are located at opposite ends of the floor (no dead ends).

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 [19]. 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 dwelling 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 [20]. 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 but implemented after the initial processing of this case study, 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. However, as discussed in section 3.2.3, this was not an issue in this case.

Heat is assessed as an incapacitation measure in the analysis. Purser [21] 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, the death 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 developed an occupant set to be exposed to the fire scenarios. We have introduced a new evacuation calculation 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 Carpet in Offices

3.1 Sequence of Calculation in the Method

In Section 2, we described how we formulated the computation of the risk of current carpet in offices for each class of fire scenarios represented by a single case. Figure 3 indicates how we combine the fire scenarios and occupant sets to run the HAZARD I software and calculate an overall estimate for the annual deaths for all fire scenarios:

1. By running FAST for a specific fire scenario, the evacuation calculation for the occupant set, and TENAB to judge survivability, we obtain an outcome in deaths per fire.
2. Since there is only one occupant set per building, this is then the total result for that scenario.
3. Using the fire scenario probability and the total number of fires (estimated using the national fire database), we obtain the number of fires for that scenario, then combine this with the deaths per fire estimate for the scenario to obtain the number of deaths.
4. These results are combined with similar results for all other scenarios to produce a sum that gives the annual death rate for fires involving carpet currently in use.

We can then compare these predicted results for the "base" case with the actual losses obtained from the national fire database. These comparisons in the first case study led to several adjustments, prior to establishing the final "base" case. These adjustments are discussed in the following sections.

3.1.1 Thermal Tenability Limit

The thermal tenability limit for convected heat used in this analysis was simply an instantaneous temperature limit of 100 °C. During the period that the release version of HAZARD I was being prepared, a new set of tenability criteria were published by Purser [21]. These were incorporated into the release version, including a time-dependent thermal limit which more closely matches data on heat tolerance in the literature. This measure was incorporated as a permanent part of the risk method, but was not revisited for this case. Thus, only the 100 °C limit was employed here. Since the 100 °C limit is more conservative, the Purser limit could only produce fewer fatalities. But there were no fatalities predicted, so the change to Purser would have no effect on the results.

3.1.2 Updated Version of FAST

When this case was begun, 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 this case because the oxygen concentrations did not drop significantly prior to complete evacuation. By comparison, this consideration of oxygen availability was crucial to the concealed combustible case due to the fact that there, the burning takes place in a very restricted volume.

3.2 Example Output

3.2.1 Fire Performance of Carpet

For assumed values of critical radiant flux for the carpet consistent with actual carpet data, the calculation produced a maximum value of involved radius (distance from the axis of the initiating fire where the carpet was burning) for the carpet. Since there were four heat release rate curves for each scenario class, and three such classes (fires initiating in an office or the corridor of the small building, or in the large space), this yields 12 scenarios. By evaluating three values of critical flux; the nominal, and values above and below as a sensitivity analysis, there were 36 conditions computed (see section 3.4). The results of these calculations are presented in table 6 below:

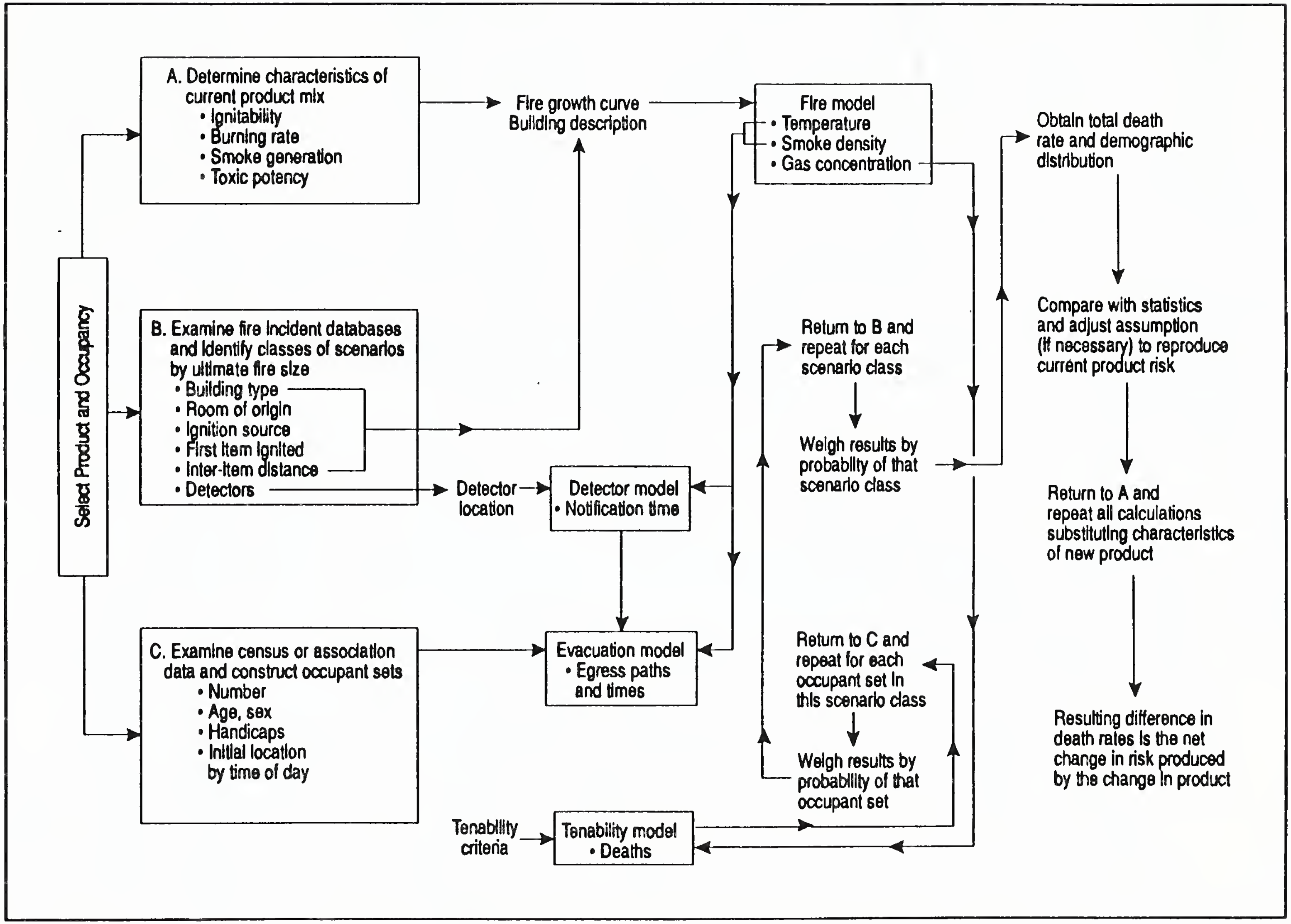

Figure 3 - Modeling Sequence to compute Fire Risk

Table 6 - Effect of carpet properties on fire spread in offices

Characterization of First Item Ignited		Critical Radiant Flux[2] (W/cm^2)			
Growth Rate[3]	Peak Heat Release[4]	$\dot{q}''_{ig}$	$\dot{q}''_e$	Time to $\dot{q}''_e$ (seconds)	Involved Radius (cm)
			Office, small building		
slow	low	1.0	0.1	685	5.3
		1.5	0.2	915	8.3
		2.0	0.5	1315	10.7
medium	medium	1.0	0.1	390	4.9
		1.5	0.2	620	8.3
		2.0	0.5	1040	10.7
fast	low	1.0	0.1	460	4.8
		1.5	0.2	690	8.1
		2.0	0.5	1100	11.0
fast	medium	1.0	0.1	490	4.9
		1.5	0.2	720	8.2
		2.0	0.5	1120	10.7
			Corridor, small building		
slow	low	1.0	0.1	235	0.3
		1.5	0.2	470	0.6
		2.0	0.5	705	2.0
medium	medium	1.0	0.1	85	0.5
		1.5	0.2	170	0.7
		2.0	0.5	290	0.7

---

[2] These two parameters are the critical external flux to the fuel surface required for ignition, and that required to sustain flame spread, respectively.

[3] Slow = t^2 (10.5kW/min^2), where t is the time after ignition
Medium = t^2 (42.2 kW/min^2)
Fast = t^2 (168.8 kW/min^2)

[4] Low = 250 kW
Medium = 500 kW

Table 6 (continued)

fast	low	1.0	0.1	60	0.5
		1.5	0.2	170	0.7
		2.0	0.5	290	0.7
fast	medium	1.0	0.1	50	0.1
		1.5	0.2	95	0.8
		2.0	0.5	425	2.0
Large building					
slow	low	1.0	0.1	260	0.4
		1.5	0.2	460	0.6
		2.0	0.5	655	1.5
medium	medium	1.0	0.1	135	0.6
		1.5	0.2	205	0.9
		2.0	0.5	280	1.6
fast	low	1.0	0.1	70	0.6
		1.5	0.2	185	0.7
		2.0	0.5	345	1.6
fast	medium	1.0	0.1	55	0.7
		1.5	0.2	110	0.9
		2.0	0.5	270	1.3

3.2.2 Required Evacuation Time

Using the evacuation model of Nelson and MacLennan [17], the following evacuation times were calculated for the two office buildings. The detailed calculation is presented in Appendix A to this report.

Table 7 - Evacuation event times for occupants of small office building
(4 floors of 5,000 sq ft per floor with 2 exits and 15 persons)

Event	Time
1. Fire starts on second floor	0
2. Evacuation begins	X
3. All persons reach stairway door	X + 7s.
4. All persons enter stairway	X + 27s.
5. Occupants have traveled down one floor	X + 47s.
6. Occupants have traveled down two floors	X + 67s.

Table 8 - Evacuation event times for occupants of large office building
(4 floors of 20,000 sq ft per floor with 2 exits and 100 persons)

Event	Time
1. Fire starts on second floor	0
2. Evacuation begins	X
3. All persons reach stairway door	X + 30s.
4. 60 persons in stairway and 35 waiting	X + 49s.
5. All persons evacuated 4th floor	X + 93s.
6. End of flow reaches 3rd floor	X + 112s.
7. All persons evacuated 3rd floor	X + 156s.
8. End of flow reaches 2nd floor	X + 175s.
9. All persons evacuated 2nd floor	X + 218s.
10. End of flow reaches 1st floor	X + 237s.

The beginning of the evacuation can be adjusted to account for delayed discovery. But for spaces occupied by awake and alert persons, one would assume this time would be short and independent of the presence of automatic detectors. Data from drills [22] has shown that observed evacuation times are about twice the times used here where highly organized and trained persons are involved, and three-times where there is no advance training or organization.

3.2.3 Occupant Safety

Based on the results presented in Tables 6-8, all occupants of the office evacuate safely for all cases examined. In most cases the people are in the stairway before the carpet becomes involved. Even where this is not the case, the people move faster than the carpet spreads flame, and conditions in the occupied spaces remain survivable until the occupants have left (see Table 9).

The fire induced conditions in the fire room immediately after the occupants vacated the space are tabulated below. Since the evacuation times were sufficiently short to preclude any effect from toxic gas exposure (as these are time-integrated values), the only possible limiting condition was the temperature of the upper layer.

Table 9 - Conditions in area of origin, immediately after evacuation

Heat Release Rate Characteristics of the First Item Ignited		Scenario Group Small Building[4] Office	 Corridor	 Large Building[5] Office space
Growth Rate	Peak Heat Rate	Layer hgt/Temp	Layer hgt/Temp	Layer hgt/Temp
slow	low	2.0 m/ 35 °C	1.7 m/ 82 °C	2.5 m/ 64 °C
medium	medium	1.5 m/ 65 °C	1.5 m/182 °C	1.8 m/124 °C
fast	low	1.4 m/ 76 °C	1.5 m/171 °C	2.0 m/103 °C
fast	medium	1.4 m/112 °C	1.5 m/227 °C	2.0 m/ 95 °C

[4] Ceiling Height = 2.4 m, conditions at 200 s.
[5] Ceiling Height = 3.05 m, conditions at 500 s.

Based on the procedures in TENAB [20], occupants are exposed to the upper layer only when the layer interface is below 1 m or when it is below 1.5 m **and** the upper layer temperature is below 50 °C. At all other times, the occupant is exposed to the lower layer. In the present case, the lower layer temperatures are at most only a few degrees above ambient during evacuation. Using the TENAB criteria, none of the occupants in these cases were exposed to the upper layer.

3.3 Base Case Comparison with Statistics

The statistics show that there are few fatalities in office fires, most of which do not occur in the daytime and no fatal fires originating in carpet at any time. The risk method predictions show no fatal fires at all. Nearly all of the fatalities contained in the statistics involve rapidly developing fatal injuries to people close to the point of ignition, a scenario the method does not include, and one which was of decidedly less importance in Case 1. However, this is not a sufficient basis for attributing a degree of quality to the calculation.

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.

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.

Fire deaths are rare in office buildings - about six per year - and the majority occur outside of normal operating hours. A large fraction involve the intimate-with-ignition circumstances that the risk method can only handle through side calculations. Because the annual death rate is so low, it is highly sensitive to the occurrence of a single fire with a high death toll. In the absence of such an event, modest percentage changes in the baseline rate of six deaths per year would have little practical meaning.

Focusing on carpeting as a product in offices, the baseline analysis indicated that carpet played no measurable role in fire fatalities. A rate of zero deaths per year was predicted without the side calculation of intimate-with ignition deaths.

Based on these results, the authors suggest that risk differences (e.g., between a new product and its baseline) would be considered to have low statistical confidence if they were less than 100% of the statistical baseline. Differences on the order of a factor of two to five increase would be considered significant if they proved to be stable under sensitivity analysis. Differences of more than a factor of five increase would be considered significant even if quite volatile under analysis. Decreases in predicted risk would not be considered significant unless they reduced the predicted risk, including the side calculation of intimate-with ignition deaths, to zero.

3.4 Sensitivity Analysis

Since this case lacks death statistics with which to compare the results, most sensitivity analyses were not possible. However, the effect of a 33% and 50% variation in the assumed critical radiant flux for ignition and about a factor of 2 in flame spread rate were examined. These results were presented in Table 6 for the convenience of the reader in comparing to the benchmark result. As can be seen, these variations have a nominally proportionate influence on the time at which the carpet begins to spread flame, and a lesser affect on the maximum area of carpet involvement.

Even these large variations in the Critical Radiant Flux do not lead to any fatalities in this computation. Remember that we did not allow carpet to spread flames from one item to another. If a combustible item is within this "area of involvement," the carpet might provide the fire spread mechanism needed to push the scenario into a higher extent of spread category, as this involved area increases. But we find that the maximum involved radius predicted for these carpets is of the order of 2 to 5 *inches*. Hence, one would expect that objects this close would ignite either by flame radiation or by direct contact from the flame on the first item, and **not** involve the carpet as an intermediary.

From this analysis one could surmise that, since the lowest critical flux examined is characteristic of carpet that just passes the "pill test," this means that no complying carpet should represent a risk of life loss from fire in an office occupancy. This conclusion is supported by the incident statistics which contain no evidence of fires or fatalities in situations represented by this analysis.

3.5 Summary of "Base" Case Assumptions

The conduct of the case required certain assumptions to be made. These were based largely on the expert judgement of the project team, and often were discussed with the Advisory Committee as a confirmatory step. These assumptions are:

- In carpeted office occupancies, the carpet is always a fixed distance (assumed to be 0.5 m) from the first item ignited.
- Fires spreading out of the room of origin have a fixed ventilation rate, and hence a maximum burning rate controlled by two open doors.
- All occupants of an office space are awake and ambulatory.
- The occupants will make use of all exits, uniformly.
- All occupants begin evacuating at the same time.
- All office spaces have two exits, one at each end of the floor. No exit is blocked by the fire.

- Evacuation time is what would be obtained if all buildings were four stories tall -i.e., four floors of the building are always evacuated.
- Fire risk is restricted to the floor of fire origin. Once an occupant leaves the floor (or was never on it), he/she is no longer at risk.
- The average fuel load in an office is 7 lbs. per sq ft.

4. Description of Method Implementation - The "New" Product Risk Computation for Carpet in Offices

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 in use.**

To calculate the risk for the "new" product requires 1) measuring its fire properties (ignitability and burning characteristics); 2) running the risk procedure using the building(s) occupant sets and associated probabilities and the scenarios from the base case with the fire properties of the "new" product; and (3) comparing the risk calculation with the base case. It is assumed that the "new" carpet is completely substitutable for the carpet in use and that changes in the product do not affect who will buy it or what kind of office 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" carpet could change the scenario probabilities. Ignitability influences both the propensity for primary ignition from the various possible heat sources (if reduced sufficiently, the carpet might become a "first item ignited"), as well as when the carpet begins to contribute when other items are first ignited.
Changes in ignitability also influence the probability of secondary ignition. As discussed in Section 2.3.4, changes in secondary ignition of the carpet involve only those scenarios where extent of spread is confined to area or confined to room. In these scenarios the overall probability remains unchanged. However, the proportion of the fires where carpet is involved (and therefore the heat release rate curve) will be changed. Appendix A in the methodology report includes the procedures for determining the shift, based upon the new carpet's ignitability, the separation distance, and the peak heat release rate of the first item ignited.

Appendix B of the methodology report describes how to construct the heat release rate curves for the "new" carpet, given a measured set of fire properties. The risk method uses an upper level temperature as an intervention trigger for the base case to cut off the fire at each extent of spread before flashover (Section 2.3.3). When a new carpet is analyzed for cases with interventions, the intervention is assumed to occur at the same *time* as in the base case scenario. This assumption is suitable for random discovery, which is most likely when people are awake and active, as in an office setting.

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

For this study, it was decided (with input from the Advisory Committee) that the "new product" case would consist of identifying the values of critical radiant flux and flame spread rate beyond which we would begin to record fatalities in daytime office fires. This was fairly straightforward, in that it required only that we determine:

- a lower limit for the critical radiant flux for spread such that the ON TARGET value was sufficient to allow flame spread during evacuation, and
- a flame spread rate sufficiently high that it could overtake evacuating occupants.

With respect to the critical radiant flux, the value (for spread) must be low enough that the carpet will spread flame without incapacitating the occupants by the flux criterion (the Derkson Curve [19]. This criterion is a time-integrated rather than a single value, so for the evacuation times obtained in this case, it would be in the range of 0.1 - 0.2 W/cm^2. This also brings the carpet into the range where it might be susceptible to primary ignitions, resulting in the need to analyze all of the "product first ignited" scenarios not currently included.

The minimum flame spread rate required to obtain fatalities would be equal to the assumed walking speed of the occupants - here assumed to be 235 ft/min. Thus, any new carpet which exhibited a flame spread rate higher than this (at the observed flux levels) might cause fatalities. We know from data on old carpet that critical flux values in this range were once observed. While it is not likely that usual carpet materials would exhibit flame spread rates this high, unusual materials (e.g., woven mats), orientations (e.g., carpet on walls), or circumstances (e.g., carpet soaked with a flammable liquid) might.

5. Conclusions and Observations

In this report, we have described a second application of a quantitative method for the estimation of the fire risk associated with a specified product class in a specified occupancy. This second case study tested the prototype risk prediction method's capabilities to deal with significant differences in incident data, burning behavior of the product, and the way of addressing the occupants.

In particular, this second case demonstrated how the risk method can be used to evaluate a product which at present does not contribute to life loss. The risk method provided a means to examine a product whose involvement is almost entirely secondary, as secondary product involvements have previously been a particular weakness of risk analysis methods. The fire model succeeded in providing a mechanism by which the important properties of a product are accounted for in the context of its end use. Properties of the product such as ignitability, flame spread, burning rate, smoke production, toxic potency, critical flux for ignition and spread, and total combustible mass are explicitly addressed as independent variables. In the specific case of office carpet, the model was able to quantify the impact of critical flux and flame spread rate in terms of the quantity of carpet ultimately involved (see Table 6), and the consequences of relaxing existing regulations on the fire risk of the product.

The deaths reported in the statistics for office occupancies mostly occur during non-business hours, and are never for carpet as a first item ignited. These are rare occurrences involving individuals performing cleaning or maintenance or in the act of committing arson. This analysis did include the scenarios which resulted in the maximum exposure to occupants in office fires. The results obtained in this case are consistent with fire experience in that office fires in general, and in particular, fires which involve floor coverings with a reasonable resistance to ignition and spread, almost never result in fatalities.

The exercise of the method on this case study revealed a few areas where some enhancements to the hazard method were necessary (e.g., section 2.4.1). This was expected since this case was outside the scope of HAZARD I. The case identified areas where current data collection systems were lacking (e.g., information on office arrangements, construction, and worker characteristics, particularly fraction of handicapped workers). In some instances it may be possible to supplement the data collected to fill these gaps. In others, 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.

The remaining case studies (concealed combustibles in hotels, and interior finish in restaurants) were selected to stretch the method in the areas of modeling not stressed in the prior cases. Thus, the reader is invited to proceed to these cases, each published in a separate report.

6. References

1. Clarke, F.B., Bukowski, R.W., Stiefel, S.W., Hall Jr., J.R., and Steele, S.A., A Method to Predict Fire Risk: The Report of the National Fire Protection Research Foundation Risk Project, available from NFPRF, Quincy, MA 02269, 1990.

2. National Academy of Sciences, National Research Council's Committee on Risk Perception and Communication, personal communication, September, 1989.

3. Bukowski, R.W., Peacock, R.D., Jones, W.W., and Forney, C.L., Software User's Guide for the HAZARD I Fire Hazard Assessment Method, NIST Handbook 146, Volume I, Nat. Inst. Stand. Tech., Gaithersburg, MD, 20899, 1989.

4 Grand, A.F., Kaplan, H.L., Beitel, J.J., Switzer, W.G., and Hartzell, G.E., A Research Study on the Potential Contribution of Carpets and Rugs to Toxic Emission Hazards in Building Fires, Final Report 01-7369, Southwest Research Institute, San Antonio, TX, 1984.

5. American Society for Testing and Materials, 1988 Annual Book of ASTM Standards, Standard Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Energy Heat Source (ASTM E648), Section 4, Vol. 04.07, ASTM, Philadelphia, PA, pg. 498-509, 1988.

6. Jones, W.W. and Peacock, R.D., Technical Reference Guide for FAST Version 18, NIST Technical Note 1262, Nat. Inst. Stand. Tech., Gaithersburg, MD, 20899, 1989.

7. Standard for the Flammability of Carpets and Rugs, DOC FF-1-70, *Federal Register*, Vol. 35, No. 74, p. 6211, April 16, 1970.

8. Anon., *Statistical Abstract of the United States: 1987 (107th edition)*, US Bureau of the Census, Washington, DC 1987.

9. Building Owners and Managers Assn. (BOMA), Washington, DC, unpublished survey data.

10. US Department of Energy, *Characteristics of Commercial Buildings - 1983*, DOE, Washington, DC, 1984.

11. Culver, C.G., Survey Results for Fire Loads and Live Loads in Office Buildings, NBS BSS 85, Nat. Bur. Stand., Gaithersburg, MD 1976.

12. Standard for the Installation, Maintenance and Use of Automatic Fire Detectors - NFPA 72E, National Fire Assn., Quincy, MA 02269, 1987.

13. Babrauskas, V. and Krasny, J., Fire Behavior of Upholstered Furniture, NBS Monograph 173, Nat. Inst. Stand. Tech., Gaithersburg, MD, 20899, 1985.

14. Babrauskas, V., personal communication.

15. Quintiere, J.G. and Harkleroad, M., New Concepts for Measuring Flame Spread Properties, T. Z. Harmathy, ed., Fire Safety: Science and Engineering, American Society for Testing and Materials ASTM STP 882; 239-267.

16. Levin, B.M., EXITT - A Simulation Model of Occupant Decisions and Actions in Residential Fires, NISTIR 87-3591, Nat. Inst. Stand. Tech., Gaithersburg, MD, 20899, 1987.

17. Nelson, H.E. and MacLennan, H., Emergency Movement, Chapter 2-6 in the *SFPE Handbook of Fire Protection Engineering*, C.L. Beyler, ed. National Fire Protection Association, Quincy, MA; 1988.

18. Pauls, J.L., Effective-width Model for Evacuation Flow in Buildings, *Proceedings, Engineering Applications Workshop*, Society of Fire Protection Engineers, Boston, MA 1980.

19. Bukowski, R.W., Peacock, R.D., Jones, W.W., and Forney, C.L., Chapter 8 in Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method, NIST Handbook 146, Volume II, Nat. Inst. Stand. Tech., Gaithersburg, MD, 20899, 1989.

20. Bukowski, R.W., Peacock, R.D., Jones, W.W., and Forney, C.L., Chapter 7 in Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method, NIST Handbook 146, Volume II, Nat. Inst. Stand. Tech., Gaithersburg, MD, 20899, 1989.

21. Purser, D.A., Toxicity Assessment of Combustion Products, Chapter 3 in the *SFPE Handbook of Fire Protection Engineering*, C.L. Beyler, ed. National Fire Protection Association, Quincy, MA; 1988.

22. MacLennan, H.A., Towards an Integrated Egress/Evacuation Model Using an Open System Approach, *Fire Safety Science, Proceedings of the First International Symposium*, Grant, C.E. and Pagni, P. eds., Hemisphere Publishing, New York (1986).

Appendix A - Escape Time Calculations

This appendix details the prediction of required escape time for occupants of the office buildings in this case, using the method of Nelson and Maclennen found in reference 14. The tables, figures, and equations referenced in this appendix are found in that paper.

A.1 Assumptions

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

- At the time of the fire, all occupants are awake and able to escape without assistance.
- Occupant behavior is not affected by the fire conditions.
- All occupants on a floor encounter the same fire and smoke conditions and, once off the fire floor, 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.
- In multi-story buildings, phased evacuation is used. This means that evacuation is limited to the fire floor, two floors above, and one below.
- Initial movement speed is 235 feet per minute for all occupants (none are handicapped or impaired) although the effect of slower speeds is easy to determine.
- The height of a story is 12 feet.
- The two exits are located at opposite ends of the floor (no dead ends).

A.2 5,000 square foot building with 8 people per exit.

A.2.1 Calculating Travel Speed

Estimate Flow Density (D), Speed (S), Specific Flow (Fs), Effective Width (We) and Initial Calculate Flow (Fc) typical for each floor.

Divide each floor in half, to produce two exit calculation zones each 50 feet long.

Determine the Density (D) and Speed (S) if all occupants try to move through the corridor at the same time. That is 8 people moving through 50 feet of an 8 foot wide corridor.

Density (D) = 8 persons/400 square foot corridor area = 0.02 person per square foot. Therefore, people move at their own pace, independent of speed of others.

Speed (S) - 235 ft/min. from Figure 4.

From Equation 4 Specific Flow (Fs) = (1-aD)KD where a = 2.86, K = 275, Fs = ([1-(2.86 x .02]) x 275 x 0.02 = 5.2 persons/min./ft. of effective width.

From Table 5, the Specific Flow (Fs) is less than the Maximum Specific Fl(Fsm). Therefore, Fs is used for the calculation of flow.

From Table 1, the Effective Width (We) of the corridor is 8 - (2 x .66) = 6.7 ft.

From Equation 6 Calculated Flow (Fc) = 1 - aD)K DWe, Fc = ([1 - 2.86 x .02]) (275 x .02 x 6.7) = 35 persons/min. This is considered the initial calculated flow for the corridors being evaluated. This is because the calculated flow rate can only be sustained if the discharge (transition point) from the route can also accommodate the indicated flow.

A.2.2 Estimating Impact of Stairway Entry Door on Exit Flow

Each door has a 36 inch clear width.

From Table 1, the Effective Width (We). We = 36 - 2(6) = 24 inches (2 ft.).

From Table 5, the Maximum Specific Flow (Fsm) is 24 persons/min.ft. effective width.

From Equation 9A, Fs (door) = Fs (corridor) We (corridor)/We (door) Fs (door) = 5.2 x 6.7/2 = 17.4 persons/min./ft. effective width. Since Fs is less than Fsm, the value of Fs is used. Therefore, the effective value is 17.4.

From Equation 5, the initial calculated flow Fc = Fs We = 17.4 x 2 = 34.8 persons/min. through a 36 inch door.

Since Fc for the corridor = 35 person/min. which equals the flow through the door, no queuing is expected.

A.2.3 Estimating Impact of Stairway on Exit Flow

From Table 1, Effective Width (We) of stairway is 44 - 6 x 2 = 32 inches (2.66 ft.).

From Table 5, the maximum Specific Flow (Fsm) is 18.5 persons/min./ft. of effective width.

From Equation 9A, the Specific Flow for the stairways Fs (stairway) is 35 x 2/2.6 = 27. Since Fs exceeds the maximum value the Fsm value = 18.5 persons/min./ft. of effective width is used. the value of 18.5 for Fs applies until the flow down the stairway merges with the flow entering from another floor. FS = (1 - aK)KD = (1 - 2.86 D)(212 D) = 18.5. Using Figure 4 or Equation 4 and Table 2, 8 ÷ 38.2 x 2.66 the density of initial stairway flow is approximately 0.16. The speed of movement during initial stairway travel is S = K - aKD, K = 275, a = 2.86 = 212 - (2.86 x 212 * 0.16) = 115 ft./min. The floor to floor travel distance = 12 x 1.85 = 22.2 ft. on stair slope plus 8 ft. travel on each of the two landings for a total travel distance of 22.2 + (2 x 8) = 38.2 ft. The time required for the flow to travel one floor level is 38.2 ft/115 ft/min. = 0.33 min. (20 sec.).

Using Equation 5 the Calculated Flow (Fc) = Fs x We 18.5 x 2.66 = 49 persons/min. After .33 min., 49 x .33 = 16 persons from each floor could be in the stairway, but since only 8 persons are on each floor, there is no queuing into the stairways and all can enter at the same time 8 x 4 floor = 32 persons in the stairway.

A.2.4 Estimating Impact of Merger of Stairway Flow and Stairway Entry Flow on Exit Flow.

From Equation 9B, Fs (out-stairway) = ([Fs (door) x We (door)] + Fs (in-stairway x We (in-stairway])/We (out-stairway) = 17.4 * 2.66)/2.66 = 31.6 persons/min./ft. effective width.

From Table 5, the maximum specific flow Fsm = 18.5. Since Fs exceeds the maximum 18.5 person/min./ft. of effective width is used.

A.2.5 Tracking Egress Flow

Assume all persons start to evacuate at fire X. Initial flow speed = 235 ft./min. to travel a 25 ft. Therefore, each floor's occupants will leave the floor in X + 25 ÷ 235 = X + .11 min.

Since there is no queuing in stairways and it takes 20 seconds to travel one floor level.

@ X + 7 sec. (.11 min) -	All persons have reached the doors to the stairways.
@ X = 27 sec. (.45 min) -	All persons have entered the stairway.
@ X + 47 sec. (.78 min) -	The 4th floor people have reached the 3rd floor. The 3rd floor people have reached the 2nd floor. The 2nd floor

people have reached the 1st floor. The 1st floor people have reached the Lobby level.

@ X + 67 sec. (1.12 min) - The 4th floor people have reached the 2nd floor. The 3rd floor people have reached the 1st floor. The 2nd floor people have reached the Lobby. The 1st floor people have evacuated.

@ X = 87 sec. (1.45 min) - The 4th floor people have reached the 1st floor. The 3rd floor people have reached the Lobby. The 2nd floor people have evacuated.

According to McLennan, large multi-floor office building demonstrated evacuation times in the range of (1) twice the modeled time where a highly organized evacuation system was present; (2) up to 3 times the modeled evacuation time when there had been no training and no organization.

A.3 Large Office Building

1. 4 (200 ft. by 100 ft.) floors
2. floor to floor height 12 ft.
3. two stairways, located at ends of building 100 people/floor

A.3.1 Calculating Travel Speed

The population will use all exit facilities on the optimum balance.
All occupants start egress at the same time.

Estimate Flow Density (D), Speed (S), Specific Flow (Fs), Effective Width (We) and Initial Calculated Flow (Fc) typical for each floor.

Divide each floor in half, to produce two exit calculation zones each 100 feet long with 50 people in each zone.

Determine the Density (D) and Speed (S) if all occupants try to move through the space at the same time.

Density = 50 persons/3000 sq. ft. → assume 30 ft. clear area effective width x 100 ft. ≈ 0.02 persons/sq. ft. Therefore, people move at their own pace, independent of speed of others. Speed (S) = 235 ft./min.

From Equation 4 Specific Flow (Fs) = $(1 - aD)KD$ where $a = 2.86$, $K = 275$, $Fs = (1 - [2.86 \times .02]) \times 275 \times 0.02 = 5.2$ persons/min/ft of effective width.

From Table 5 the Specific Flow (Fs) is less than the Maximum Specific Flow (Fsm). Therefore, Fs is used for the calculation of flow.

From Table 1, the Effective Width (We) of the passage way is 30 - (2 x .33 obstacles) = 30 ft.

From Equation 6 Calculated Flow (Fc) = (1 = aD)K DWe, Fc = (1 - 2.86 x .02)(275 x .02 x 30) = 156 persons/min. This is considered the initial calculated flow for the passageway being evaluated. This is because the calculated flow rate can only be sustained if the discharge (transition point) from the route can also accommodate the indicated flow.

A.3.2 Estimating Impact of Stairway Entry Door on Exit Flow

Each door has a 36 inch clear width.

From Table 1, the Effective Width (We), We = 36 - 2(6) = 24 inches (2 ft.).

From Table 5, the Maximum Specific Flow (Fsm) is 24 persons/min/ft. effective width.

From Equation 9A, Fs (door) = Fs (passageway) We (corridor)/We (door) Fs (door) = 5.2 x 30/2 = 78 persons/min./ft. Since Fs is more than Fsm, the value of Fsm of 24 is used.

From Equation 5, the initial calculated flow Fc = Fs We = 24 x 2 = 48 persons/min. through a 36 inch door.

Since Fc for the passageway is 156 persons/min. while Fc for the single exit door is 48, queuing is expected. The calculated rate of queue buildup will be 156 - 48 = 106 persons/min.

A.3.3 Estimating Impact of Stairway on Exit Flow

From Table 1, Effective Width (We) of the stairway is 44 - 12 = 32 inches (2.66 ft.).

From Table 5, the Maximum Specific Flow (Fsm) is 18.5 persons/min./ft. effective width.

From Equation 9A, the specific flow for the stairway, Fs (stairway) = 24 x 2/2.66 = 18 person/min./ft. effective width. In this case, Fs is less than Fsm and Fs is used.

The value of 18.0 for Fs applies until the flow down the stairway merges with the flow entering from another floor.

Using Figure 4 or Equation 4 and Table 2, the density of initial stairway flow is approximately 0.145 persons/sq. ft. of exit route. Fs = (1 - aD)KD = (1 - 2.86 D)(212 D) = 18, 212D - 606 D^2 = 18.

From Equation 2, the speed of movement during initial stairway travel is S = 212 - (2.86 x 212 x .145) = 124 ft./min., S = K - aKD.

The floor to floor travel distance is 38.2 feet. The time required for the flow to travel one floor level is 38.2/124 = 0.31 min. (19 sec.).

Using Equation 5, the Calculated Flow (Fc) is 18 x 2.66 = 48 persons/min.

After 0.31 min., 48 x .31 = 15 persons will be in the stairway from each floor. If floors 1-4 all exit at once, there will be 15 x 4 = 60 persons in the stairway. After this time, the merging of flows between the flow in the stairway and the incoming flows at the stairway entrances will control the rate of movement.

A.3.4 Estimating Impact of Stairway Flow and Stairway Entry Flow on Exit Flow

From Equation 9B, Fs (out-stairway) = [Fs (door) x We (door)] * Fs (in-stairway) x We (in-stairway)/We out-stairway = (24 x 2 + 18 * 2.66)/2.66 = 36 persons/min.ft. effective width.

From Table 5, Fsm for the stairway is 18.5 persons/min./ft. Since Fsm is less than the calculated Fs, Fsm is used.

A.3.5 Tracking Egress Flow

Assume all persons start to evacuate at time zero.
Initial flow speed = 156 persons/min.

Assume that congested flow will reach the stairway in 30 sec.

> @ 30 sec. - Flow starts through stairway doors Fc through doors is 48 persons/min. for the next 19 sec.
>
> @ 49 sec. - 60 persons are in each stairway and 35 are waiting in a queue at each stairway entrance door.

Note: Progress from this point on depends on which floors take dominance in entering the stairways. Any sequence of entry may occur. To set a bound, we will use dominance from highest to lowest floor.

The remaining 35 persons waiting at each stairway entrance on the 4th floor enter through the door at the rate of 48 persons/min. The rate of flow through the stairs is regulated by the 48 person/min. rate of flow of the discharge exit doors.

The descent rate of the flow is 19 sec. per floor.

> @ 93 sec. (1.5 min.) - All persons have evacuated the 4th floor.
>
> @ 112 sec. (1.9 min.) - The end of the flow reaches the 3rd floor.
>
> @ 156 sec. (2.6 min.) - All persons have evacuated the 3rd floor.
>
> @ 175 sec. (2.9 min.) - The end of the flow reaches the 2nd floor.
>
> @ 218 sec. (2.6 min.) - All persons have evacuated the 2nd floor.
>
> @ 237 sec. (4 min.) - The end of the flow reaches the 1st floor.

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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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