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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 incorporates the predicted outcomes 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 first developmental case: fires involving upholstered furniture in homes. 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 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

Upholstered furniture (sofas and chairs) in detached single family homes was selected as the initial product/occupancy pair. This choice was made for several reasons. First, upholstered furniture plays a prominent role in fatal fire scenarios. In 1983-1987, there were an estimated annual 1070 deaths (23% of all structure fire deaths), 2450 injuries (10% of all structure fire injuries), and $249M in direct losses (4% of all structure damage) attributable to U.S. structure fires reported to fire departments where upholstered furniture was listed as the first item ignited [4]. Second, a large volume of fire data has been accumulated for these incidents. Validation of the risk methodology and its predictions is enhanced when sufficient data are available. Third, because of their role in residential fatalities, upholstered furnishings have been extensively studied in the laboratory and test methods are available which measure their burning characteristics [5]. Finally, the fire model which is an integral part of the fire risk assessment methodology was developed for use on this type of building [6]. This combination of national fire experience data, laboratory studies and fire development made upholstered furniture in detached single family dwellings a good choice to test the fire risk assessment methodology.

Upholstered furniture includes all types of chairs, sofas and ottomans which have cover fabrics over filling materials. Since (as shown in Table 2) national fire experience indicates that nearly 80 percent of the fires involving upholstered furniture as the first item ignited occur in living rooms (66.7 percent in living room, den, and lounges) and bedrooms (11.2 percent), it was decided to restrict this demonstration to furniture in these two types of rooms. A more complete analysis would also include kitchens, dining rooms, and storage areas, where upholstered furniture's major contribution may be as a fuel source for fires originating in other items.

We also narrowed the analysis to single-family detached houses. This was done primarily in consideration of modeling limitations. Unlike apartments, detached dwelling fires can be modeled without concern for barrier breaching between housing units (e.g., burn-through of doors, walls, ceilings) and complex smoke movement through elevator shafts, HVAC (heating ventilation and air conditioning) systems and interstitials (void spaces within walls or above ceilings) -- where both modeling and data are weak. U.S. Census data indicate that roughly 70 percent of single family houses are one-story, with the remainder either split level or two or more stories. The selection of a single house type of one-story limited the computational burden without seriously compromising the value of the case study.

Even with this restriction to two rooms and a single house type, the base case analyses involved specification of 64 fire scenarios; 16 fire scenarios when upholstered furniture was the first item ignited and 48 fire scenarios when items other than upholstered furniture were first ignited. The evacuation simulation was run twice for each occupant set, once with and once without operational smoke detectors. Since 220 occupant sets were derived from population and activity analyses, 440 evacuation model runs were run per fire scenario (all together over 28,000 runs). In addition, for the cases where upholstered furniture was the first item ignited, numerous sensitivity analyses were performed, involving many more runs. This report now continues with the details of how we implemented each of the steps for this particular case.

2. Description of Method Implementation - Set Up for Upholstered Furniture in Single Family Dwellings

2.1 Selection of Upholstered Furniture in Single Family Dwellings.

In the first step we define upholstered furniture in terms of the NFPA 901 categories and characterize the population of upholstered furniture now in use in terms of fire properties, size and location. In this step we establish the link between the national fire experience data and the upholstered furniture as a separate category in NFPA 901 under form of material first ignited. We will use the statistics derived for upholstered furniture using this coding to determine the frequency of fire scenarios involving furniture as the first item ignited and also to validate the method's fire severity predictions in terms of deaths per fire.

We used a combination of sources to derive the fire properties, size and location of the upholstered furnishings in use. First, a group of experts were empaneled consisting of:

- Gordon Damant of the California Bureau of Home Furnishings,
- John Gerard of the National Fire Protection Association,
- Beatrice Harwood of the Consumer Product Safety Commission, and
- Steve Noble of the Business and Institutional Furniture Manufacturers Association.

This panel identified the broad types of furniture in use and estimated the relative proportions of each type in use [7]. Upholstered furniture construction has been evolving from materials such as cellulosic fabrics and natural fiber or latex padding to typical modern constructions of thermoplastic coverings, polyester batting and polyurethane cushions. The resulting three types of furniture were characterized as:

Type	Cover Fabric	Padding	Cushioning	Fraction in Use
I	Cellulosic	Untreated Cotton	Latex or Innerspring	0.17
II	Cellulosic	Cotton	Latex/Polyurethane	0.42
III	Thermoplastic	Polyester	Polyurethane	0.41

Type I represents furniture common in the early 1950's; type II represents furnishings common prior to ignition-resistance technology; and type III is described as current (those which comply with a voluntary industry standard promulgated by the Upholstered Furniture Action Council, UFAC). The panel estimated the fraction of each type from a CPSC report [8], in which a census of upholstery materials was carried out and projections made for the relative amounts in the present furniture population.

The panel used a compilation of test data [5] to select for each furniture type, values for the properties needed to conduct the modeling simulations using HAZARD I. This includes whether the item will smolder when ignited by a cigarette, when the transition to flaming would occur, and the peak heat release rate for the flaming portion of the fire.

Type	Smoldering Time (min)	Time to Peak Heat Release (min)	Peak Heat Release (kW)
I	60	20	400
II	40	10	600
III	90 (few smolder)	2	1000

In addition, the panel assigned a weight of 25 kg and a toxic potency of the smoke produced of LC_{50} = 30 mg/ℓ.

Using these data together with other sources, the set of fire properties for a composite of upholstered furniture representing the mix in use was developed. These data are in Table 1.

Table 1 - Composite Fire Properties of Upholstered Furniture

Property	Value Employed
Mass	25 kg (55 lbs)
Cigarette Ign.	60%
Critical flux for Ign.	20 kW/m^2
Smolder rate for cigarette ign.	.00006 kg/s for 1000 s followed by .0003 kg/s for 1700 s
Smolder Rate for flaming ign.	.0003 kg/s for 720 s
Fire growth rate	40 kW/m
Peak rate of heat release	980 kW
Heat of Comb.	15 MJ/kg
Heat of Vapor.	3 MJ/kg
Smoke Potency	900 mg-min/ℓ
Smoke Ext. Area	300 m^2/kg

The same expert panel also estimated the percentage of rooms in each room type having upholstered furniture. (Table 2 includes a more detailed list of rooms in dwellings in terms of the NFPA 901 code for area of origin.)

Room	Percentage with Upholstered Furniture
• living room	100 percent
• bedroom	60 percent
• dining room	50 percent
• kitchen	10 percent
• storage area	10 percent

The panel then estimated an average separation distance between upholstered furniture and other items in each of the typical rooms with furniture. We used these estimates in step 4 to determine if and when upholstered furniture will be ignited secondarily, in fires initiating in items other than upholstered furniture.

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

- linked upholstered furniture to the NFPA 901 categories,
- estimated fire properties for "composite" upholstered furniture,
- designated rooms where furniture may be present with estimates of the percentage of such rooms having furniture, and
- estimated the separation distance between upholstered furniture and other items.

2.2 Identify and Specify the Physical Characteristics of the Single Family Dwelling

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 use U.S. Census of Housing data, U.S. Department of Energy surveys, fire experience data, and building code requirements.

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. Census data in the *Statistical Abstract* [9] indicates that in 1970, 74% of new detached housing was one-story with the remainder in the form of split level housing or housing with two or more stories. The percentage of single story houses declined to 65% in 1975, 60% in 1980, and 54% in 1984. Since these percentages apply to new housing only and comparable numbers are not generally available for the housing built more than fifteen years ago, we have estimated that roughly 70 percent of existing homes are single story. The Statistical Abstract also indicates the median number of rooms per occupied housing unit is 5 or 6 when single household homes are considered. It is also known that the median and mean number of bedrooms is three. Homes

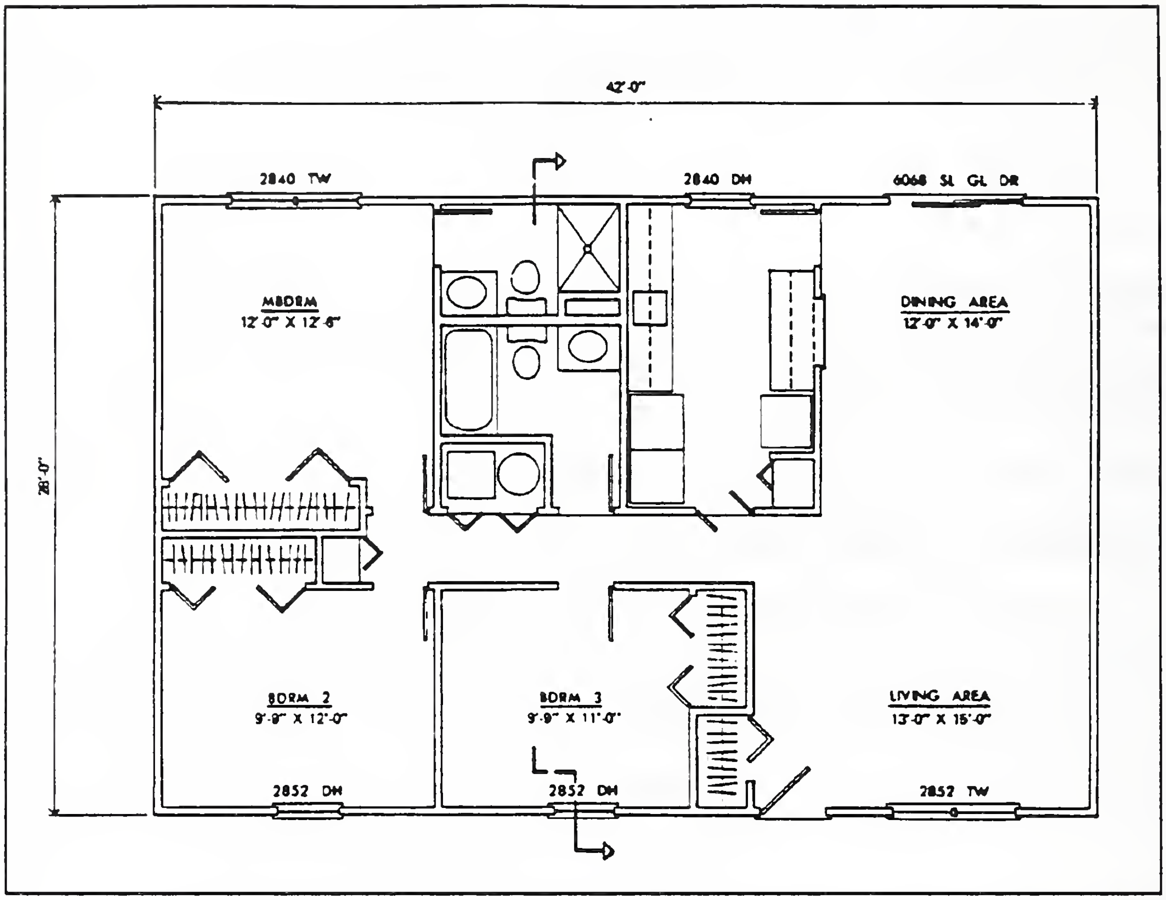

Figure 1 - 6 Room Ranch House

having fires tend to involve poorer households more often, hence smaller housing. So the number of rooms typically found in a fire-related single-family home is between 5 and 6.

For this demonstration, we have chosen the 6-room layout shown in Figure 1. The thermal properties of the walls and ceilings are for 1/2 inch gypsum board, and the floor's thermal properties are for wood. Based on a survey [10], the fuel load (wood equivalent) of the combustible contents for a typical residential room was set at 23 kg/m^2. When multiplied by the effective heat of combustion of wood (the value used in deriving the wood equivalency) and the room area, the fuel load per square meter converts to the total energy which can be released in the room.

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. For dwellings we have aggregated the rooms which would behave similarly in the hazard model (similar size, occupant activity and fuel load). The living room includes dens, recreation rooms, family rooms, libraries, lounges and offices. The bedroom includes all sleeping rooms as designated in NFPA 901. Dining rooms and kitchens are each separately identified and are not aggregated with other rooms. Storage areas include closets, attached garages and carports, crawl spaces and trash areas. But in the end, only living rooms and bedrooms were represented in the analysis.

We used the national fire statistics to identify the rooms where most fires occur, paying particular attention to the product as a first item ignited. Table 2 shows the results of one such analysis. Note that living rooms and bedrooms account for 78 percent of the fires where furniture is the first item ignited; while kitchens, dining rooms, and storage areas make up almost all of the remainder. The other areas in Table 2 have been either distributed into a room class with similar properties (e.g., library or office into living room) or not analyzed because upholstered furniture is not normally present (e.g., concealed roof/ceiling space).

For dwelling units, the most widely used and recognized fire safety feature is smoke detectors. The presence or absence of an operational smoke detector is a key determinant of evacuation time. In 1984 the probability of a dwelling in the general population having a detector was around 0.75 [11]. However, a distinction can be made between the general population and dwellings where fires occur. The national fire databases provide information on the probability that a building will have a detector, given that it has a fire. It is also possible to estimate the probability that the detector is operational. As of 1984, the probability of having a detector, given a fire was 0.284 [11]. The probability that the detector was working, given a detector and a dwelling fire, was 0.674. Therefore, the probability of having a working detector, given a dwelling fire is 0.284 x 0.674 = 0.19. The fire data do not convey the number or the placement of detectors. Therefore, for this analysis a minimum code-complying arrangement was used (i.e., a single detector was located in the center hallway of the ranch house).

So in step two, we have:

- specified a 6-room ranch house to represent single family dwellings,
- identified two rooms (living rooms and bedrooms) where most upholstered furniture fires originate, and
- determined that smoke detectors, while present in three-fourths of homes, can only be counted on to be present and functional in nineteen percent of the homes having a fire.

Table 2 - Where Home Fires Start - Total and Upholstered Furniture

Analysis of 1984 Structure Fires Reported to Fire Departments in Dwellings or Mobile Homes by Selected Area of Origin (NFPA 901 codes are in parentheses)

	Percentage of Fires	
Areas of Origin	Upholstered Furniture Ignited First	All Fires
Living room, den, lounge (14)	66.7	10.5
Bedroom (21-22)	11.8	11.6
Storage areas, crawl space (41-49, 71)	6.2	9.2
Dining room (23)	2.2	1.0
Kitchen (24)	1.4	20.6
Library or office (16,27)	0.1	0.1
Exterior balcony, open porch (72)	1.7	1.1
Unspecified function area (39)	1.5	0.3
Chimney (57)	0.0	20.9
Heating room (62)	1.0	3.6
Laundry room (26)	0.4	3.2
Exterior wall surface (76)	0.0	3.0
Concealed roof/ceiling space (74)	0.2	2.3

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 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 upholstered furniture contributes to the fire, for those fires initiating with items other than upholstered furniture.

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, the risk method provides a procedure for deducing the involvement of the upholstered furniture prior to flashover, at which time all items in a room become involved in the fire.

In step 2, we selected a 6-room ranch house as the building representing single family dwellings and the living room and bedroom as the "areas of origin" where fire originate. Our treatment of the remaining 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 upholstered furniture it is necessary to account for (a) fires initiating with the upholstered furniture and (b) fires originating with everything else, which could eventually involve the furniture. Of course, in a dwelling there are a very large number of categories of items which could be ignited, listed in NFPA 901. If we treat each one as a separate item the computational burden would be very great. Fortunately, the hazard model uses as an input not the item, but its burning characteristics. Therefore, the method provides the following scheme to reduce the number of items to a more manageable size.

The fire incident data specify which items were first ignited. If furniture was not the first item ignited, then the question becomes what was first ignited. The method describes nine burning characteristic classes to simplify the potentially hundreds of items. The items are classified 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). 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 upholstered furniture is in a class by itself and since three other classes had no items identified, the original nine classes reduce to six, five of which can secondarily ignite the upholstered furniture. 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 as presented in Table 4, or small scale test (cone calorimeter) data on a sample of material of a type from which the item might be made, as in Table 5. The documentation for these assignments can be found in Tables 4 and 5.

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	901 code	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 the item would relate to the total burn time.

The numbers in column 2 refer to the NFPA 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.

Once we had identified the burning characteristic classes for items first ignited and linked them to the coding used in the national fire data base, we established numerical values for the quantitative burning behavior associated with each class. The fire growth rate 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 (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.

After an item has reached its peak heat release rate it is assumed that the rate of heat release declines linearly (with time) to zero over a time equal to that 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 5, this 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 results in the optical density which (in EXITT) affects the occupants' speed of movement and potentially whether their egress path is blocked requiring an alternate path selection. Here, a review of the data shows that there is a distinct clustering of yield fractions for natural materials (cotton and wood) at about .003 and synthetics (polyurethanes and olefins) at about .03.

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. Here, 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. We further assumed that cigarette-ignited upholstered furniture smoldered for 45 minutes prior to flaming combustion. We finally settled on a two-step function [14]: a constant mass loss rate of 0.00006 kg/s for 1000 seconds representing the burn-through of the cover fabric, followed by a constant mass loss rate of 0.0003 kg/s for the remaining 1700 seconds representing smoldering of the padding. We had originally used the latter rate throughout the smoldering period (see section 3.1.3). If ignition of the upholstered furniture was from a non-smoking source we assumed a 720 second constant mass loss rate of 0.0003 kg/s. This shorter duration smolder period represents the time estimated for a small, flaming source to initiate a large, self-sustaining flaming combustion. From this point on, the heat release rate curve for the item subjected to a flaming source was used.

2.3.3 Final Extent of Fire Growth

For single family dwellings, 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 (considered equivalent to 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 to delineate the class. The measure is peak upper level temperature and the values used are presented below:

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.

2.3.4 Secondary Ignition of Upholstered Furniture

If furniture is not the first item ignited, the fire experience data do not tell us if or when furniture would become involved. Therefore, we have had to develop a procedure for deducing furniture's secondary involvement.

The upholstered furniture (along with other combustibles in the room) is assumed always to become involved in fires spreading beyond the room of origin (because we assume that these all go to flashover). Further, for the class "confined to object" **and** furniture not the first item ignited, the furniture never ignites (by definition). For the remaining classes (fires confined to the area or room of origin), the secondary ignition of furniture is assumed to depend on the ignitability of the furniture, the separation distance between the first item and the furniture, and the peak heat release rate of the first item ignited. The additional dependence on exposure time is not considered by the model at this time.

Using data from the experimental work of Babrauskas [14], a maximum distance for ignition was determined, based upon an assumed furniture ignitability of 20 kW/m^2.

Peak Rate of Heat Release for First Item	Maximum Distance (inches) to Upholstered Furniture for Ignition
Low	12
Medium	24
High	35

For each specific NFPA 901 class of items first ignited, we estimated what proportion of them will be close enough for ignition and the average distance for just those items close enough for ignition. To capture some of the variation in actual item-to-furniture separations, we introduced a simplified probability distribution with a standard deviation of six inches. Using this distribution, a set of rules was derived for calculating the average actual distance to just those items close enough to ignite the product. Table 6 gives for each of five item classes both the probability of being close enough for ignition and the average separation distance for these items (if that item is close enough) to the furniture to be ignited.

Table 6 - Percentage of Fires Close Enough to Ignite Upholstered Furniture and Average Distance from Item to Upholstered Furniture for Those Fires

Item	Area of Origin				
	Bedroom (21-22)	Lounge (14,16,27)	Dining Room (23)	Kitchen (24)	Storage areas (40-49, 71)
Slow Rate of Rise, Low Peak Rate of Heat Release Class (11.8")					
18. Thermal Insulation	83%/8.33"	45%/10.80"	0%	0%	100%/2.34"
43. Book	45%/10.80"	0%	0%	0%	83%/4.77"
44. Magazine, newspaper	83%/4.77"	83%/4.77"	45%/6.80"	45%/6.80	100%/2.34"
Medium Rate of Rise, Low Peak Rate of Heat Release Class (11.8")					
22. Nonupholstered chair	45%/10.80"	17%/9.35"	45%/6.80"	45%/6.80"	100%/2.34"
33. Linen other than bedding	100%/2.34"	100%/2.34"	100%/2.34"	0%	0%
34. Clothing not on a person	0%	0%	0%	0%	45%/6.80"
35. Clothing on a person	100%/2.34"	100%/2.34"	100%/2.34"	100%/2.34"	100%/2.34"
36. Curtain, drapery	83%/4.77"	83%/4.77"	83%/4.77"	83%/4.77"	45%/6.80"
37. Fabric, yard goods	0%	45%/6.80"	45%/6.80"	0%	45%/6.80"
38. Luggage	45%/6.80"	45%/6.80"	45%/6.80"	0%	45%/6.80"
45. Toy, game	83%/4.77"	83%/4.77"	45%/6.80"	45%/6.80"	83%/4.77"
61. Electrical wire, cable insulation	83%/4.77"	83%/4.77"	45%/6.80"	45%/6.80"	100%/2.34"

"Lounge" includes living rooms, dens, rec rooms, family rooms, libraries, and offices. "Storage areas" include closets, garages and carports (but not those coded as a detached garage under Fixed Property Use 881), crawl spaces, trash areas, and other storage areas. Codes for NFPA 901 Area of Origin are shown in parentheses. Item class distances are estimated minimum distances to ignite, and are shown in parentheses after the class description.

Table 6 - (continued)
Area of Origin

Item	Bedroom (21-22)	Lounge (14,16,27)	Dining Room (23)	Kitchen (24)	Storage areas (40-49, 71)
Medium Rate of Rise, High Peak Rate of Heat Release Class (35.4")					
15. Interior wall covering	100%/6.45"	100%/6.45"	100%/6.45"	100%/6.45"	100%/2.34"
17. Structural member	100%/6.45"	100%/6.45"	100%/6.45"	100%/6.45"	100%/2.34"
23. Desk, table, cabinetry	100%/12"	100%/12"	100%/12"	100%/24"	100%/2.34"
24. Ironing board	45%/30.80"	45%/30.80"	45%/30.80"	45%/30.80"	45%/30.80"
29. Unclassified furniture	100%/12"	100%/12"	100%/12"	100%/24"	100%/2.34"
Fast Rate of Rise, Low Peak Rate of Heat Release Class (11.8")					
14. Floor covering, surface	100%/2.34"	100%/2.34"	17%/9.35"	17%/9.35"	17%/9.35"
16. Ceiling covering, surface	0%	0%	0%	0%	0%
42. Decoration	0%	0%	0%	0%	83%/4.77"
46. Awning, canopy	0%	0%	0%	0%	83%/4.77"
47. Tarpaulin, tent	0%	0%	0%	0%	83%/4.77"
51. Box, bag	83%/4.77"	83%/4.77"	45%/6.80"	45%/6.80"	100%/2.34"
52. Basket, barrel	17%/9.35"	45%/10.80"	45%/6.80"	45%/6.80"	100%/2.34"
53. Pallet, skid	83%/4.77"	83%/4.77	45%/6.80"	45%/6.80"	100%/2.34"
54. Rope, cord, twine, yarn	83%/4.77"	83%/4.77"	45%/6.80"	45%/6.80"	100%/2.34"

"Lounge" includes living rooms, dens, rec rooms, family rooms, libraries, and offices. "Storage areas" include closets, garages and carports (but not those coded as a detached garage under Fixed Property Use 881), crawl spaces, trash areas, and other storage areas. Codes for NFPA 901 Area of Origin are shown in parentheses. Item class distances are estimated minimum distances to ignite, and are shown in parentheses after the class description.

Table 6 - (continued)

Item	Area of Origin				
	Bedroom (21-22)	Lounge (14,16,27)	Dining Room (23)	Kitchen (24)	Storage areas (40-49, 71)
Fast Rate of Rise, Medium Peak Rate of Heat Release Class (23.6")					
25. Appliance housing	45%/18.80"	45%/18.80"	0%	45%/18.80"	100%/18.80"
31. Mattress, pillow	100%/16"	100%/12"	100%/12"	100%/12"	100%/2.34"
32. Bedding	100%/16"	100%/12"	100%/12"	100%/12"	100%/2.34"
41. Christmas tree	45%/18.80"	45%/18.80"	45%/18.80%	45%/18.80"	100%/6.45"
58. Cleaning supplies	0%	0%	0%	0%	100%/6.45"
62. Transformer	0%	0%	0%	0%	0%
63. Conveyor belt	0%	0%	0%	0%	0%/
64. Tire	0%	0%	0%	0%	0%
65. Fuel	0%	0%	0%	0%	100%/2.34"
81. Dust, fiber, lint	0%	0%	0%	0%	100%/2.34"
82. Explosive	0%	0%	0%	0%	100%/2.34"
83. Atomized, vaporized liquid	0%	0%	0%	0%	100%/2.34"
84. Chips	0%	0%	0%	0%	100%/2.34"
86. Gas or liquid in or from pipe or container	0%	0%	0%	0%	100%/2.34"
88. Adhesive	0%	0%	0%	0%	100%/2.34"

"Lounge" includes living rooms, dens, rec rooms, family rooms, libraries, and offices. "Storage areas" include closets, garages and carports (but not those coded as a detached garage under Fixed Property Use 881), crawl spaces, trash areas, and other storage areas. Codes for NFPA 901 Area of Origin are shown in parentheses. Item class distances are estimated minimum distances to ignite, and are shown in parentheses after the class description.

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 categories, 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 room of origin. The probabilities also are made conditional on the time of day to support the evaluation of the fire's effects on occupants, since location and activity of occupants are so time dependent. The following briefly describes the procedure used to calculate the scenario probabilities for upholstered furniture in dwellings.

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,
(d) Form of Heat of Ignition, and
(e) Time of Day.

2. We filled the matrix with NFIRS (National Fire Incident Reporting System) national estimates for 1980-1984 structure fires in one- or two-family dwellings excluding mobile homes 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 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.

7. The total of all matrix entries remained the same, from step #2 to step #7, and was the denominator for calculating probabilities.

The steps followed in this procedure are demonstrated below:

2.3.6 Allocation Procedure for Calculating Probabilities in Case 1

1. A matrix is created whose dimensions are (terms in italics are those used in NFPA 901):

(a) *Area of Fire Origin* The NFPA 901 categories are grouped as indicated and matrix operations are performed on one area grouping at a time.

(b) *Form of Material First Ignited* The NFPA 901 categories are used as is at this point, except that 97, 98, and 99 are also treated as unknowns. These represent multiple forms of material (i.e., multiple items) and form of material not applicable or unclassified.

(c) *Final Extent of Flame Damage* The NFPA 901 categories 4-7, representing fires spreading beyond the room of fire origin, are grouped. Categories 8, 9, and 0, representing unclassified, unknown, and inappropriate codes are grouped as unknowns.

(d) *Form of Heat of Ignition* The NFPA 901 categories 30-39 (smoking materials) are grouped and called smoldering. The NFPA 901 categories 01-29 and 40-99 are grouped and called flaming.

(e) *Time of Day* The groupings are 7:00 a.m. - 5:59 p.m. (day), 6:00 p.m. - 10:59 p.m. (evening), and 11:00 p.m. - 6:59 a.m. (night).

2. The matrix is filled with NFIRS national estimates for 1980-84 structure fires in one- or two-family dwellings, excluding mobile homes (i.e., Type of Situation Found 11, Fixed Property Use 410-419, not Mobile Property Type 17), already scaled to include a proportional allocation of fires with unknown area of fire origin. The scaling factor is a constant for a particular year and is based on all fires in the residential structure fire category.

3. The expanded set of fires with unknown form of material first ignited is proportionally allocated over the knowns. This means that, for each combination of fixed values of area of origin, final extent of flame damage, form of heat ignition, and time of day, the number of fires with each known form of material first ignited is scaled up by a scaling factor consisting of the total number of fires with those fixed values on the four dimensions divided by the number of those fires with those four fixed values for which the form of material first ignited was known.

4. The fires with partially known forms of material first ignited are similarly allocated, i.e., those coded 10, 19, 20, 30, 39, 40, 49, 50, 59, 60, or 69. Each is allocated over the knowns corresponding to its first digit. For example, fires coded 10 or 19 (structural element or covering of unknown or unclassified form) are allocated over fires coded 11-18 (the various structural element and covering classes that are fully specified).

5a. Fires with unknown final extent of flame damage are proportionally allocated, following the approach described in #3.

5b. Fires with unknown form of heat of ignition are proportionally allocated.

5c. Fires with unknown time of day are proportionally allocated.

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

7. The total of all matrix entries remains the same, from step #2 to step #7, and is the denominator for calculating probabilities.

We have now developed the fire scenario structure for modeling fires in single-family detached dwellings. This structure is based on using a ranch house and limiting the areas of origin to living rooms and bedrooms. We have defined the categories of first items ignited as upholstered furniture and five other categories based on their burning characteristics. The heats of ignition have been divided into two classes: a smoldering class, which is defined as cigarette ignitions of upholstered furniture and mattresses (fast/medium class), and a flaming class, which is applicable to all first items ignited. We have limited the final extent of flame damage to four categories and have described the procedure for determining the secondary involvement of upholstered furniture in fires initiating with other items. Finally we have calculated the probabilities associated with each fire scenario.

2.4 Adapting the Fire Model for Upholstered Furniture in Dwellings and Constructing Heat Release Rate Curves for Fire Scenarios

2.4.1 Adapting the Fire Model

The fire and smoke transport model used for this case study was FAST [6]. The scope of this model makes it most applicable to building arrangements where room dimensions, connections, and construction materials are like those found in single family dwellings. Further, the modeling of fires in contents (i.e., items within dwellings but not a part of the structure) did not require any technical improvements beyond the capabilities of FAST version 18.3, in use at the time that this case study was run. This was not the case with the other three case studies. The reader is referred to those reports for a discussion of the identification and implementation of required features in the fire model employed for a given case.

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 upholstered furniture's contribution was evaluated both for fire scenarios which initiate with the furniture and for those fires which start with each of the five classes (see section 2.3.1) of first item ignited which eventually involve the furniture. For fires which initiate with the furniture, the rules specify when other items in the room become involved (if necessary) to reach flashover. For fires initiating with an item other than the furniture, the rules specify at which extent of spread the product is secondarily ignited, and when the rest of the room contents become involved.

All fires in a particular room must follow one of the paths depicted in Figure 2. 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.

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

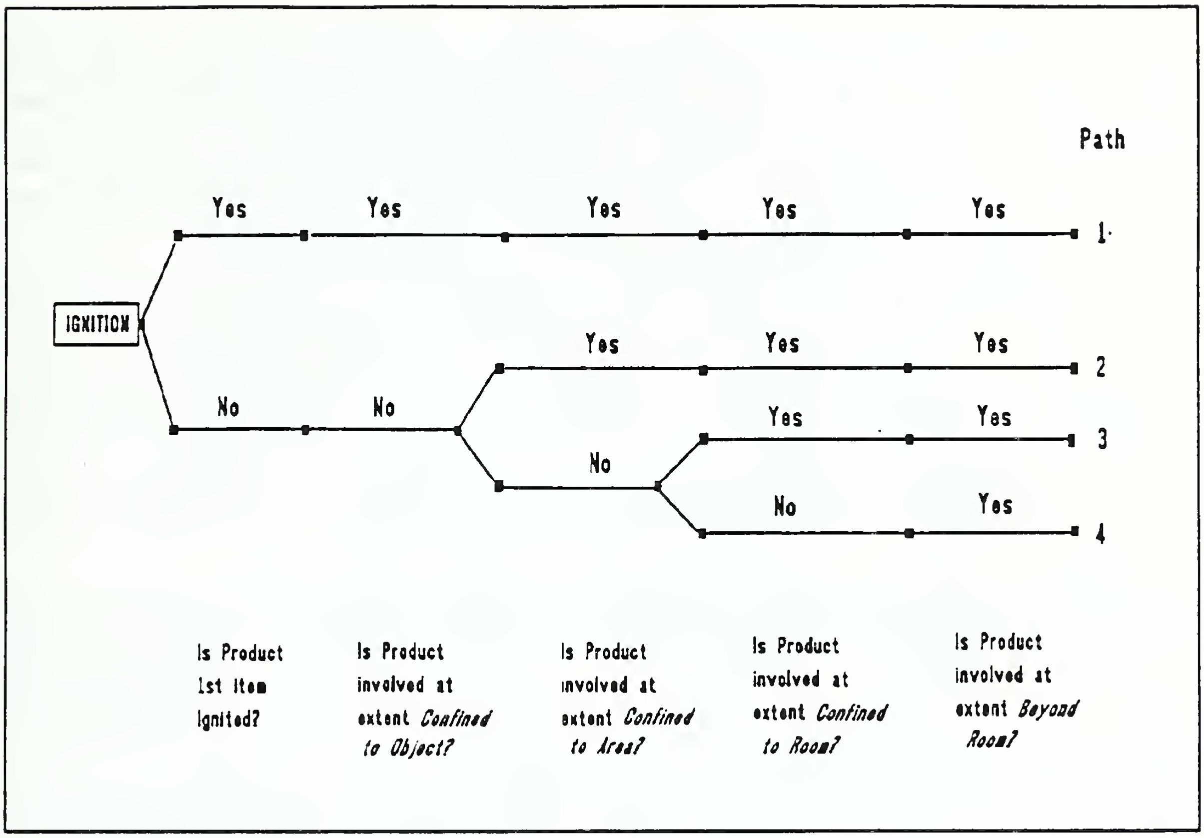

Figure 2 - Event tree indicating at what *Extent of Spread* the product becomes involved.

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 those still in the house.

In summary, the FAST model is applicable for modeling upholstered furniture fires in detached single-family dwellings without any modification. We have developed the heat release rate input curves for the fire scenarios associated with the first items ignited in living rooms and bedrooms. Moreover, we have derived a protocol in which FAST runs are carried out for flashover fires, and the 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 (family makeup by age), location (within and outside the house) and condition (asleep or awake and incapacitation by physical impairment or due to drugs or alcohol) at ignition. 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 [15]. These characteristics are used in the evacuation model to set speed and to simulate behavior such as alerting and/or assisting others or requiring assistance. We then used the HAZARD I tenability program (TENAB) to determine whether or not occupants succumb to the conditions to which they are exposed or successfully escape.

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. Information is provided on the frequency of fires by time of day. We have combined this with information from the U.S. Census and other sources on occupancy composition and activity patterns to imply location probabilities. By using this procedure, we generate occupant set probabilities by time of day *that are independent of any influence a particular occupant set might have on ignition likelihood.* When and where better information is available linking occupant sets with awareness of the fire, it should be used.

The U.S. Census Bureau's publication *Household and Family Characteristics* [16] reports on the Current Population Survey, providing information on family and non-family households with one to seven or more members. We limited the household size considered to five members to keep the number of combinations to a manageable size, and because this includes 98% of families. The number of households by family type is summarized in Table 7. Other tabulated information derived from Census data (shown in Table 8 and Table 9) allows estimation of the age of occupants (for several age classifications) by household size. For modeling purposes, children are grouped 0-3 years, 3-12 years and 12-18 years. Adults are grouped into two classifications, 18-65 years and 65 and older. A sample of occupant sets for the three person household case is shown in Table 10.

Table 7 - Number of Households by Family Type and Size

(Numbers in thousands)

Type \ Size	1 person	2 persons	3 persons	4 persons	5 or more persons	Total
Non-Family	20,602	2,768	497	155	70	24,092
Family						
* Married couple	---	19,220	11,346	11,666	8,118	50,350
* F-Household	---	4,747	2,938	1,383	1,060	10,128
* M-Household	---	1,382	520	218	116	2,236
Family-Total	---	25,349	14,804	13,267	9,294	62,714
Total	20,602	28,117	15,301	13,422	9,364	86,806

The U.S. Census Bureau has also collected information on the number of individuals with various disabilities and functional limitations [17]. Of particular interest to our analysis is the number of persons who need assistance from another person to get around within their house. Table 11 divides these incapacitated persons into individuals 15-65 and persons over 65. We have used these numbers to estimate the proportion of households with incapacitated members. Since we do not have information for children under 15, we have assumed an incapacitation rate equal to those in the 15 to 65 year age group. Using these statistics and restricting our estimates to permit only one incapacitated individual per household, we developed a modified occupant set. The three person household case is shown in Table 12.

Table 8 - Basic Information used in the Construction of Family Household Occupant Sets

(Number in thousands)

Size		2 persons	3 persons	4 persons	5/more persons	Total
A) No. of Families		25,349	14,804	13,422	9,294	62,714
B) No. of Families by No. of children under 18 yrs	0	22,753	5,415	2,158	1,268	32,594
	1	2,596	7,591	1,907	1,014	13,108
	2	---	1,799	8,476	1,370	11,645
	3	---	---	718	3,768	4,486
	4-	---	---	---	1,873	1,873
C) No. of Families with children under 18		2,596	9,390	11,101	8,025	31,112
D) No. of Families with children [12-17] but no child [<12] (% : within C)		1,040 (40.0%)	2,772 (29.5%)	2,905 (26.2%)	1,856 (23.1%)	8,573 (27.6%)
E) No. of Families with children [3-11] but no child [<3] (% : within C)		1,170 (45.1%)	3,538 (37.7%)	5,350 (48.2%)	3,978 (49.6%)	14,036 (45.1%)
F) No. of Families with children [<3] (% : within C)		386 (14.9%)	3,080 (32.8%)	2,846 (25.6%)	2,191 (27.3%)	8,503 (27.3%)
G) No. of Families with elderly [65≤] (% : within C)		8,698 (34.3%)	1,624 (11.0%)	637 (4.8%)	712 (7.7%)	11,672 (18.6%)
H) No. of Families with 2 elderly [65≤] (% : within C)		5,290 (20.9%)	751 (5/1%)	141 (1.1%)	184 (2.0%)	6,366 (10.2%)

Table 9 - Distribution of Elderly[1] between Family and Non-Family Households

(Numbers in thousands)

	Family	Non-Family	Total
A) No. of households	62,706	24,082	86,789
B) No. of households without elderly	51,048	15,613	66,661
C) No. of households with elderly (% : within A)	11,658 (18.6%)	8,470 (35.2%)	20,128 (23.2%)
D) No. of persons of elderly	18,038	8,665	26,703
E) No. of households with 2 elderly [E = D-C] (% : within A)	6,380 (10.2%)	195 (0.8%)	6,575 (7.6%)

[1] "Elderly" are persons 65 or older.

Table 10 - Distribution of Occupants by Age Classifications for Three Person Households

(Numbers in thousands)

3 person Households (15,301)

If Family Type only -------------> (14,804)

A) With no child (5,415)

Ad , Ad , Ad[4]	5,415-(751+367) = 4,297	....	29.0%
Ad , Ad , E	(1,624-751)* .42 = 367	....	2.5%
Ad , E , E	751	....	5.1%

B) With 1 child (7,591)

Ad , Ad , GK	7,591*0.295 = 2,239	....	15.1%
Ad , Ad , MK	7.591*0.377- 506 = 2,355	....	15.9%
Ad , Ad , SK	7,591*0.328 = 2,490	....	16.8%
Ad , E , MK	(1,624-751)* .58 = 506	....	3.4%

C) With 2 children (1,799)

Ad , GK , GK	1,799*0.295 = 531	....	3.6%
Ad , GK , MK	1,799*0.377*0.33 = 224	....	1.5%
Ad , MK , MK	1,799*0.377*0.67 = 452	....	3.1%
Ad , MK , SK	1,799*0.328*0.89 = 525	....	3.6%
Ad , SK , SK	1,799*0.328*0.11 = 65	....	0.4%
		Total	100.0%

[4] Ad - adults (18 to 65)
E - elderly (65 or older)
GK - child (12 to 18)
MK - child (3 to 12)
SK - child (under 3 yrs)

Table 11 - Distribution of Incapacitated[5] Persons (15 years or older)

(Numbers in thousands)

Age	Number	Percent	Total Population
15 to 65	1,174	0.8	154,565
65 and older	2,569	9.7	26,422
Total	3,743	2.1	180,987

[5] Incapacitated is defined as requiring assistance from another person to get around within the house.

Table 12 - Summary Distribution of the Occupant Sets for the 3 Person Households

(% : within 14,902)

1)	A[6]	A	A	4,168	28.0%		13)	A	A	In	234	1.6%
2)	A	A	E	324	2.2%		14)	A	E	In	261	1.8%
3)	A	E	E	594	4.0%		15)	E	E	In	8	0.1%
4)	A	A	G	2,172	14.6%		16)	A	G	In	58	0.4%
5)	A	A	M	2,285	15.3%		17)	A	M	In	113	0.8%
6)	A	A	S	2,416	16.2%		18)	A	S	In	56	0.4%
7)	A	E	M	446	3.0%		19)	E	M	In	5	0.0%
8)	A	G	G	520	3.5%							
9)	A	G	M	220	1.5%							
10)	A	M	M	443	3.0%							
11)	A	M	S	515	3.5%							
12)	A	S	S	64	0.4%							

[6] Note: A - adults (18 to 65)
E - elderly (65 or older)
G - child (12 to 18)
M - child (3 to 12)
S - child (under 3 years)
In - incapacitated

Since the fire scenarios occur at different rates by time period, and since very different occupant sets are expected in the same household in different time periods, it is essential to combine properly the fire scenarios with the expected occupant sets by time of day. This factor was addressed through the initial location of each member of an occupant set either in a specific room within the house or outside the structure. These assignments were based on data collected on family time use [18]. The tabulated data provide information on time spent on various activities by household member. Activities include food preparation, dishwashing, shopping, cleaning, maintenance, clothing care, physical care, nonphysical care, management, paid work, unpaid work, organization participation, social/recreation, personal care, and eating. While such information does not provide the information on location in the house, we have assigned locations for each activity, allocating the time spent between locations within the house (kitchen, living room and bedroom) and outside. Using these data and judgement we have developed a "most probable" location by household characteristic for three time periods (Table 13). The time periods are daytime (7:00 am to 5:59 pm), evening (6:00 pm to 10:59 pm) and night (11:00 pm to 6:59 am).

To account for the time spent in the house, during the daytime, working adults are differentiated from non-working adults, and very young children with both parents working are differentiated from children with a parent that is at home. This distinction requires a regrouping of families into those with all adults working and those with an adult not working. Census data indicate that in 45 percent of married families both parents work, while in head of household families 56 percent of the heads of household are employed [9]. Using this split we are able to regroup families and provide an estimate of "most probable" location, which was further simplified to living room and bedroom, since times spent in other rooms was minimal. The results for a two person household are presented in Table 14 as an example.

Because use of alcohol and drugs has been implicated as playing an important role in response to fire, those individuals intoxicated by alcohol are also estimated in the occupant sets. Our analysis of data in the 1986 *Statistical Abstracts of the United States* indicate that during any one day between 1.8 and 4.0 percent of the population 18 or older have consumed 5 or more drinks at a single sitting. Because we could not estimate drug use, we used an estimate of three percent of the population as being intoxicated by alcohol and drug consumption. These values were incorporated into the **night time** occupant sets only.

Table 14 indicates for each occupant set (configuration and location) by time period the number of estimated households. The probability that a specific occupant set will be in a house during a time period can be estimated by dividing the household estimate by the total number of US households (86,789,000). It should be noted that during the daytime a significant number of households are vacant or absent of one or more members. For example, in Table 14, thirty percent of the two person households (occupant sets 4, 5, 6 and 9) are vacant and another 43 percent (occupant sets, 1, 2, 7, 11 and 12) have one member absent.

Because of these absences, households with different numbers of residents quite often are expected, especially in the daytime, to contain the same number of occupants with identical characteristics. The input requirement for the hazard analysis is not family size, per se, but the actual number of occupants in the house, their location and characteristics. Therefore, we have combined identical occupant sets for households regardless of size.

Table 13 - Most Probable Location for Occupants by Time of Day[7] [14]

Occupant	Location	
	Day (7 am - 6 pm)	Evening (6 pm - 11 pm)
Baby (1 parent works)	Living room	Bedroom (asleep)
Baby (both parents work)	Outside	Bedroom (asleep)
Young child (1 parent works)	Outside	Living room
Young child (both parents work)	Outside	Living room
Older child	Outside	Living room
Working/Adult	Outside	Living room
Non-working/Adult	Living room	Living room
Elderly	Living room	Bedroom (asleep)
Incapacitated	Bedroom (awake)	Bedroom (asleep)

[7] Note: Midnight (11 pm - 7 am) - all occupants are assumed to be asleep in bedrooms except those intoxicated by alcohol assumed to be asleep in the living room.

Table 14 - Location by Time of Day for 2 Person Household Occupant Sets

Occupant Location by Time of Day

Occupant Set	Daytime			Evening			Midnight		
	Location		Households (in thousands)	Locetion		Households (in thousands)	Location		Households (in thousends)
No. (1)	10[8]	11	8538	11	11	15523	13	13	14592
No. (2)	10	21	2087	11	23	3727	13	23	3503
No. (3)	21	21	4388	23	23	4388	23	23	4125
No. (4)	10	10	577	11	31	1030	13	33	999
No. (5)	10	40	648	11	41	1158	13	43	1123
No. (6)	10	50	214	11	53	382	13	53	371
No. (7)	10	62	425	11	62	759	13	63	736
No. (8)	21	62	1139	23	62	1139	23	63	1105
No. (9)	10	10	6985				13	74	1043
No. (10)	11	21	1640				23	74	375
No. (11)	11	30	453				33	74	31
No. (12)	11	40	510				43	74	35
No. (13)	11	51	168				53	74	11
No. (14)	11	82	334				63	74	57

[8] Note: This 2 digit code designates the occupant end their location.

This first digit refers to the occupant's characteristics:

1 - adult   3 - older child   5 - beby   7 - intoxiceted

2 - elderly   4 - younger child   6 - incepaciteted

The second digit locates the occupant:

0 - outside   2 - bedroom awake   4 - living room asleep

1 - living room ewake   3 - bedroom asleep

For example, 10 represents an adult outside the house.

Table 15 - Summary of Daytime Occupant Sets

	Household Size (households in thousands)					
Occupant Set	1 person	2 person	3 person	4 person	5 person	Total
11*	12342	11588	5850	5427	2870	38077
62	859	425	241	274	227	2026
11 11	---	6028	731	265	318	7342
11 51	---	168	1607	1371	1517	4763
11 11 62	---	---	127	23	33	183
11 11 11	---	---	270	55	79	404
11 51 51	---	---	29	137	81	247
11 51 62	---	---	26	30	57	113
11 11 11 62	---	---	---	1	3	4
11 51 51 62	---	---	---	2	4	6
0	8424	7401	6155	5524	3863	31367

*Note: This 2 digit code designates occupants and their location. The first digit refers to the occupant's characteristics:

1 - adult   3 - older child   5 - baby   7 - intoxicated
2 - elderly   4 - younger child   6 - incapacitated

The second digit locates the occupant:

0 - outside   2 - bedroom awake   4 - living room asleep
1 - living room awake   3 - bedroom asleep

For example, 11 represents an adult in the living room.

Table 16 - Parameter Values for the Deterministic Decision/Evacuation Model

Occupant/ Location	Age	Sex	Location	Capability	Sleep Status	Sleep Penalty (Decibels)	Speed (M/Sec)
Adult (11)	21	Female	Liv. Rm.	Capable	Awake	0	1.3
Adult (13)	21	Female	BR*	Capable	Asleep	0	1.3
Elderly (21)	81	Female	Liv. Rm.	Capable	Awake	0	1.0
Elderly (23)	81	Female	BR	Capable	Asleep	10	1.0
Older Child (31)	13	Female	Liv. Rm.	Capable	Awake	0	1.3
Older Child (33)	13	Female	BR	Capable	Asleep	5	1.3
Younger Child (41)	7	Female	Liv. Rm.	Capable	Awake	0	1.0
Younger Child (43)	7	Female	BR	Capable	Asleep	10	1.0
Baby (51)	2	Female	Liv. Rm.	NH**	Awake	0	NA***
Baby (53)	2	Female	BR	NH	Asleep	0	NA
Incapacitated (62)	21	Female	BR	NH	Awake	0	NA
Incapacitated (63)	21	Female	BR	NH	Asleep	0	NA
Intoxicated (74)	21	Female	Liv. Rm.	Capable	Asleep	20	1.0

* BR - specific bedrooms are assigned using an algorithm which takes into account number of adults and number of children, characteristics of each and distribution of occupants among 3 bedrooms

** NH - needs help to evacuate

*** NA - not applicable, speed depends upon rescue

Table 17 - Occupant Combinations (Characteristics and Locations) for Daytime and Evening Fires

Occupant Set/Location	Households (in thousands) Daytime	Evening
11*	38077	13216
23	0	6527
62	2026	859
11 11	7342	16553
11 23	0	3727
23 23	0	4388
11 41	0	1158
11 53	0	382
11 62	2299	759
23 62	0	1139
11 51	4763	0
11 11 11	404	7090
11 11 23	0	335
11 23 23	0	614
11 11 41	0	2589
11 11 53	0	2497
11 23 41	0	461
11 41 41	0	458
11 41 53	0	532
11 53 53	0	66
11 11 62	183	302
11 23 62	0	270
23 23 62	0	8
11 41 62	0	117
11 53 62	0	58
23 41 62	0	5
11 51 51	247	0
11 51 62	113	0
11 11 11 11	0	4793
11 11 11 23	0	74
11 11 23 23	0	59
11 11 11 41	0	2191
11 11 11 53	0	476
11 11 23 41	0	65
11 23 23 41	0	52
11 11 41 41	0	2573
11 11 41 53	0	1885
11 11 53 53	0	233
11 23 41 41	0	299
11 41 41 53	0	164
11 41 53 53	0	20
11 11 11 62	4	233
11 11 23 62	0	19
11 23 23 62	0	3

11 11 41 62	0	146
11 11 53 62	0	40
11 23 41 62	0	22
23 23 41 62	0	1
11 41 41 62	0	85
11 41 53 62	0	42
11 53 53 62	0	5
23 41 41 62	0	3
11 51 51 62	6	0
11 11 11 11 11	0	2299
11 11 11 11 23	0	161
11 11 11 23 23	0	81
11 11 11 11 41	0	1081
11 11 11 11 53	0	265
11 11 11 23 41	0	130
11 11 23 23 41	0	62
11 11 11 41 41	0	1461
11 11 11 41 53	0	329
11 11 11 53 53	0	39
11 11 23 41 41	0	169
11 11 41 41 53	0	2708
11 11 11 11 62	0	154
11 11 11 23 62	0	28
11 11 11 41 62	0	90
11 11 11 53 62	0	15
11 11 23 41 53	0	24
11 23 23 41 62	0	2
11 11 41 41 62	0	92
11 11 41 53 62	0	67
11 11 53 53 62	0	5
11 23 41 41 62	0	4
11 41 41 53 62	0	37
11 41 53 53 62	0	2

*Note: This 2 digit code designates the occupants and their location. The first digit refers to the occupant's characteristics:

1 - adult 3 - older child 5 - baby 7 -intoxicated
2 - elderly 4 - younger child 6 - incapacitated

The second digit locates the occupant:

1 - living room awake 2 - bedroom awake
4 - living room asleep 3 - bedroom asleep

For example, 11 represents an adult in the living room.

Table 18 - Occupant Combinations (Characteristics and Locations) for Nighttime Fires

Occupant Set/Location	Households (in thousands)	Occupant Set/Location	Households (in thousands)
13	12820	13 13 23 43	59
23	6331	13 23 23 43	47
63	859	13 13 33 33	2039
74	592	13 13 33 43	1238
13 13	14592	13 13 43 43	2204
13 23	3503	13 13 43 53	1772
23 23	4125	13 13 53 53	219
13 33	999	13 23 43 43	281
13 43	1123	13 33 33 33	180
13 53	371	13 33 33 43	110
13 63	736	13 33 43 43	222
23 63	1105	13 43 43 53	159
13 74	1043	13 43 53 53	19
23 74	375	13 13 13 63	98
33 74	31	13 13 23 63	17
43 74	35	13 23 23 63	3
53 74	11	13 13 33 63	69
63 74	57	13 13 43 63	104
13 13 13	3920	13 13 53 63	38
13 13 23	305	13 23 43 63	21
13 23 23	559	23 23 43 63	1
13 13 33	2111	13 33 33 63	50
13 13 43	2220	13 33 43 63	34
13 13 53	2347	13 43 43 63	82
13 23 43	433	13 43 53 63	41
13 33 33	521	13 53 53 63	5
13 33 43	220	23 43 43 63	3
13 43 43	444	13 13 13 74	234
13 43 53	517	13 13 23 74	16
13 53 53	64	13 13 43 74	118

*Note: This 2 digit code designates the occupant and their location. The first digit refers to the occupant's characteristics:

1 - adult 3 - older child 5 - baby 7 - intoxicated
2 - elderly 4 - younger child 6 - incapacitated

The second digit locates the occupant:

1 - living room awake 3 - bedroom asleep
2 - bedroom awake 4 - living room asleep

For example, 13 represents an adult in the bedroom asleep.

Table 18 (continued)

13 13 63	227
13 23 63	253
23 23 63	8
13 33 63	58
13 43 63	114
13 53 63	56
23 43 63	5
13 13 74	388
13 23 74	85
13 43 74	304
33 43 74	37
43 53 74	18
13 63 74	38
13 13 13 13	1718
13 13 13 23	65
13 13 23 23	52
13 13 13 33	444
13 13 13 43	693
13 13 13 53	433
13 13 13 33 43	195
13 13 13 43 43	227
13 13 43 43 53	300
13 13 13 53 53	35
13 13 23 43 43	154
13 13 33 33 33	783
13 13 33 33 43	567
13 13 33 43 43	1140
13 13 43 43 53	842
13 13 43 53 53	103
13 33 43 43 53	1757
13 13 13 13 63	66
13 13 13 23 63	25
13 13 23 23 63	4
13 13 13 33 63	15
13 13 13 43 63	32
13 13 13 53 63	14
13 13 23 43 63	22
13 23 23 43 63	2
13 13 33 33 63	41
13 13 33 43 63	40
13 13 43 43 63	45
13 13 43 53 63	28
13 13 53 53 63	5
13 23 43 43 63	4
13 33 33 33 63	16
13 33 33 43 63	12
13 33 43 43 63	43
13 43 43 53 63	36
13 43 53 53 63	2
13 13 53 74	43
13 23 43 74	5
13 43 43 74	368
13 43 53 74	113
13 53 53 74	14
33 33 43 74	15
43 43 53 74	5
43 53 53 74	1
13 13 63 74	12
13 43 63 74	21
13 13 13 13 13	797
13 13 13 13 23	137
13 13 13 23 23	69
13 13 13 13 33	191
13 13 13 13 43	231
13 13 13 13 53	233
13 13 13 23 43	115
13 13 23 23 43	55
13 13 13 33 33	276
13 33 43 53 63	36
13 13 13 13 74	141
13 13 13 23 74	36
13 13 13 43 74	64
13 13 13 53 74	32
13 13 23 43 74	22
13 13 33 43 74	84
13 13 43 53 74	29
13 13 53 53 74	4
13 43 43 53 74	53
13 43 53 53 74	6
33 43 43 53 74	54
13 13 23 63 74	13
23 43 53 63 74	23
13 33 43 43 74	159

Furthermore, occupant categories expected to behave in a similar manner and to share a common location have been merged together to reduce the total number of combinations and corresponding EXITT runs. For example, in daytime cases elderly occupants (located in the living room and able to perform rescue) have been merged into the adult category, while in evening cases the elderly (located in bedrooms) remain distinct. Older children located in the living room with adults and able to perform rescue have been merged into the adult category. No merging of occupant categories was attempted for the night-time cases. The summary matrix with occupant set distribution for the daytime cases is shown in Table 15.

The deterministic evacuation model requires the specification of input parameter values for age, sex, location, capability to get around without assistance, sleep status, relative difficulty of awakening from sleep and speed of movement. A sleep penalty is specified which is the number of decibels above the normal value needed to awaken the occupant. Table 16 contains the values selected for each occupant class. These initial values were suggested by Levin [19]. Because the sex of an occupant in the model results in only minor differences in behavior, all occupants are treated as females. Incapacitated occupants and babies can move only with the assistance of adults, elderly or older children. Intoxicated occupants are considered only at night. They are given a sleeping penalty (this results in a long delay prior to awakening), but once awake they can evacuate without assistance.

To this point, we have estimated the probability of each occupant set and their location in the house for each of three time periods. These results are summarized in Tables 17 and 18.

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 [20]. 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 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 in 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 residential fuel can be characterized with an appropriate level of specificity. New furniture can be tested to determine its 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 a lethality condition (in addition to the Ct parameter) and as a limit on burning rate, as discussed in section 3.1.4. This revised version of TENAB 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.

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 of death, it may ultimately be from toxicity or oxygen deprivation, but only because the victims were prevented from escape by convected heat.

To summarize the fifth step, we have developed the occupant sets exposed to the fire scenarios by time of day and have estimated their associated probabilities. We have also 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 Upholstered Furniture in Single Family Dwelling

3.1 Sequence of Calculation in the Method

In Section 2, we described how we formulated the computation of the risk of current upholstered furniture in residences 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 HAZARD I for a specific fire scenario and occupant set, we obtain an outcome in deaths per fire.

2) We then run each occupant set for that same fire scenario.

3) This gives us an estimate of total deaths per fire for that scenario, weighting the results for each occupant set by the probability of that occupant set.

4) 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.

5) These results are combined with similar results for all other scenarios to produce a sum that gives the annual death rate for fires involving upholstered furniture currently in use.

We then compared these predicted results for the "base" case with the actual losses obtained from the national fire database. These comparisons led to several adjustments, prior to establishing the final "base" case. These adjustments included both changes to the model as well as the assumed fire properties for upholstered furniture, and are discussed in the following sections.

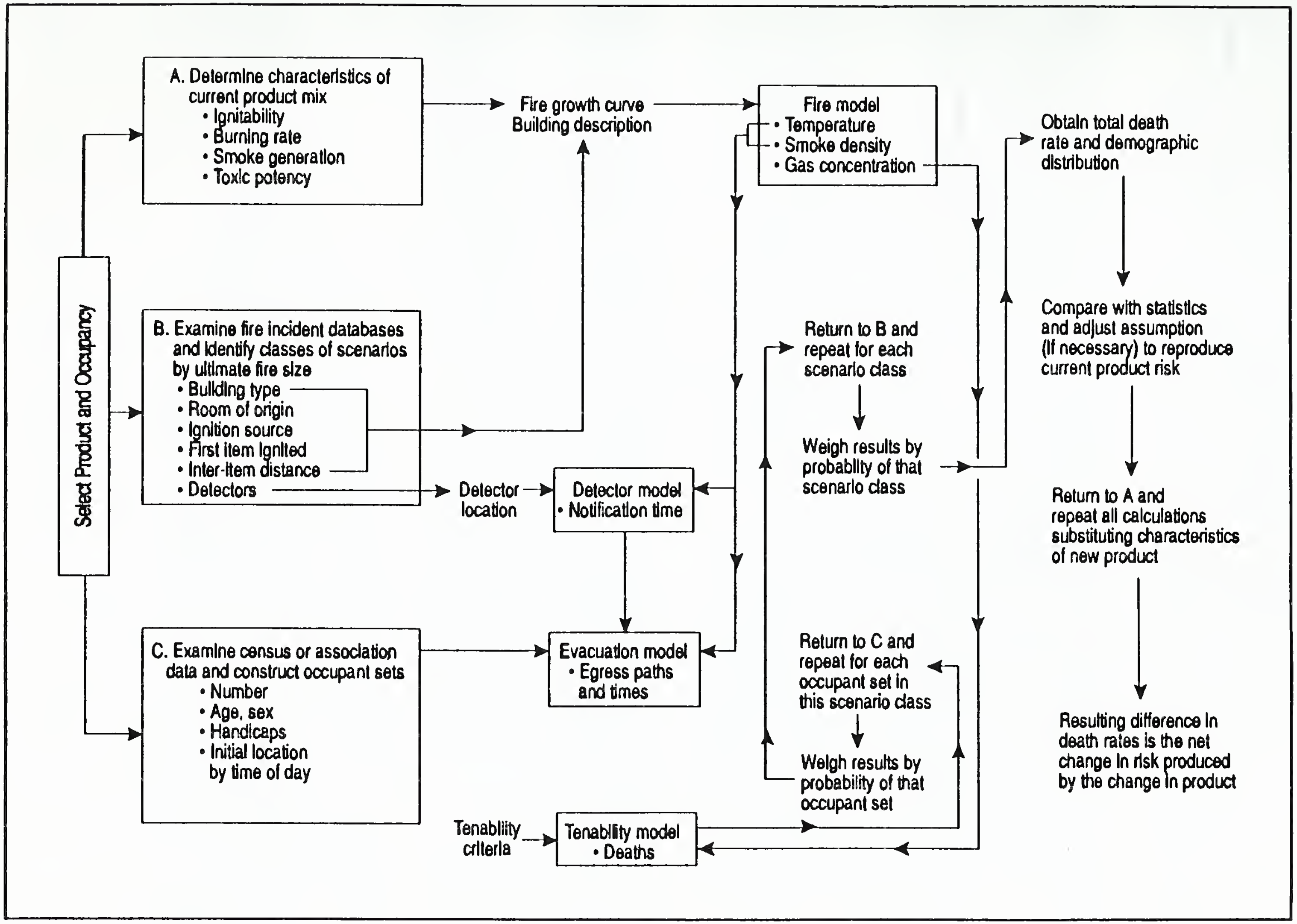

Figure 3 - Modeling Sequence to Compute Fire Risk

3.1.1 Thermal Tenability Limit

A set of tenability criteria for tempeature and toxic gas exposures were recently published by Purser [21]. These were incorporated into the release version of HAZARD I, including a time-dependent thermal limit which more closely matches data on heat tolerance in the literature. These measures were used as an adjustment to the "base case" prediction and were incorporated as a permanent part of the risk method.

3.1.2 Additional Smolder Period

The method was underpredicting deaths in flaming fires, and one theory as to why was that warning and escape were happening too quickly. HAZARD I predicted that in the smoldering fires, the smolder period was producing combustion gases which accumulated a toxicity exposure prior to the occupant becoming aware of the fire. Since it is conceivable that upholstered furniture materials may pyrolyze for some period before becoming fully involved, it was decided to examine the impact of a short smoldering period ahead of any flaming combustion. A twelve minute duration was selected arbitrarily.

3.1.3 Changing the Shape of the Smoldering Heat Release Curve

In the initial calculations, an estimate of the burning rate for smoldering materials (0.0003 kg/s) was employed since no measurements were found in the literature. Later, test data were obtained which exhibited a different behavior. Thus, a two-stage rate was developed (see section 2.3.2) to better correspond to these measurements.

3.1.4 Updated Version of FAST

In the initial calculations for this case, the version of FAST available did not account for the effect of oxygen availability on burning rate. This was not considered a major shortcoming for the upholstered furniture case, but was crucial to the concealed combustible case due to the fact that there, the burning takes place in a very restricted volume.

However, when the base case calculations were being re-done after calibration, the new version of FAST was employed. Thus, this case includes the effect of reduced oxygen, both on the fire, and on the occupants. The former results in the distribution of energy release to several locations in the building once the original fire location becomes vitiated, and the latter increases the toxic potency of the smoke at the same time.

3.1.5 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 for this case and made a part of the risk method. These are the values presented in section 2.3.3.

3.2 Example Output

The output of the method is a series of tables giving fire death rates in various demographic categories such as age or sex of victim, time of day, type of building, room of origin. We present these results in a tabular format similar to that normally used for the presentation of fire incident data. This provides a certain familiarity and makes comparisons easier. Some examples of the results of the upholstered furniture analysis are presented in tables which follow.

Confidence in the model's fine structure will depend on the extent to which the details of the predicted base case results correspond to the actual fire death rates. These detailed results will also tell a great deal about the kinds of fires and occupants that account for the largest portion of changes in the risk of introducing a new product.

We examined the sensitivity to some assumptions made because data were not available. For example, when occupants attempted escape by using windows, we looked at the impact of whether they: (a) always escape, (b) never escape, or (c) require a set time period during which they were exposed to the conditions within the room. Finally, criteria for the conditions under which rescuers from outside might save those unable to escape on their own or with the aid of other household members were examined.

The results shown in Tables 19 through 23 were obtained for the class of fire scenarios sharing these characteristics: upholstered furniture first item ignited, ignition sources other than smoking materials, starting in the living room of a ranch house and spreading beyond the living room with bedroom doors open.

Table 19 is a summary of expected deaths per 100 fires with and without smoke detectors for day, evening and night. These results are obtained by accounting for the predicted lethal impact of the scenario on each occupant set in proportion to its share in the general population. Table 20 relates the death per fire values to a cause, either toxicity of smoke (measured by the concentration-time product) or convected heat. Table 21 details how the death per fire numbers are divided among the occupant types and provides a basis for further insight as to their relative vulnerabilities to a particular fire scenario. Table 22 displays the predicted use of windows as a secondary escape route (because the primary route was blocked by heavy smoke) by the various occupant types.

Table 23 illustrates an output of the risk method which has combined the predicted results in Table 19 for fires with detectors with results for fires without detectors - using a factor to account for the probability of having a functional detector, given a fire. For example, at night the weighted death per 100 fires number (23.56 in Table 23) was derived by multiplying the death per 100 fire values, with and without detectors (1.00 and 29.74, respectively) in Table 19 by their respective probabilities for detector presence. Since the probability of having a working detector, given a fire, was determined to be 0.19, the probability of no detector or a non-functional detector equals 1.0-0.19 = 0.81. Therefore, the weighted value is computed as 0.19 (1.00) + 0.81 (29.74) = 23.56. The resulting weighted death per fire values in Column 5 of Table 23 can be compared with the results derived from an analysis of the fire incident statistics for this scenario (Column 3). Columns 2 and 3 were derived from national fire data. Column 2 indicates the probability of this scenario occurring given that a fire has occurred. Column 3 is the result of dividing the total deaths occurring for this scenario by the total fires for this scenario, recorded over a five year period. Column 4, the average annual deaths, was derived by multiplying the product of Column 2 and Column 3 by the expected fires occurring in this occupancy during one year - obtained from national estimates. Column 6, the total predicted deaths from the risk model computation, was obtained by multiplying the product of Columns 2 and 5 by the expected number of fires per year occurring in this occupancy. Comparing the deaths predicted, (Column 6) with the fire incident data (Column 4) indicates an under-estimation of day and evening deaths and an over-estimation of night time deaths. A possible explanation for these discrepancies appears in the next section.

It is possible to create tables similar to Table 23 which take into account other factors, such as the mix of housing types (ranch vs two-story), bedroom door status (open vs closed) or other tenability and escape criteria. The ability of the risk method to account for these factors makes it potentially useful not only for product evaluation but for evaluation of other fire safety strategies as well.

Example Outputs from the Risk Model

Upholstered Furniture First Ignited, Flaming Fire, Ranch House, Living Room Fire, Fire Spread Beyond Room of Origin, Bedroom Doors Open. Tenability Criteria: CT=900, g-min/m^3

Table 19 - Deaths Per 100 Fires, All Causes Combined

With Smoke Detectors			Without Smoke Detectors		
Day	Evening	Night	Day	Evening	Night
2.73	1.50	1.00	2.73	1.50	29.74

Table 20 - Deaths Per 100 Fires for Each Cause

	With Smoke Detectors			Without Smoke Detectors		
Cause	Day	Evening	Night	Day	Evening	Night
O_2 deprivation	0.00	0.00	0.00	0.00	0.00	0.00
CT	0.00	0.00	0.00	0.00	0.00	0.00
Convect heat	2.73	1.50	1.00	2.73	1.50	29.74

Table 21 - Deaths Per 100 Fires by Occupant Type

	With Smoke Detectors			Without Smoke Detectors		
Occupant	Day	Evening	Night	Day	Evening	Night
Adults	0.13	0.17	0.00	0.13	0.17	0.19
Elderly	0.00	0.00	0.00	0.00	0.00	0.00
Child, 12-18	0.00	0.00	0.00	0.00	0.00	0.00
Child, 3-12	0.00	0.00	0.00	0.00	0.00	0.00
Child, 0-3	0.13	0.17	0.01	0.13	0.17	28.18
Impaired	2.47	1.16	0.99	2.47	1.16	1.08
Drunk	0.00	0.00	0.00	0.00	0.00	0.00

Table 22 - Persons Escaping at Windows per 100 Fires by Occupant Type

Occupant	With Smoke Detectors			Without Smoke Detectors		
	Day	Evening	Night	Day	Evening	Night
Adults	0.00	0.00	0.00	0.00	0.00	147.37
Elderly	0.00	0.00	0.00	0.00	19.26	26.14
Child, 12-18	0.00	0.00	0.00	0.00	0.00	21.85
Child, 3-12	0.00	0.00	0.00	0.00	0.00	2.18
Child, 0-3	0.00	0.00	0.00	0.00	0.00	11.09
Impaired	0.00	0.00	0.00	0.00	0.00	4.07
Drunk	0.00	0.00	0.00	0.00	0.00	0.00

Table 23 - Comparison of Risk Model Results with Fire Incident Data Analyses

People Reaching Windows Escape & No Help Arrives for Rescue

PROB(SMOKE DETECTOR) = 0.19
PROB(RANCH HOUSE) = 1.00
PROB(2-STORY HOUSE) = 0.00
PROB(CLOSED DOORS) = 0.00

TIME OF DAY	PROBABILITY (X1000)	DEATHS PER 100 FIRES ACTUAL	TOTAL DEATHS ACTUAL	DEATHS PER 100 FIRES COMPUTED	TOTAL DEATHS COMPUTED
1	2	3	4 (2x3xN*)	5	6 (2x5xN)
DAY	2.11080	5.62	48.49	2.73	23.56
EVENING	0.95470	3.55	13.85	1.50	5.85
NIGHT	1.27230	8.77	45.61	24.28	126.28
TOTAL	4.33780		107.96		155.69

*N = 409,000 fires/year

3.3 Base Case Comparison with Statistics

The base case consisted of living room and bedroom fires. The base case results are divided into two groups of fire scenarios. The first group consists of those scenarios where upholstered furniture was the first item ignited. We will be comparing the total deaths predicted by the risk method with the national fire database estimates for the identical scenarios. We will also be looking at how well our results compare when we examine the finer structure (smoldering versus flaming ignitions and the distribution of deaths by time of day).

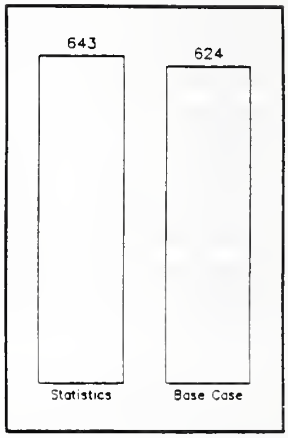

Figure 4 - Annual deaths, living room and bedroom fires, furniture first item ignited.

Figure 4 indicates that the risk model and fire database estimates are in good agreement for the "base" case when upholstered furniture was the first item ignited. When we compare upholstered furniture fires by type of ignition in Figure 5, this agreement is maintained with the percentage of deaths from smoldering equaling 77 percent (statistics) versus 74 percent (predicted by the method).

The risk model prediction of deaths by time of day (Figure 6), however, does not do nearly as well. The statistical values indicate 59 percent of deaths occur at night while the method predicts 88 percent. This discrepancy might be explained by the assignment of occupant location and behavior (sleep status by time of day). All occupants are assumed awake during the day, all of the elderly are asleep during the evening, and all occupants are assumed to be asleep at night. Clearly, vulnerability to fire increases for those individuals asleep (particularly without smoke detectors). To adjust this imbalance, the distribution for sleeping status could be shifted, such that some people are awake at night and some are asleep during the day. However, there are no data known on which to base such an improvement. If decisions are to be based on changes in predicted fire risk that are sensitive to this type of variable, then special studies will need to be conducted first to establish the proper distribution.

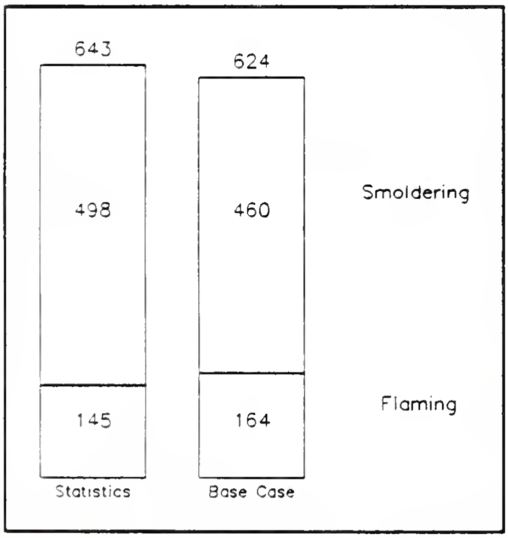

Figure 5 - Distribution of deaths by type of ignition.

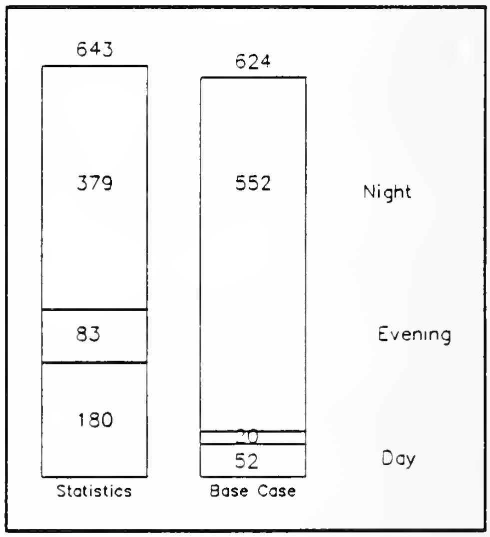

Figure 6 - Distribution of deaths by time of day.

In the second group are those living room and bedroom scenarios where items other than upholstered furniture are first ignited and the secondary ignition of upholstered furniture is deduced from the methodology. Figure 7 summarizes the results from the scenarios when upholstered furniture was *not* the first item ignited. We can see that the method overpredicts the total deaths by almost 50 percent, with the bulk of these excess deaths in the smoldering fire scenarios.

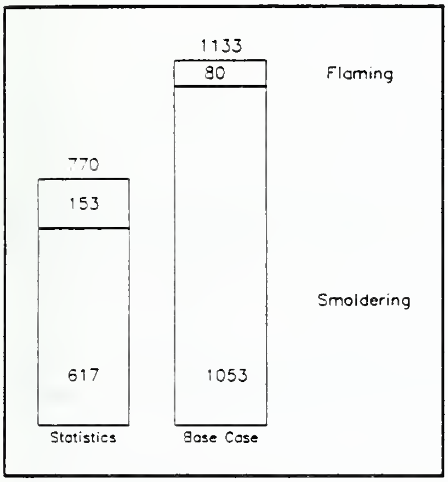

Figure 7 - Furniture ignited second, by primary ignition type.

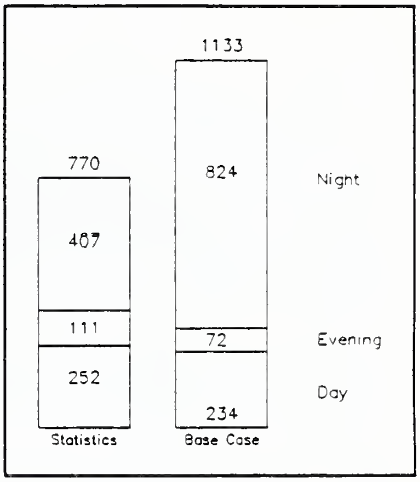

Figure 8 - Furniture ignited second, by time of day.

When we examine time of day predictions, Figure 8 indicates that the night time fire deaths are over-predicted by 100 percent. A more detailed analysis seen in Figure 9 reveals much better agreement by an aggregate of 141 of the 144 scenarios represented and a gross overprediction by the other three scenarios. Three flaming, night time, living room scenarios (represented by the slope/peak heat release rate combinations fast/medium, medium/high, and medium/low) add 509 deaths over and above the number expected. Therefore, without the overprediction by these three scenarios the total deaths would be 624 (predicted) vs. 770 (statistics). Also, the flaming model results would be 544 rather than 1053. This means the other scenarios underpredict the total by only about 20 percent, well within the limit of the method. This is indicative of the power of this type of methodology in helping us understand the reasons for the results and where improvements can be most effectively made.

3.3.1 Judging the Quality of Agreement

What is considered "good agreement" is often subject to argument or at least to individual interpretation. As the risk method is applied, comparisons to incident data (using 5 year averages to smooth out the influence of individual fires) are made to calibrate the "base case." The "new product case" involves comparisons to both the incident data and the base case. In each area, these comparisons involve both absolute numbers (of deaths) and distributions (X% smoldering and Y% flaming). Obviously, criteria are needed for judging the quality of such comparisons.

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 different 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. Pending more experience, we therefore propose that numerical differences of less than 10% are considered "excellent", between 10% and a factor of 2 (100%) are "good", and greater than a factor of 2 are "poor."

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.

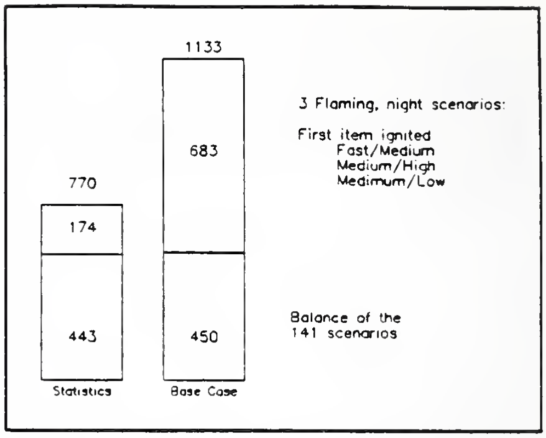

Figure 9 - Impact of selected scenarios on results.

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 systemmatic 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.

In this case, Figures 4 and 7, if combined, indicate that the predictions were within 25% of the actual fire death rates. This is the best degree of correspondence found in any of the cases. Part of the reason is that the numbers are large enough (over a thousand deaths per year) that percentage differences on the order of 25% are meaningful in terms of numbers of deaths.

Based on these results, the authors suggest that risk differences between the baseline and new product would have low statistical confidence if they were less than 10%. Differences on the order of 10% to 50% would be considered significant if they proved to be stable under sensitivity analysis. Differences over 50% would be significant even if sensitivity analysis shows them to be strongly influenced by assumptions.

3.4 Sensitivity Analysis

A selected set of studies were conducted to test the sensitivity of the results to changes in key assumptions. Since several of these factors could not be substantiated without extensive research well beyond the scope of this project, their importance was tested through variation in modeling.

The sensitivity studies performed covered the three input categories: occupant, fire modeling, and building. The occupant variables examined focused on assumptions related to escape through windows and rescue by persons outside the residence, smoke awareness at night and location of occupants impaired by alcohol at night. Fire modeling variables included the extent of the smoldering period for upholstered furniture and the impact of breaking of a window in the fire room at flashover, providing an additional source of oxygen. And finally, we looked at the sensitivity to a change in the building size (volume).

3.4.1 Occupant Sensitivity Studies

When an occupant exits the building, reaches a window, or dies, the program records the time, the room, the occupant's condition (dead or alive), the cause (if applicable) and the level for each of the tenability measures. In the risk software, occupants reaching windows are treated as being in the room at the window, until evacuation through the window is achieved. In this way, the tenability measures will continue to be computed and the occupant is exposed to the fire's effects. Three evacuation alternatives were tested. The base case assumed that anyone reaching a window could immediately open the window and escape. We then examined the impact of allowing rescue by persons outside the house. As two other alternatives, we examined the effect of a delay time which varied for each occupant category, and during which exposure to room conditions continued. These delay times (chosen to be consistent with other delay times in EXITT) are shown below:

Occupant	Delay Time (Seconds)
Adult	20
Elderly	40
Older Child	20
Younger Child	60
Baby	Infinite
Disabled	Infinite
Intoxicated	40

In addition, the third alternative assumed that all persons still in the house and alive ten minutes after the first person escaped would be rescued. The results are shown in Figure 10.

The most pronounced effect of adding a delay time to window escapes was for the faster acting flaming fire scenarios, where the death prediction is increased by 68 persons. The smoldering fire scenario prediction also increased by 28, producing an overall increase of 96 deaths or about 15 percent. The additional provision for rescue (10 minutes after the first evacuation) only reduced the total by 4 deaths. Thus, we feel that the addition of a delay time at windows may be significant, but allowing for rescue is not.

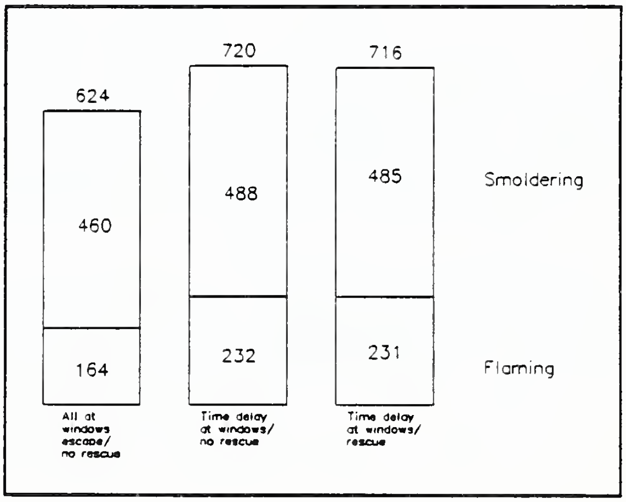

Figure 10 - Sensitivity of Evacuation Alternatives.

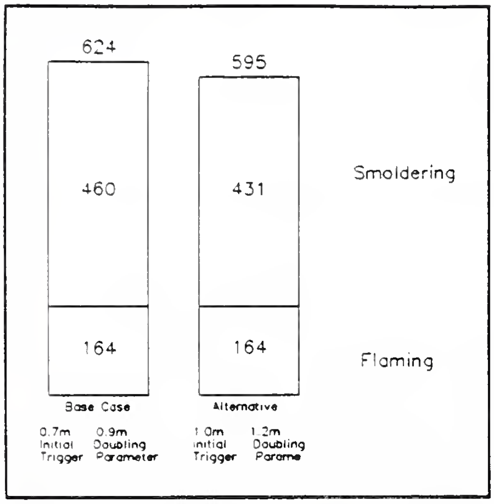

Figure 11 - Sensitivity of smoke layer height on results.

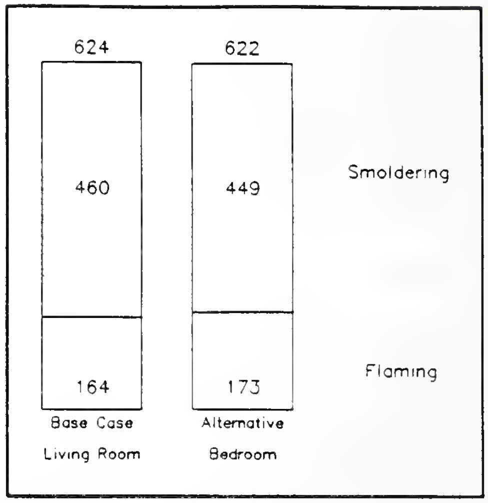

Figure 12 - Sensitivity to location of Intoxicated.

Next we examined the sensitivity of the modeling of how an occupant becomes aware of the fire when asleep, and in the absence of a smoke detector. The EXITT model uses a parameter (height of smoke layer above the floor) to convert smoke density from the FAST model to a factor which alerts sleeping occupants. The base case used 0.9 meter as an initial trigger, with the strength of the stimulus doubling at 0.7 meter. The alternative used a 1.2 meter initial trigger with 1.0 meter doubling trigger. Figure 11 shows that the smoldering fire deaths were decreased somewhat, while the flaming fires remained unchanged. An overall decrease of five percent indicates this occupant modeling parameter is not important within this range.

The third and final occupant sensitivity study addressed the location of the occupants intoxicated by alcohol at night. The base case assumes all such occupants are asleep in the living room. The alternative placed the intoxicated people asleep in the master bedroom. Figure 12 indicates the totals are virtually unchanged and, therefore, location of those intoxicated is not important.

3.4.2 Fire Modeling Sensitivity Studies

The first fire modeling study addressed the effect of the assumed duration of the smoldering period prior to flaming. A question was raised as to how sensitive these cause of death results are to the length of smoldering. In the base case, the upholstered furniture ignited by cigarettes was modeled as a smoldering ignition assumed to smolder for 45 minutes prior to a transition to flaming. This was followed by growth through the various extent of spread classes, and eventually to flashover if appropriate to the class. No occupants died during the initial 45 minutes, and after transition to flaming the cause of death was always convected heat, although lethal smoke toxicity (Ct) followed within a few minutes.

To test the sensitivity of the result to the assumed 45 minute smoldering period, the bedroom and living room upholstered furniture fires were run as three hour smoldering fires without transition to flaming. The base case results predicted no deaths when the fire was confined to the upholstered furniture (45 minutes of smolder followed by transition to flaming, raising upper level temperature to 100 °C). The three hour smoldering fire, however, resulted in 3 deaths - all in the bedroom fire scenarios and all caused by smoke toxicity. Therefore, we see that a three hour smolder period does not add a significant number of deaths, but the deaths occurring are now caused by toxicity.

The second fire modeling change addressed the phenomenon of ventilation-limited fires at flashover. In the base case, the fires become oxygen starved near flashover. This is because there is only minor leakage of air into each room with the windows closed. This oxygen limitation can prevent the simulation from reaching the 600 °C (flashover) level or even cause the temperature to decrease rapidly in the fire room soon after reaching this level.

The sensitivity alternative consisted of breaking out a window at the time when the flux to the floor reached 2.5 watts/cm^2 (flashover). This allowed the temperature to continue to increase after the window breaks. However, the additional ventilation and higher resulting temperature produced *no* change in deaths from the base case. This means that the conditions in the house were already beyond the point of survivability at flashover and the additional heat generated did not contribute to further deaths. For larger homes where occupants might survive at more remote locations, we might expect that window breakage might have a more adverse impact on the death rate.

3.4.3 Building Sensitivity Analysis

Various studies have indicated that fires occur more frequently among the lower socio-economic population segment. These families tend to have smaller homes. The base case house has 6 rooms. To test the influence of reducing the number of rooms and total volume, the base case house was modified by eliminating a small interior room, thereby also reducing the total volume by 10 percent. Figure 13 indicates the total deaths increased by 22 percent from 624 to 762. Since flaming scenario deaths remained virtually unchanged, the entire increase occurred for the smoldering fire scenarios. The reduced volume acted to concentrate the fire effects and trap additional occupants. The major change occurred for smoldering living room fires at night.

As Figure 14 demonstrates, the smaller house prediction for deaths where the extent of spread is confined to the room of origin was 52 deaths compared to 7 for the base case. When flashover fires are considered, the smaller house yields 509 deaths compared to 414 for the base case. This accounts for the predicted increase. Thus, house volume is an important parameter, since the analysis indicates that a 10 percent decrease in volume increases deaths by 22 percent.

3.5 Summary of "Base" Case Results

We have seen that for the scenarios where upholstered furniture is ignited first, the "base" case total death prediction is in good agreement with the estimates from the national fire database. This agreement extends not only to the total deaths but also to the fraction of deaths attributable to smoldering and flaming fire scenarios. We do not do nearly as well when predicting deaths by time of day - overpredicting the number of deaths in night time scenarios.

When items other than upholstered furniture are ignited first, we overpredicted the total deaths by approximately 50 percent. A more fine grained analysis revealed that three night time flaming scenarios out of 144 accounted for the entire overprediction with the remaining 141 scenarios combined underpredicting by about twenty percent. This may be attributable to misclassification of the items in the three scenarios.

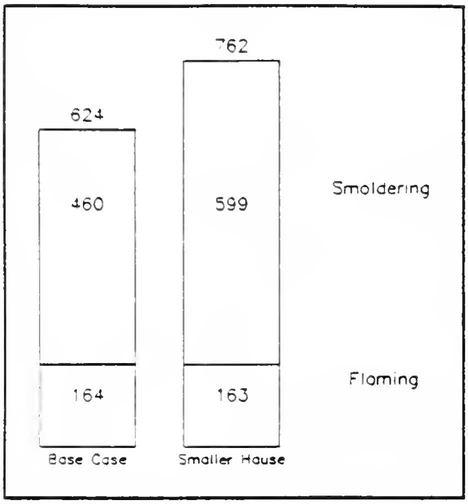

Figure 13 - Sensitivity to reduced house volume.

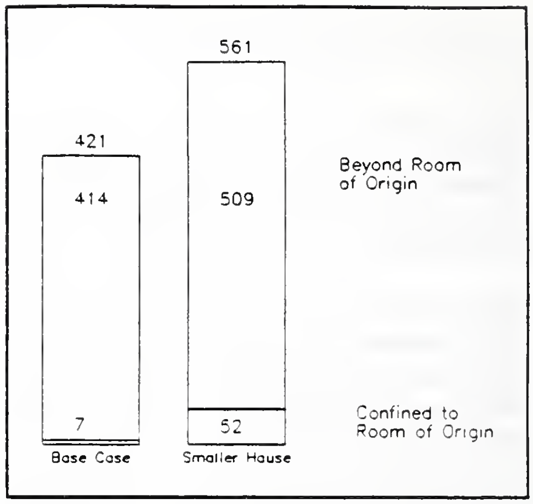

Figure 14 - Reduced volume for smoldering, by extent of spread.

Sensitivity studies relating to occupants addressed three input factors, evacuation/rescue, alerting based on smoke height, and location of intoxicated occupants. We noted that allowing rescue 10 minutes after the first person escaped had virtually no effect on results, while adding a delay time for each occupant to escape from windows increased predicted deaths by 15 percent.

Changing the smoke layer height at which occupants are alerted at night from 0.9m to 1.2m and changing the location of those intoxicated by alcohol from living rooms to bedrooms made a negligible difference in results.

Sensitivity studies for fire inputs addressed smolder time for upholstered furniture and ventilation limited fires at flashover. Increasing smolder time from 45 minutes to three hours resulted in very few deaths during the smolder period all caused by toxicity. Breaking the window in the room of fire origin at flashover (at 2.5 watts/cm^2), while dramatically increasing upper layer temperatures, had no effect on deaths in the ranch house. This most likely would not be true for larger buildings. But in the ranch house, those physically able to escape were out of the house and those remaining at flashover were either already dead or unable to escape.

The building size sensitivity study produced the most dramatic effect. Decreasing house volume by 10 percent increased deaths by 22 percent.

4. Description of Method Implementation - The "New" Product Risk Computation for Upholstered Furniture in Single Family Dwellings

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

The "base case", once completed and sharpened, 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 results with the base case. It is assumed that the "new" furniture is completely substitutable for the furniture in use and that changes in the product do not affect who will buy it or what kind of home it will be in, etc.

4.2 Modeling Changes in the Fire Properties

Changes in the product's fire properties result in changes to the fire hazard and risk results. Changes in ignition resistance for the "new" upholstered furniture would change the scenario probabilities. Ignitability influences both the propensity for primary ignition from the various possible heat sources, as well as how the upholstered furniture contributes when other items are first ignited. With respect to the propensity for primary ignition, the "new" upholstered furniture would be subjected to the same battery of ignition tests (one for each of the representative heat sources) as the base case furniture. The results of the laboratory tests will be compared with base line results to obtain a ratio of the "new" furniture's overall propensity to be ignited to the overall propensity for the base line mix of products. This ratio is used to adjust the scenario probabilities where upholstered furniture is the first item ignited. This procedure is explained in detail in Appendix A of the methodology report.

Changes in ignitability also influence the probability of secondary ignition. As previously discussed in Section 2.3.4, changes in secondary ignition of the upholstered furniture 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 upholstered furniture 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 furniture'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" upholstered furniture, 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 the new furniture is analyzed for the daytime and evening cases, 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. However, at night time, if the fire's effects are the intervention trigger, then the *total* energy (area under the heat release rate curve) released is more appropriate as the criteria for intervention, because energy release corresponds to the noises of fire which tend to awaken occupants. Changes in the upholstered furniture can dramatically alter the course of the fire. Intervention can now occur after flashover or after the fire has already died out.
In addition, changes in the upholstered furniture's fuel load may lead to reductions in fuel load for a room, such that it is insufficient to achieve flashover. The total "base" case fuel load for the room is adjusted by subtracting out the "base" case upholstered furniture contribution and adding back the "new" furniture's fuel load.

Finally, toxic potency and smoke density are important factors which are input to the HAZARD I model. Toxic potency is a tenability limit used to assess the occupant's ability to survive the exposure to the fire atmosphere, while the smoke density impacts the occupant's ability to evacuate.

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

For this example, we have selected "new" upholstered furniture with the same fire properties as the "base" case. However, the materials used in the "new" product result in smoke with a ten-fold increase in toxic potency (90 mg-min/ℓ) over the "base" case. This means that the lethal level of smoke is reached earlier in the fire with less fuel burned and with a lower upper layer temperature. Our example will model the primary ignition of the furniture in living rooms and bedrooms.

Figure 15 compares the results, indicating a 46 percent predicted increase from 624 to 909 deaths, with the cause of death dramatically changed. Smoldering fire scenarios contribute three-fourths of the increase while flaming scenarios contribute the remaining one-fourth. For the base case, the cause of death was always convected heat. However, as Figure 15 indicates, toxicity (Ct) is now the causal factor in 96 percent of the deaths.

It is evident from these results that the risk methodology will respond to gross changes in toxicity both in terms of the number of deaths and the cause of death.

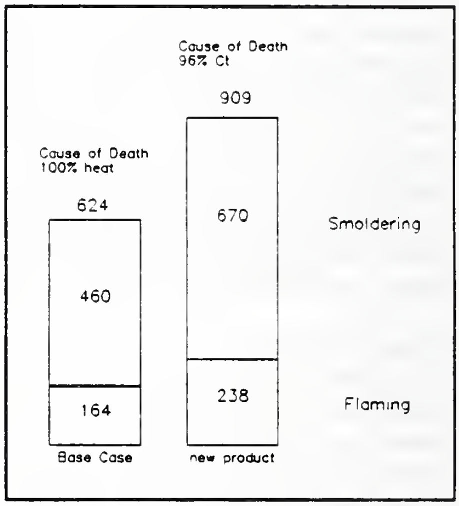

Figure 15 - Changes in death rate and cause for the "new product"

5. Conclusions and Observations

In this report, we have described the initial application of a quantitative method for the estimation of the fire risk associated with a specified product class in a specified occupancy. This initial case study provided a benchmark against which the prototype risk prediction method's capabilities could be measured against the goals of the project as originally conceived. In some cases, the performance of the method was better than expected for the first application. In others, differences were attributable to shortcomings in the method arising from a lack of technical knowledge of fire phenomenology or a lack of detail in required data. Thus, this effort was beneficial in identifying key needs for improved fire science or data.

In particular, this first trial demonstrated the ability of the risk method to provide a reasonable agreement with the national estimates for fire losses, including detailed demographic breakdowns for death rates by type of housing, time of day, age group, detector presence, and type of ignition. The method provides a structure for developing detailed fire scenario descriptions which include not only primary ignitions as documented in current incident databases, but also secondary product involvements which have never before been addressable. And the method succeeded in providing a mechanism by which nearly all of the important properties of a product are accounted for in the context of its end use. Properties of products 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. Although not a focus of the project, the effect on societal risk of such factors as market penetration or sales demographics could be examined using the method.

Sensitivity studies performed as part of this case study showed that, for this case, the method was insensitive to:

- occupant inputs relating to rescue by the fire department,

- the smoke height assumed to alert sleeping occupants where there is no working smoke detector,

- fire inputs relating to the assumed length of smoldering prior to initiating of flaming combustion in the upholstered furniture, and

- the addition of additional oxygen at flashover through the breaking of windows by the fire effects.

The methodology proved sensitive to changes in the assumed volume of the ranch house and to order of magnitude changes in toxicity of smoke. As a result of the work described herein, improvements to the risk method were identified and implemented.

The exercise of the method on this case study revealed few areas where the state-of-the-art in fire science was lacking. This was expected since this first case was selected to be compatible with the scope of HAZARD I. However, the case did identify many areas where current data collection systems were lacking. 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 three case studies (carpet in offices, concealed combustibles in hotels, and interior finish in restaurants) were selected to stretch the method in the areas of modeling not stressed in this case. Thus, the reader is invited to proceed to these cases, each published in a separate report.

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

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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