Development of a Method for Predicting the Fire Risk of Products

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Abstract

A method of predicting risk is described which uses prototype product and occupancy characteristics as a basis for calculating fire hazard by deterministic modeling. Reported fire experience is then applied to predicted hazard to yield prediction of fire risk. Some results of the method's application to residential furniture are described.

1.0 Introduction

This paper describes the work of the National Fire Protection Research Foundation's Project on Fire Risk. The objective of the project is to develop a quantitative method for predicting the expected life safety risk associated with the use of new and existing products. "Product" is defined as an item capable of being evaluated by laboratory-scale fire performance tests and therefore generally does not include building design features. Fire death is the measure used to quantify life safety risk. In practical terms, the method seeks to predict the fire death rate associated with classes of items amenable to laboratory fire testing and for which the experimental fire experience associated with their use is reported.

In the following sections, the logic and design of the method will be described, followed by a brief description of results applied to a test case: residential upholstered furntirue.

2.0 Description of the Method

2.1 Overall Logic

Reported fires incidents and fire deaths can be classified by scenario, i.e., by commonalities of item ignited, ignition source, etc. The number of fire deaths associated with each fire scenario involving a product in an occupancy is:

D_i (number of deaths) = n_i (number of fires of scenario type i) x d_i (average number of deaths per fire in scenario i)

The total number of deaths is then the sum over all scenarios involving the product. The method attempts to predict D_i for the important scenarios by calculating D_i, the deaths per fire, a severity measure which can be in principle determined by the fire properties of the product, the environment in which it burns, and the capabilities of those expsoed to the fire. The method does not attempt to predict n_i, but uses fire experience.

The scenarios must be formulated in a manner which corresponds to the terminology used in fire statistics. Fire statistics almost never report the performance of a single product, but the performance of an entire class of item-first-ignited. In the absence of knowing the type and frequency of occurrence of each type of product included in a given class, some estimate must be made of the composite, or average, properties of products now in use. If this estimate can be made, and if a hazard calculation using these properties reproduces the number of deaths per fire actually observed, this is evidence that the hazard prediction method for the produce is reasonable. Once a tested hazard prediction is in hand, it can be used to predict how much improvement or deterioration in life safety is associated with products having a given set of fire properties, using the level of risk associated with existing products (and properties) as a reference.

2.2 Steps in the Process

2.2.1 Step 1 - Choice of Product and Occupancy

Some products and occupancies are more likely to give satisfactory results than are others. The product of study must have an analogue in current use, from which it may differ in fire properties and size, but not in intended use or location. It should appear specifically or be contained within the list of items-first-ignited used as a basis for categorization in NFPA 901.

The first case chosen was residntial upholstered furnishings. Specifically, the effort is confined to furnishings in one- and two-family dwellings. This case was chosen first because, upolstered furniture fires have been relatively well-studied in the laboratory, and test methods have been developed which address specifically their burning characteristics. Second, there exist relatively abundant data on which to attempt to validate the finished assessment.

2.2.2 Step 2 - Fixing the Occupancy Characteristics

The result of this step is to identify, and describ for fire-modeling purposes, one or more prototype occupancies in which the fires involving the product will occur. The first task in this step is to decide on the number of prototypes needed. For example, housing statistics show that about 70% of 1 and 2 family housing had the living space on one floor and almost all the rest were two-storied, so two prototypes were thought necessary to represent fire buildup in residences. The information needed to model residential occupancies, the source of the informtion and the rationale for the many estimates which had to be made in the absence of data, are all compiled in brief in Table 1.

2.2.3 Step 3 - The Scenario Generator - Expressing the Scenarios in Fire Reporting Terms

To relate to fire experience, severity must be calculated for scenarios for which the numbers of fires are reported. Fires are characterized in the NFPA 901 Reporting System (as well as national systems used in many other countries) by item-first-ignited. The severity of a reported fire is classified by one of fire levels of flame spread: confined to the object of origin; extending beyond the item of origin in the immediate area of origin; extending beyond the area but not involving the entire room; spreading beyond the room of fire origin; and, finally, spreading beyond the floor of origin.

The extent of flame spread is used to infer quantitative information. Conditions for facile flame spread beyond the object of origin can be viewed as requiring some minimum level of radiatn heat flux imposed by the hot upper layer of the room, approximately 1 kW/m^2, which requires an upper layer temperature in the room of approximately 100°C thus, spread confined to the object of origin will produce conditions below this level. The method defines fires in which the flame spread is confined to the area of origin to be receiving radiant flux of aobut $3kW/m^2$, which corresponds to an upper layer temperature of about 200°C. At radiance levels in the neighborhood of 15 kW/m^2, remote ignition of combustibles begins to occur, and this is defined as the onset of spread throughout the room of origin: an upper layer temperature of 450°C corresponds to this radiance level. Similarly, spread beyond the room of origin occurs between 450°C and 700°C.

Relating upper room temperature to the extent of spread provides a crosswalk between four spread classifications and the estimates of fire size. If the fire is curtailed by extinguishment, or by its own failure to spread, then its temperature profile in the room is described by the curve at the left in Figure 1. The height to which it grows is the temperature it reached before declining. The maximum temperature a reported fire reaches is taken to be 100, 200, 450, or 700°C, depending on whether the fire is confined to the object, the area, the room, or goes beyond the room, of fire origin. Using the results of room fire modeling (1), it is possible to define a heat release curve with a shape which produces the temperature profile required in each scenario. The slope of the heat release rate curve is controlled by the fire buildup properties of the product ignited and the other combustibles in the room. Its peak is the size it reaches before the room temperature exceeds the criteria just discussed. For fires leaving the room of origin, the maximum rate of burning is defined by the size of the doorway; the duration of burning is controlled by the room's fire load. The four heat release curves, one for each degree of spread allowed in the scenarios, are also illustrated in Figure 1. Since scenarios described this way are associated with a reported number of fire incidents, the result is a way to marry frequency with severity - i.e., a way to calculate risk.

2.2.4 Step 4 - Designing the Fire Model

1. General Considerations

Several relatively versatile, well documented, compartment fire models now exist, and the one used in this work is FAST (Fire And Smoke Transport) model developed by the Center for Fire Research, National Institute of Standards and Technology (2).

The FAST model uses the heat release rate curve for the room of fire origin developed in Step 3. The model calculates the temperature and flows in a compartment network of specified dimensions, geometry and heat transfer properties. In addition, smoke characteristics in the network, such as toxicity and obscuration, are estimated if the heat of combustion smoke toxic potency and smoke mass optical density are provided for the materials burning. The input data needed to construct the room heat release rate curve and determining tenability are listed in Table 2.

The fire scenarios discussed previously have all presupposed that the product immediately begins to flame once ignited. This need not be true of upholstered furniture which, if directly ignited by a cigarette, can undergo smoldering combustion. Smoldering scenarios were modeled by attaching a smoldering period of this duration tot he beginning of the burn curve.

The parameters needed to specify furniture's contribution to fire growth are: its resistance to cigarette ignition (presently a pass-fail determination); the rate of fire buildup determined by the method of Babrauskas using the cone calorimeter (3); the heat of combustion and the peak heat release rate of the material, the mass optical density of the smoke produced; and the toxicity of the smoke.

To deal specifically with the scenarios in which the upholstered furniture is secondarily ignited from another item, the average distance that the furniture would be from other sources of ignition (i.e. other items first ignited) was estimated by a panel of fire experts. The ignitability of the furniture, also determined from the cone calorimeter, is used to determine the flux needed to ignite the product. Once these data are provided, it is possible to define heat release curves for all room fires in the scenarios where upholstered furniture will be involved. The FAST model then computed the temperature movement of smoke throughout the prototypical residences as a function of time. From these considerations subsequent portions of the method can determine the effect of the fire on residential occupants.

The fire load commonly found in residential occupancies is more than sufficient to carry to flashover any room in which upholstered furniture is likely to be found. Furthermore, the size of the overall residence is sufficiently small that, once a fire reaches flashover, lethal conditions throughout the house are quickly reached. Therefore, it is unnecessary in this particular case to describe the fire in detail once it spreads beyond the room of origin.

2.2.5 Step 5 - Describing Escape Capabilities of Occupants

The characteristics of occupants likely to be found in a given structure are used to construct occupant sets. Each occupant set is one possible population of the structure. Describing the occupants in terms of the speed at which they move, their capacity for unaided escape, and the ease with which they are alerted; the various sets are weighted based on their probable occurrence in the building population. The characteristics of family and non-family households with up to seven members is available from census reports (4). In addition, occupant sets have been adjusted to reflect the likelihood of one or more such people being temporarily incapacitated by drugs or alcohol. In total, over 200 different occupant sets have been identified to help describe the makeup of American residences.

The actual escape capabilities of these occupants from the residences was modeled using an existing evacuation model, EXITT developed at the National Institute of Standards and Technology.

2.2.6 Step 6 - Evaluating Effect of Fire Conditions on Occupants

The method uses three criteria for the cessation of further unaided efforts to escape: accumulated temperature exposure which incapacitates the victim, sufficient heat flux to cause severe thermal injury, and inhalation of a lethal dose of smoke, based on its $L(Ct)_{50}$, or smoke potency.

Each occupant is followed through the occupancy and the temperature, radiant heat flux and smoke concentration to which the occupant is exposed is continuously recorded. When one of the criteria for cessation of escape is exceeded, escape is stopped.

The smoke toxicity of the product is an input to this model. In many fires, material in addition to the product is burning, and for such materials the toxicity of the smoke is assumed to be 900 mg minutes per liter. The photometrically determined smoke obscuration, (the optical density of the smoke) is used in the residential evacuation model to slow down or stop efforts to escape, but is not in itself a criterion for fatality. Tenability criteria do not change from case to case.

2.2.7 Calibrating the Model - The Base Case

The computational method is first used to predict fire experience for the version of the product now in use - the "base case". One or more prototype products must be identified which represent what appears in the present environment and thus has determined present fire experience. The estimated product characteristics which control the fire behavior of the upholstered furniture now in use are listed in Table 3. Most of the values were assigned by an expert panel drawn from the advisory committee, using values obtained by Babrauskas (4) and market survey information compiled by the Consumer Product Safety Commission. According to the survey, about 60% of existing furniture is of "older" manufacture-cellulosic upholstery, cotton batting and urethane or latex foam cushioning. Furniture which is covered with thermoplastic fabric - some 40% of existing stock - does not usually ignite by cigarette, but when alight, it grows rapidly and has a high peak heat release rate. Benchmark values of fire properties are simply a weighted average of the two types.

2.2.8 Step 8 - Prediciting the Fire Risk for a New Product

Once a satisfactory representation of the base case has been obtained, the same hazard model can be used to predict the risk associated with a product of any specified set of fire properties. This is accomplished by replacing the properties of the prototype base case product with those representing the new or test product and carrying out the same calculations, leaving unchanged the balance of data used (see Table 1) prediction is the risk associated with the changed set of fire properties.

3.0 Results and Discussion of Residential Furnishings

3.1 General Observations and Simplifications

For residential furnishings, a complete analysis requires simulating fires within the following combinations:

> Employing 2 types of residences - a one story ranch house and a two-story occupancy; starting the fires in 5 different rooms - living room, bedroom, kitchen, dining room and storage area; drawing four kinds of heat release curves - fires in which the furniture was the first item ignited from a flaming sources, from a smoldering source, fires where the furniture was the second item ignited (9 possible fire growth patterns) and fires where the furniture was present but did not ignite unless the fire involved the whole room (9 possible fire growth patterns)

This gives a total of 200 modeling runs for the base case. Each fire was subdivided into four levels of spread, effectively producing 800 fire scenarios. Each of 220 occupant sets is evaluated for escape from each fire. Thus, a total of over 160,000 outcomes are possible. In addition, escape was evaluated both in the presence and the absence of working smoke detectors.

As a practical matter, not all of these fires are of equal importance in fire deaths. Computation was confined to those rooms and those fire types which fire experience identified the major actual contributors to fire death. About 50% of the total number of possible calculations have been performed, but they account for over 90% of the reported.

3.2 Results

Upholstered furniture is categorized by sequence of ignition - first or second item ignited. The results for items first ignited are presented in Tables R1-a and b. The severity of smoldering fires is slightly under predicted while the impact of flaming is over predicted. The most apparent explanation for this fact is that only cigarette ignitions are classified as smoldering ignitions, when in fact it is known (see Babrauskas) that cellulosic furniture stock often burns in a smoldering or semi-smoldering mode, even when ignited by a flaming source. Also, smoldering ignitions are probably under-reported.

The under-prediction of smoldering risk could also be due to two factors: too high a $L(Ct)_{50}$ in the base case or too short a smolder time. Changing the $L(Ct)_{50}$ to a lower value, however, would be both arbitrary and probably have more effect on the mode of death than the number of deaths. This is because incapacitating temperature, depleted oxygen and accumulation of a fatal smoke dose all occur fairly close together in time.

Table R1-b classifies the results further by time of day. The reported numbers indicate 60% of deaths occur at night while the method predicts 90%. This result certainly is an effect of the location and behavior distribution of the different occupant types. For example, the method assumes all occupants are awake during the day; only the elderly are asleep during the evening; and all occupants are asleep at night. In fact, many children and some adults are asleep during the day, and vice-versa.

Prediction for furniture that is secondarily ignited are similar. Table R3-a indicates more deaths calculated than reported due to flaming and the reverse trend for smoldering. However, this time the difference is substantial - calculations are off by 50 to 70%. Three of the night living room scenarios. These three scenarios which represent fast and medium fire growth at the onset account for half of the deaths in Table R3a. A total of 164 deaths are expected from statistics while 643 were calculated. If some of the first-items ignited are mis-classified and in a category where their burn characteristics are less intense, or the categories are clumsily formulated, the predicted deaths would be too high.

The possibility that that some of the furniture fire growth rates are chosen too high dramatically illustrates the sensitivity of the situation to the fire growth rate of the item ignited. Since most people require an irreducible minimum amount of time to escape, any fire which produces untenable conditions in a time comparable to that needed escape time is very dangerous. A small increase in buildup rate can mean a big change in lethality. If the onset of lethality moves from "just after" to "just before" escape is accomplished, a large difference in deaths per fire is observed.

3.3 Residential Upholstered Furniture Sensitivity Studies

Once the base case for upholstered furniture was established, several studies were performed to test modeling parameters and assumptions.

In the base case, a person reaching a window was assumed immediately to escape through the window. Alternative assumptions build in a delay time before evacuating and permit rescue 10 minutes after the first person evacuates. Results indicate a 40% (720 vs. 624) increase (over the base case) in deaths due to flaming ignition and 6% (488 vs 460) for smoldering ignition when a delay time in escaping through a window is added. Almost no additional effect is seen even when rescue is available. Early escape (perhaps through a window) is more crucial to survival than being rescued later on.

According to the method, a person who is asleep may become aware of a fire because of smoke detector actuation, smoke layer height, or the smell of smoke. The base case uses a layer height of 0.9 meter as an initial trigger. The alternative examines the effect of higher smoke level (1.2m) (i.e., earlier notification).

Not surprising, the total death numbers are lower when persons are alerted at a higher smoke level, Table S1-b. However, the effect is only noticeable (an increase of 7%) for smoldering fires. Flaming fire deaths were essentially not affected.

In the base case, the occupants who are intoxicated by alcohol are asleep in the living room at night. The alternative places them in the bedroom. This produces a decrease in smoldering deaths due and an increase due to flaming fires but, the net result is that the total deaths are virtually unchanged (622 vs. 624).

Houses where fires occur frequently are small. The base case ranch house contains six rooms. To observe the effect of smaller house the house volume was reduced by 10%. The effect is an increase in the total number of deaths, due to a 30% increase in deaths due to smoldering. Reducing the house volume effectively increases the smoke concentration, so for smoldering fires, where smoke quantity is an important factor more deaths can be expected in a smaller house.

An open window intensifies the fire. In the base case windows remain closed at flashover. The effect of opening a window at a heat flux of 2.5 watts/cm^2 is negligible. This is because, by flashover, survival is minimal, so aggravating the fire condition at that point has very little effect.

The under-prediction of smoldering fire deaths in the base case prompted a test of the results when the smolder period was extended to 3 hours. With a 3 hour smolder period alone, three additional deaths are predicted. All the deaths are in the bedroom and are caused by smoke toxicity.

The $L(Ct)_{50}$ value (900 mg-min/l) that was used in the base case is not well-established. If it is too high deaths due to smoldering ignitions would be under predicted, so a test of the effect of decreasing the product dose to 90 mg-min/l was made such a decrease leads to a 45% increase in total deaths. The effect is similar for both smoldering and flaming fires. The majority of the deaths (about 96%) are due to smoke toxicity compared to zero percent in the base case.

4.0 General Discussion and Outlook

The risk method described here is an attempt to direct the enormous amount of fire science and technology developed in recent years to help describe fire hazard to predicting fire risk. The approach chosen is to view the world as if it were made up of a few kinds of fire, each occurring many times, which produce observed fire experience. This assumption may not be correct: it is possible that a small fraction of "bad actors" actually accounts for a disproportionately large share of losses. To the extent that his bias does exist it makes the method "conservative" because an acceptable model must produce real fire experience from the benchmark product. It will make a new product's performance appear somewhat worse than it really is - - and will make a product with the properties of the "bad actors" appear awful.

However, the effects of such a possibility are reduced because of the use of expert panels that includes fire professionals. This group would see the bad actor more often than often it actually occurs in the marketplace, so its properties implicitly color their view of the "average" product.

The other fact arguing against a badly-skewed base case calculation is the fact that fire experience shows that losses come disproportionately from the larger fires. These almost always involve more than the preoduct alone, so its effects are felt as part of the total burning assemblage.

Another key assumption is that it is possible to predict fire experience based on a probabilistically weighted set of deterministic models. It is assumed that fire deaths are caused by the effects of average, typical or "composite" products. The reason deaths per fire are relatively low, then, is that the fires these products produce rarely are encountered by someone with the vulnerability to succumb. For example, in residences none of the fire scenarios, even the most severe, always kills everyone in the house: only those who are warned too late or unable to escape unaided. The sensitivity of the model in predicting death therefore depends not only on the ability to correctly model the fire's physical characteristics, but also on the refinement of the occupancy sets - the more detailed they are, the more "sensitivity" the method has. The prediction method works less well if less is known about the makeup of occupants.

Resolution can be improved by doing either or both the following:

Postulating scenarios, which are more unlikely but at the same time more severe in the fire environment they provide;

Building more detail in occupancy sets; for example, by describing those who are in the building out of working hours, those who are disabled, etc.

The limitation on these two efforts is that the data needed to assign probabilities to such scenarios and occupancy sets are not readily available, and it is laborious to collect them. However, one can use the method to estimate how <u>changes</u> in the product would impact risk by identifying the product characteristics which would be needed to raise the fire risk above zero. Obviously, how sensitively the method does this would still depend on its ability to discriminate effects.

Thus, the method can be applied most easily to occupancies about which much is known - - both as respects fire experience and occupant capabilities.

This is not to say that the method is not just as useful (or even more useful) for other occupancies, but making it useful to predict risk takes data which may be harder to find.

References

1. c.f., McCaffrey <u>et</u> <u>al</u>, Estimating Room Temperatures and the likelihood of flashover using fire test data correlations, <u>Fire Technology</u>, <u>17</u>, 198 (1981).

2. Jones, W., "A Multicompartment Model for the Spread of Fire, Smoke and Toxic Gases," <u>Fire Safety Journal</u>, <u>9</u>, pp. 55-79 (1985).

3. Babrauskas, V., Krasny, J., "Fire Behaviour of Upholstered Furniture," National Bureau of Standards, Gatihersburg, MD, November 1985.

4. U.S. Bureau of the Census, Current Population Reports, Series P-20, No. 411, <u>Household and Family Characteristics:</u> March 1985, U.S. Government Printing Office, Washington, D.C., 1986.

TABLE 1

Occupancy Characteristics Needed for Risk Analysis Method

Information Needed	Source of Data or Basis for Estimate	Rationale for Estimate or Assignment
Number of prototype occupancies	Expert panel identified two prototypes-single and 2-story house; census data provides population in each prototype	Movement of smoke and heat between rooms may be slow in comparison to its movement up a stairway. Residents trapped on second floor may have to use windows for escape; those on single floor can use doors as well.
For each prototype: Floor area, size and layout of roo	Housing census/expert panel	Housing data gives number of rooms, panel estimated room size of each
For each prototype: Number of floors	Housing census	Almost all 1 and 2 family dwellings are 1 or 2 floors; single apartments not part of analysis, those outside of dwelling unit are not at risk.
For each prototype: Location and number of exits	Expert panel identified single exit from ground floor of house	Most of population lives in dwellings with one or two exits on ground floor. Preliminary calculations show that escape of occupants is relatively insensitive to presence of a second exit. Use of windows as exits and possibility of rescue was not estimated, but examined as a sensitivity issue.
For each prototype: Location and number of windows	All windows to vent fire and smoke assumed closed	Although windows will break in fire room, this will generally occur after lethal conditions are reached. Flow of smoke into rest of structure is relatively unaffected by window status.
For each prototype: Whether doors between compartments are open or closed	All doors between compartments assumed to be open	No good basis for assigning door status. Sensitivity analysis carried out for residences shows that closed doors have little impact on fire deaths.

FIGURE 1
Room temperature showing
cutoff levels for limited spread

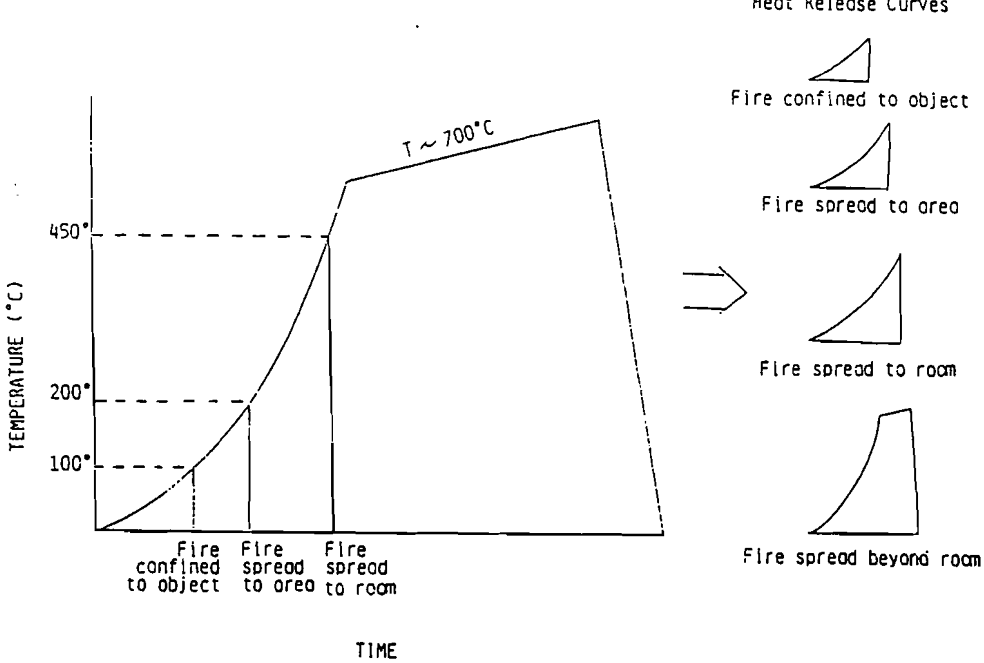

TABLE 2

Input Data Needed for FAST Fire Model

A. For Construction of Room Heat Release Rate Curve		
Quantity Needed	**Significance**	**How Obtained**
1. Mass of Product	Determines length of time product burns, and its total contribution to heat release	Measurement
2. Ignitability: Resistance of product to cigarette ignition	Determines whether product will appear in scenarios where cigarette is ignition source	Measurement
3. Ignitability: Resistance of product to flaming ignition	Determines whether product will ignite secondarily in scenarios when it is not first item to ignite	Measurement - minimum flux for ignition via cone calorimeter or LIFT apparatus
4. Rate of increase of heat release rate of product	Determines how fast room heat release increases due product's contribution	Direct measurement using rate of heat release apparatus. Rate fitted to a quadratic expression, i.e., heat release proportional to square of time. In smoldering scenarios, a rate of smoldering is also required, as well as a smoldering time
5. Rate of increase of heat release for all other items first ignited except product	Determines room heat release rate and when product will be ignited when it is not first item to ignite; used with A-3	Assignment to one of three categories slow, medium or fast - by expert panel
6. Peak heat release rate of product	Determines product's maximum contribution to room heat release rate	Measurement in furniture calorimeter or calculation from surface area and measured heat release/unit area
7. Peak heat release of all items first ignited except product	Determines room heat release rate at early stage of fire when product may not be involved	Assignment to one of three categories - low, medium, or high - - by expert panel
8. Rate of increase for heat release rate for items ignited by product, or by other items first ignited	Determines room heat release rate at latter stages of fire	Assigned to be a universal value of 11 kW/sec², and allowed to continue to grow until room fully involved This crude approximation is justifiable in cases where product is no longer important source of fire and where no better information is available.
9. Distance of product from other items first ignited in room	Determines when, in combination with A-3 and A-5, product receives sufficient radiant heat to ignite	Estimated by expert panel
10. Room fire load, excluding product	Determines how long room fire burns	Estimated from published sources
11. Heat of combustion of product	Determines how much smoke produced per joule of product energy	Measurement by integrating heat release rate curves over time
12. Heat of vaporization of other items, not product	Determines balance of smoke produced by materials other than product	Assigned a value of 5 MJ/kg, which is typical of a 50-50 cellulosic-synthetic mix

B. For Determining Tenability and Predicting Escape of Occupants		
Quantity Needed	**Significance**	**How Obtained**
1. Smoke potency of product	Determines how much of product must burn before lethal smoke conditions produced	Measurement as L(Ct)50 or analysis of toxic combustion cases using N-gas methodology
2. Smoke potency of other items, not product	Determines contribution of other fuels toward buildup of lethal conditions	Assigned an L(Ct)50 value of 900 mg-min/l, typical of wood or polyurethane
3. Specific smoke extinction area (mass optical density) of product	Determines product's contribution to smoke obscuration, and thus speed of escape of occupants	Measurement by cone calorimeter modified NIST smoke box, or similar apparatus
4. Specific smoke extinction area of other items, not product	Determines contribution of other fuels to smoke obscuration	Assigned a universal value of 300 m²/kg

Table R1-a

Calculated vs. Reported Deaths
(Scenarios where furniture is the item first ignited)

	Flaming	Smoldering	Total
Reported	145	498	643
Calculated	164	460	624

Table R1-b

Breakdown of Calculated vs. Reported Deaths by Time of Day
(Scenarios where furniture is the item first ignited)

	Day	Evening	Night	Totals
Reported	180	83	379	643
Calculated	52	20	552	624

Table R3-a

Calculated vs. Reported Deaths
(Scenarios where furniture is secondarily ignited)

	Flaming	Smoldering	Total
Reported	617	153	770
Calculated	1050	80	1130

Table S1-a

Sensitivity Results for Evacuation Alternatives

Deaths	No rescue, no window delay (Base Case)	No rescue; window delay	Rescue, window delay
Total	624	720	716
Smoldering	460	488	485
Flaming	164	232	231

Table S1-b

Sensitivity Results for Waking Cues

Deaths	0.9 Meter (Base Case)	1.2 Meter
Total	624	595
Smoldering	460	431
Flaming	164	164

Table S1-c

Sensitivity Results for Placement of Intoxicated Persons

Deaths	Living Room (Base Case)	Bedroom
Total	624	662
Smoldering	460	449
Flaming	164	173

Table S1-d

Sensitivity Results for Decreasing the House Volume

Deaths	Base Case	Smaller House
Total	624	762
Smoldering	460	599
Flaming	164	163

Table S1-e

Sensitivity Results for Decreased $L(Ct)_{50}$ Value

Deaths	$L(Ct)_{50}$ = 900 mg-min/l (Base Case)	Bedroom
Total	624	909
Smoldering	460	671
Flaming	164	238

NOTE: 1. Cause of death in New Product Case is 96% smoke toxicity, 4% convected heat

2. Cause of death in Base Case is 100% convected heat