CONCEPTS FOR LIFE SAFETY ANALYSIS

by

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IN: The 7th Society of Fire Protection Engineers Symposium. Quantitative Methods for Life Safety Analysis. University of Maryland, College Park, MD. March 5-7, 1986.

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ABSTRACT

An overview of the need, methods, and resources appropriate for life safety analysis of fire hazards is presented. An outline of the elements of a fire hazard analysis system with appropriate references is given.

INTRODUCTION

In simplest terms the methodology of protecting life in case of fire is to assure that people and conditions that can harm people do not occupy the same space at the same time. This has been recognized as long as anyone has made an effort to analyze the relationship of buildings and design to human well being. In the U.S the real organization of this effort dates to the era of about 1910 through 1930. During that period the concept of the Building Exits Code and other means of regulatory codification emerged.

The code approach was and still is based on a mixture of judgment and empirical data largely derived from fires and large scale tests. Three or four decades ago this approach was sufficient. Most buildings were inherently massive and highly compartmented. Wood and paper were the prime combustibles of concern. The rate of change in building technology was slow. The cumulative history of how buildings reacted when exposed to fire and fire stresses was an adequate prediction of future expectations. It was in that atmosphere that the Building Exits Code and the rest of the system of consensus codes arose.

The code system addressed the total charge of public health and safety. Wherever credible technology existed it was incorporated. But where it was not available a form of judgment decision was used. In the case of fire safety, credible technology input has been a minor factor and judgment has dominated. The result is a relatively rigid set of requirements. The objectives and expectations of these requirements are infrequently recorded. Consequently the value and intent of the requirements are not necessarily apparent.

Virtually every code has an equivalency clause that permits alternative approaches provided equal performance can be achieved. It is, however, difficult to demonstrate the required equivalency when the factors that need to be considered were established on a judgment basis.

As a result the code document rather than the fire safety purpose becomes the objective. Expertise becomes entombed in relating fixed requirements to building materials and systems. Innovation, rational design, and cost control are constrained and frustrated.

The opportunity now exists, however, to undertake quantitative analysis of fire hazard and to apply sound engineering to hazard management decisions.

This change is possible because of advances in fire science and engineering that have progressively emerged over the last two decades. During this period a relatively small but fortunately persistent group of research scientists and engineers have labored in laboratories and universities around the world. They have dedicated their efforts to determining the basic principles of unwanted fire; measuring the variables involved; and developing coordinated engineering methods to predict the course of fire, response of fire safety features, and the resulting impact on people, property and productive missions.

As a result there is an emerging fire protection engineering technology with the power to evaluate fire safety performance of a building or other facility that may differ widely from current prescriptions of traditional code requirements. Technical assessment of the impact of a fire safety decision as it applies to a specific building or set of circumstances is possible. It is now reasonable to make an analytical evaluation of major elements of fire development and impact from the moment of ignition to the final determination of the results of a fire.

Figure 1 provides one way of looking at the elements that make up such a system. This figure is also an outline of the discussion of methodology covered in the main body of this paper.

GENERAL CONCEPTS

Modern fire protection engineering hazard analysis, whether for life safety or other purposes, is predicated on the ability to predict analytically the impact of potential fire situations on fire safety objectives. The core of this ability rests on predictive analytical models. These models are assemblies of engineering computations that quantify the response of an environment to the stresses imposed by an accidental fire. The level of fire stress and the environmental response both change with time, location, and the fire invoked changes in the environment. These factors require that most models be based on mathematical expressions that simultaneously account for time dependent interactions of multiple variables. Therefore, most models use partial differential equations as the method of solving the engineering computations. In view of this and other factors, computers are usually the only practical means of executing the calculations. The advent of the inexpensive, relativity high capacity micro computer, however, is rapidly bringing the needed computing power to the desk of ever engineer.

This paper identifies several selected computer models, complementary data, and equations now available to the engineer. It is important, however, that engineers using models have an understanding of engineering principles, physical laws, and fire phenomena addressed in the analysis involved. Some important phenomenon and engineering principles include:.

a. Thermal inertia. Thermal inertia can be defined as the resistance of a material to change in temperature when a change occurs in the surrounding environment. While there is some disagreement regarding the proper exponent in the mathematical expression for thermal inertia, all agree that it involves the product of thermal conductivity, density, and specific heat of the material. The lower the thermal inertia of a material the faster the exposed surface of that material reaches the temperature of the surrounding environment and the faster radiant energy raises the temperature of the impacted material. This response to exposing conditions is important in terms of how quickly a combustible material reaches its ignition temperature, how fast it burns when ignited, and the rate of flame spread across its surface. Thermal inertia, also, plays an important part in determining the energy absorbed by walls, ceiling, and other material in a space. Thermal inertia has an important impact on both the onset of flashover in a space and the eventual impact of fire on the space.

Thermal inertia is a transient phenomenon. Once a material has been heated sufficiently so that there is a consistent rate of heat transfer from the exposed surface(s) to the cooler unexposed surface (or to the core of a material that is surrounded by fire), the rate of temperature rise on the exposed surface of a material becomes a function of thermal conductivity without regard to density or specific heat. For thin materials this occurs early in the fire. For thicker materials with high thermal inertia the period of time required to reach this condition can be quite extensive.

b. Entrainment. As a fire burns a portion of the energy produced is radiated from the flame and thereby transferred out of the fire plume. Typically, in accidental fires, about 1/3 of the energy is lost from the plume in this manner. The residual energy remains in the gases rising from the fire and creates the fire plume.

These rising gases are turbulent and continuously entrain air or whatever other gas is present immediately outside the plume. As the plume rises above the flame, the plume becomes more influenced by the entrained air than by the fire product gases. The mass of entrained air is substantially greater than the mass of combustion products. This has lead to a frequent approximation that equates the amount of smoke to the mass of air entrained into the plume above the fire. Such an approach is presented by Butcher and Parnell [1] in their text on smoke control.

The amount of gas in the fire plume over the flame increases by almost the square of the increase in the height above the fire. Entrainment is usually the largest single determinant of the amount of smoke and associated gases present, the temperature of the gases, and the degree of dilution of the fire products produced.

c. Conservation of energy. The most obvious stress introduced into an environment by fire is thermal energy. All of the energy produced must be accounted for in the engineering hazard analysis.

If all of the energy released by a fire were contained in the atmosphere of the room of fire origin, the result would be an increase in temperature proportional to the volume of the space and the specific heat of the atmosphere. Based on the usual values for specific heat and weight of air at room temperatures, the temperature rise would be about 0.85 C per kJ per cubic meter (ie: 3.2 F per btu per cubic foot.) Such could occur, however, only in a space with infinitely high thermal inertia and no vents or other openings, much more typical of an electric furnace than a building.

In building fires significant amounts of energy are transferred from the room of origin by convection, conduction, radiation, and the mass transfer of heated gases. The determination of this energy balance is a critical part of all computations concerned with fire growth and the transport of heated fire products. One critical function of a good fire growth model is to track the energy released from burning materials, where it goes and the impact of that energy on the surroundings at any specific time.

Typically some of the energy produced by a fire is radiated from the flame and absorbed by every surface within view of the fire, some is convectively transferred to the ceiling, walls, and other surfaces exposed to the hot gases generated, and some is moved from the room of origin to other locations in the flow of gas leaving the room. The remaining energy resides in and heats the smoke layer in the room. In the early stages of a fire (before the heated surfaces reradiate energy to the room environment) this is the only important energy input to the smoke layer. As other surfaces heat up radiation from them becomes a factor. Some models such as FAST [2] and Harvard [3] include detailed consideration of heat transfer. Others such as ASET [4] involve simplifying approximations.

d. Conservation of mass. As a fire burns, the fuel loses weight. The mass lost from the fuel enters the environment as a combination of gases, liquids, and solids born away from the fuel by the fire plume. This same plume entrains air adding an additional mass of gas to the plume. By this same process air is drawn into the room. Some of this air provides combustion air for the fire. Some is directly entrained into the plume. All add mass to the environment. In cases where forced ventilation is present (due to either mechanical or natural forces such as wind or stack effect) the ventilation also adds or removes mass.

The fire growth and smoke transport models track this mass, determine its location, and proportion it according to the amount contributed by the combustion process versus the entrained gases. Where toxicity or obscuration are to be evaluated the fraction of the combustion products that are toxic or obscuring material are accounted for separately.

e. Conservation of momentum. As a fire plume rises the material in the plume has a momentum imparted to it by the fire energy and any other force (eg: wind, stack effect, or fans.) When the plume strikes a ceiling or similar overhead barrier this momentum carries it across the ceiling, out any openings, and potentially through the facility. Those models that track the flow of gases from room to room track momentum as a driving force in movement of fire products. It is frequently expressed as the pressure head developed by the moving mass rather than mass times velocity. The principles involved in the movement of smoke and fire gases are the same as the principles involved in the movement of water in pipes.

ELEMENTS OF FIRE HAZARD ANALYSIS

Figure 1 is used as a rational basis to discuss the availability and limitations of analytical techniques for conducting hazard analysis of a broad range of fire effects. Figure 1 is conceptual in nature. It shows elements of a system designed for fire risk or hazard analysis of a specified set of conditions (ie: scenario.) The basis of this concept is simulation modeling. The overall concept, however, is flexible. Any number of simulations may be made. Also, a choice can be made to use only a subset of the system depicted in figure 1.

If the objective is to evaluate a single hazard scenario it is necessary to run only a single simulation. An example of a single scenario is the growth of hazardous conditions for a given room or other space from a specified fire. All affecting parameters would be described.

However, the objective may be to determine the ability of a facility to perform satisfactorily against the maximum reasonable fire potential during its life. In that case it is necessary to exercise all of those scenarios that collectively represent the maximum (or design) fire stress on the facility. Careful engineering analysis is required in the selection of scenarios to be evaluated.

Finally, if the objective is to measure the risk of a given type of harm (eg: death, injury, property loss, interruption of operations.) a more universal exercise will be needed. This requires that all important scenarios be evaluated. An important scenario is one that has either a potential of frequent occurrence or significant impact. To measure risk each scenario must also be weighted on the basis of frequency of occurrence of that scenario.

BURN

The element BURN appraises the energy and material product imposition involved in a fire. Advanced mathematical fire models such as the Harvard model [3] contain subroutines to compute some of these variables. The Ohio State (OSU) model [5] tracks the spread and burning rates of wall materials but not of furniture or other contents. Other models such as Tanaka's [6], ASET [4], and FAST [2] do not have this capability. These latter models require that the burning rate variables be specified as an input.

One way to fill the need for specified burning rate information is with appropriate tests and a catalog of data. A modest but growing catalog of burning rate data for furniture items now exists. The catalog is based primarily on tests conducted in a large scale Furniture Calorimeter test apparatus at NBS [7] and similar equipment at Factory Mutual Research Corporation (FMRC). Other burning rate data have been derived from well instrumented tests conducted for other purposes.

A major portion of the existing catalog covers furniture items typical of healthcare facilities. Another major portion covers domestic furniture. A third portion covers fuel typical of storage occupancies. Recently Gross [8] published a collection of data covering several common materials and furniture items. Other collections have been published by Lee [9] and Alpert and Ward [10]. Figure 2 summarizes burning rate data derived from several sources.

There are several different small scale bench type calorimeters able to test the arrangements of materials used in furniture. The work of both Babrauskas [11] and Tewarson [12] represent important efforts in this area. These small scale tests are relatively simple and inexpensive to conduct. To date, however, there is only one successful correlation. This correlation relates the results of the NBS Cone Calorimeter to the full size burning rates of upholstered furniture.

A preliminary generalized prediction method is being examined by Walton and Babrauskas [13]. The basis for this method is the observed triangular (or occasionally trapezoidal) shape of the rate of heat release curves observed in test burns. These correlations hold promise for the future and are being examined against test data. However, only the upholstered furniture correlation is sufficiently developed to suggest usefulness in the immediate future.

SPREAD

The element SPREAD is limited to fire spread under conditions where the unburned materials are exposed to environmental conditions less than that necessary to initiate flashover. The element FLASH addresses situations where flashover causes fire spread. The element SPREAD does, however, include both the spread of fire by:

a. Transmission of radiant energy from a burning item to another item.

b. Surface flame spread from the burning portions of a room lining or other surface to unburned portions of the same or a contiguous surface.

A method for predicting the ignition of separated fuel packages from a free burning item has been proposed by Babrauskas [14]. This proposal was developed from Furniture Calorimeter and similar test data. The data has been converted to graphic form, relating ignition to the rate of free burn energy release of the exposing item. The data has also been expressed as formulas appropriate for computers or other computational methods.

A model of the progressive spread of flame over complex furniture is being developed by Dieterberger [15] at the University of Dayton Research Institute. His approach involves energy balance and ignition energy transmission calculations between a series of finite increments covering the entire exposed surface of the furniture item. This approach has important potential and is nearing the state of development usable in those models that have the capacity of processing the extensive calculations and data involved.

The OSU model [5] develops predictions of flame spread on a combustible wall. The model assumes that vertical flame spread is instantaneous. Lateral flame spread (away from the source flame) is empirically determined from observed rates of lateral flame spread during tests conducted in the OSU calorimeter. Quintiere and Harkleroad [16] have proposed an analytical method of predicting lateral flame spread based on fire properties measured in a standard test.

Quintiere [17] has published his views on the theory of flame spread, both concurrent with and opposed to the direction of the flame. In view of these advances it is expected that rational consideration of surface flame spread will be the next important sub-routine added to models.

FILL

The element FILL considers fire induced changes in the environment in the room of fire origin and rooms or spaces open to that room. This element covers those portions of the environment sufficiently close to the fire that the hot gases produced by the combustion process dominate the movement of fire products.

Fire research efforts in recent years have concentrated on the prediction of the location, temperature, and composition of hot smoke in rooms of fire origin and nearby spaces.

Several simple formulas are being proposed as first order predictions. Some of these predict the time to fill a space with smoke, the temperature of the smoke, and the onset of flashover. A compilation of a number of these formulas has been assembled by Quintiere and Lawson [18]. A similar compilation has been assembled by Nelson [19].

Of greater capability are the computer based mathematical models. These calculate descriptions of key fire processes as simultaneous functions and report a moment by moment description of the fire impact. The development of these models has been reported in the literature and at previous seminars. Of most significance to fire hazard appraisal are the several that have progressed to become more useful in terms of user friendliness. For example Walton [20] has adapted ASET [4] from a mode requiring a large computer and the use of FORTRAN to a simple form using BASIC that can be run on a personal computer.

ASET is however limited in both the physics included and the scope of application. If the extent of the space open to the fire exceeds one room Harvard VI [3], the Tanaka model [6], FAST [2] and several other models are better suited. Of these FAST and the Tanaka model or a multi-room version of ASET appear to be the most amenable to incorporation into engineering fire hazard analysis.

DETECT

The element DETECT covers the discovery of the fact of fire. While human discovery is an important factor, the coverage in this presentation is limited to discovery by heat or smoke actuated devices.

Alpert and his colleagues at FMRC [21] and Evans at NBS [22] have developed methods for predicting the activation time of heat detectors and sprinklers. A portion of the results have been reduced to table and graphics published as an appendix to the National Fire Protection Association (NFPA) standard on detection systems[23]. The data as presented in the NFPA standard is best suited for industrial or other facilities involving large rooms or similar open spaces where wall effects are small. Evans' work has concentrated on the response in smaller spaces. The response of heat actuated devices in smaller rooms is complicated by the heat buildup in the upper portion of the room. This tends to cause the devices to operate more rapidly.

Evans [22] has proposed a predictive method usable with fire growth models that accounts for the impact of hot smoke buildup in a small room. Evans and Stroup [24] have developed computer programs suitable for the PC type of computer becoming common in engineering offices.

Heskestad and Delichatsious [25] have shown reasonable correlation between temperature rise of hot gases in the ceiling jet and the response of smoke detectors. This correlation indicates that for the types of materials likely to be present in most common occupancies smoke detectors will operate when the ceiling jet temperature increases about 13 C (23 F) above ambient. That is the burning rate needed to produce approximately 13 C (23 F) temperature rise produces the amount of smoke needed to operate typical smoke detectors.

Baum and Mulholland are developing approaches to the prediction of the initial wave movement of smoke and hot gases down a corridor open to a burning room and the characterization of smoke conditions in that wave. One objective of this work is to predict the smoke concentrations sufficient to activate detectors in corridor locations away from the initial fire plume. Significant progress has been made. For the most part, however, the "simplified" approaches have not yet reached a field usable state.

ATTACK

The element ATTACK covers the ability of fire suppression systems to either terminate or change the combustion process. For automatic systems, such as automatic sprinklers, the activation of the system is separately considered under DETECT. While there is a massive amount of experience with various suppression systems, the basic physics of fire termination through application of an extinguishing agent is poorly defined.

Budnick [26] reviewed the state-of-the-art of sprinkler systems for residential use. A major empirical effort is underway at FMRC [27] to develop new methods of providing sprinkler protection in selected types of high piled storage. Evans [28] has reported on the results of recent tests that investigated fire control with fire hose streams. None of these are, however, at a state where they can be quantitatively incorporated into an engineering analysis. This is expected to remain a void in the computational approach to fire hazard assessment for some time to come. In the interim the void will be bridged with judgment based on subjective evaluation of field experience.

The element FLASH considers the onset of flashover. The transition from fuel controlled burning to flashed over fully developed burning is of such significance as to require consideration in any fire hazard analysis.

Most fire growth models predict upper level temperatures. A few, such as the Harvard family of models, also predict the content of that layer, the radiation from it, and the impact of that radiation on unignited materials. In the later case the prediction of flashover can be based on the response of target materials. In most cases, however, flashover is estimated to occur when the model predicts that the upper layer temperature exceeds a critical level. This critical temperature is often estimated at 500 C (932 F).

A number of researchers have proposed simple equations for predicting the energy level that will induce flashover in a given space. Babrauskas [29] has published a review comparing several of the proposed approaches. A readily usable approach is that proposed by Thomas [30].

FLOW

The model element FLOW addresses the movement of smoke and gases through portions of buildings not significantly impacted by the thermal energy of the source fire or the energy contained in the migrating smoke.

FLOW addresses two general areas. These are:

a. The rate of leakage of fire products from the principal area of fire impact to other areas.

b. The movement of the air mass polluted by that leakage.

The basic source of all of the work in this area continues to be the models and methods originated by Wakamatsu [31]. Recently the American Society of Heating Refrigeration and Airconditioning Engineers (ASHRAE) and NBS jointly published a handbook on smoke control authored by Klote and Fothergill [32]. That manual provides a current reference of the basic engineering formulas and procedures involved in these areas.

The key to joining the established smoke movement models to the other portions of the system appears to rest in evaluation of the leakage from the principal area of fire involvement (hot gas zone) to the rest of the building. Standard fluid flow calculations are being used at this time and appear to satisfy the need.

One model, the Michigan Tech (MTU) model [33] has been developed to track smoke flow from a fire in an underground mine. This model has been adapted for some studies of smoke flow in buildings. The MTU model has also been compiled on a floppy disk.

Klote and Jones at NBS are attempting to combine fire growth modeling, as described in the element FILL, with the methods of predicting smoke movement through more remote portions of the building, as covered in this element. The object of this effort is produce a consistent model that will track smoke from the source fire through the building.

BUST

The element BUST addresses:

a. The total time-temperature or time-energy course of a fire.

b. The impact of this exposure on the structural elements involved.

BUST includes both the ability of a compartment to contain a fire and the stability of the structural framing under extended high temperature fire exposure.

A number of the models discussed under the element FILL have the computational capability of describing the fire environment for the full duration of a fire. They can, in some manner, predict both fuel controlled and ventilation controlled burning. Most of the models and most related validation tests have concentrated on the early (preflashover) stages of fire development. There are, however, alternatives that can be used instead. These are models designed primarily to predict post flashover time-temperature curves. They include COMPF2 developed by Babrauskas [34] and the correlations produced by Magnusson and Thelandersson [35].

World wide there are a number of computational approaches for estimating the impact of a given time -temperature or time-energy exposure on a building member. Jeanes [36] has listed many of these in an organized approach. More recently Bresler et al [37] have developed FASBUS. FASBUS models the distribution of structural forces and impacts through a structural system exposed to high intensity fire.

TELL

The model element TELL considers alarms and other means of transmitting intelligence regarding the fire situation. Tell addresses the building occupants and others who need the information to take actions or make decisions. It is axiomatic that a person must be aware of the possible existence of a dangerous situation before he can initiate any response. While there is much folklore involved in the development of alarm signals, there is little technical data and no existing model. There is a small data base, principally related to arousal from sleep. Pezoldt and Van Cott [38] showed that subjects tend not to awaken quickly to loud uniform sounds when in the deepest stages of sleep. They are more likely to awaken to a meaningful varying sound, such as the mixed tones common to smoke detectors. Nober, Pierce and Well [39] conducted experiments using simulated smoke detector alarm signals to produce arousal data based on alarm loudness. Kahn [40] has experimented with the potential of persons being awakened by smoke odor. Levin [41] outlined this and other work in a recent overview paper. Levin is also attempting to develop a model covering the scope of human behavior under fire conditions. Figure 3, is a preliminary outline of his approach.

DECIDE

The core of the modeling attempts being undertaken by Levin reside in the element DECIDE. This element evaluates the manner in which persons perceive and determine the response that they will take when they receive information indicating a possible threat. The key considerations currently being modeled by Levin relate to the level of ambiguity of the information reaching the deciding person. The work of Keating [42] and others indicates that persons will investigate rather than take protective actions if they are uncertain about the situation or level of threat. An exception appears to occur with those responsible for the well being of another. Examples are a mother of an infant or a nurse caring for invalid patients. The initial investigation actions are but the start of a model of emergency decisions. Work ahead will consider information gathering (from fire cues, alarms, signs, building layout, etc.) and the iteration of decisions as the emergency proceeds. A complete engineering analysis will require that the emergency decision portion be included. However, the prime worth of the current work is as support of judgment estimates of the decisions that persons make and the time involved in making them.

MOVE

The element MOVE considers the actual movement of persons in evacuating to escape a fire. MOVE can also consider those approaching a fire for purposes such as rescue or attacking the fire. More has been accomplished in this element than in the other aspects of human response to fire. Both Kisko [43] and Alvord [44] have developed models. The work of Kisko centers on mass movement of persons where congestion can be an important factor. That of Alvord centers on small or moderate size buildings where individual movement dominates the time required to complete emergency action. The models developed by these researchers and others provide several optional means of appraising the flow of persons during an emergency. Each requires a data base. The principle data base for egress flow is derived from the work of Pauls [45].

IMPACT

Impact is the evaluation of the harm or damage that a simulation indicates will occur to persons or property. The appraisal is most useful when done in terms of overall impact rather than the impact of a specific factor (eg: toxic exposure or radiation.)

Currently most of the newly evolving data relates to either the toxicity of specified products of combustion or harm from exposure to effects generated by and transported from a fire. Other impacts such as direct contact with flame continue to be treated separately, usually as a regression from fire incident statistics.

Analytical approaches to evaluation of impact have been proposed by Bukowski [46] and Hartzel [47].

SUMMARY

Fire protection engineering is at a cross road. The current method of development of fire safety criteria based on the consensus of committees representing either a balance of interests or the desires of enforcers can continue. It is probable that reasonable safety will be provided. Such will however be rigid, slow to respond to change, and subject to the pressure of vested interests. Alternatively, quantitative engineering analysis can be applied to fire protection criteria. The promise is measured safety, innovation and cost effectiveness. The application will require qualified professional engineering. The key is whether the fire protection engineering profession is willing to spend the effort and take the professional responsibility to make this happen.

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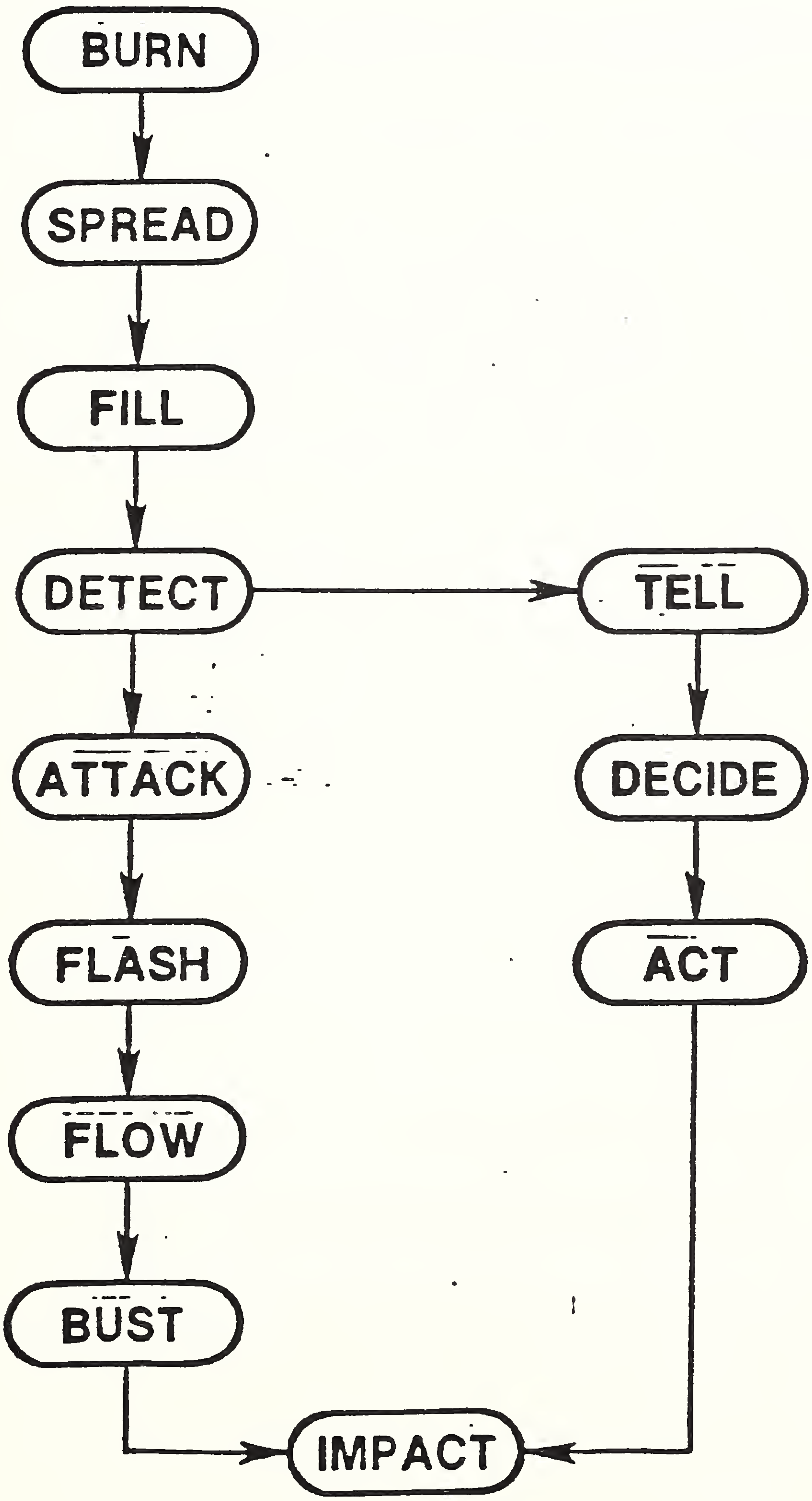
ELEMENTS OF FIRE HAZARD ANALYSIS



H.E.Nelson Nov. 1984

FIGURE 1

SOME TYPICAL PEAK RATES OF HEAT RELEASE

BTU/SEC/ SQ. FT. OF FLOOR AREA	GROWTH RATE	POTENTIAL FUEL
1.5	S	FIRE RETARDED TREATED MATTRESS (INCLUDING NORMAL BEDDING)
15*	M	LIGHT WEIGHT TYPE C UPHOLSTERED FURNITURE**
35*	S	MODERATE WEIGHT TYPE C UPHOLSTERED FURNITURE**
35	F	MAIL BAGS (FULL) STORED 5 FEET HIGH
50*	M	COTTON/POLYESTER INNERSPRING MATTRESS (INCLUDING BEDDING)
60*	M	LIGHT WEIGHT TYPE B UPHOLSTERED FURNITURE**
60*	S	MEDIUM WEIGHT TYPE C UPHOLSTERED FURNITURE**
65	VF	METHYL ALCOHOL POOL FIRE
70*	S	HEAVY WEIGHT TYPE C UPHOLSTERED FURNITURE**
80*	F	POLYURATHANE INNERSPRING MATTRESS (INCLUDING BEDDING)
90*	M	MODERATE WEIGHT TYPE B UPHOLSTERED FURNITURE**
125	M	WOODEN PALLETS 1-1/2 FEET HIGH
145*	M	MEDIUM WEIGHT TYPE B UPHOLSTERED FURNITURE**
150*	F	LIGHT WEIGHT TYPE A UPHOLSTERED FURNITURE**
150	F	EMPTY CARTONS 15 FEET HIGH
175*	M	HEAVY WEIGHT TYPE B UPHOLSTERED FURNITURE**
175	F	DIESEL OIL POOL FIRE (>ABOUT 3 FT. DIA.)
175	VF	CARTONS CONTAINING POLYETHYLENE BOTTLES 15 FEET HIGH
220*	F	MODERATE WEIGHT TYPE A UPHOLSTERED FURNITURE**
225*	F	PARTICLE BOARD WARDROBE/CHEST OF DRAWERS
290	VF	GASOLINE POOL FIRE (>ABOUT 3 FT. DIA.)
340*	VF	THIN PLYWOOD WARDROBE WITH FIRE RETARDANT PAINT ON ALL SURFACES (50IN. X 24IN. X 72IN. HIGH)
350	F	WOODEN PALLETS 5 FEET HIGH
360*	F	MEDIUM WEIGHT TYPE A UPHOLSTERED FURNITURE**
450*	F	HEAVY WEIGHT TYPE A UPHOLSTERED FURNITURE**
600*	VF	THIN PLYWOOD WARDROBE (50IN. X 24IN. X 72IN. HIGH)
600	F	WOODEN PALLETS 10 FOOT HIGH
900	F	WOODEN PALLETS 16 FOOT HIGH

FIGURE 2 (PART 1 OF 2) - SOME TYPICAL PEAK RATES OF HEAT RELEASE

NOTES:

* Peak rates of heat release were of short duration. These fuels typically showed a rapid rise to the peak and a corresponding rapid decline. In each case the fuel package tested consisted of a single item.

** The classification system used to describe upholstered furniture is as follows:

Light weight = Less than about 5 lbs. per square foot of floor area. A typical 6-foot long couch would weigh under 75 lbs.

Moderate weight= About 5-10 lbs. per square foot of floor area. A typical 6-foot long couch would weigh between 75 and 150 lbs.

Medium weight =About 10-15 lbs. per square foot of floor area. A typical 6-foot long couch would weigh between 150 and 300 lbs.

Heavy weigh = More than about 15 lbs. per square foot of floor area. A typical 6-foot long couch would weigh over 300 lbs.

Type A = Furniture with untreated or lightly treated foam plastic padding and nylon or other melting fabric.

Type B = Furniture with untreated or lightly treated foam plastic padding or with nylon or other melting fabric but not having both.

Type C = Furniture with cotton or well treated foam plastic padding and having cotton or other fabric that resists melting.

The estimated heat release rates are based on furniture having simple lines. For ornate or convoluted shapes increase the indicated rates by up to 50% based on elaborateness.

GROWTH RATES

S = Slow. Burning rate in the range of a t-squared fire that reaches 1000 btu/sec in 600 seconds.

M = Moderate. Burning rate in the range of a t-squared fire that reaches 1000 btu/sec in 300 seconds.

F = Fast. Burning rate in the range of a t-squared fire that reaches 1000 but/sec in 150 seconds.

VF = Very Fast.Burning rate in the range of a t-squared fire that reaches 1000 btu/sec in 75 seconds.

FIGURE 2 (PART 2 OF 2) - SOME TYPICAL PEAK RATES OF HEAT RELEASE

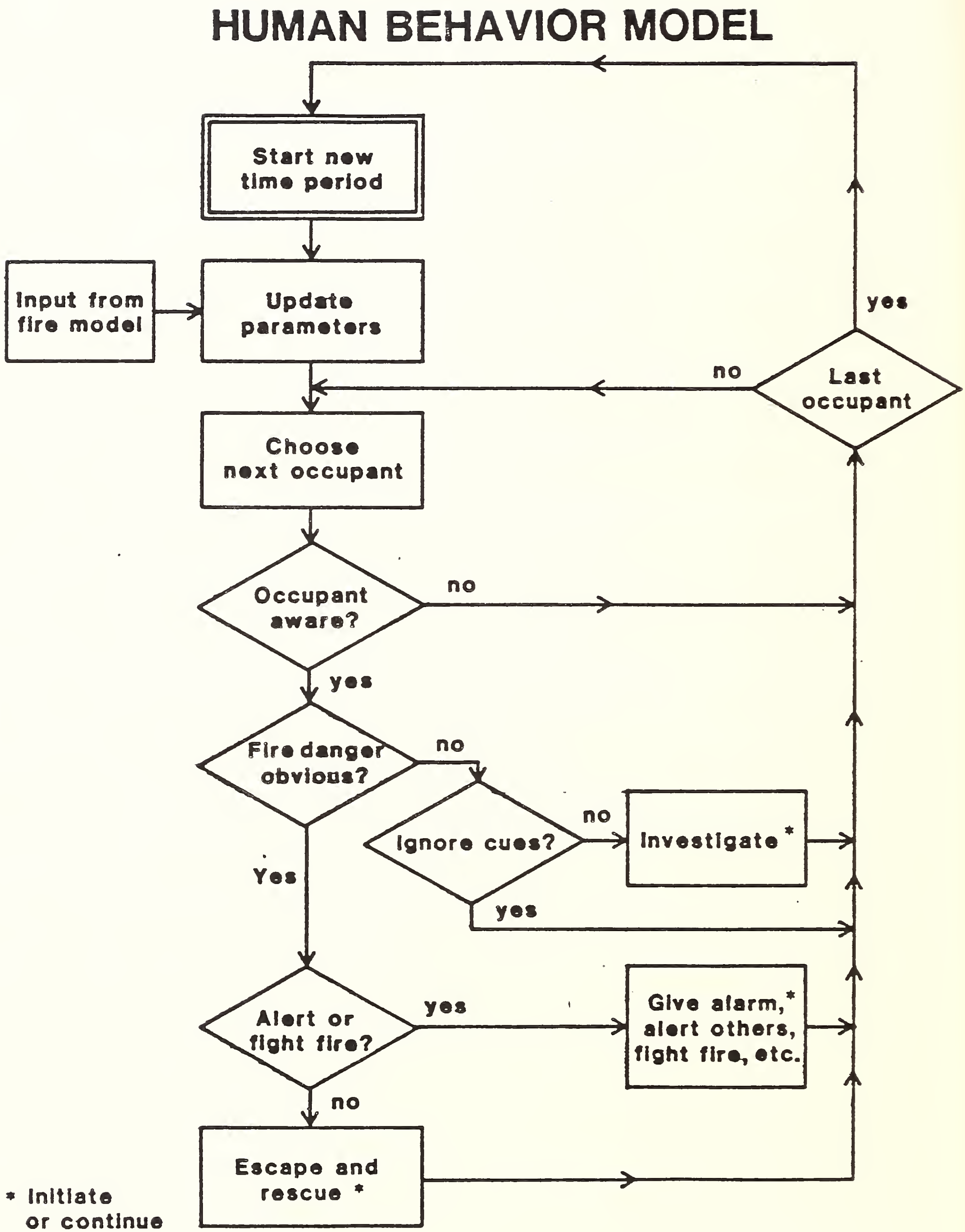

HUMAN BEHAVIOR MODEL
Start new time period
Input from fire model
Update parameters
Choose next occupant
Occupant aware?
no
yes
Fire danger obvious?
no
Ignore cues?
no
Investigate *
yes
Yes
Alert or fight fire?
yes
Give alarm,* alert others, fight fire, etc.
no
Escape and rescue *
Last occupant
no
yes
* Initiate or continue

FIGURE 3