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The Application of Models to the Assessment of Fire Hazard From Consumer Products

Richard W. Bukowski

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THE APPLICATION OF MODELS TO THE ASSESSMENT OF FIRE HAZARD FROM CONSUMER PRODUCTS

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Abstract

The differences among models of fire, fire hazard, and fire risk are described. The use of field, zone, and network models for fire hazard assessment is discussed. A number of available single and multiple compartment models are described. Key considerations with respect to the use of the current models by the Consumer Product Safety Commission for hazard assessment from upholstered furniture and mattress fires is presented. Modifications necessary to improve the capability of these models for hazard assessment are identified. Model validation, output presentation, and data sources are discussed. Recommendations on specific models for the sponsor to consider for further study and use are provided.

Key words: computer models; fire models; hazard assessment; mattresses; toxicity; upholstered furniture

1. INTRODUCTION

Over the past decade, the field of fire modeling has progressed to the point that quantitative predictions of fires in buildings can be made to an accuracy which is useful for engineering purposes. Over the past two years, the Center for Fire Research (CFR), National Bureau of Standards (NBS), has been working on the application of fire modeling techniques to the prediction of the hazard to occupants from building fires. The framework of the CFR Program [1][1] and the application of these techniques to specific, product related hazard analyses for upholstered furniture [2], and plenum cables [3] have recently been published.

Since the mission of the Consumer Product Safety Commission (CPSC) is to protect the public from hazards associated with products, the potential usefulness of these techniques for the evaluation of fire, and particularly combustion toxicity hazards associated with accidental fires involving combustible consumer products is apparent. Thus, CPSC contracted with CFR to review the current state of fire and hazard modeling and to recommend specific models which might be currently useful by CPSC for this purpose and to identify modifications to these models which would improve their usefulness.

2. APPLICATION OF MODELS

A model is any set of equations which mathematically represents some physical process. Thus, a model describes what is likely to occur as the process being modeled proceeds. The widespread availability of powerful computers has resulted in the development of models for many complex phenomena. For example, climate modeling forms the basis for most weather predictions done today. These climate models are made up of mathematical expressions for such forces as solar heating and the earth's rotation which cause the development and movement of weather patterns across the earth. In a

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[1] Numbers in brackets refer to the references at the end of this report.

similar fashion, fire models contain equations which describe the processes of combustion, heat transfer, and fluid flow produced by a fire within a specific geometry.

2.1 Fire Models

Fire models predict the environmental conditions within one or more physically bounded spaces as a result of fire contained therein. They predict how much heat, smoke, and gases are produced by the fire and how each of these quantities is distributed through the building over time. Some important points about fire models as they currently exist must be understood in order to appreciate their capabilities and application.

Most current fire models have been developed for specific purposes such as to describe a single phenomenon (filling of a compartment) or a specific application (aircraft interior fires) rather than for general use. Fires involve many highly complex phenomena and no single fire model describes all of these phenomena to the same level of detail. Within a given model, specific phenomena may be described empirically, semi-empirically, by partial or complete physics, or may not be included. The level of detail included for any specific process depends both on the level of technical understanding of the process available at the time the model was written and on the specific purpose for that model. Thus, a user must understand the individual model's range of validity and how that applies to the purpose for which the model is being used.

2.2 Hazard Models

A hazard model is one which predicts the consequences of an exposure to a specified set of conditions over time. Thus, a hazard model uses the information on the conditions produced by the fire over time from the fire model and evaluates the impact of these conditions on that which was exposed. In most cases, the hazard of interest is that to occupants of the building. But hazard models could also be used to evaluate property damage as a result of the fire.

Hazard is scenario dependent. That is, hazard must be evaluated for a single, specified set of conditions involving a specific fire in a specific building with a specific set of occupants and their associated physical capabilities.

2.3 Risk Models

Risk models predict the cummulative threat posed by all possible hazardous events (scenarios) weighted by their probability of occurrence. Thus an event which is very hazardous but relatively unlikely to occur would be similar in risk to an event which is less hazardous but more likely to occur.

From the above, it can be seen that fire models form the phenomenological base for hazard models, and hazard models for risk models. For engineering purposes for the evaluation of potential impact or benefits of product design changes, material selection, or other hazard migation strategies, hazard models would be the most appropriate. However, eventually, some consideration of risk will have to be made. This is because changes which reduce the hazard for one scenario may potentially result in increased hazard from some other scenario. Depending on the probability of occurrence, the overall benefit could be either positive or negative. An example of this might be that a flame retardant which would reduce the hazard from flaming ignitions might also promote the propensity of a material to smolder and increase the hazard from smoldering ignitions. Depending on the relative probabilities of smoldering and flaming ignitions for the product, the overall risk associated with that product might be increased or decreased accordingly.

3. MODELING TECHNIQUES

There are three general categories of fire modeling techniques; field models, zone models and network models.

Field models divide a space into a 1, 2, or 3-dimensional network of relatively fine elements and, using the governing partial differential equations of the phenomena of interest, calculate the conditions in each element as a function of time. These models provide very high resolution and detail but are computationally intensive; a simple combustion problem in a single compartment requiring a significant time on the largest super computer. Thus, they represent an excellent research tool but generally are not as yet too practical for problem solving.

Zone models divide each compartment into a small number of volumes, including at a minimum an upper layer, a lower layer and a fire plume region. These models work well in the compartments nearest the fire where stratified conditions exist because of the significant driving force of buoyancy. The turbulence normally associated with fires causes mixing within the layers which lead to conditions that are reasonably replicated by the uniform layer approximation of the zone models. These models are more computationally simple than field models and, given a numerical routine to solve the equations, can run multiple compartment simulations in real time on a mid-sized computer.

Network models assume that compartments are uniform in space. These models can be used to solve problems involving very large numbers of nodes (compartments) efficiently. At some distance from a fire, products are well mixed and are driven by the now-dominant forces of HVAC, stack effect, and wind. Network models are therefore well suited to the realm at some distance from the fire source.

From this, it is clear that the most effective approach for treating the problem at hand is to marry these three techniques into a hybrid model which can provide the detail necessary for useful hazard predictions while maintaining practicality for problem solving. In fact, this is probably the only approach with enough computational efficiency to be used for predictions in large structures due to the large numbers of compartments therein. Thus, the direction of the work at CFR in hazard model development is to use the zone model for the near-fire compartments where buoyancy and stratification are the key phenomena. This model would include field model-type elements in special zones, as required (e.g., the zone which represents the ceiling material, where transient heat conduction requires a field equation analysis). Once beyond the distance where stratification is significant the network technique will be used to map the distribution of products in the rest of the structure.

4. DISCUSSION OF AVAILABLE FIRE MODELS

In addition to the categories of field, zone, and network models which relate to the number of spaces into which each compartment is divided for solution, fire models can also be categorized as single compartment models or multiple compartment models relating to the number of rooms in the structure to be analyzed.

4.1 Single Compartment Models

By far, most currently existing fire models are single compartment models. Some of the more common single compartment models are shown in Table 1. These models range from very simple such as ASET (Available Safe Egress Time) [4] which is intended to estimate the upper layer temperature and filling time for a fire in a single compartment, and COMPF2 (Computation of Post Flashover Model 2) [5] which calculates only post-flashover temperatures and flows, to Harvard V [6] and OSU (Ohio State University) [7] which contain relatively complex phenomena and predict numerous aspects of a time dependent room fire. The Cal Tech (California Institute of Technology) model [8] is a filling model similar to ASET, and DACFIR (Dayton Aircraft Cabin Fire Model) [9] is designed to model a fire involving the seating of a commercial aircraft over only the first 5 to 10 minutes after ignition.

While each of these models has appropriate applications, only the Harvard V and OSU provide sufficient detail for a rigorous hazard analysis. The OSU code was developed by Smith at Ohio State University expressly for the purpose of extending measurements taken in the OSU calorimeter (ASTM E906) to compartment fire predictions. Thus, the utility of this model is generally limited to cases where data from the OSU calorimeter is available on the material in question. The Harvard code, however, is more general purpose and will be more generally applicable. Currently, there are several versions of the Harvard V Code available. These versions, identified as 5.1, 5.2, 5.3, etc. represent modifications for the inclusion of extensions by specific researchers. For example, 5.2 and 5.3 both contain vent mixing and contamination of the lower layer not included in 5.1. CFR is currently working on the assemblage of a "standard" version of Harvard V containing all applicable extensions. When completed and fully documented this will be the model of choice for single room calculations, particularly when it is desired to include combustion phenomena.

4.2 Multiple Compartment Models

Models which calculate the transport of energy and mass through multiple compartments of a structure are a relatively recent development. The three currently available are listed in Table 2. The Building Research Institute (BRI or Tanaka) [10] and Harvard VI [11] models were published in 1983 and the initial version of FAST (Fire and Smoke Transport) [12] was released one year later.

The BRI model can be used to predict the distribution of fire products in an arbitrary number of compartments on multiple floors. It contains a relatively simple combustion algorithm for steady-state combustion. Two major drawbacks of this model involve the lack of vent mixing and a cumbersome solution algorithm for solving the compartment to compartment transport.

The lack of vent mixing means that all energy and mass released by the fire is retained in the upper layers of each compartment. Thus, temperatures, smoke, and gas levels in the upper layer are over-estimated and the rate of filling of each compartment is slower than would be experienced in real life. The solution algorithm for transport is cumbersome because the user must specify the order in which fire products will enter each compartment. For compartments in a straight line this is obvious; but for complex geometries this often leads to failures of the model in reaching a solution (convergence).

Harvard VI is multi-compartment extension of Harvard 5.1. As with the BRI code, Harvard VI does not currently contain vent mixing. In addition, the current version of Harvard VI can only handle three compartments. The model was initiated near the end of the Center for Fire Research Program at Harvard, and was not completed prior to the retirement of Dr. Emmons. Dr. Morita from Science University of Tokyo worked on Harvard VI during a one year guest worker assignment at CFR. During his stay, he got the program running, but there are still some subroutines which do not work. At present there is no official released version of Harvard VI (although there is a report on the model).

FAST is the most widely distributed and used multi-compartment model. FAST does contain vent mixing and has a reliable, robust equation solver which does not require any unusual user setup. The first released version (version 16) can calculate any number of compartments on a single floor. Version 17, scheduled for release in the fall of 1985 includes vertical shafts and thus can handle multiple floors.

FAST has little combustion within it, requiring that the fire be entered in terms of a mass loss rate, heat of combustion, and species yields. It accepts this data in the form as produced by the furniture calorimeter [13] or cone calorimeter [14]. Where more detailed combustion is needed as input, such as multiple items burning, it is possible to use Harvard V to predict the combustion phenomena and then enter the energy and species release rates predicted by Harvard V into FAST for the remainder of the calculation. Version 18 will include improved combustion, and the upholstered furniture combustion model of Deitenberger [15] will be incorporated into a future version of FAST. These changes will allow a broader range of applicability for FAST in that it will be able to calculate the changes in burning rate and species yields as a function of the surrounding compartments, as opposed to its current "free burning" assumption.

5. REQUIREMENTS FOR ASSESSING HAZARD

The major components of a hazard assessment model are shown in Figure 1. Each of these components is currently being addressed in the CFR program and exist in various stages of development.

Details on the current status, capabilities, and limitations of the component models shown in Figure 1 are beyond the scope of this report. The following sections will discuss factors necessary for the current use of models to assess occupant hazard from consumer products; particularly upholstered furniture and mattresses.

5.1 Combustion

Within the hazard model, the combustion process represents the primary source term. That is, it describes the release rates of energy, smoke, and gas species. As shown in the left main block of Figure 1 and as discussed earlier, the combustion process can be described as a specified fire using the data produced by small- or large-scale burns of the product, or can be calculated using a combustion model. For the particular case of upholstered furniture and mattresses, a considerable bank of data exist, largely from CPSC-sponsored work at NBS. Since the bulk of this data was taken in conjunction with the development of the oxygen consumption calorimeters and since the specified fire input to the model was tailored to accept the data from these calorimeters, there should be no need to resort to the more complex procedure of using the combustion model for hazard analysis involving these products unless the scenario to be studied involves multiple items burning.

5.1.1 Flaming Combustion

Most of the data available in these product categories involves flaming combustion. Significant quantities of small- and large-scale calorimeter data are available on individual materials [16], fabric/filling combinations [17], mock-ups [18] and complete items [19]. Data from room experiments are also available [20]. Most of the data, however, was taken under "free-burning" conditions with adequate ventilation for complete combustion. Thus, the ability to precisely model post-flashover release rates may currently be limited. Design modifications to the cone calorimeter to allow the measurement of energy and species release rates under post-flashover combustion conditions have already been initiated.

5.1.2 Smoldering Combustion

Significantly less data are available on energy and species release rates from smoldering combustion in upholstered furniture and mattresses. While a large number of smoldering experiments have been conducted they have focused primarily on the aspects of smolder propensity (ignition probability) and have not involved the key analytical measurements necessary to specify the energy and species release rates. Since in the case of smoldering, radiation (which does not scale) is not important, the data necessary to describe the process can be readily obtained through bench-scale experiments. Simply running a cigarette ignited crevice mock-up test (as used by the state of California) in the cone calorimeter without any externally applied flux would provide the necessary data.

The most difficult aspect of modeling smoldering combustion in either upholstered furniture or mattresses would involve predicting the transition from smoldering to flaming. Since the trigger mechanism is not understood it is not currently possible to predict its occurrence with confidence. Thus, the best that one could do would be to (somewhat) arbitrarily select a transition time based on experience.

5.2 Transport

Version 16 of FAST, can be used to predict the distribution of energy and species throughout multiple compartments on a single floor. Version 17, to be released this fall, includes a vertical shaft allowing multi-floor calculations. This shaft is described as a tall room in which an upper layer forms and fills the compartment in the same manner as other compartments are modeled. While this is a good approximation for open shafts such as elevator or utility shafts, considerably more detail must be included before stairwells can be adequately modeled. Since we assume that the initial CPSC focus will be on residential occupancies, this should not pose a major problem for the present. Of particular importance to this issue is the fact that a two story test facility is currently under construction in building 205 which will simulate a townhouse, complete with stairway. With the addition of this facility and the research planned for it, studies of floor-to-floor transport in such a structure will be forthcoming along with the necessary revisions and improvements to the model to better describe these phenomena.

5.3 Effect on Occupants (Tenability Limits)

Most researchers agree that processes of biological response are less exact and understood than the physical sciences. Thus the methods currently available to address exposure-response are crude. Initial efforts (e.g., as currently provided in FAST) involve the definition of critical concentration-time products using the NBS toxicity protocol. The model calculates the mass concentration of combustion products in each layer (for each compartment) as a function of time by distributing the fuel mass lost among the compartments and dividing by the layer volume. This distribution is a function of the mass flow rates through the interconnected volume, driven by the buoyancy of the fire gases. The ratio of the time integral of this mass concentration to the critical concentration-time product is defined as the fractional lethal dose (FLD).

While this provides a starting point, it is insufficient in the long term since it does not describe such important factors as the cause of the observed effect, variations in uptake rate as a function of activity, or the effect of a varying concentration of individual species components which may change with time or distance from the combustion site due to reaction or loss to surfaces. Additionally, animal experiments conducted to date have not clearly demonstrated how sublethal effects such as incapacitation and exposure to irritants can be reliably included in the predicted exposure-response. These are clearly important factors for which some algorithms must be developed.

To try to address these issues, CFR has engaged in studies of the exposure-response of animals to a number of the primary toxic species, individually and in combination [21]. Species studied include carbon monoxide, carbon dioxide, hydrogen cyanide, reduced oxygen, and hydrogen chloride (being studied at SwRI with respect to both lethality and incapacitation on a grant). Simultaneously, Japanese researchers have been studying these and a few additional gases with incapacitation as an end point [22,23]. At this time, considerable data has been generated and its analysis has resulted in the development of some mathematical expressions based on empirical correlations to these data. While such empirical correlations will again be valuable as an interim step, it is recognized that the final method must include kinetic uptake models which include the effect of activity on respiration rate, uptake, elimination, and metabolic changes in absorbed toxicants which impact on the eventual results of the exposure.

Another portion of the exposure-response element is that of the evacuation process and the behavioral aspects of occupants during this process. In this area at CFR, Alvord has published an evacuation model for large buildings [24]. This model can be used to predict the period of time any occupant spends in any compartment and thus provides input necessary along with the concentration-time history provided by the transport model to obtain exposure-dose.

Working in conjunction with or to be included within the escape and rescue model is a decision/behavioral model under development by Levin. This will model certain aspects of typical human behavior in fire situations such as the response to initial, ambiguous cues concerning the fire and the tendency of males to investigate before taking escape actions. The model also includes such factors as the need to rescue infants and to assist the elderly or handicapped individuals.

5.4 Fire Protection Systems/HVAC

The ability to model the operation of fire protection systems such as detectors and sprinklers or smoke control systems is an important factor in hazard analysis since it impacts on the notification aspect (and thus the point at which evacuation begins), and on the potential to control both the fire and the generation and spread of its products. In addition, HVAC systems can be a factor in mixing within a compartment and as a distribution path within large buildings. Thus, these systems need to be included in the overall hazard modeling.

5.4.1 Modeling Fire Protection Systems

Currently, it is possible to predict accurately the operation of heat-activated devices (heat detectors and sprinklers) as a function of predicted conditions in the room of origin [25]. Estimates of the operating times of smoke detectors as a function of soot mass concentration or number concentration can be made with less accuracy for optical and ionization types, respectively [26].

Modeling the extinguishment process by sprinklers is not as advanced and may not be practically achieved for a few more years. Work on this is ongoing at NBS, Mission Research, Inc., and Factory Mutual Research Corporation in the U.S.

5.4.2 HVAC Systems

Currently, the transport models do not include forced convection either as a source of mixing or as a distribution path. For residential occupancies (small structures) this should not be a major drawback. For a larger structure, both factors need to be addressed and work on them is ongoing. We expect, within one year, to include a convection heater within a room to address the inter-layer mixing phenomena produced by it. Longer term research is needed before inclusion of HVAC systems as a transport path can be accomplished.

5.5 Validation

In order to be useful in a practical sense, models must be validated. That is, we must be able to establish the statistical accuracy of the predicted quantities. This requires much more than simply making direct comparisons with selected experimental results. Thus, CFR, in conjuction with the Center for Applied Mathematics (CAM) of the National Bureau of Standards has established a project to develop techniques to be used for this purpose. A summary report on validation was recently published by Davies [27], and a report on comparisons of FAST to a series of gas burner experiments in two and three room configurations will be published in the fall of 1985.

Interestingly, the ease of validating a model against test data is in many ways inversely proportional to the complexity of the modeling technique used. That is, comparisons are most direct for field models since they produce values of physical quantities at a specific point in space which corresponds directly to the location where the quantity was actually measured in an experiment. Zone models, on the other hand, produce what corresponds to a bulk average value within a layer. The average must be derived from experimental data by averaging some number of measured values within a layer which is continuously changing in volume. Since the measurements are taken at fixed points, one must determine according to an operational definition of layer interface location (which itself must be applied to the data) when they are within one layer or the other. Differences between measured and predicted values might be attributed to the poor quality or accuracy of the data, the paucity or low frequency of the data, the somewhat arbitrary definition of layer interface location, the poor performance of one or several of the predictive algorithms which make up the overall model, or a combination of these. This is not to say that model validation cannot be accomplished, but only that it represents a complex problem.

5.6 Managing the Output

The output produced by models is in much the same form as data from large-scale fire experiments. That is, they give temperatures, flows, smoke densities, gas concentrations, radiant flux, etc. at fixed time intervals over the course of the simulation. The difference lies in the fact that fire experiments are expensive and time consuming to run, so their number is generally limited to a few, carefully selected scenarios.

Model runs, on the other hand, are easy to set up and inexpensive to produce, so the limitation with models is the ability to analyze and understand the large amount of data which is so readily available. Thus, it is critical that the models be provided with the capability of presenting their data in a way which is more easily understood, consistent with the purpose for which the model is being used.

Many applications will involve quantitative comparisons among numbers of model runs where parameters of interest have been varied. Here, general graphic techniques where X-Y plots of predicted variables can be presented from one or more runs on a single graph would be useful.

Such a capability is provided for FAST with a program called Fastplot (described in the appendix of ref. 12). For a more qualitative understanding of what would happen throughout an entire facility (especially a complex one) for a given set of conditions, this kind of presentation may not be appropriate. The large number of plots would lead to a confusing and unclear picture of the sequence of events.

To address this latter problem, we are developing a computer graphic technique which presents the information provided by the model in a two- or three-dimensional pictorial format along with graphical or tabular presentation of key quantities. This pictorial representation includes color coded hazard information which is also keyed to the data to show the relative contribution of a given parameter to the hazard condition present. In this way, key information is presented to the user in an easily understood manner similar to watching an experiment. Critical events can be noted during the graphical presentation and analyzed later by using the data graphics routines. With the evacuation sub-model, the graphics output can include occupants' progress displayed along with the environmental conditions to show either successful evacuation or the time, location, and condition which ultimately prevents escape. Mitigation strategies are then apparent to delay the onset of the limiting condition sufficiently to allow successful evacuation.

6. DATA SOURCES

The compilation of available data necessary to run the models and the overall hazard analysis is a critical part of the program. Gross at CFR has prepared a "pilot" data base report [28] which includes data on common construction materials and references to data on fuels. With this report as an example, CFR intends to solicit the cooperation of industry in the production and contribution of data on their products in the proper format for use in modeling. With specific regard to upholstered furniture and mattresses as stated earlier, the bulk of the data has been produced recently in oxygen consumption calorimeters. Other test methods do not present data in a form compatible with the models. Therefore, a considerable amount of historical data is not directly usable. Since large amounts of data are necessary to handle the general problems, it is not feasible that CFR or any other single organization can produce this amount of data. This is the reason why the cooperation of industry will be necessary in order to compile the amount of data in the proper form. Our experience to date in discussing this with industry is that they are willing to cooperate and expend the resources necessary to accomplish the goal. Certainly, CPSC can be a key factor in fostering this industry cooperation.

Once compiled, CFR intends to catalog the data in two forms. The first will be a hard-copy catalog containing all of the information in a generic form. Second, a computer data base will be generated which will facilitate access to the data by modelers. Eventually, it is hoped that an "expert system" can be developed which will not only access all available data but will help in the selection of the most appropriate data for the problem at hand. CFR is currently developing capabilities in the expert system technology and is obtaining the necessary hardware and software to develop such a system.

7. RECOMMENDATIONS

Based on the current state of technology, it is felt that the capabilities exist to conduct product-related hazard analysis using predictive fire models. This is particularly true for the focus of CPSC on upholstered furniture and mattresses where a significant data base exists in the form necessary for use of these models. Currently, the most appropriate model to use for this is FAST, with Harvard V where the specified fire needs to be replaced with the combustion model. In addition to the state-of-the-art technical capabilities of these two models the fact that they are both the subject of ongoing improvement and support is a critical factor in their recommendation. Also, the further development of FAST, in particular, will be for use in hazard (and risk) assessment modeling as opposed to general fire modeling application such as Harvard VI or the BRI model.

Since the principle focus of the CFR program in developing hazard and risk modeling techniques involves the application of these techniques to materials and products questions, continued CPSC financial support will be leveraged with the substantial CFR investment and the related work sponsored by other agencies and industry. In addition to assistance in refining the capabilities of these techniques, CPSC financial support will assure that the specialized needs of CPSC, particularly as to the modifications made to the models to improve performance, will be considered and addressed within this overall program. The now-operational fire simulation laboratory will assist in the transfer of this technology to CPSC personnel without the current need for hardware expenditures. Following training in their use, both FAST and FASTPLOT can be run by CPSC staff from the Tektronix 4010 terminal at Westbard

Towers. As budgetary pressures in both agencies continue to increase, the necessity and benefits of a continuation of cooperation in the development of these techniques is essential.

8. REFERENCES

1. Bukowski, R.W. and Jones, W.W., Development of a Method for Assessing Toxic Hazard, Fire Journal, Vol. 79, No. 2, 24-26, 28-29, 82, March 1985.
2. Bukowski, R.W., Evaluation of Furniture Fire Hazard Using a Hazard Assessment Computer Model, Fire and Materials, in press.
3. Bukowski, R.W., Toxic Hazard Assessment of Plenum Cables, Fire Technology, in press.
4. Cooper, L.Y., A Mathematical Model for Estimating Available Safe Egress Time in Fires, Fire and Materials, Vol. 6, Nos. 3 and 4, 135-144, 1983.
5. Babrauskas, V., COMPF2 - A Program for Calculating Post-Flashover Fire Temperatures, NBS TN 991, National Bureau of Standards, Gaithersburg, MD, June 1979.
6. Mitler, H.E. and Emmons, H.W., Documentation for CFC V, The Fifth Harvard Computer Fire Code NBS-GCR-81-344, National Bureau of Standards, Gaithersburg, MD, October 1981.
7. Smith, E. and Satija, S., Release Rate Model for Developing Fires, presented at the 20th Joint ASME/AIC National Heat Transfer Conference, August 1981.
8. Zukoski, E.E. and Kaboda, T., Two-Layer Modeling of Smoke Movement in Building Fires, Fire and Materials, 4, 17 (1980).
9. Smith, E.E., Computer based hazard assessment using heat release rate test data, Fire Safety Journal, Vol. 9, Nos. 1 and 2 (1985).
10. Tanaka, T., A Model of Multiroom Fire Spread, NBSIR 83-2718, National Bureau of Standards, Gaithersburg, MD, August 1983.
11. Gahm, J.B., Computer Fire Code VI, NBS-GCR-83-451, National Bureau of Standards, Gaithersburg, MD, December 1983.
12. Jones, W.W., A Model for the Transport of Fire, Smoke, and Toxic Gases (FAST), NBSIR 84-2934, National Bureau of Standards, Gaithersburg, MD, September 1984.

13. Babrauskas, V., Lawson, J.R., Walton, W.D. and Twilley, W.H., Upholstered Furniture Heat Release Rates Measured with a Furniture Calorimeter, NBSIR 82-2604, National Bureau of Standards, Gaithersburg, MD 20899 (1982).

14. Babrauskas, V., Development of the cone calorimeter - a bench scale heat release rate apparatus based on oxygen consumption, Fire and Materials, 8, 81-95 (1984).

15. Dietenburger, M.A., Furniture Fire Model, NBS-GCR-84-480, National Bureau of Standards, Gaithersburg, MD, November 1984.

16. Tewarson, A., Seale Effects on Fire Properties of Materials, NBS-GCR-85-488, National Bureau of Standards, Gaithersburg, MD, February 1985.

17. Babrauskas, V., private communication.

18. Krasny, J.F. and Babrauskas, V., Burning Behavior of Upholstered Furniture Mock-Ups, J. of Fire Sciences, Vol. 2, No. 3, 205-235, May/June 1984.

19. Babrauskas, V., Upholstered Furniture Heat Release Rates: Measurements and Estimation, J. of Fire Sciences, 1, 9-32, Jan/Feb 1983.

20. Babrauskas, V., Upholstered Furniture Room Fires-Measurements, Comparison with Furniture Calorimeter Data, and Flashover Predictions, J. of Fire Sciences, 2, 5-19, Jan/Feb 1984.

21. Levin, B.C., Determination of the Toxicological Effects of Fire Gases, Alone and in Various Combinations, for use in Toxic Hazard Assessment Models, presented at the Third Canada-Japan-USA Trilateral Study Group Meeting on Toxicity, Ottawa, Canada, October 1984, to be published.

22. Sakuri, T., Incapacitation Test Using Several Pure Gases and Their Mixtures, presented at the Third Canada-Japan-USA Trilateral Study Group Meeting on Toxicity, Ottawa, Canada, October 1984, to be published.

23. Nishimarv, Y. and Tsuda, Y., Study of Physiological Disorders in Rats Caused by Poisionous Gases, presented at the Third Canada-Japan-USA Trilateral Study Group Meeting on Toxicity, Ottawa, Canada, October 1984, to be published.

24. Alvord, D.M., The Fire Emergency Evacuation Simulation for Multifamily Buildings, NBS-GCR-84-483, National Bureau of Standards, Gaithersburg, MD, December 1984.

25. Evans, D.D., Thermal Activation of Extinguishing Systems, NBSIR 83-2807, National Bureau of Standards, Gaithersburg, MD, March 1984.

26. Mulholland, G. and Jones, W.W., private communication.

27. Davies, A.D., Applied Model Validation, NBSIR 85-3154, National Bureau of Standards, Gaithersburg, MD, January 1985.

28. Gross, D., Data Sources for Parameters Used in Predictive Modeling of Fire Growth and Smoke Spread, NBSIR 85-3223, National Bureau of Standards, Gaithersburg, MD 20899 (1985).

Table 1. Single Compartment Models

Name	Type
Harvard V.X[1]	Time dependent room fire
Cal Tech	Smoke filling
DACFIR	Aircraft, early time, state transition
OSU[2]	Time dependent room fire, OSU apparatus
ASET	Smoke filling
COMPF2	Post-flashover temperatures

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[1] Multiple fuel items

[2] Wall burning (primitive)

Table 2. Multiple Compartment Models

Harvard VI	Lower layer fixed at ambient conditions
BRI	
FAST	Two layer with vent mixing and lower layer contamination

INTERRELATIONSHIPS OF MAJOR COMPONENTS OF A FIRE HAZARD MODEL

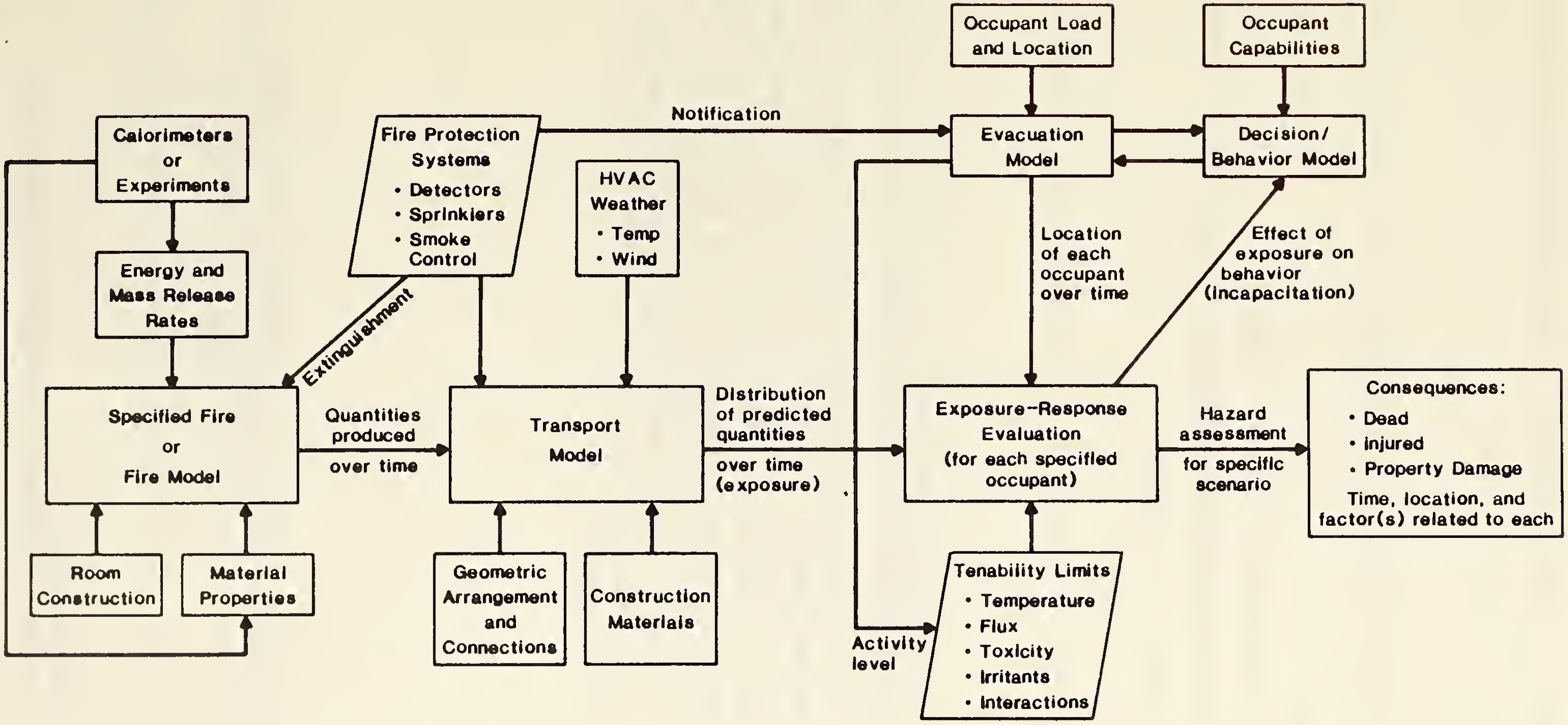

Figure 1

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10\. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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)*

The differences among models of fire, fire hazard, and fire risk are described. The use of field, zone, and network models for fire hazard assessment is discussed. A number of available single and multiple compartment models are described. Key considerations with respect to the use of the current models by the Cosumer Product Safety Commission for hazard assessment from upholstered furniture and mattress fires is presented. Modifications necessary to improve the capability of these models for hazard assessment are identified. Model validation, output presentation, and data sources are discussed. Recommendations on specific models for the sponsor to consider for further study and use are provided.

12\. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

computer models; fire models; hazard assessment; mattresses; toxicity; upholstered furniture

13\. AVAILABILITY

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