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BUILDING RESEARCH ADVISORY BOARD

Federal Construction Council

Technical Report No. 67

(NASA-CR-148513) PROGRAM FOR DEVELOPING AND IMPLEMENTING A NEW APPROACH TO DESIGNING FOR FIRE SAFETY IN BUILDINGS (National Academy of Sciences - National Research) 38 p HC $4.00 CSCL 13L G3/31

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Program for Developing and Implementing A New Approach to Designing For Fire Safety in Buildings

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Program for Developing and Implementing A New Approach to Designing For Fire Safety in Buildings

Technical Report No. 67

Prepared by
Task Group T-57
of the
Federal Construction Council
Building Research Advisory Board
Commission on Sociotechnical Systems
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D. C. 1975

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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of the

BUILDING RESEARCH ADVISORY BOARD

The Federal Construction Council serves as a planning, coordinating, and operating body to encourage continuing cooperation among federal agencies in advancing the science and technology of building as related to federal construction activities.

In this pursuit, its specific objectives include: Assembly and correlation of available knowledge and experience from each of the agencies; elimination of undesirable duplication in investigative effort on common problems; free discussion among scientific and technical personnel, both within and outside the government, on selected building problems; objective resolution of technical problems of particular concern to the federal construction agencies; and appropriate distribution of resulting information

The Council as such comprises ten members appointed by the BRAB Chairman from among BRAB membership, plus one member from the senior professional staff of each of the supporting federal agencies (currently nine), also appointed by the BRAB Chairman on nomination from the individual agencies; all appointments are subject to approval by the President of the National Academy of Sciences.

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TASK GROUP T-57
SYSTEMS APPROACH TO FIRE-SAFE DESIGN

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FOREWORD

For a number of years many fire specialists, building designers, and construction program managers--in both the public and private sectors--have expressed dissatisfaction with the traditional method of providing for fire safety in buildings (i.e., through reliance on codes and standards that prescribe specific measures to be taken in the design and construction of buildings to minimize the potential for a fire occurring and to protect property and life should a fire occur).

Recognizing the validity of this concern, the Federal Construction Council established Task Group T-57 to study the situation and, if possible, to propose a solution. As a result of its study the Task Group outlined and the FCC approved initiation of an FCC program for promoting the development and implementation of a new approach to designing for fire safety in buildings. This report describes that program and presents the rationale on which it is based.

This report, prepared by Task Group T-57, has been approved by the Federal Construction Council and the Building Research Advisory Board. Both the Council and the Board wish to thank the Task Group members for their generous contributions of time, effort, and expertise.

Walter R. Hibbard, Jr., *Chairman*
Building Research Advisory Board

CONTENTS

Page

I. BACKGROUND 1

II. PURPOSES OF THE PROGRAM 3

III. ACTIVITIES OF THE PROGRAM 9

FIGURES

1. The dimensions of building fire safety design 5

2. Decision-tree diagram developed by the GSA Public Buildings Service 7-8

3. Functioning of the FCC Program for Developing and Implementing a New Approach to Designing for Fire Safety in Buildings . . . 10

APPENDIXES

A. Findings of FCC Task Group T-57 Regarding the Traditional Approach to Ensuring Fire Safety in Buildings and the Feasibility and Desirability of Developing a New Approach . . 12

B. FCC Task Group T-57 Subcommittee Report: Qualitative Evaluations--Determination of the Probability of a Module Becoming Fully Involved in Fire and Transferring from One Module to Another (containing Figures B-1 through B-10) . . . 14

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I
BACKGROUND

Task Group T-57 was formed by the Federal Construction Council (FCC) in response to increasing federal construction agency concern about fire safety in buildings. Specifically, the agencies' concern focused on the lack of uniformity in the large number of fire-protection design standards and the extensive influence of these standards on the design and construction of federal buildings.

Initially, the Task Group was charged to review all agency standards and requirements pertaining to building fire protection, to analyze the technical and economic implications of those standards and requirements, and to determine the feasibility of recommending a single fire-protection design standard comprising an amalgamation of all existing standards for use by all federal construction agencies. After reviewing a number of existing agency standards and requirements, the Task Group concluded that fulfilling its original charge would be minimally productive since no means were available either for comparing the diverse provisions of different agency standards and requirements or for determining whether buildings designed and constructed according to existing standards and requirements meet agency fire-protection goals. Additionally, the Task Group concluded that pursuing its original charge could be highly counterproductive since it was not possible to articulate and evaluate agency fire-protection goals in a manner that could reduce the growing disaster-potential created by placing ever-larger numbers of people in ever-more hostile environments or to propose design and construction solutions that would meet such goals in the most cost-effective manner.

The Task Group believed that in order to mitigate the original apprehensiveness of the federal construction agencies it would be necessary to forsake the traditional approach to developing and implementing fire-protection requirements and it asked the FCC for permission, which was granted, to formulate the program for developing and implementing a new approach to designing for fire safety* in buildings described in this report.

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*In this report, the term "fire safety" encompasses life safety, building integrity, property loss, and operations preservation considerations.

The Task Group made its request and the FCC gave its approval on the basis of the Task Group's conclusions* that:

1. Fire safety in buildings should not be dealt with primarily through regulations; rather it should be treated as a design problem and addressed, like other aspects of building design, in an analytical fashion throughout the building planning and design process.

2. Widespread acceptance by building owners and users, regulatory officials, and insurers of the idea that building fire safety is a design problem and the concept that using a systems approach to building fire safety is valid will require:

   a. Development of formal building fire-safety analytical capability;

   b. Development and demonstration of technical criteria that will have applicability to various types, sizes, and configurations of buildings and to various settings, occupancies, and functions of such buildings; and

   c. Education of adequate numbers of design professionals competent in building fire-safety planning and design.

3. Although the building community has already begun developing the required analytical capability and gives every indication that it is willing and able to accelerate that development, actual progress will depend upon the demand for application of the developed technology to planning, design, and regulation of public and private buildings. Similarly, a few fire-safety specialists are already familiar with the analytical approach and have begun applying it--to the extent possible given the limited development of the technology. However, many more trained practitioners would be needed for full implementation of the new technology, and the rate at which such practitioners are trained will depend on the demand for such professionals by the building community.

4. The development of the needed technology and the training of the professionals needed to implement the technology would be speeded up if the federal construction agencies required professional fire-safety design analysis as an integral and continuing part of the design process for federally owned and financed buildings.

To successfully utilize the demand-creating strategy that it believes will be effective in stimulating progress in the field of fire-safety design, the Task Group developed the program outlined in this report.

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*The findings of the Task Group on which these conclusions are based are presented in appendix A.

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II
PURPOSES OF THE PROGRAM

The immediate purpose of the FCC program for developing and implementing a new approach to designing for building fire safety is to provide a mechanism for:

1. Stimulating, guiding, and assisting the research community in the development of needed analytical capability;

2. Preparing and periodically updating model guidelines and technical criteria that federal agencies can use to incorporate professional fire-safety design analysis as an integral and continuing part of the design for federally owned and financed buildings;

3. Encouraging federal construction agencies to require fire-safety design in accordance with such guidelines and criteria; and

4. Promoting acceptance and implementation of the analytical approach to fire-safety design by the nonfederal government portion of the building community.

The ultimate intent of the program is to promote the evolution of the existing regulatory design/research framework in which building fire-safety technology is applied into one that permits a comprehensive and integrated view of building fire safety and makes fire-safety design a conscious and inseparable part of the total building design process. Implicit in this goal is the development of a formal technology that will permit precise articulation of building fire-safety needs in quantitative terms (taking into account the benefits, risks, and costs), the development of alternative design solutions to meeting those needs, and the evaluation of those solutions.*

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*To test the thesis that a quantitative approach to fire-safety design and regulation might be developed, Task Group T-57 appointed a subcommittee to develop a mathematical model that could be used in determining the probability of a work station becoming fully involved in fire and transferring fire from one work station to another. The subcommittee comprised Task Group members Harold E. Nelson and Dan Gross and Dr. Joseph A. Navarro, a systems analyst from the Institute of Defense Analysis. The results of the subcommittee's study are presented as appendix B.

When fire safety in buildings is viewed in a systems context,* it is evident that there is more involved than, for example, merely ensuring time for the evacuation of a building. As shown in Figure 1, fire safety is at lease an octo-dimensional regulatory and design problem, each dimension of which has a number of alternative facets, such as those presented in the decision-tree format in Figure 2. If regulators and owners of buildings could specify acceptable probabilities of risk to people, property, and functional activities as part of the fire-safety objectives of building and if designers could identify probabilities of risk associated with each of the means available for taking care of the facets shown in Figure 2, then a thoroughly rational approach to fire safety in buildings would be available.

The expanded view of the fire-safety regulatory and design problem depicted in Figure 2 serves two purposes: (1) it provides a method for merging intuitive judgment with available knowledge to create buildings that meet specified fire-safety objectives,** and (2) it provides a framework within which research endeavors can and should take place.***

---

*An outgrowth of operations research, systems analysis has become a widely used method for studying and developing optimum solutions to complex problems involving a large number of interrelated factors. Through systems analysis, problems that previously could be dealt with only on the basis of judgment, intuition, and experience can be solved, either wholly or in part, using mathematics.

**The GSA now applies this method of expressing and evaluating building fire-safety capabilities to all new buildings having 100,000 square feet or more in gross floor area and to all new buildings having five or more stories above grade. See General Services Administration, Building Fire-safety Criteria, PBS P5920.9, Change 2, 27 April 1972. Such decision trees have long been used by the ERDA and NASA in analyzing risks associated with their programs.

***On the basis of the systems engineering hypothesis that strategy (i.e., ways of using resources to achieve objectives), technology (i.e., available strategies), and economy (i.e., efficient technology) are inseparable parts of the same problem, then the most effective research effort to be coupled with the fire-safety regulatory and design problem would be one that improves the capability of regulators and designers to evaluate available strategies and, at the same time, seeks to make more strategies available for evaluation and to translate ideas for potential strategies into products, processes, or techniques that bring the concept to realization.

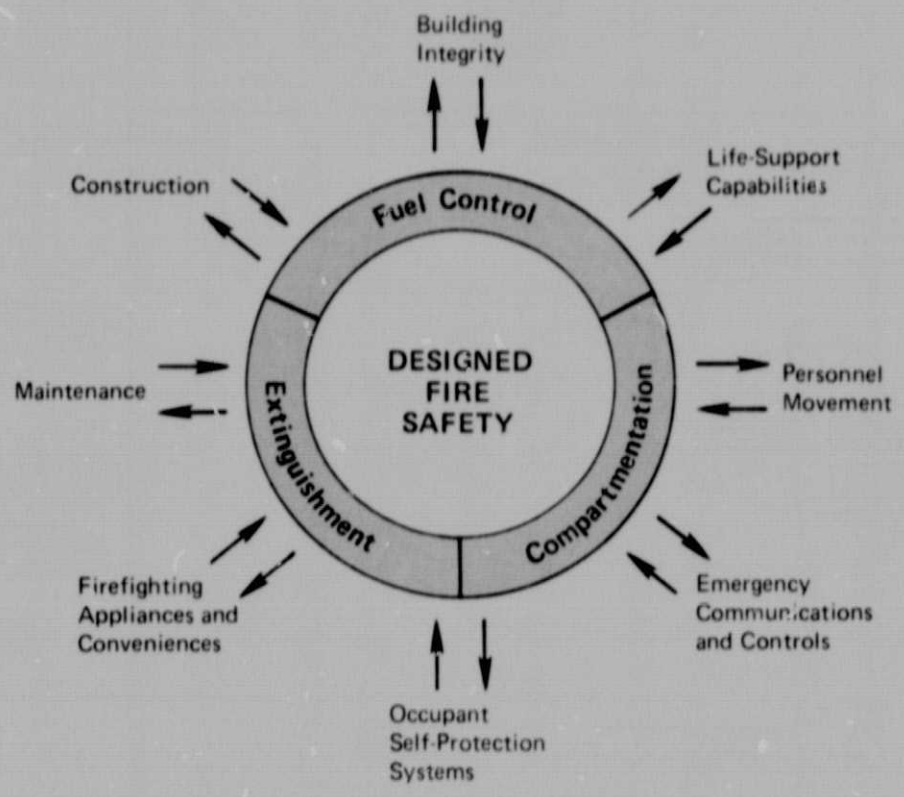

FIGURE 1 The dimensions of building fire-safety design.

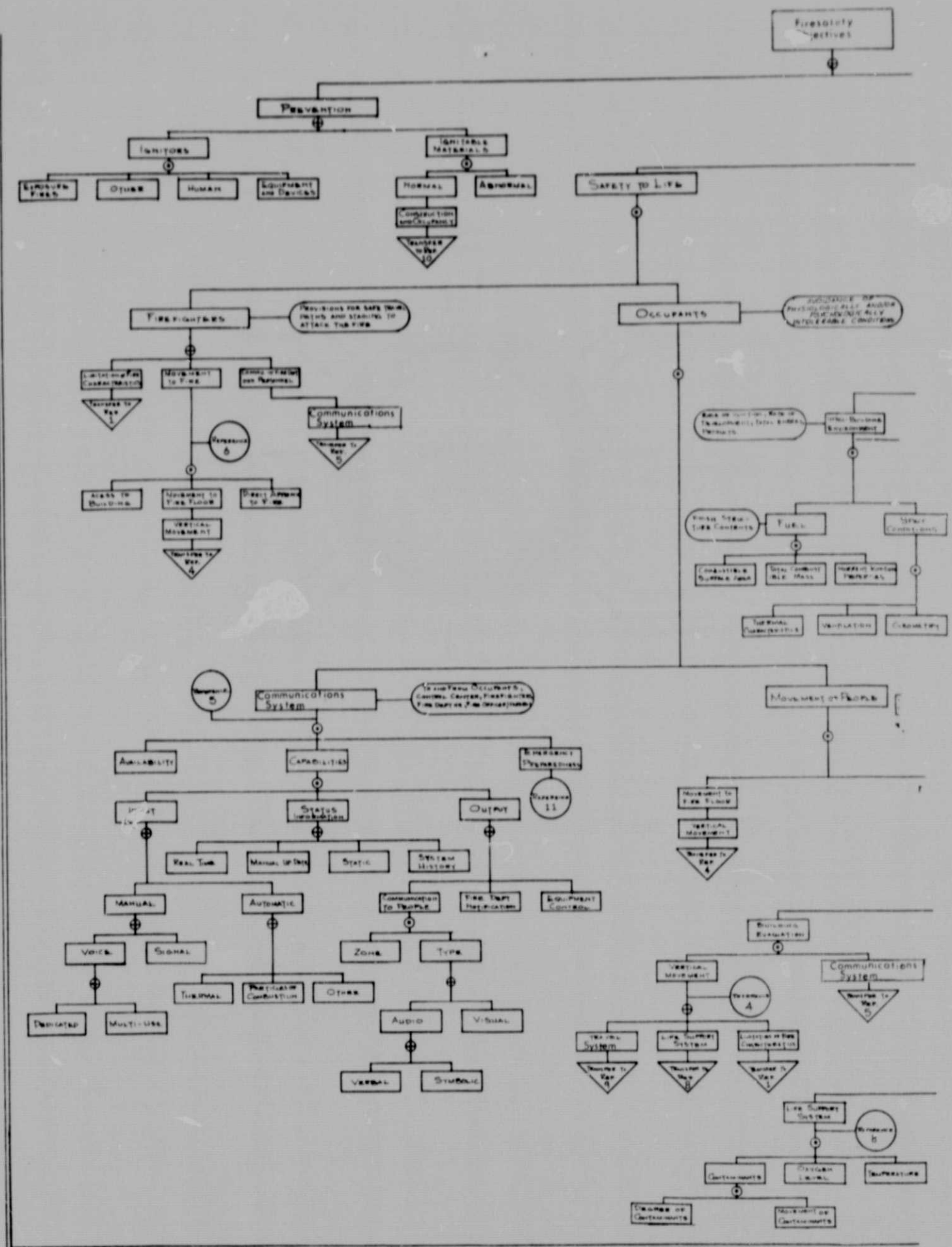

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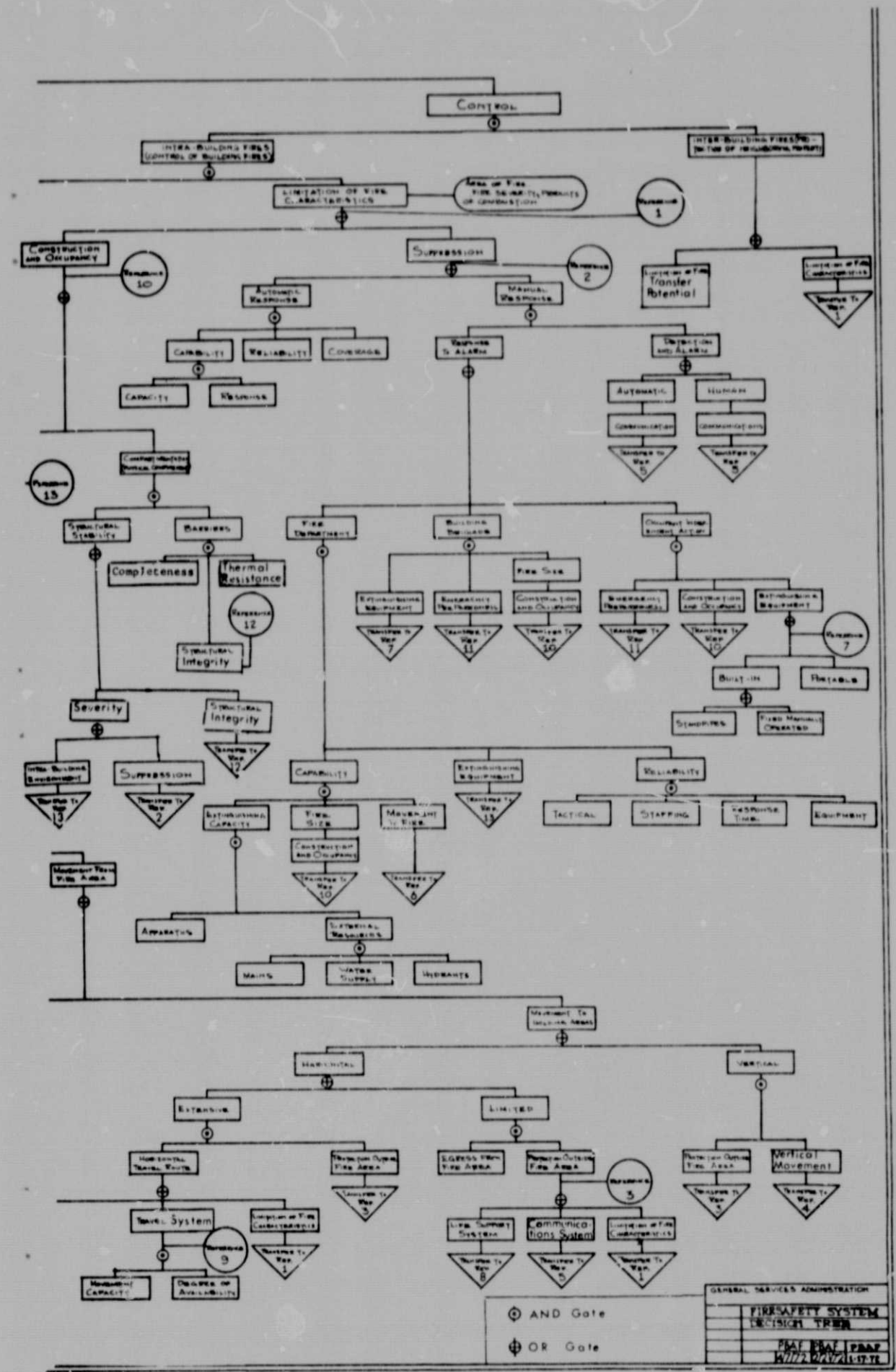
FIGURE 2 Decision-tree diagram developed by



the GSA Public Buildings Service.

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III
ACTIVITIES OF THE PROGRAM

The new FCC program on building fire safety is designed to impact on building community processes as shown in Figure 3 and is to be carried out under the direction of the Council by the FCC Standing Committee on Fire Protection and Safety Engineering.

To address the program objective of stimulating, guiding, and assisting the research community in the preparation of needed analytical capability, the Standing Committee will:

1. Devise a rational framework for relating the objectives and costs of fire safety in building research projects to needs of the federal construction agencies. To be based upon the expanded concept of fire safety in buildings illustrated in Figure 2, this framework should facilitate the evolution and priority ranking of research projects in terms of qualitative value and return-on-investment to the federal construction agencies.

2. Establish and maintain communication with the GSA Public Buildings Service and other federal construction agencies to obtain continuing input concerning their experience in applying a systems approach to expressing and evaluating fire safety in buildings.

3. Monitor, on a continuing basis, the current and contemplated research projects relating to fire safety in buildings.

4. Report periodically to the federal construction agencies on the kinds of research projects needed to meet their needs and the relative value of such projects.

To prepare and periodically update recommended model guidelines and technical criteria that federal construction agencies can use to incorporate professional fire-safety design analysis as an integral and continuing part of the design for federally owned and financed buildings, the Standing Committee will:

1. Prepare suggested statements of work and tasks to be performed in the total scope of the design cycle that describe what should be done and when to integrate fire-safety design into the federal building planning, programming, budgeting, and execution process.

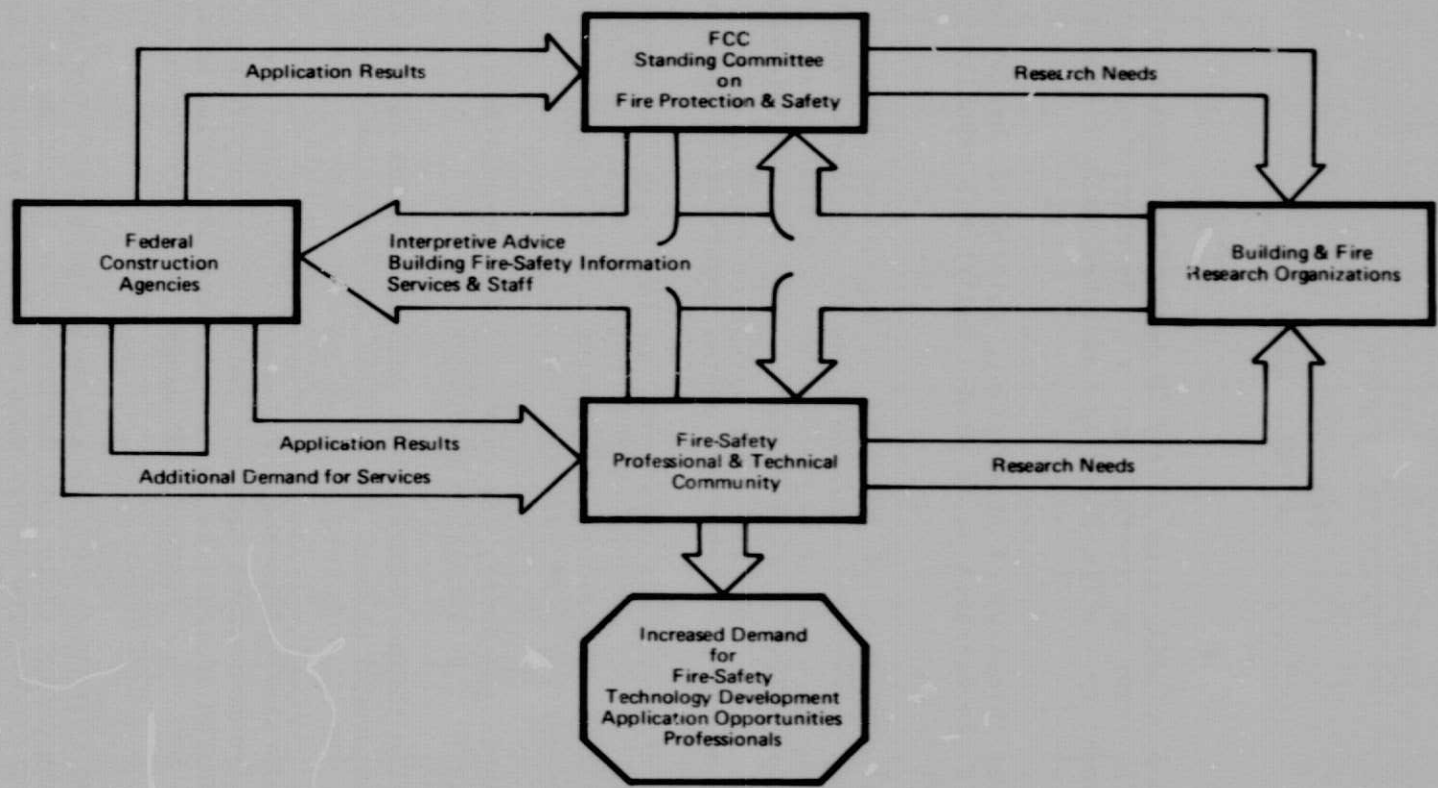

FIGURE 3 Functioning of the FCC Program for Developing and Implementing a New Approach to Designing for Fire Safety in Buildings.

2. Prepare criteria that agencies can use to indicate to fire-safety professionals suitable methods of performing fire-safety analyses for federally owned or financed buildings.

Through publications and seminars for federal and nonfederal building owners and users, building regulatory officials, building insurers, architects and engineers, and researchers, the Standing Committee will encourage federal construction agencies to require fire-safety design in accordance with such guidelines and criteria and promote acceptance and implementation of the analytical approach to fire-safety design by the nonfederal government portion of the building community.*

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*Full development of the analytical approach ultimately will depend on its acceptance by the nonfederal government sector since it is this sector that purchases, regulates, and supplies most construction in the United States.

APPENDIX A

FINDINGS OF FCC TASK GROUP T-57 REGARDING THE TRADITIONAL APPROACH TO ENSURING FIRE SAFETY IN BUILDINGS AND THE FEASIBILITY AND DESIRABILITY OF DEVELOPING A NEW APPROACH

FINDING 1

There is considerable evidence that the current approach to fire safety in buildings has not kept pace or is not consistent with other changes in building technology.

a. Heretofore, fire safety in buildings has principally been a regulatory concern, rather than a planning and design concern.

b. As in most other kinds of regulations relating to buildings, the stipulation of fire safety requirements has historically been made in terms of go/no-go/must-do/must-not-do provisions relating to individual aspects of buildings such as fire-rating of materials and means of egress.

c. Historically, most of the several hundred fire research projects pursued annually are funded by the federal government, are addressed to highly specialized topics having limited direct applicability to the fire safety in buildings problem, and, for those projects concerned with building matters, are focused on producing methods of testing the thermal and smoke-generating properties of individual building materials.

d. Few practitioners of the design professions have been schooled in building fire safety matters beyond the point of knowing that certain matters are generally stipulated in codes of one sort or another and that these stipulations need to be accommodated in building designs.

FINDING 2

There is considerable evidence that a performance concept approach to fire safety in buildings could be evolved and implemented in a relatively short period of time.

a. Notwithstanding its limited application thus far to building fire-safety problems, there now exists an extensive body of learning about applying operations research and systems analysis techniques (including the use

of probabilistic mathematics) both in the planning and designing of individual buildings as well as in the planning for the delivery of local government services.

b. Significant technological advancements have been made for other purposes in such areas as structural framing systems, extinguishment systems, detection/communications systems, travel/movement systems, closed environment systems which might have direct or extendable applicability to building fire safety.

c. Although the building research community has only addressed in a sporadic fashion during the past several years the notion of analytical methodologies for building fire safety design, the Department of Commerce, through the National Bureau of Standards, is preparing to take a strong leadership position in developing analytical methodologies for use in designing for building fire safety, but the Bureau cannot take on the additional role of creating the demand for applying these methodologies to public and private buildings.

FINDING 3

There is considerable experience--both within and outside the building community--that suggests that evolvement and implementation of a drastically new approach to a historical problem requires both an identifiable focal point for advocating the new approach and a vehicle for demonstrating the value of the new approach.

a. Existing organizations within the building community concerned with building fire safety matters either have entrenched ideas about dealing with building fire safety as a regulatory problem and are unlikely to pursue the idea that building fire safety is also a planning/design problem or are not in an advantageous position to advocate and demonstrate the new approach. In either case, these organizations are not in a position either to help create the demand for the needed underlying formal analytical technology or to interact strongly with the building research community in the development and refinement of applicable methodologies.

b. Reports and background papers relating to the creation of proposed organizations such as the U.S. Fire Administration and the National Institute of Building Science do not warrant a presumption that these proposed organizations could or would advocate and demonstrate a new approach to building fire safety.

FINDING 4

There are many indications that the trend of the federal government in dealing with historical societal problems requiring either significant technological advances or drastic technological redirection for solution is one of demonstration of ideas and encouragement of technological development and application.

APPENDIX B

FCC TASK GROUP T-57 SUBCOMMITTEE REPORT: QUALITATIVE EVALUATIONS--DETERMINATION OF THE PROBABILITY OF A MODULE BECOMING FULLY INVOLVED IN FIRE AND TRANSFERRING FROM ONE MODULE TO ANOTHER

1. INTRODUCTION

In order to test the thesis that a quantitative approach to fire-safety design and regulation was possible, FCC Task Group T-57 formed a subcommittee to develop a mathematical model that could be used in determining the probability of a work station becoming fully involved in fire and the fire transferring from one work station to another. The subcommittee comprised two Task Group members, Harold E. Nelson and Daniel Gross, and Dr. James A. Navarro, a systems analyst from the Institute of Defense Analysis. This appendix presents the results of this subcommittee's work.

It must be recognized that the mathematical model developed by the subcommittee is not suitable for use by practitioners since it was created merely to illustrate the type of procedure that might be used in designing for fire safety in a quantitative manner. In the following discussion of the model, numerous values have been assumed, and it should be noted that before this or any similar model could be used in practice, such values would have to be determined through actual research.

Basically, the model deals with relationships among the factors associated with the generation and propagation of fire. It does not consider heat, smoke, and toxic gas aspects of fire even though these aspects are important to any determination, for design and regulatory purposes, of the probable extent to which life, property, and mission can be affected by fire. Additionally, the element of time is not considered in this initial approach even though it too is essential to such a realistic determination. Further, the identification of factors and their relationships is limited to consideration of building environments in which the type and kind of combustibles available for generation and propagation of fire are representative of the contents or materials of construction that comprise the major portion of the federal construction program; consideration is not given to flammable or explosive atmospheres. In the material that follows, factors and relationships are first generalized and then illustrated in an example.

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2. GENERALIZATION

a. Basic Concept

After a fire has started at some point in a building (e.g., a waste container in an office or a ceiling lighting fixture in a shop), the flame aspect of the fire is free to propagate within the limits of available fuel and the environment of the building if extinguishment is not applied. The view taken here is that:

(1) A building is an array of interconnecting modules comprising air mass, contents, and building components. The boundaries of a module can be either circulation areas or surrounding building components, and modules can have different sizes and shapes (e.g., interstices within walls, floors, roofs, ceiling; ducts and shafts; spaces within rooms; rooms or areas of one story; and more than one story of a multistory building). The modules form a network physically interconnected by partitions, floors, ducts, and shafts that may or may not isolate and confine the air mass to each module because of door openings, punctures in the building components, and interconnecting ducts.

(2) The process by which flame propagates in a building includes surface flame spread, flash over, energy transfers, and combustion gas motions that occur within and between the modules.

(3) The extent of flame propagation in a building can be determined probabilistically in terms of: (a) the nature, form, and distribution of fuel within the modules; (b) the thermal properties of the horizontal and vertical boundaries of the modules; (c) the pattern and amount of ventilation occurring within and among the modules; and (d) the geometry of the modules.

In taking this approach to determining the extent to which flame can propagate in a building, it is useful to consider the building as comprising the following modules and networks of modules that may need to be progressively analyzed:

(1) Individual Work Station--a module consisting of a habitable area within a room or undivided building. The area usually is associated with an activity but is more directly related to the cluster of potential fuel (e.g., storage racks, furniture grouping, workbench, patient unit in a hospital ward). The area is bounded by circulation areas or by surrounding walls and partitions.

(2) Room--a module comprising a network of work station modules bounded by walls, partitions, floors, and ceilings.

(3) Floor--a module comprising a network of room modules on the same level.

b. Basic Approach

The analysis of every building does not necessarily have to begin with the lowest level of analysis, that of individual work stations. For example, if the principal reason for investigating the extent to which flame can propagate in a building is to determine how to prevent large-area fire involvement, the analysis might properly begin with rooms rather than individual work stations. On the other hand, if the principal reason for the investigation is to determine the potential danger to life, the analysis might better start with individual work stations.

Nonetheless, to illustrate the types of data and judgments needed in order to apply this concept in analyzing the potential for fire involvement of a building, the ensuing discussion proceeds from consideration of how a work station module becomes involved in fire and spreads to other work stations modules until a room module is involved in fire.*

To ascertain the probability of a work station module becoming fully involved in fire, it is necessary to be able to describe quantitatively the relationship that exists between the probability of fire involvement and the combustible characteristics of the module. The single most important characteristic to be considered is the amount of free combustible material** in the module, herein expressed as the ratio between the exposed surface area of this material and the total floor area of the module.

The "ignitability" of the combustible material influences the probability of total involvement and can be taken account of in order-of-magnitude steps. On the basis of data available and judgment, a graphic representation of the relationship between the probability of fire involvement and the combustible characteristics of the module then can be prepared. Figure B-1 illustrates such a graphic representation. The representation can be refined by considering other combustible characteristics of the module such as heat content, rate of heat release, and activation energy.

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*As used herein, the terms "involved in fire" and "fire involvement" mean a fire has developed to such an intensity that it threatens to spread to another module. Such an intensity does not necessarily require that a fire extend to all portions of the module in which it is developing.

**Free combustible material is exposed material (e.g., the exposed surface of a desk, whereas not the papers within the desk).

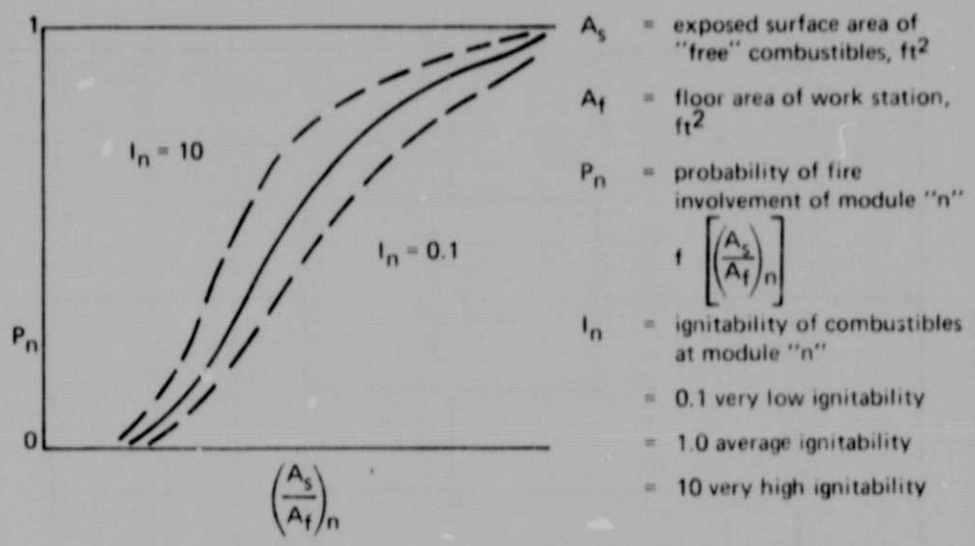


FIGURE B-1 Relationship between the probability of fire involvement and the combustible characteristics of a work station module.

To ascertain the probability of a room module becoming fully involved in fire, it is necessary to ascertain the probability of fire propagating among work station modules. In essence, the problem is one of ascertaining:

(1) The probability of fire propagation among work station modules or from work station modules to room module boundaries by flame spread along combustible surfaces.

(2) The probability of fire propagation among work station modules or from work station modules to room module boundaries by radiation (convection, conduction, and flying brands may be considered as minor variations).

(3) The probability of total involvement of all work station modules by, for example, flash over.

Figure B-2 illustrates the physical processes that need to be evaluated for a room module; Figure B-3 illustrates the corresponding probabilities that need to be ascertained.

The probability of fire propagation by flame spread can be readily defined as a function of the combustible characteristics of the exposed surface materials. The probability of fire propagation by other means, however, needs to be defined in terms of a number of influential factors; i.e., the separation between work station modules and the thermal, geometric, and ventilation characteristics

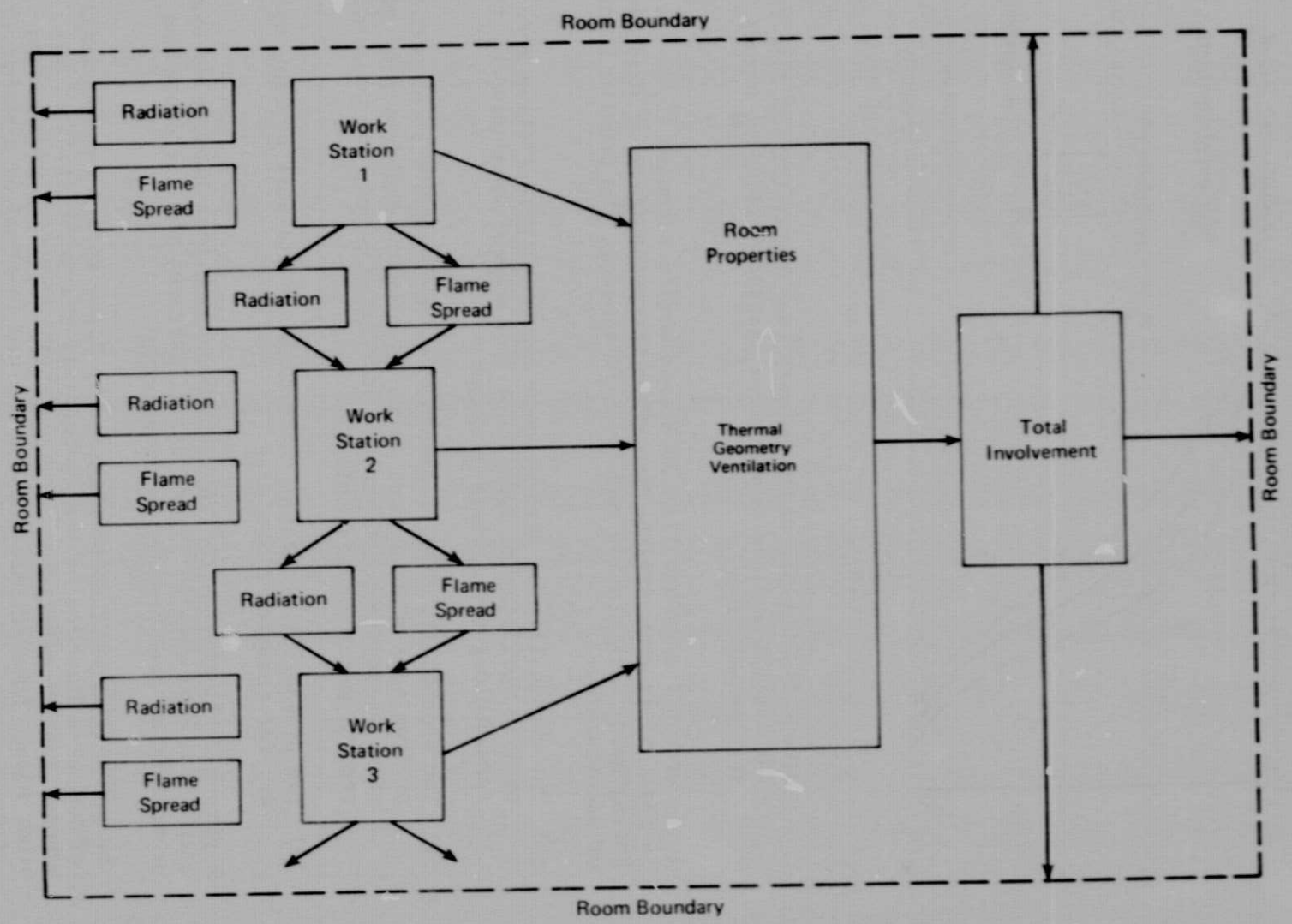
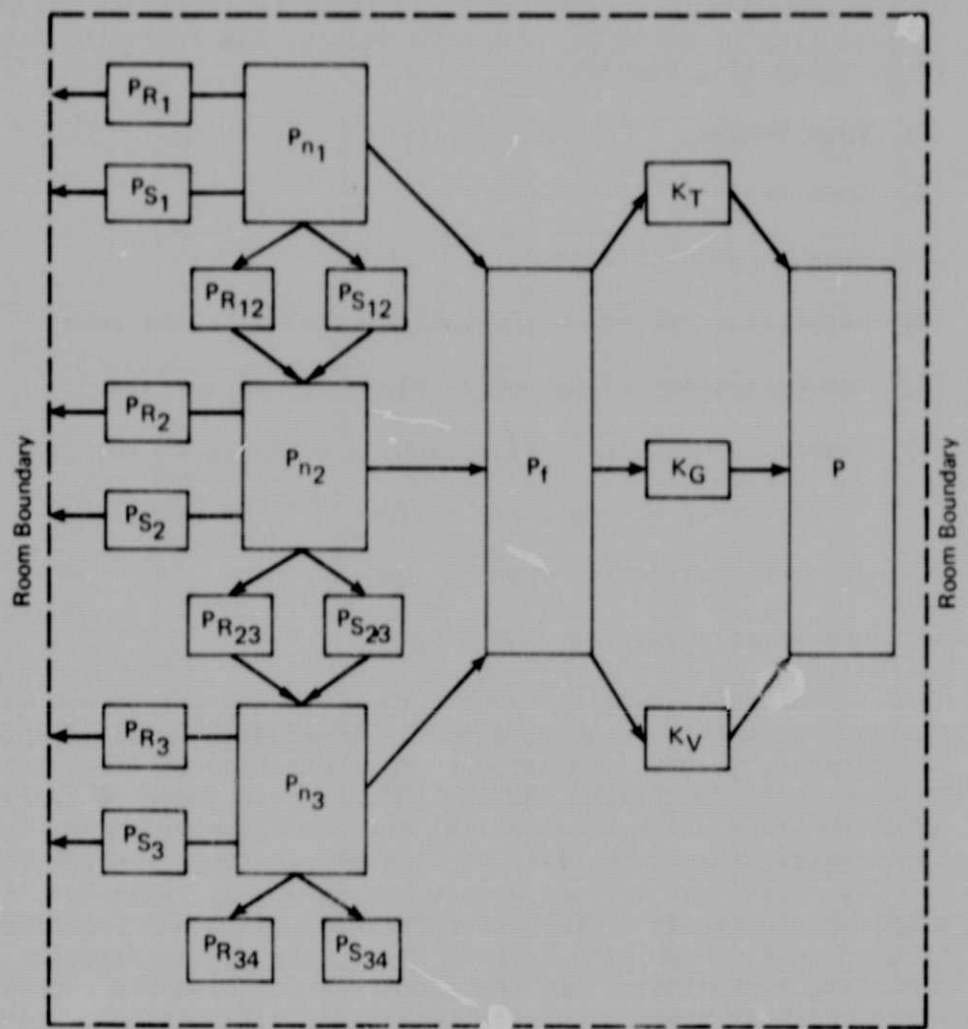


FIGURE B-2 Processes that need evaluation in a room module.



P_{n_1} = probability of fire involvement of Work Station 1 due to fuel load

$P_{R_{12}}$ = probability of fire spread by radiation from Work Station 1 to Work Station 2

$P_{S_{12}}$ = probability of fire spread by surface flame spread from Work Station 1 to Work Station 2

P_f = probability of fire involvement of room module due to fuel load

K_T = thermal properties factor

K_G = geometry factor

K_V = ventilation factor

P = probability of fire involvement of room module

FIGURE B-3 Probabilities that need evaluation in a room module.

of the room module. Accordingly, in order to ascertain the probability of full fire involvement of a room module, the following factors need to be taken into account:

(1) Room volume,

(2) Room height,

(3) Room length (or width),

(4) Separation between work station modules in the room,

(5) Combustibility of potential flame spread surfaces,

(6) Thermal conductivity of enclosing surfaces of the room,

(7) Surface area of enclosing surfaces of the room,

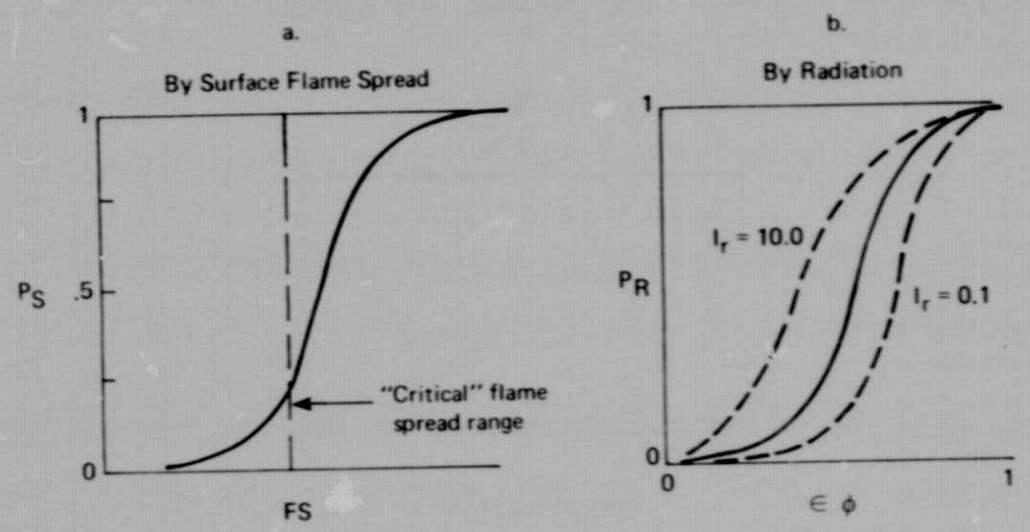
(8) Area of ventilation opening, and

(9) Height of ventilation opening.

To ascertain the probability of fire propagating from one work station to another or to room module boundaries by flame spread, it is necessary to create a graphic representation of the relationship between this probability and the flame spread index of surfaces connecting work station modules like the one illustrated in Figure B-4a. To ascertain the probability of fire propagating from one work station to another or to room module boundaries by radiation, it is necessary to create a graphic representation of the relationship between this probability and the emissivity characteristics of the radiating work station and the geometric relationship between the radiating work station and the receiving work station or room module boundary like the one shown in Figure B-4b.

To ascertain the probability of total involvement of a room module, it is necessary to describe quantitatively the relationship between this probability and the fuel, thermal, geometric, and ventilation characteristics of the room module. This can be accomplished on the basis of data and judgment by creating, in a manner analogous to that used to represent the probability of fire involvement of a work station described earlier, a graphical representation of the probability of fire involvement as a function of the combustible load and the thermal, geometrical, and ventilation characteristics of the room module. Such representations are illustrated in Figures B-5 (combustible load) and B-6 (thermal geometric and ventilation properties).

The curves illustrated in Figure B-6 are prepared on the basis that $K_T = 1$, $K_G = 1$, and $K_V = 1$ are characteristics of a typical room and are intended to take into account that burning of combustibles located



P_S = Probability of spread to adjacent work station due to flame spread on solid surfaces

FS = Flame spread index on surfaces connecting work stations

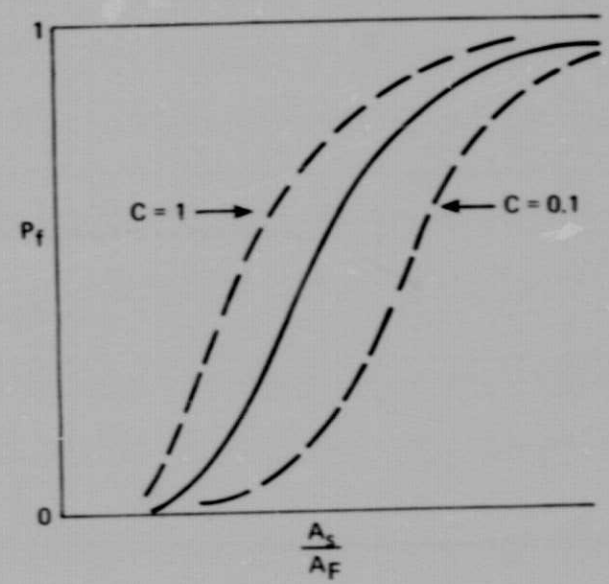
P_R = Probability of spread to adjacent work station due to flame spread by radiation

ϕ = Configuration factor (function of geometry between radiator and receiver)

$\in$ = Emissivity of radiating flames and/or surfaces

I_r = Ignitability of item receiving radiation

FIGURE B-4 Probability of propagation of flame.



C = Ratio of the projected area of fuel (furnishings) to the floor area of room

P_f = Probability of fire involvement of room due to fuel load

FIGURE B-5 Probability of fire involvement of room module due to fuel load.

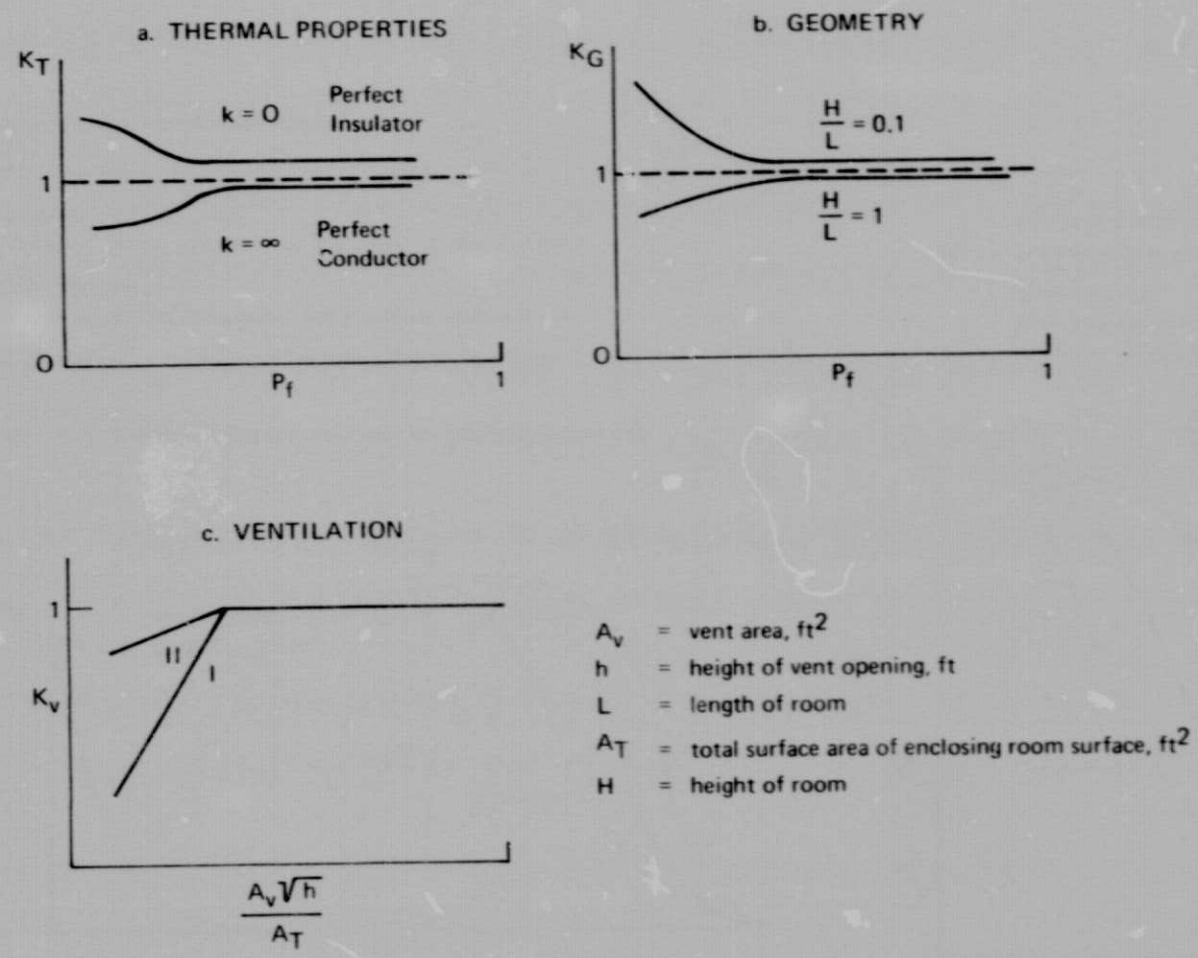


FIGURE B-6 Thermal (K_T), geometric (K_G), and ventilation (K_V) factors for room modules. ($P = P_f\ K_T\ K_G\ K_V$)

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in one or more work stations may be sufficient to produce full fire involvement of a room. Whether or not this happens with a marginal amount of fuel depends upon the characteristics of the room (K_T, K_G, K_V) that have an appreciable affect on the overall heat balance and the temperature levels reached.

The thermal properties factor, K_T, represents the extent to which heat is lost by conduction through the walls. If heat conduction is minimized ("perfect insulator," k = 0), this heat energy is available to raise room temperatures; if conduction is maximized ("perfect conductor," k = ∞), more heat is removed and room temperatures are lower. The curves illustrated in Figure B-6a are a representation of this effect on calculated temperatures presented by Kawagoe and Sekine in Estimation of Fire Temperature-Time Curve in Rooms -- Second Report (BRI Occasional Report No. 17, March 1964).

	Room Temperature at 1 Hour	
k	$\frac{A\sqrt{h}}{A_T} = 0.02$	$\frac{A\sqrt{h}}{A_T} = 0.06$
0.1 (Insulation)	900 C	1160 C
0.5 (Plaster)	780 C	1090 C
1.0 (Concrete)	640 C	970 C

The geometry factor, K_G, represents the effects of room shape (e.g., increased radiation from flames deflected along low ceilings). Although expressed here in terms of an aspect ratio (height/length or width), there may be justification for considering actual dimensions (also in including fuel height). In the recent model fire experiments of the International Council for Building Research, Studies and Documentation, the most suitable scaling correlations (of the time for flames to spread from the point of ignition to cover the entire surface of the combustible fuel) could be expressed in terms of the height of the compartment and the height of the fuel.

The ventilation factor, K_V, represents the important influence of air on the rate of burning (and on such items as temperature and radiation). Thomas, Heselden, and Law in Fire Research Technical Paper No. 18, summarized the two kinds of behavior in fully developed compartment fires:

(1) In the first regime (I), the burning rate is approximately proportional to air flow, which is induced by stack effect; the window area and height are important and the amount and surface area of the fuel are unimportant.

(2) In the second regime (II), the burning rate is nearly independent of air flow, which is largely entrained, and the characteristics of the fuel are important.

This qualitative analysis shows how fire reaches the boundary limits of a room (wall, door, duct, etc.). At the room boundary, the effects of fire must be evaluated in terms of:

(1) Propagation through openings (doors, windows, ducts, fixtures, etc.) by flame impingement, radiation, and convection.

(2) Propagation through, and effect on, structural members.

3. ILLUSTRATIVE EXAMPLE

A schematic drawing of a room module, an office, is shown in Figure B-7. The office module is 24 by 30 by 10 feet; it has three doors, each 36 by 80 inches, and no windows. The walls are insulated metal partitions, the ceiling is noncombustible low-density mineral-base tile, and the floors are concrete with vinyl asbestos tile covering. The furniture consists of metal desks, chairs with plastic cushions, and metal tables and bookcases. Other furnishings include a flammable carpet with high ignitability and flame spread characteristics located in the northeast corner and a flammable poster board located on the west wall of the room. The bookshelves contain a mixture of books, pamphlets, loose-leaf notebooks, and miscellaneous papers. The room also contains piles of paper located as illustrated in Figure B-7.

An analysis is to be made to determine the maximum probabilities of each work station and of the entire room becoming fully involved in fire, assuming that a fire starts in Work Station 1. The analytical procedure to be followed is:

Step 1: Determine the probability of full fire involvement of Work Station 1 based on fuel.

Given — A_s/A_f,
Ignitability factor of fuel is 10.

Solution — The answer is arrived at by use of the ignitability graph, Figure B-8a. The probability based on ignitability of fuel is 0.9. This indicates a high probability that fire will fully involve Work Station 1 because of the availability of combustible fuel (paper, books, and contents of book cases).

Step 2: Determine probability of fire spread from Work Station 1.

Given — The room enclosure which consists of noncombustible materials with very low flame spread ratings.

Distances from Work Station 1 to Work Stations 2 and 5, and the nearest open door.

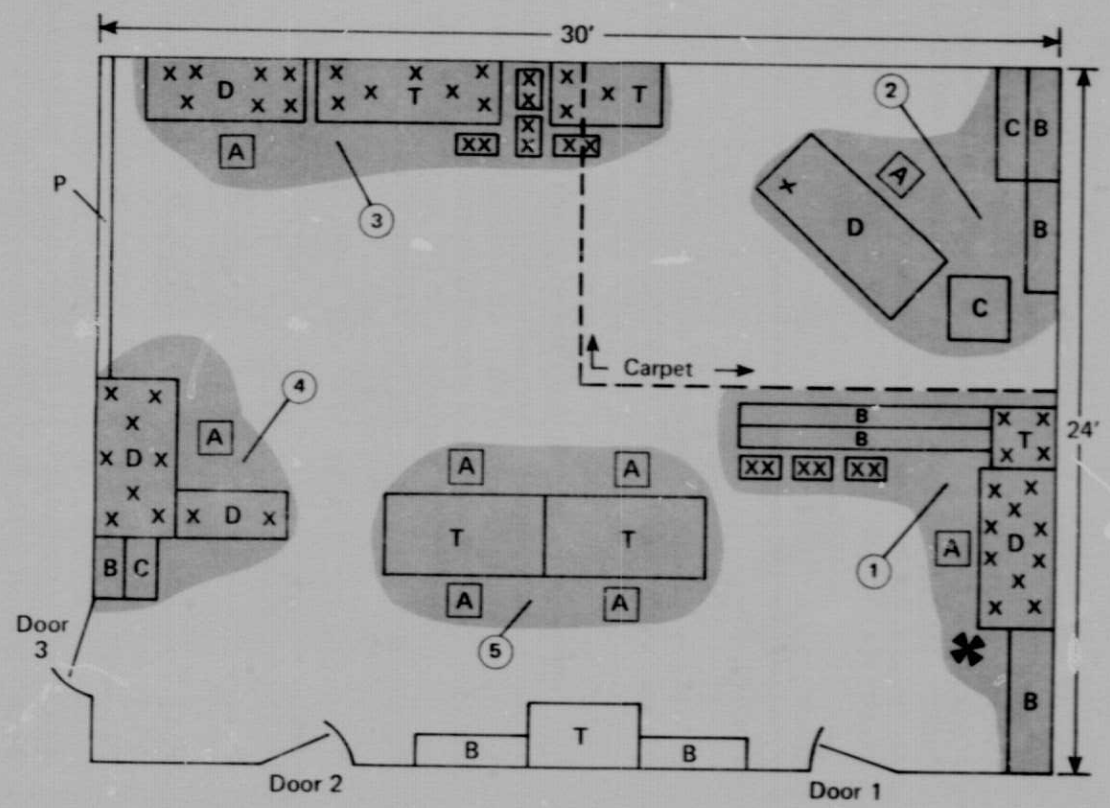

FIGURE B-7 Schematic layout--office module.

Solution — There are two possible avenues of fire spread from Work Station 1 to each of the three points in question; one avenue is based on surface flame spread and the other on radiation.

Solutions are arrived at by use of the radiation and surface flame spread graphs, Figures B-8b and B-8c. respectively.

Use of the radiation graph requires knowledge of the ignitability of the irradiated combustible surfaces, the emissivity of the radiating flames, and the configuration factor. Assuming a high ignitability factor (10) for paper at Work Station 2, emissivity is judged to be about 0.5, based on the depth of expectant flames from the fully involved Work Station 1. The configuration factor depends upon the geometry of the radiating flames in Work Station 1 relative to the nearest receiving surface in Work Station 2.

A similar process is used to determine the probability of spread by radiation from Work Station 1 to Work Station 5 and to the open door.

Use of the surface flame spread graph requires knowledge of only one factor, the flame spread rating of the connecting surface(s). In this case the walls, ceiling, and floor have very low ratings since they are noncombustible materials with only the floor tile having any potential for spreading flame.

Referring to Figures B-8b and B-8c, the solutions are:

$P_R 1, 2 = 0.80$	$P_S 1, 2 < 0.10$
$P_R 1, 5 = 0.65$	$P_S 1, 5 < 0.10$
$P_R 1$, Door = 0.20	$P_S 1$, Door < 0.10

The high probability of fire spread by radiation from Work Station 1 to Work Station 2 indicates that this will be the most likely means and direction of fire spread.

<u>Step 3</u>: Determine probability of full fire involvement of Work Station 2.

Given — A_s/A_f,
Ignitability factor of fuel is 10.

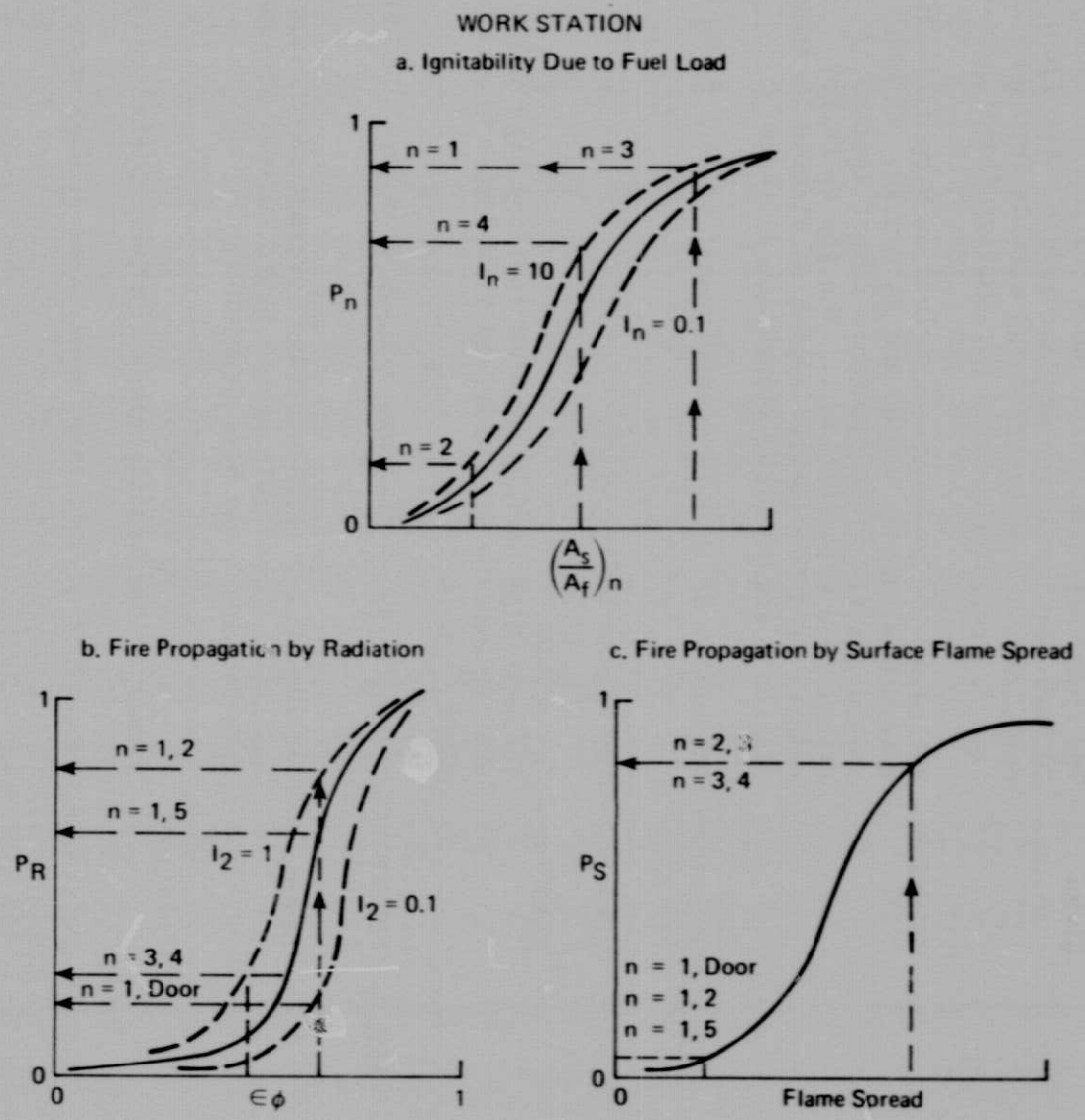

FIGURE B-8 Probabilities of work station ignitability and of fire propagation between work stations.

Solution — Following the same analytical procedure as in Step 1, it is determined that P_{n_2} equals 0.30. This low probability indicates that there is a much smaller chance that a fully developed fire will evolve at Work Station 2.

Step 4: Determine probability of fire propagation from Work Station 2 to Work Station 3.

Given — The room enclosure, fuel in Work Station, and distance to Work Station 3, the nearest module. The floor of Work Station 2 is carpeted and extends into Work Station 3, providing a media for surface flame spread.

Solution — Following the procedure described in Step 3, it is determined that $P_S = 0.80$ and $P_R < 0.10$. Flames spread readily along flammable carpet ignited by flames from Work Station 1. The low P_R factor results from the limited amount of flaming in Work Station 2 and the long separation distance.

Step 5: Determine probability of full fire involvement of Work Station 3.

Given — See Figure B-7.

Solution — $P_{n_3} = 0.90$
There is high surface area of fuel and high ignitability, causing fire to spread from carpet to curtains, paper, and so forth.

Step 6: Determining probability of fire propagation from Work Station 3 to Work Station 4.

Given — See Figure B-7 which provides information on distances and shows combustible poster board located between Work Station 3 and Work Station 4.

Solution — $P_R = 0.30$ $P_S = 0.80$
Flames spread readily along flammable poster board.

Step 7: Determine probability of full fire involvement of Work Station 4.

Given — See Figure B-7.

Solution — $P_{n_4} = 0.70$
There is high ignitability and moderate surface area of combustible (paper).

Step 8: Determine probability of fire propagation from Work Station 4 to Work Station 5 and open door.

Given — See Figure B-7 which shows distances to open door and to Work Station 5.

Solution — To open door: $P_R = 0.30$, $P_S < 0.10$. To Work Station 5: $P_R = 0.10$, $P_S < 0.10$

Step 9: Determine probability of full fire involvement of room.

Given — A_s/A_f (area of all exposed combustibles located in Work Stations 1 through 5 related to entire room floor area), compaction of fuel, and characteristics of room enclosure as shown in Figure B-7. Room enclosure is well insulated (K = 0), ventilation is through open doors with $A_V\sqrt{h}/A_T$ equal to 0.08, geometry factor H/L equal to 0.33.

Solution — The probability of full room involvement is the product of P_f, K_T, K_G, and K_V. These factors are determined from the graphs presented in Figure B-9 as:

$P_f = 0.4 \quad K_T = 1.1 \quad K_V = 0.75 \quad K_G = 1.1$

$P = 0.4 \times 1.1 \times 1.1 \times 0.75 = 0.36$

Fuel factor is moderate to high due to quantity and distribution (compactness) of combustibles. With doors open and no forced air supply, the fire is ventilation-limited, ($K_V < 1$). If air is supplied by HVAC system, ($K_V = 1$). Figure B-10 illustrates the results of this analysis and the likely route that fire will propagate.

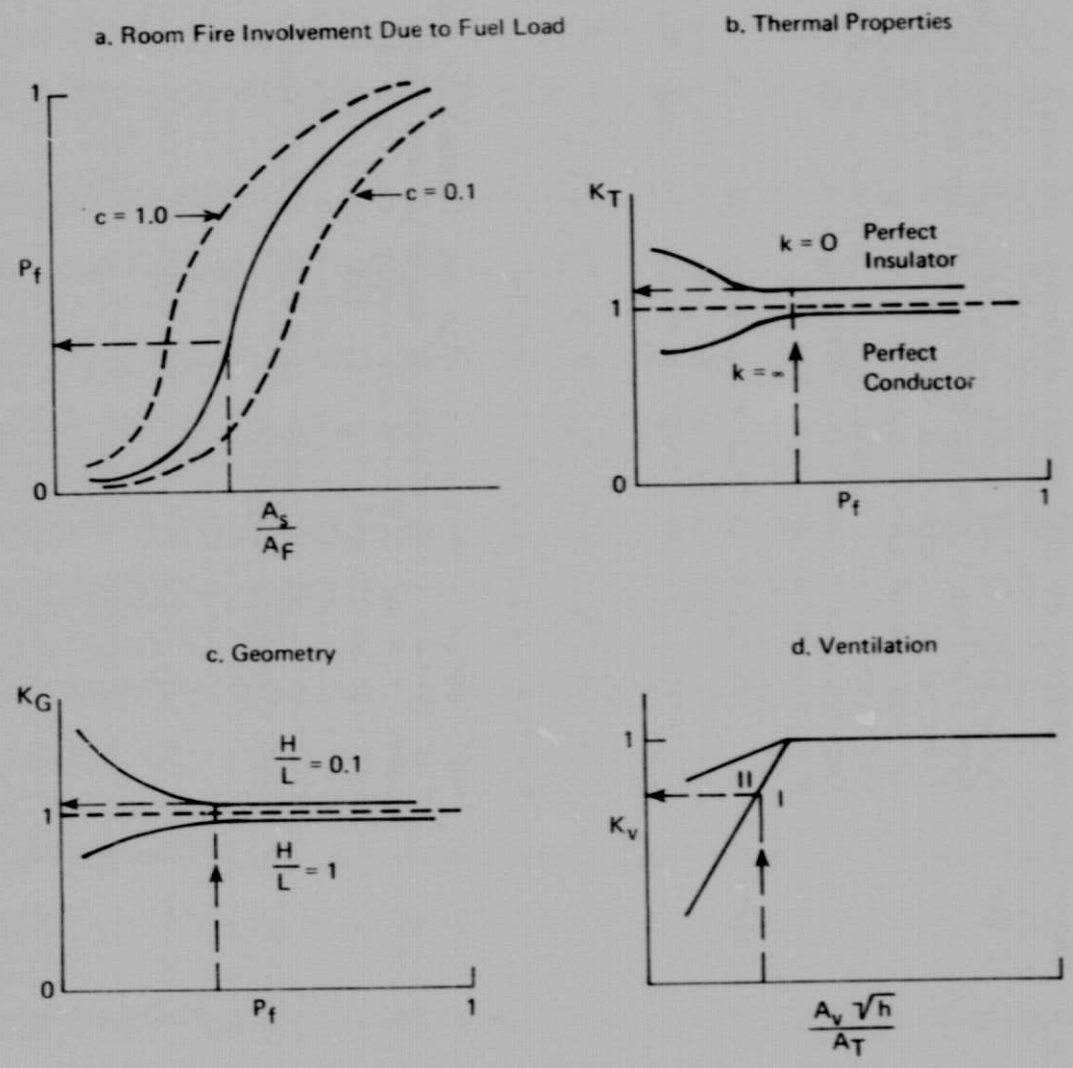

FIGURE B-9 Probability of total involvement in fire of all work stations in room module.

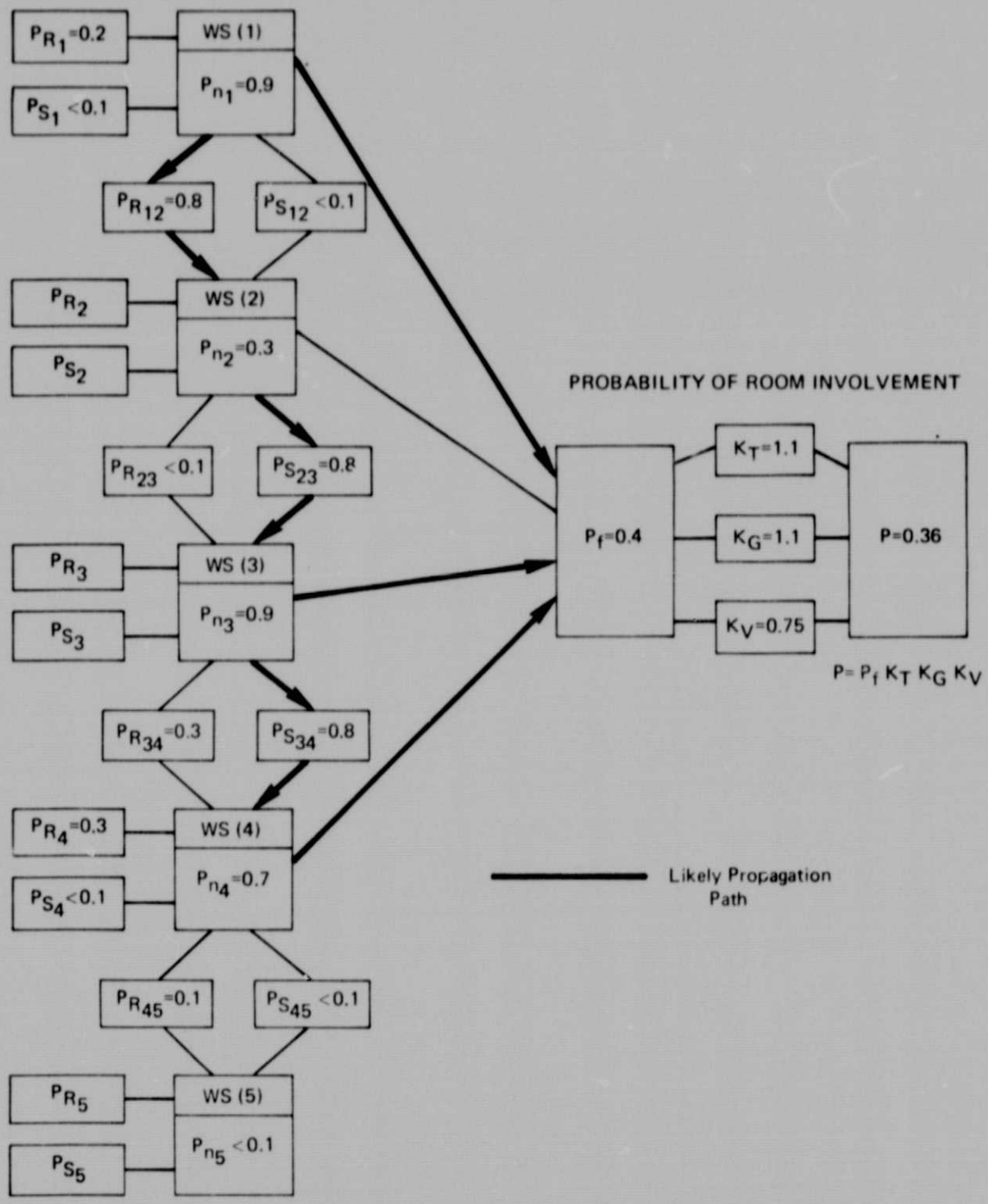

FIGURE B-10 Probability of and likely propagation path to full involvement of room module in fire.