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The Basic Structure of the Fire Protection Design Assessment System

Harold E. Nelson
William D. Walton

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
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THE BASIC STRUCTURE OF THE FIRE PROTECTION
DESIGN ASSESSMENT SYSTEM

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ABSTRACT

The purpose of the Fire Protection Design Assessment System is provide design engineers with a tool to improve their ability to appraise the overall fire safety in a facility and evaluate the impact of fire protection measures. The system is based on deterministic fire prediction techniques and will be implemented through an interactive computer program. This report describes the components and basic structure of the system. The inputs to the system include data on the building layout, combustibile contents, fire resistance, detectors, sprinklers, smoke control system, occupants and the fire safety objectives. The outputs include the predicted fire generated conditions within the building as a function of time and an evaluation of the user specified fire safety objectives.

Key Words: compartment fires; computer programs; fire growth; hazard analysis; life safety; mathematical models; room fires; smoke; toxicity.

1. INTRODUCTION

The design of fire safety for buildings has traditionally been accomplished through the use of building and fire codes. While this method of design has provided for an "adequate" level of fire safety in most instances it has at least one major weakness. It does not permit the engineer to design the building for a specified level of fire performance under a given set of fire conditions. Building and fire codes assume that the fire threat and the desired fire performance will be the same for all buildings of a similar type and with similar contents and use. The code approach does not, for example, take into consideration factors such as the importance of the facility. Therefore, the code approach may result in over design or under design, depending on the circumstances. More importantly, the specific level of fire safety is unknown.

The purpose of the Fire Protection Design Assessment System is to provide design engineers with a tool to improve their ability to appraise the overall fire safety in a building or special purpose facility and evaluate the impact of special fire protection measures.

In structural design, the complete building is considered. Design is based on code prescribed load values (gravity,

earthquake, wind) according to geographical location. In this "deterministic" fire safety design system, the designer is being given the opportunity to assume loads, i.e. combustible contents, rate of burning, combustion products, etc., and to examine localized fire effects.

The Fire Protection Design Assessment System provides a means to evaluate scenarios involving different spaces and different conditions in a given space. It is based on the prescribed release of energy and products of combustion and the resultant flow of heat and mass according to established principles and data from laboratory fire experiments. The system guides the user through the process. The user must, however, designate the room and item of origin and the physical situation he wishes to analyze. (eg: A fire starting on the bed in a bedroom; comparing the value of sprinklers, detectors, door closers, and wall fire ratings.)

The system consists of a modular computer program. The initial version of the system limits user choices to a selection of the fire scenario and the type of output desired. As the system matures, it will allow the user to select alternate calculation procedures to evaluate the fire phenomena. The choice will depend on the computer resources available, the type of problem to be analyzed and the output desired.

2. FUNDAMENTAL ASSUMPTIONS

The design assessment system is based primarily on physical and chemical relationships governing the growth of fire and its impact on the structure, contents and occupants. These relationships have been drawn from the ongoing research at the Center for Fire Research and other research and engineering organizations in the U.S. and abroad. They represent the state-of-the-art in fire prediction for engineering assessment. In general, the available fire prediction techniques focus on only one aspect of fire phenomena. This evaluation system blends a number of these prediction techniques into a uniform and consistent package. In a number of cases the results from one prediction are used as input to another.

The main component of the system is a zone fire model. This model predicts the fundamental properties of the fire generated environment such as the temperature and location of the hot gases. This model requires the solution of a set of simultaneous differential equations. In addition to the base fire model, a number of supplemental calculations requiring the solution of algebraic equations are performed. The calculations provide items such as heat flux from the fire and the movement of people.

The system divides any story of a building into four segments.

These are:

1. The room of fire origin (actual or design assumed).
2. The entirety of the adjacent room, rooms or spaces open to the room of fire origin.
3. Rooms, spaces or floors separated from the either of the two preceding segments by barriers that restrict the flow of heat, smoke and hot gases.
4. The space outside the building.

The system assumes there are no large unprotected vertical openings (eg: open stairs, atria, shafts) in the facility and that leakage from the fire area or nearby smoke laden spaces is through the spaces around closed doors or other small leakage spaces. This assumption makes it possible to assess the pressure required for smoke control.

3. SYSTEM ORGANIZATION

The design assessment system can be broken down into five major elements. These elements are Building Data, Fire Safety

Objectives, Computations, Results and Alternative Approaches. A schematic showing the organization of these elements is shown in Figure 1.

The first two, the Building Data and Fire Safety Objectives elements are the data input section of the system. The system is designed to be interactive, that is the user will be prompted with questions concerning the input. The next element, Computations, is the computational heart of the method. This consists of the assembled, coordinated set of models, formulas, and data for making the design assessment. The fourth element, Results, is the output section of the system. The user may select from several different output formats depending on the type of assessment desired. The last element, Alternative Approaches, assists the user if he desires to appraise alternative fire safety arrangements.

Although the system is interactive in nature, it has the capability of generating and reading data files. The user may select to save the system inputs which were entered interactively in a computer file for use at a later time. Previously created data files may be used intact or modified by the user.

A detailed discussion of each of the element is provided below.

3.1 Building Data

The Building Data element contains the description of the facility and its occupancy. The user provides data on the layout and construction of the facility and the fire protection systems. The user may elect to evaluate the impact of changes in arrangement, materials, use, protection, or occupants.

A modular system for fire safety design or management is being used. The modules are Architectural, Fuel Package, Structural Capabilities, Detection Equipment, Sprinklers, Smoke Control, and Occupants. A diagram of the organization of the Building Data element is presented in Figure 2.

The contents of the Building Data modules are:

3.1.1 Architectural

This module contains the dimensions (height, length, width), openings (windows, doors), and leaks (cracks around closed doors, pokethroughs). It also contains the property data for the building materials (ceiling, walls, floor). Data on common materials (concrete, gypsum board, wood, etc.) are included in the program and the user need only enter the generic name.

The Building Data element consist of separate entries for the room of fire origin and those spaces open to that room. The initial version of the system treats the adjacent spaces as a single combined area.

3.1.2 Fuel Packages (Combustible Contents)

The system assumes that the fire exists only in the room of fire origin. The system requires that the fuel packages be described in terms of their rate of heat release. This heat release data may be obtained from fire test data or a fire description formula. Some common fuel packages will be included in the system and can be specified by name.

In addition to the rate of heat release the user may provide the rate of production of other fire products such as smoke particulate mass or CO. The concentration of these products in the building spaces will be calculated during the fire.

As shown in figure 2, the Building Data element can accommodate descriptive information on the first ignited fuel package, several exposed fuel packages, and the total fuel in the room of fire origin. In addition to the heat release data, the height above the floor of the top surface of the first fuel ignited package is required. Where separate fuel packages are involved the distances between the packages must be given.

3.1.3 Structural Fire Resistance

The Structural Fire Resistance module contains the data necessary to compute the duration of the fire and the effective fire resistance required of building assemblies to withstand a complete burn-out of the fire room. The effective fire resistance will be compared to the rated fire resistance of the building assemblies. The data includes the combustible fuel load in the room, the size of the room and openings to the room, and the rated fire resistance of the building assemblies bounding the room.

3.1.4 Detection Equipment

The Detection Equipment module contains information on thermal and/or smoke detectors located in the room of fire origin. The system assumes that the detectors are at or near the ceiling level. The required data are the lateral distance (actual or maximum potential) from the fire to the detector and the proximity of the detector to a wall. For heat actuated detectors, the activation temperature and the response time index (RTI) or other sensitivity data (such as the UL listed spacing) is needed.

3.1.5 Sprinklers

The Sprinkler module treats sprinklers in the same manner as heat actuated detectors. The data required are the location of each sprinkler head with respect to the fire and the walls, the activation temperature and RTI value.

3.1.6 Smoke Control

The system provides smoke control evaluations in the form of:

- a. The rate and total amount of leakage of fire products through small openings (eg: the cracks around closed doors, small transfer grills, pipe chases, pokethroughs.)
- b. The rate of smoke removal and the impact of such on the accumulation of smoke in the vented space.
- c. Critical counter pressures needed to prevent smoke passage through a crack.

Much of the data required is taken from the architectural module. The user must identify the barrier(s) of concern in terms of size and location of the leakage openings. For smoke venting calculations the size of the vents (or capacity, if powered), the means for initiating the opening of the vents (or

starting if powered) and the size (or capacity) of low level air intakes are required. To determine if the building HVAC or smoke control system will prevent smoke flow through cracks, the pressure differential between compartments developed by the HVAC or smoke control system must be given.

3.1.7 Occupants

The Occupants module assembles the data needed to estimate the time required for egress. The system does not calculate the start up time between the moment of awareness (alarm or other fire cue) and the instant the actual evacuation movement starts. The system allows the user to make an estimate of this time or the system can compute the time available for start up activities. The user enters the number of occupants in:

- a. The room of fire origin.
- b. Those spaces open to that room.
- c. Other spaces using the same exit routes as persons in the other two spaces.

The occupants are graded by overall capabilities (able or handicapped) and condition (awake, asleep, etc.). The user must enter the number of occupants involved, the maximum travel

distances, the extent of vertical (stair) travel and the number and sizes of doors available for egress.

3.2 Fire Safety Objectives

The Fire Safety Objectives element allows the user to control the manner and criteria of fire safety evaluation. This element permits the user to examine selected conditions or events and/or set specific levels of performance or design limits. A diagram of the organization of the Fire Safety Objectives element is presented in Figure 3.

The user may examine conditions or time to events from the following list:

1. Upper (smoke) layer temperature
2. Depth of smoke layer
3. Smoke layer characteristics (eg: visibility, toxicity)
4. Thermal radiation from the fire
5. Time to flashover
6. Fire duration
7. Time to exceed fire resistance rating of a building assembly
8. Detector activation
9. Sprinkler activation

10. Smoke leakage
11. Evacuation time required

The user may elect to set design limits in the following areas:

1. Human tolerances
 - a. Heated gas temperature
 - b. Thermal radiation from heated gases and surfaces
 - c. Optical density of smoke
 - d. Toxic concentrations and dosages
2. Building assembly tolerances
 - a. Fire resistance
 - b. Smoke transmission
3. Contents tolerances
 - a. Exposure to heated gases
 - b. Thermal radiation from heated gases and surfaces
 - c. Chemical exposure

The user may select any or all of the above and may use the suggested values or modify them to meet specific needs.

In addition the user may have the method measure the "Margin of Safety" between the time require for egress and the onset of conditions intolerable to humans.

3.3 Computations

As previously mentioned, the main computational component of the system is a zone fire model. ASET (Available Safe Egress Time) a zone fire model written by L. Y. Cooper at the Center for Fire Research has been selected as the base model. The design assessment system utilizes the basic physics contained in the ASET model and utilizes significant enhancements to meet the objects of the system. Since the system is modular, the base model can be changed as more sophisticated models and more powerful computers become available.

The Fire Protection Design Assessment System addresses a number of areas which are not addressed by the present zone fire models. In order to accommodate these areas two approaches have been taken. The first is the addition of computational routines which will be called directly by the base model. The primary output of the zone fire model is the depth and temperature of the hot smoke layer. The depth and temperature as a function of time are determined by solving the appropriate equations over a series of small time intervals. In order to determine other parameters as a function of time the equations must be solved over the same series of time intervals. Examples of parameters which must be solved as a function of time are smoke layer constituency, time to flashover, detector and sprinkler activation, smoke leakage and evacuation time.

A second method of adding areas not addressed by the baseline zone fire model is the use of independent calculations. These are calculations which are not explicitly a function of time, however they may require as input the results of the time dependent calculations. An example of an independent calculation is effective fire resistance.

3.4 Results

The results provided by the system consist primarily of those items selected in the Fire Safety Objectives element. If the user has selected specific conditions to be examined they will be presented in tabular form as a function of time. If the time to events or design limits have been selected, the system will report each of the events or limits and the time required to reach it. A diagram of the organization of the Results element is presented in Figure 4.

Provisions will be included for the graphical presentation of the results. Since computer graphics are dependent on the computer and its peripherals the exact form of the graphical output has not been determined.

3.5 Alternative Approaches

The design assessment system is primarily a deterministic system and is not intended to be an expert system. There are however, some simple rules which can be used to evaluate the results and provide the user with a systematic means of evaluating alternatives.

If the predicted performance of the facility is deemed unsatisfactory, the user may wish to examine alternative approaches. Unsatisfactory performance may occur for example, when the time required for egress is greater than the time for the onset of hazardous conditions. Upon determining that the performance is unsatisfactory the user may request a list of potential alternative approaches. This list will correspond closely to the building data modules in section 3.1. From this list the user can select approaches which are potentially viable for the facility being examined. The system will then apply some simple rules to select the most promising approaches. Since the models used to predict fire performance can not in general be solved in reverse, the system will have to be rerun to examine the effect of the alternative approaches.

4. SYSTEM IMPLEMENTATION

This paper has presented the capabilities and the basic structure of the Fire Protection Design Assessment System. The primary relationships describing the physical processes and algorithms for their implementation have been developed. The development of a computer program which implements the system in stages is underway. At the end of each stage the program will be evaluated for usability and the results will be compared with available full scale fire test data. The completed program will undergo field evaluation before final release and will include program documentation as well as a user's guide.

FIRE PROTECTION DESIGN ASSESSMENT SYSTEM

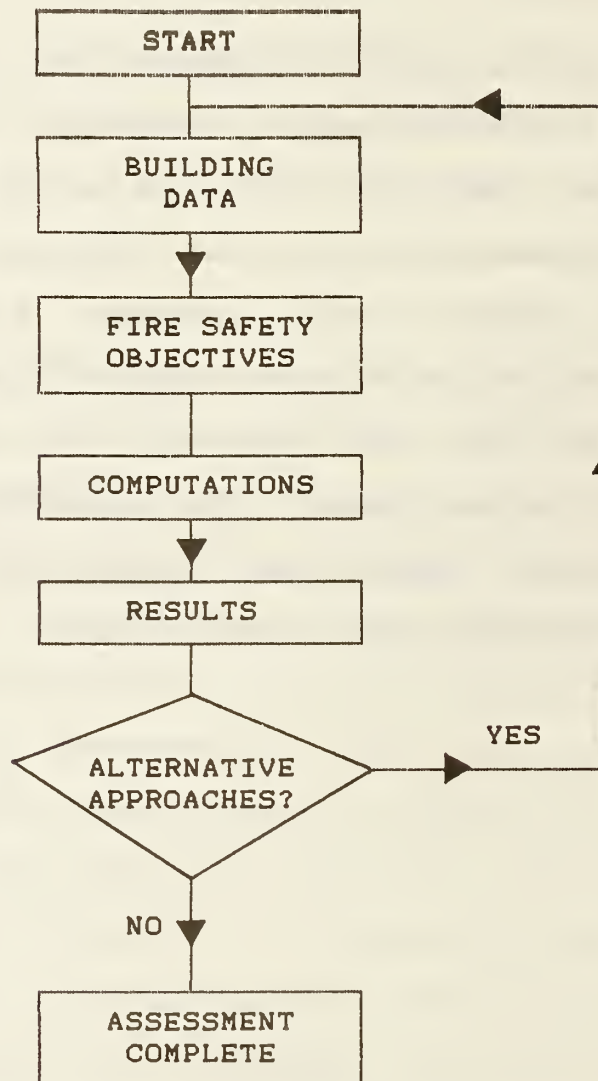


Figure 1. Fire Protection Design Assessment System General Model

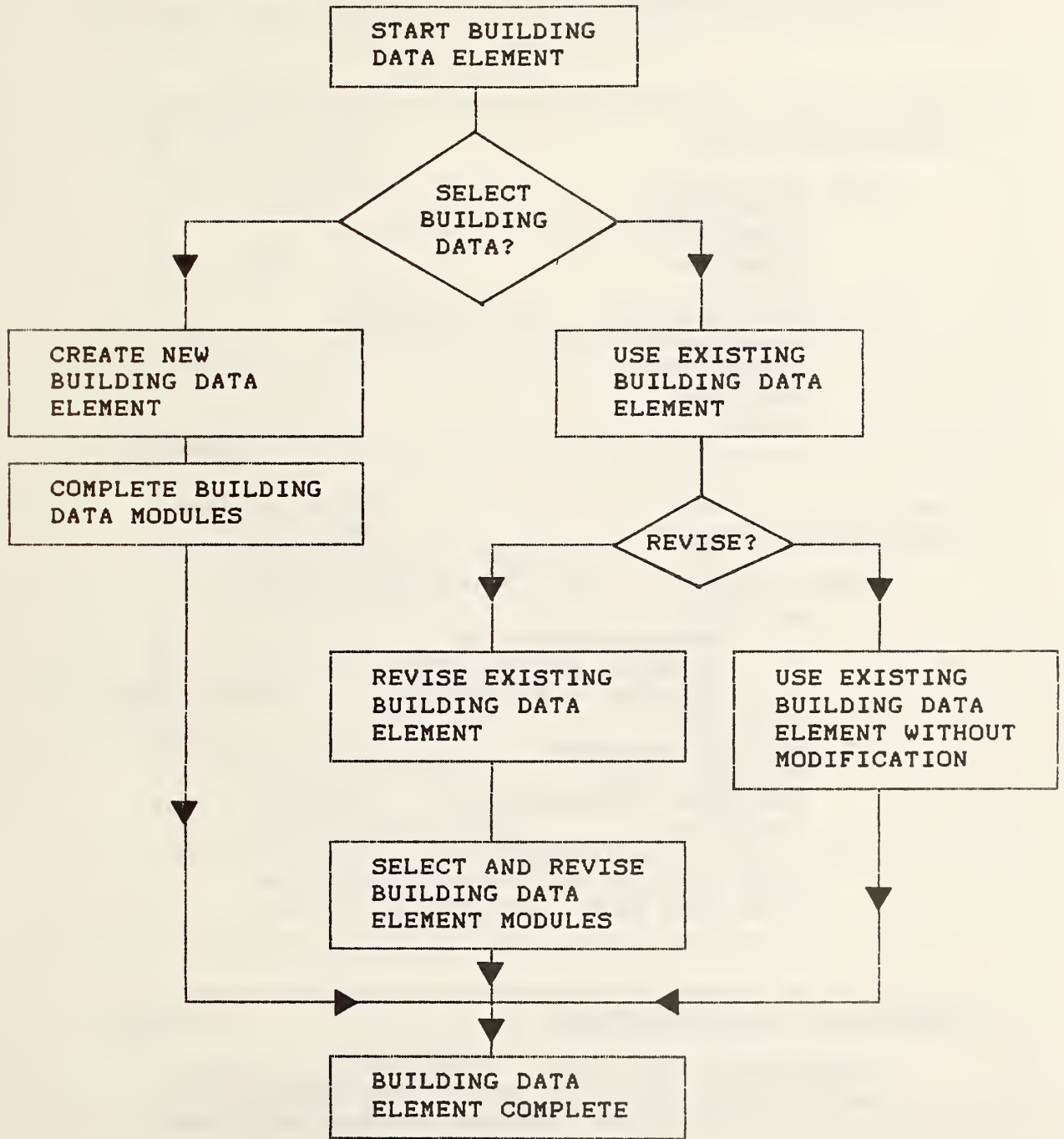


Figure 2. Building Data Element

BUILDING DATA MODULES

ARCHITECTURAL DATA

ROOM OF ORIGIN
DIMENSIONS
MATERIALS
OPENINGS
LEAKS
ADJOINING SPACE(S)
DIMENSIONS
MATERIALS
OPENINGS
LEAKS

FUEL PACKAGE DATA

FIRST IGNITED
RATE OF:
ENERGY PRODUCTION
MATERIAL DESTRUCTION
PRODUCT(S) PRODUCTION
LOCATION
EXPOSED FUEL PACKAGES
BURNING RATES
IGNITION SUSCEPTIBILITY
LOCATION
TOTAL FUEL (ROOM OF ORIGIN)
MASS AVAILABLE
PYROLYSIS RATE

STRUCTURAL FIRE RESISTANCE

COMBUSTIBLE FUEL LOAD
RATED FIRE RESISTANCE OF BUILDING ASSEMBLIES

Figure 2. (continued) Building Data Element

BUILDING DATA MODULES

DETECTION EQUIPMENT

ROOM OF ORIGIN
SMOKE
 LOCATION
HEAT
 POSITION
 RESPONSE TIME
 ACTIVATION TEMPERATURE

SPRINKLERS

ROOM OF ORIGIN
LOCATION
RESPONSE TIME INDEX
ACTIVATION TEMPERATURE

SMOKE CONTROL

VENTS
 SIZE (CAPACITY)
 LOCATION
 INITIATION METHOD
HVAC OR SMOKE CONTROL SYSTEM
 PRESSURE DIFFERENTIAL
 INITIATION METHOD

OCCUPANTS

NUMBER OF OCCUPANTS
CAPABILITIES
CONDITION (AWAKE, ASLEEP, ETC.)
MAXIMUM TRAVEL DISTANCE
DOORS
STAIRS

Figure 2. (continued) Building Data Element

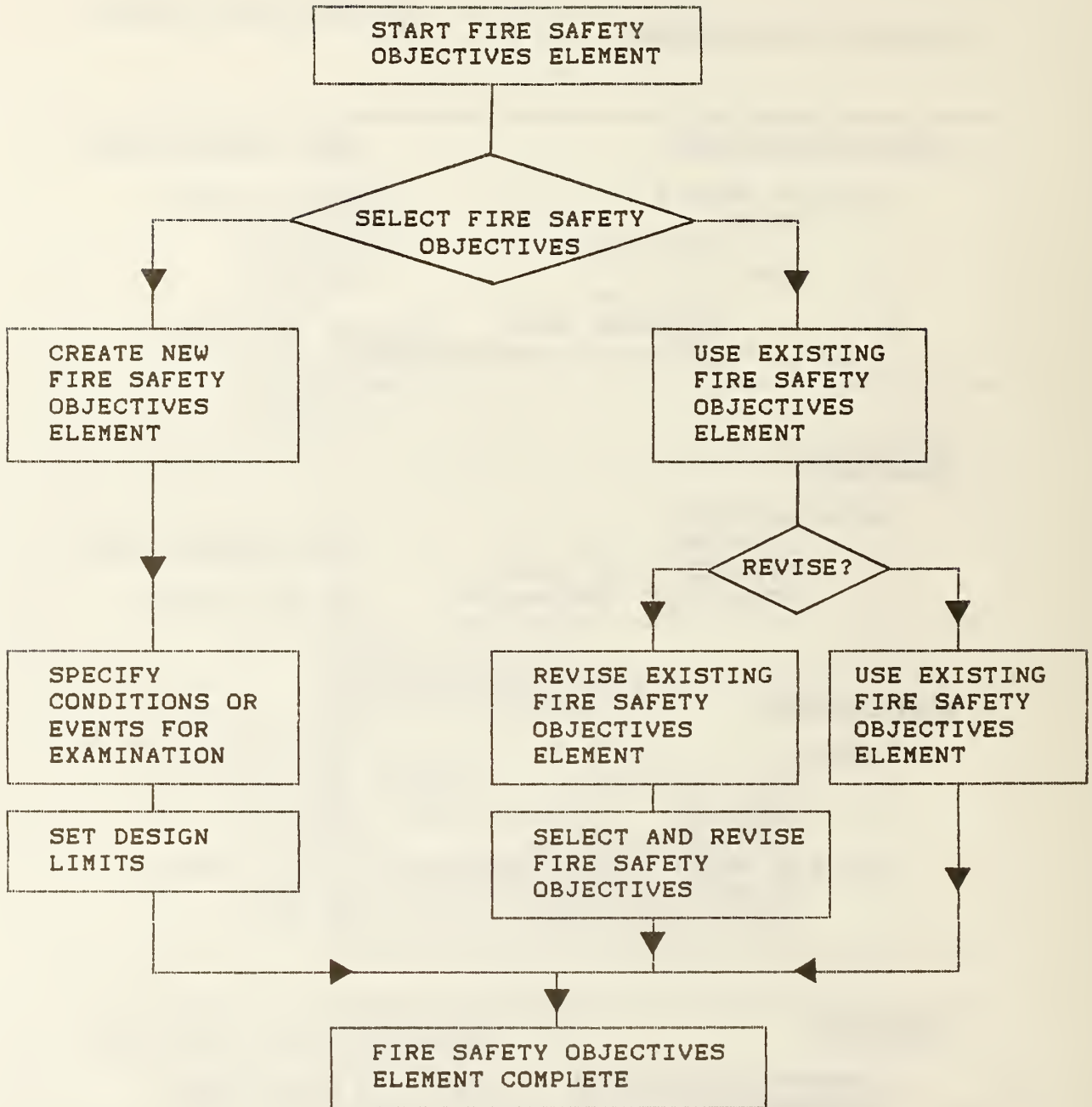


Figure 3. Fire Safety Objectives Element

CONDITIONS OR EVENTS FOR EXAMINATION

SMOKE LAYER TEMPERATURE
SMOKE LAYER LOCATION
SMOKE CONSTITUENCY
 OPTICAL DENSITY
 TOXIC CONCENTRATION
TIME TO FLASHOVER
FIRE DURATION
FIRE RESISTANCE OF A BUILDING ASSEMBLY
DETECTOR ACTIVATION
SPRINKLER ACTIVATION
SMOKE LEAKAGE
EVACUATION TIME

DESIGN LIMITS

HUMAN TOLERANCES
 HEATED GAS TEMPERATURE
 THERMAL RADIATION
 SMOKE OPTICAL DENSITY
 SMOKE TOXICITY
BUILDING ASSEMBLY TOLERANCES
 FIRE RESISTANCE
 SMOKE TRANSMISSION
CONTENTS TOLERANCES
 HEATED GAS TEMPERATURE
 THERMAL RADIATION
 CHEMICAL EXPOSURE

SAFETY MARGIN

TIME AVAILABLE FOR EGRESS
TIME TO UNTENABLE CONDITIONS/TIME REQUIRED FOR EGRESS

Figure 3. (continued) Fire Safety Objectives Element

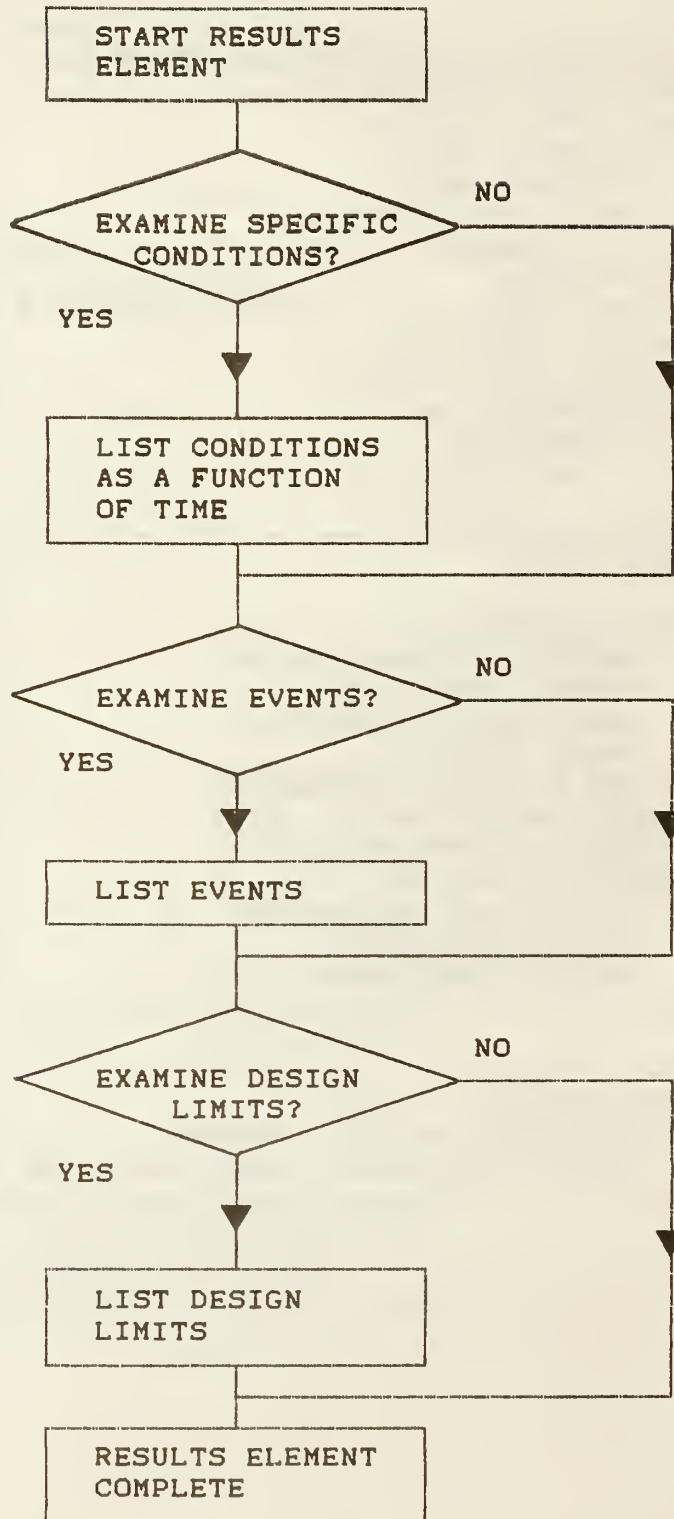


Figure 4. Results Element

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here) The purpose of the Fire Protection Design Assessment System is to provide design engineers with a tool to improve their ability to appraise the overall fire safety in a facility and evaluate the impact of fire protection measures. The system is based on deterministic fire prediction techniques and will be implemented through an interactive computer program. This report describes the components and basic structure of the system. The inputs to system include data on the building layout, combustible contents, fire resistance, detectors, sprinklers, smoke control system, occupants and the fire safety objectives. The outputs include the predicted fire generated conditions within the building as a function of time and an evaluation of the user specified fire safety objectives.				
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