

Volume TWO (2)

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 - [206] : Potential interaction of Length onto Fuel Supply and Distribution (Dilution model only).
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 - [210] : Potential interaction of External Leakage onto Passive

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Appendix 2. Development details

Introduction

The Life Safety model described in the conceptual section was developed into a quantitative evaluation tool over an eleven month period commencing February 1985 using a structured group process.

The aims of the development exercise were to quantify the model and to test the conceptual soundness.

The structured group is referred to as the Delphi group. Its functions were to:-

- (1) Review and comment on the concept(s) within the model.
- (2) Assign relative values to the relational links identified and discussed by the group.
- (3) Review and comment on the performance of the model.

Much of the conceptual evolution of the model ran in parallel with the involvement of the Delphi group in the development process. This section of the thesis reports these processes.

The record of the development process is based on the information used by the Delphi group for decision making. The development occurred in a number of stages, represented by the following sub-sections:-

- (1) Listing and definitions of factors.
- (2) Diagrams of the model framework.
- (3) Common factors in the model.
- (4) Time stages derivation.
- (5) 'Impact' values theory and derivation.
- (6) Derivation of 'Original Impact' vectors.
- (7) 'Interaction' values theory and derivation.
- (8) Derivation of interaction matrices

- (9) Manipulation technique for derivation of 'Modified Impact' values.
- (10) Derivation of matrices for modified impacts.
- (11) Derivation of 'Relative Contributions' for each level.
- (12) Listing and discussion of +/- factors with respect to Life Safety.
- (13) Net Safety or Threat theory.
- (14) The concept of 'Criticality'.
- (15) Discussion of factors.

(1) Listing and Definitions of Factors

Diagram D1 is a listing of each factor as considered by the Delphi group for the development of the evaluation tool. The definitions of the factors included in the model are listed below. There are three levels below the objective - each was considered.

Definitions

Primary level factors

Mode of Escape - The term Mode of Escape is to do with the capability to escape of the fraction of the population of the building which is threatened. This concept is the ability of the threatened population to effect escape optimally from a unit level of threat that may be imposed by the degrading environment, assuming that if assistance is required it is available, at the time of the event relevant for any given fraction of the population. Mode of Escape, distinct from egress, is the mode adopted in the event, which need not be that intended originally.

Escape Route Layout - this term deals with the layout of, and the inter-relationships between the building spaces. Any building space, whether a designed escape route, or otherwise, may be used as part of an escape route: eg; the movement from initial location in a building to the protected escape route, or a refuge. The design covers factors affecting ease of use (note that a blockage occurring during, as opposed to before the event will be a modification of the optimal escape route design/ layout - not a factor of it).

Smoke Release - The term Smoke Release covers the release of products of combustion as a fuel or combination of fuels burns. The products of combustion will not only be smoke particles but also toxic gases.

Smoke Movement - The spreading of products of combustion within and between building spaces. The way in which products move will be influenced by these airflow mechanisms:-

Ambient stack (temperature-induced flow)

Fire stack (fire-induced flow)

Mechanically-induced flow

Natural (Wind Induced Flow)

Smoke Control - The control of the spread of the products of combustion. This may involve techniques of dispersing products of combustion in a large space, removal from, or containment within a space (or set of spaces).

Fire Spread - The likelihood of fire spreading in the space of origin and the potential for fire spread between spaces. Fire spread includes the propagation of the flame boundary across materials within a space and/ or across the surface materials of a space, and the potential for flame spread between spaces.

Secondary level factors

Communication - The term communication encompasses the transferral of information to or from (1) an individual at any stage of the event. Communication of information may be important for varying reasons throughout the event - in making the threat apparent (2), assessing options for escape, and the (continuing) execution of an escape plan (3).

There can be no certainty that the communicated information will be directly relevant to the fire event, or that it will be correct (4) and complete.

Notes

(1) Information transferral from an individual: - in group environments leadership formation or discussion of problem definition (the threat from the fire/ smoke, etc.) and solution (escape plan), the to/ from nature of communication is likely to

be important.

(2) Making the threat apparent in a timely fashion may be affected significantly by the time wasted ignoring or the misinterpretation of ambiguous cues - do not confuse misinterpretation with a low value of communication. They are distinct and can occur for different reasons. Misinterpretation, as the phrase implies, is concerned with the interpretation of information - this occurs after communication has taken place. The actual value of communication need not be the stumbling block. However, the quality of the information may be contributory to its ease of interpretation. Perceptibility, directionality, coding, clarity, logic, credibility, and coverage may all affect quality.

(3) The strategy of life safety will remain, the tactics (escape plans) may be updated or drastically altered in the light of new information.

(4) Incorrect conclusions may result from misinterpretation (see note (2)) or incorrect information, eg: public address systems giving incorrect facts about the event. The weak link in each case may be different.

Mobility - The term mobility describes the overall ability of the individual to effect escape. Limitations of psychological, physical, or physiological capability may all directly affect mobility. The broadness of this term leads to the prima facie inconsistency that an ambulant person (in normal language - a mobile person) may (because of psychological reasons, eg; sleep) be classified as immobile.

Training - The term training is concerned with knowledge. Knowledge about the building, the fire event, and fire safety. This knowledge may be, in terms of the event, relatively static or relatively dynamic. Obviously knowledge of the event will be dynamic: nil at first, increasing throughout the event. Knowledge of the building is pre-existent and the potential

contribution constant. Knowledge of escape routes is a combination of (1) Building knowledge a cognitive map of the whereabouts and relationship of the route(s) to the building spaces, and (2) Specific fire safety knowledge: knowing that the designated routes are escape routes.

Ease of Use - The ease or otherwise with which all the building spaces may be used for escape. Use of a route requires that it may be so identified, and the relationship with other building spaces ascertained. Further, the degree of obstruction to movement because of the design, usage by other escapees, or as a direct result of the threat will alter the ease of use. Where escape is achieved without movement or by use of refuge facilities the contribution of the ease of use will be correspondingly restricted.

Exit Route Capacity - This applies to the aspects of route suitability for evacuation population. The term capacity relates to the dynamic flow capacity of the route - the number of people entering or leaving per time interval. This is relevant for people in the $T_{(\text{relative safety})} - T_{(\text{safety})}$ stage of escape by egress, more relevant to those in the $T_{(\text{action})} - T_{(\text{relative safety})}$ stage, who may require to queue to enter the relative safety of the protected route. (or indeed, a refuge).

Rate of Burning - The rate of weight loss of fuel or combination of fuels under combustion.

Smoke Yield - The characteristic of a material to yield a combination of gases, vapours, and dispersed solid particles. This characteristic will depend on the fuel concerned, and may be affected by the way in which it is burning; the density and toxicity of the smoke will be a function of these.

Ambient Stack - This is the normal stack effect in a building - the pressure differential due to the internal temperature being different to the external air temperature. If the internal temperature is greater than the external temperature there will

be a tendency for the air to move upwards.

Inverse stack can occur. This normal air movement has nothing to do with the fire, but may carry smoke around the building. The height across which the pressure differential works will be contributory factor.

Fire Stack - This is a measure of the smokes own buoyancy relative to the surroundings and will depend on the difference in temperature of the fire producing the buoyant plume and the ambient temperature.

Mechanically Induced Flow - The resultant air, and thus smoke, movement from any mechanical plant operating for this purpose. Smoke movement by mechanical induction is distinct from smoke control in that smoke control is intentional during a fire and should commence and continue throughout the event. Smoke movement by mechanical induction is likely to be pre-existent.

Wind Induced Flow - This is any air, and thus smoke, movement caused by wind induced pressure (acting through leakage areas) it is distinct from smoke control by natural pressure for the same reasons as mechanically induced flow.

Volume and Energy of Smoke - The energy of the smoke as a measure of its buoyancy. The difference in temperature compared with ambient temperature. The volume of smoke defines the amount of smoke that must be safely handled within the space.

Wind - Any wind induced pressure at points on the fires of the buildings, depending on wind speed and direction, building height, and surrounding height. This pressure is available to act across leakage areas.

External and Internal Leakage - This is defined as the equivalent orifice area of these leaks in the surfaces forming the boundaries of a space. In combination with any pressure differential across that orifice area air or smoke flow will occur.

Ambient Temperature - The surrounding temperature within the space concerned of the air. This will be influenced by any air conditioning or heat gain of space.

Reservoir Size and Design - The geometrical layout and volume of any reservoir within the space concerned (or the whole space) that may safely be filled with smoke or diluted smoke.

Air Pressure Developed - The pressure developed for use across a leakage area whether by mechanical or natural means. The operating philosophy may determine how much pressure is developed and how it is distributed.

Inlet Area - The area available as a fresh air inlet for smoke control by removal system. Required to allow proper functioning of the system - the efficiency of the system is dependent on the distribution and positioning.

Exhaust Area - The area across which the pressure for removal of smoke will act to create a flow. The number of vents and the sizes related to available pressure and in conjunction with a balanced inlet area will affect efficiency of a removal system.

Surface Characteristics - The characteristic of the fuel surface to allow spread of flame, depending on the flame spread characteristic and geometrical layout of the fuel (vertical/horizontal).

Fuel Supply and Distribution - This term relates to the continued supply of fuel for combustion and the proximity of other materials to provide fuel for the fire spread.

Passive Fire Stopping - Any element of the building structure that provides a resistance to the spread of fire without needing to be activated, eg; compartment walling, fire door (unless chocked open!).

Active Fire Stopping - Any part of the building or its fittings that provide a resistance to the spread of fire when activated, eg; roller shutter on escalator, doors. This cannot be active until $T_{(detection)}$ at the earliest.

Fire Suppression - Any activity, whether automatic or manual, to try and put out the fire. The use of extinguishers, sprinklers.

Tertiary level factors

Aural Existence - This describes the existence of any aural information about the fire event in total. This is broad enough to include ordinary sounds, since they may mask the untoward noises made by the fire, etc. As the event progresses and information of different types may exist, eg; sounds of flames, glass cracking, fire alarm sounders, people talking (or not talking), shouting, running, the ambient noise level changing, etc. Rapid change is most likely to be received, but there is no statement in this factor of communication of the information. Communication only occurs when perception occurs. Note, any alarm related noises may only occur after $T_{(detection)}$, $T_{(perception)}$, or $T_{(action)}$, etc., and that ambiguous cues are relevant in the $T_{(ignition)} - T_{(detection)} - T_{(perception)}$ stages.

Visual Existence - Similar to aural: - covers provision of adequate light, changes in lighting level, seeing peoples actions, smoke, signs, flashing lights, etc.

Tactile Existence - This is the existence of tactile information - temperature and, particularly change in temperature, and the building shape and surface texture are important for movement and location information. Also, the movement of other people will be included.

Gustatory/ Olfactory - The combined smell/ taste. At tertiary level considerations it is difficult to separate these factors; the point is the existence of information that would be detected

as smell/ taste, such as smoke.

Perception of Aural/ Visual/ Tactile/ Gustatory/ Olfactory Information - separate from the existence of sound, sight, etc. is the perception of it. The ability to perceive does not imply meaningfulness, but rather the reception of it only, ie; it is acceptable allowable (in terms of the model) for the sound of a fire bell to exist, and to be perceived as existing, but if the person does not have the general fire safety knowledge of what the bell means, the communication of the information in the sound does not occur. This term deals with the ability to perceive the existing sound, or sight, etc.

Psychological Capability - The conscious reasoning power of the individual to recognise and make decisions based on information and required knowledge and so to detect, perceive, plan, and execute escape tactics during the event. Apart from mental limitations, the capacity may be modified by sleep, alcohol, medicines, etc.

Physical Capability - The capability to move oneself and perform the physical activities required for escape.

Physiological Capability - The term is concerned with the functioning of the body, and importantly its continuing function throughout the event.

Building Knowledge - The knowledge of the arrangement of the building spaces relative to the occupants location. A cognitive map of the building.

Event Knowledge - The knowledge built up during the event about the event, aspects of knowledge of fire location, blocked routes, paths taken, acts performed, etc. all forms this knowledge. Knowledge may be incorrect.

General Fire Safety Knowledge - Awareness of general procedure in a fire. How to use an extinguisher, the meaning of signs.

Specific Fire Safety Knowledge - The term covers that knowledge which the ordinary person would not be expected to have. Knowledge of routes, muster points, extinguisher location, coded information, procedures.

Location Identification - The ease with which the person can identify their location in a building relative to exits/ refuges.

Route Choice Identification - The ease with which a person at any particular location in a building can identify where the nearest escape route(s) or protected refuge is, and also identify that they are still on a protected route when using it.

Obstruction - This term covers any temporary or permanent obstruction to movement, within the time frame of the event. Examples of obstructions include locked doors, blocked routes, queues, narrow sections of routes.

Choice of Alternative Routes - The ease with which alternative protected routes may be identified, and the provision of such routes.

Width of Route - The effective width of the route or part of a route or building space for people movement. Criteria for effective width cover edges of corridors, use of stair width, etc.

Length of Route - The effective length of the route in terms of dynamic capacity for evacuation.

Rate of Heat Release - The rate at which heat is given out by the fire for the release of volatiles and pre-heating of fuel, also to the plume. *

Oxygen Supply - The availability of a plentiful or otherwise supply of oxygen to support the combustion process and influence characteristics of smoke released.

*
Footnote: Some heat is also radiated (to the fuel). That which goes to the hemisphere above the fire is lost to the plume and fire.

Fuel Geometry and Orientation - The way in which the fuel is arranged to allow the development of the fire.

Ignition Source - This term covers the provision of some type of ignition source for starting combustion. The effectiveness of the ignition source to start combustion will vary with the ease of ignition of the fuel.

Bulk Density - The density of material/ fuel as may affect its rate of burning.

Mode of Burning - Flaming or non-flaming combustion.

Type of Material - Aspects of the fuel as may affect the smoke yield properties.

Internal Temperature - Ambient temperature for the air in the space concerned.

External Temperature - The external temperature of the air as concerned for stack effects.

Height (Smoke Movement) - The internal height of the space concerned with for internal temperature.

Fire Temperature - The rate of heat given out by the fire and generating the plume. *

Ambient Temperature - As defined elsewhere.

Air Pressure Developed - As defined elsewhere.

External Leakage - As defined elsewhere.

Internal Leakage - As defined elsewhere.

Volume of Space and Design - As defined elsewhere.

*

Erratum: In the context of its use, the term identified as Fire Temperature should be referred to as Fire Size, and should be considered accordingly.

Smoke Mass Flow Rate - The rate of smoke/ entrained air production requiring dilution by smoke control.

Nature of Smoke- Any cooling/ ageing effects.

Surroundings - The nature of the surrounding topography and its influence on the characteristics of the wind. (Turbulence/ Velocity profile).

Speed - The wind speed at the relevant height and location.

Direction - The predominant direction of the wind.

Height - The relative height of the building to the wind flow.

Integrity - This term relates to any large holes in a surface, open windows.

Permeability - Equivalent orifice area of a leaky surface. Including cracks around windows.

Air Conditioning - Any air handling procedure including temperature changes (is this still the real meaning?)

Heat Gain of Space - cf; the greenhouse effect.

Space Shape - A geometrical description of the spatial arrangement.

Available Power - The available pressure difference for handling smoke.

Operating Philosophy - The way in which the available power is used.

Geometry - This term deals with the vertical/ horizontal orientation of the fuel surface and the impact this may have on

flame spread.

Flame Spread Characteristics - The meaning as used in classifying materials for flame spread.

Compartmentation - The restriction by enclosure of fire spread.

(2)Diagrams of the model framework

There were a number of diagrammatic representations of the model hierarchy created at the early conceptual stages **prior** to developmental commencement. Sections of these are shown in diagrams D2-D48 (July 1984), also presented to the Delphi group for information; diagrams D49-D56 represent the rationalised hierarchical structure used for the development of the model by the Delphi group. This hierarchical structure was limited to the tertiary level and remained unchanged throughout the development process.

The listing and definitions provided earlier correspond to this structure.

(3) Common Factors in the model

A number of common factors occur in the model. See diagram D57. This is partially because of the inclusion of three techniques of smoke control, determined by a number of similar factors. In addition aspects of fire spread and smoke release, and factors describing the geometrical nature of the building in the context of people and smoke movement, are similar.

It was necessary that these factors were identified, and treated accordingly in the quantification of the model. Multiple occurrences represent multi-faceted relevance, not necessarily greater potential influence. This is particularly relevant during the development of the interactive nature of the model and is discussed later.

The concept of common factors also created problems in their contribution and how to model their relationships in the model. It was considered that they may be modelled as interacting onto each other with a maximum score, but this would have rendered the handling of the number and value of interactions invalid, and so an option of considering the factors as contextually different contributors based on a common absolute value of some sort was used. Where more than one of such common factors interacted onto a factor only the highest score interaction was chosen (to avoid misrepresentation of the scale of the interaction contribution).

A note on common interactions.

On a few occasions when the factors in the model were considered for interactivity, a number of common factors were found to interact onto a subject factor. For example, the tertiary factor internal temperature [267] and secondary factor ambient temperature [311] are similar and both were identified as having a potential interaction onto external leakage [273]. See diagram D58. Note also that the factors internal leakage (smoke movement, mechanical induced pressure) [274] and internal leakage

(smoke movement, wind induced pressure) [274] both interact onto external leakage [273]. In each case a higher interaction value is chosen if unequal.

Hence potential interactions of factors 3 and 4 are omitted. To have included these in the derivation of the modified impact values for the factors in the model would have distorted the true interactions occurring (ie; if internal temperature interacts (in one form or another) twice, it should not have double the importance). So the factor chosen to represent the commons was the one with the highest value in the modification of the original impact value. Refer diagram D58.

This occurs on a number of occasions in the model and is taken account of in this manner each time. The factors affected are listed below, together with the relevant common factors. Note that this applies to all three smoke control models.

Subject Factor	Common Factor
Existence of Tactile Information	Internal Temperature * Ambient Temperature (2) Ambient Temperature (3)
Mode of Burning	Fuel Geometry and Orientation Geometry *
External Leakage	Internal Temperature * Ambient Temperature
External Leakage	Internal Leakage (wind) * Internal Leakage (mech)
Internal Leakage	Internal Temperature * Ambient Temperature
Fuel Supply and Distribution	Geometry * Fuel Geometry and Orientation

Fire Stopping
(Passive and Active)

External Leakage (2) *
External Leakage (3)

Fire Stopping
(Passive and Active)

Internal Leakage (2) *
Internal Leakage (3)

Notes.

- (1) * indicates the representative factor.
- (2) Internal Leakage (mech) and (wind) refers to the impact of Internal Leakage to mechanically and wind induced flow.
- (3) 2 indicates secondary level, 3 tertiary.

(4) Time stages derivation

The time stages adopted for the modelling exercise were discussed in the conceptual section. It is not proposed to repeat that discussion here. A summary of the time stages assumed is given below, and the corresponding time-related activities of people in fires associated with them. See diagram D59. The Delphi group was initially asked to consider the potential contribution of each factor in turn to Life Safety at each particular time stage. At first the group considered each factor for a single time stage only. This was the third (of five) stages, representing the time between perceiving that there is a threat to escape from, and acting to make good the escape (hatched on diagram D59). The activities associated with this time stage are commonly investigation (Sime (45), Canter (28)) and planning. Leadership formation including associated delays are included in this time stage. To create a meaningful starting reference point for the group this was considered to occur at 1 minute into the event. Diagram D60 was issued to the Delphi group (August 1985).

(5) 'Impact' Values theory and Derivation

Introduction

The representation of relationships in the model of the Life Safety System was made using two conceptual types of relationship. These were termed impacts and interactions, and were distinguished by the nature of relationship they represented. At this stage of the development only impacts were considered, to give a sound potential base of direct relationships from which to develop a interactive aspect of the model (modelled by interactions, and discussed later).

Original Impacts

The impact values discussed by the Delphi group in December represent the importance of one factor to another factor directly above it in the hierarchy, and upon which the other factor depends. These values were on a scale of 1 - 10 and fell into one of three bands; high, medium or low importance.

The term given to describe a direct relationship between two factors is Impact. If a secondary factor depends on a tertiary factor, the tertiary factor is said to have an impact on the secondary factor.

See discussion of this in the conceptual section earlier. Impact was defined for the purposes of the developmental exercise as:

Impact: An impact occurs between a lower and a higher factor in the hierarchy. The levels must be adjacent, and existence of an impact between two factors implies dependence of the higher on the lower.

In considering impacts, the Delphi group was asked to verify that all impacts could potentially occur at the notional time of 1 minute into the event, in the time stage $T(\text{perception}) - T(\text{action})$. This was then expanded to include the impacts for all

other time stages; $T(\text{ignition}) - T(\text{detection})$, $T(\text{detection}) - T(\text{perception})$, $T(\text{action}) - T(\text{relative safety})$, $T(\text{relative safety}) - T(\text{safety})$. This allowed a series of potential frameworks for different time stages to be set. An impact may occur, or not occur, at any stage of the event for an individual, and work was done to consider the potential impacts throughout a "perfect" event. It was found that many impacts cannot occur (within the definitions of the framework) until a particular defined time stage for that individual, or group of individuals, is reached. For example smoke control by containment can make no contribution to life safety until activation which, depending on the activation technique, may not occur until after $T(\text{detection})$, $T(\text{perception})$, or $T(\text{action})$. In the case of activation by the individual; after $T(\text{perception})$ or $T(\text{action})$.

Initially the Delphi group considered the potential impacts of factors at one time stage only. Following this, consideration was expanded to cover all the potential impacts of all the factors during each of the time stages.

Note that a potential impact is not the same as a relative contribution. The relative contribution is a measure of the factor's contribution to Life Safety in comparison with all the other factors. It also takes into account the increased significance of the factor as a result of potential interactions. At this stage, looking at the potential impact of each of the factors in turn, they are being considered as if they were discrete. The subsequent stages of development are designed to reflect the inter-related nature of contributions.

This section of the thesis is largely diagrammatical, with explanatory notes where useful. The style of the question posed in the evaluation of the factor is important, and is thus repeated for each impact consideration. Each factor is considered for a potential impact on the factor directly above it.

Note that the values in the fourth and fifth time stages are similar because the functional characteristics of each stage are potentially similar, only the performance actually alters the

two. The values for potential original and modified impacts will be the same.

Note also that the third time stage value is that derived by the delphi group and the value used is the arithmetic mean.

Primary level factors

Consider **Mode of Escape** [322] for all time periods:- does it have any a potential impact on Life Safety?

$T(\text{ignition}) - T(\text{detection})$. Yes

The potential impact on Life Safety of Mode of Escape may be realised if detection is by people. Communication of ambiguous cues may be significant in detecting the fire.

$T(\text{detection}) - T(\text{perception})$. Yes.

The time required to make the step from detection to perception is significantly dependent on capability aspect. In the case of manual detection the delay between detection and perception may only be as long as it takes to recognise the fire (fractions of a second). Automatic detection is assumed, for the purposes of the exercise, to include 'instantaneous' automatic triggering of the alarm system. The delay between detection (the alarm sound existing) and perception depends on the awareness and ability to perceive stimuli and training and mobility sub-factors also.

$T(\text{perception}) - T(\text{action})$. Yes

As considered by the Delphi group. Arithmetic mean 8/10.

$T(\text{action}) - T(\text{relative safety})$. Yes

Continued feedback on the event is required, whether it is visual, to see the route; aural, to hear instructions; mobility to effect movement; or training to know what to do. Vital to Life Safety.

$T(\text{relative safety}) - T(\text{safety})$. Yes.

Continued importance. Still vital to Life Safety. See diagram D61.

Consider **Escape Route Layout** [323] for all time periods: - does it have a potential impact on Life Safety?

$T(\text{ignition}) - T(\text{detection})$. No

The layout of the escape routes does not have any direct impact on Life Safety (in a fire) at this stage of the event. The Escape Route Layout knowledge may improve training before the event (existing knowledge) but it does not affect Life Safety directly before detection.

$T(\text{detection}) - T(\text{perception})$. No.

The layout of the routes is still irrelevant to Life Safety. Until $T(\text{perception})$, there is (prima facie) no fire from which to escape, so the routes cannot play a part.

$T(\text{perception}) - T(\text{action})$. Yes.

As considered by the Delphi group. Arithmetic mean 9/10. (High)

$T(\text{action}) - T(\text{relative safety})$: Yes.

During this time stage the layout of all the spaces in the building and their inter-relationships will have a fundamental impact on Life Safety. Factors of ease of use, together with capacity, will be very important to Life Safety for people choosing escape by movement (whether to the outside or to a place of refuge).

$T(\text{relative safety}) - T(\text{safety})$. Yes.

Once inside the protected route the capacity and ease of use will be important, so will escape route design. See diagram D62.

Consider **Smoke Release** [324] for all the time stages:- does it have a potential impact on Life Safety?

$T(\text{ignition}) - T(\text{detection})$. Yes.

Even if the fire has not been detected there is a threat to Life safety from the smoke released. It may also be the source of an ambiguous cue that leads to detection.

$T(\text{detection}) - T(\text{perception})$. Yes.

The potential threat is still present.

$T(\text{perception}) - T(\text{relative safety})$. Yes.

As considered by the Delphi group. Arithmetic mean 7/10 (High).

$T(\text{action}) - T(\text{relative safety})$. Yes.

The potential threat continues.

$T(\text{relative safety}) - T(\text{safety})$. Yes.

Note that although the $T(\text{relative safety}) - T(\text{safety})$ stage involves the use of protected routes (or refuges) the potential impact of smoke release on Life Safety is still present. The reason that safety is maintained is not because the a potential impact of Smoke Release on Life Safety has decreased, but because smoke control or compartmentation is protecting people. If protection failed (refer Victoria Nurses' Home, appendix 3) then smoke would prevail. Note also that the potential is constantly high.

The smoke release will harm people at any time during the event, and if there is initially only a small quantity of smoke released then the actual value of the impact of smoke release is small

(the potential, although not realised is still high!). See diagram D63.

Consider **Smoke Movement** [325] at the following times:- does it have a potential impact on Life Safety?

$T(\text{ignition}) - T(\text{detection})$. Yes.

At an early stage in the event it can be expected that Smoke Movement will have little resultant impact on Life Safety. This does not mean there is no potential impact, there is a considerable potential impact at all time stages - detection may be too late for some people, and smoke movement will have realised its potential. Note that because smoke movement depends on fire stack the actual value of this component may be initially low and grow with time or the fire size grows - the potential is still present.

$T(\text{detection}) - T(\text{perception})$. Yes.

For same reasons as above.

$T(\text{perception}) - T(\text{action})$. Yes.

As considered by the Delphi group. Arithmetic mean 6/10 (medium).

$T(\text{action}) - T(\text{safety})$. Yes.

In a route the potential impact of Smoke Movement will be present, and compartmentation and smoke control will maintain environmental tenability. See diagram D64.

Consider **Smoke Control** [326] at the following times:- does it have a potential impact on Life Safety?

Consider Smoke Control by **Dilution**.

$T(\text{ignition}) - T(\text{safety})$. Yes

The a potential impact is the same at all stages. This system is passive, so requires no activation. Arithmetic mean 6/10 (medium). See diagram D65.

Consider Smoke Control by **Containment** and **Removal**:

Each of these systems potentially provides some protection prior to activation: Passive smoke Containment will be provided by the building structure, and the build up of a buoyant smoke layer is a preliminary to smoke Removal.

Consider **Fire Spread** [327] at the following times: - does it have a potential impact on Life Safety?

$T(\text{ignition}) - T(\text{safety})$. Yes.

There will be a potential impact of Fire Spread on Life Safety throughout the event. See diagram D66.

Secondary level factors

Consider **Communication** [296] at the following times: - does it have a potential impact on Life Safety (through Mode of Escape)?

$T(\text{ignition}) - T(\text{detection})$. Yes.

There is a potential. If communication has a part to play in the detection of the fire associated with a scenario or any ambiguous cues (direct or indirect), then there will be an impact on Life Safety at that time period.

$T(\text{detection}) - T(\text{perception})$. Yes.

After detection, the time required until perception will depend on the ability to perceive information.

$T(\text{perception}) - T(\text{action})$. Yes.

As considered by the Delphi group. Arithmetic mean 8/10.

Continued use of senses for assessing information required for decision making.

$T(\text{action}) - T(\text{safety})$. Yes.

Continued use of senses for travel. See diagram D67.

Consider **Mobility** [297] at the following times: - does it have a potential impact on Life Safety (through Mode of Escape)?

$T(\text{ignition}) - T(\text{detection})$. Yes.

Limited to alertness required to detect a fire, or follow up ambiguous cues.

$T(\text{detection}) - T(\text{perception})$. Yes.

Psychological capacity important in making the step from detection to perception (and is a sub factor of Mobility).

$T(\text{perception}) - T(\text{safety})$. Yes.

As considered by Delphi group. Arithmetic mean 7/10. Of constant potential impact on Life Safety once action commences. See diagram D68.

Consider **Training** [298] at the following times:- does it have a potential impact on Life Safety (through Mode of Escape)?

$T(\text{ignition}) - T(\text{detection})$. No.

At this time training plays no part in Life Safety. Any fire prevention training has played its part (or not as the case may be!) and escape training is of no importance until after perception.

$T(\text{detection}) - T(\text{perception})$. Yes.

Specific training may allow a quick step from detection to perception.

$T(\text{perception}) - T(\text{action})$. Yes.

As considered by the Delphi group. Arithmetic mean 5/10 (medium).

$T(\text{action}) - T(\text{safety})$. Yes.

Route knowledge and event knowledge have a a potential impact on Life Safety. See diagram D69.

Consider **Ease of Use** [299] at the following times:- does it have a potential impact on Life Safety (through Escape Route Layout)?

$T(\text{ignition}) - T(\text{perception})$. No.

The routes are not being used for escape from a fire yet.

$T(\text{perception}) - T(\text{action})$. Yes.

As considered by the Delphi group. Arithmetic mean 7/10.

$T(\text{action}) - T(\text{relative safety})$. Yes.

Very important for way finding and route choice.

$T(\text{relative safety}) - T(\text{safety})$. Yes.

Very important for usage of protected routes. See diagram D70.

Consider **Exit Route Capacity** [300] at the following times:- does it have a potential impact on Life Safety (through Escape Route Layout)?

$T(\text{ignition}) - T(\text{perception})$. No.

$T(\text{perception}) - T(\text{action})$. Yes.

As considered by the Delphi Group. Arithmetic mean 8/10 (high).

$T(\text{action}) - T(\text{relative safety})$. Yes.

Capacity will be of significance in escape by movement (or refuge), and should ideally match clearing rate of protected route.

$T(\text{relative safety}) - T(\text{safety})$. Yes.

Particularly relevant to Life Safety. See diagram D71.

Consider **Rate of Burning** [301] at the following times:- does it have a potential impact on Life Safety (through Smoke Release)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

The Rate of Burning will have a high a potential impact on Life Safety. The fire growth rate may mean the actual impact of Rate of Burning follows a curve. The potential impact on Life Safety is still present. See diagram D72.

Consider **Smoke Yield** [302] at the following times:- does it have a potential impact on Life Safety (through Smoke Release)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

It will have a a potential impact on Life Safety. The amount of Smoke Yield may depend on mode of burning and fire growth, but the a potential impact of smoke yield is constant and high. Arithmetic mean of Delphi Group 8/10. See diagram D73.

Consider **Ambient Stack** [303] at the following times: - does it

have a potential impact on smoke movement at the following times?

$T(\text{ignition}) - T(\text{perception})$. Yes.

It is pre-existent and will be of constant a potential impact throughout the event. Note that a concept of reduced significance as, say, the fire grows is false. Smoke movement by ambient stack still has the same potential impact on Life Safety, but is relatively unimportant in the actual event. It is possible that Ambient Stack will have an impact.

$T(\text{detection}) - T(\text{action})$. Yes.

As considered by the Delphi group. Arithmetic mean 5/10 (medium).

$T(\text{action}) - T(\text{safety})$. Yes.

See diagram D74.

Consider **Fire Stack [304]**:- does it have a potential impact on Life safety at the following times (for Room of Origin)?

$T(\text{ignition}) - T(\text{detection})$. Yes.

In the vicinity of the fire this may be quite significant. This is potentially significant (slow or fast fire).

$T(\text{detection}) - T(\text{safety})$. Yes.

Delphi group arithmetic mean 7/10. Smoke Movement factors will continue throughout the event. See diagram D75.

Consider **Mechanically Induced Flow [305]** - does Mechanically Induced Flow have any impact on smoke movement at the following times?

$T(\text{ignition}) - T(\text{detection})$. Yes.

The potential to move smoke is there at the start of the event. It is pre-existent and as such can be considered to be available at $T(\text{ignition})$.

$T(\text{detection}) - T(\text{perception})$. Yes.

After $T(\text{detection})$ the mechanically operated system may be automatically or manually switched to another mode, or off. (A power supply may fail, but this is not a direct consideration here (It is a 4th level factor)). However, this change will only impact on the actual value. Smoke Movement may be influenced by mechanical flow at this time, and there will be a potential impact on Life Safety.

$T(\text{perception}) - T(\text{safety})$. Yes.

Some impact potential, but alters as position in building alters. Delphi group arithmetic mean 6/10 (medium). See diagram D76.

Does **Wind-Induced Flow** [306] have a potential impact on Smoke Movement at the following times?

$T(\text{ignition}) - T(\text{safety})$. Yes.

The potential for wind impact is significant at all times. It is constant, and in relation to other factors it will by summation determine the smoke movement. Delphi group arithmetic mean 5/10 (medium). See diagram D77.

Does **Volume and Energy of Smoke** [307] have a potential impact on Smoke Control at the following times (Dilution model)?

$T(\text{ignition}) - T(\text{detection})$. Yes.

If dilution technique is used then Volume and Energy will have an impact on it at any time throughout the event.

$T(\text{detection}) - T(\text{safety})$. Yes.

The potential is at constant maximum. The impact on Life Safety will be available because the dilution system will be maintaining (and thus impacting on) Life Safety. Delphi group arithmetic mean 8/10 high. See diagram D78.

Consider **Wind** [308]. Does it have a potential impact on Smoke Control at the following times (Dilution model)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

It is of constant a potential impact and pre-existent. Delphi group arithmetic mean 5/10 (medium). See diagram D79.

Consider **External Leakage** [309] - does it have a potential impact on smoke control at the following times (Dilution model)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Equivalent orifice area is static. Delphi group arithmetic mean 6/10. See diagram D80.

Consider **Internal Leakage** [310]: - does it have a potential impact on Smoke Control at the following times (Dilution model)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

It has a constant, pre-existent value for all times. Delphi group arithmetic mean 5/10 (medium). See diagram D81.

Consider **Ambient Temperature** [311]: - does it have a potential impact on Life Safety through Smoke Control at the following times (Dilution model)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

The pre-existent static potential of ambient temperature to affect Life Safety via smoke control by dilution will continue throughout the events. It may become less important relative to other factors as the space becomes infiltrated by smoke, but the potential is constant. Delphi group arithmetic mean 6/10 (medium). See diagram D82.

Does **Reservoir Size and Design** [312] have a potential impact on smoke control at the following times (Dilution model)?

$T(\text{ignition}) - T(\text{detection})$. Yes.

It will have a constant impact on Life Safety via smoke control. If it fails because it is too small, this is a function of combination of volume of smoke and size of space. If properly designed it is assumed that this is a satisfactory volume.

$T(\text{detection}) - T(\text{safety})$. Yes.

Delphi group arithmetic mean 8/10 (high). See diagram D83.

Does **Air Pressure Developed** [313] have a potential impact on smoke control at the following times (Containment model)?

$T(\text{ignition}) - T(\text{detection})$. No.

Unless the operating air conditioning system is of the level and type to keep smoke out of the space, then before $T(\text{detection})$ there will be no 'Air Pressure Developed'.

$T(\text{detection}) - T(\text{perception})$. Yes.

Once triggered into its variable mode, or dedicated unit switched on there is a potential impact on Life Safety for a system (via containment) and this remains the same for as long as the unit works. For the remainder of the event (including $T(\text{relative safety}) - T(\text{safety})$) there is a constant potential value. Delphi group arithmetic mean 8/10 (high). See diagram D84.

Does **Volume and Design of Space** [314] have a potential impact on Smoke Control at the following times (Containment model)?

$T(\text{ignition}) - T(\text{detection})$. No.

Smoke Control has not yet been initiated. Any air movement by one mode of a variable system which is not included for smoke control will come under smoke movement.

$T(\text{detection}) - T(\text{perception})$. Yes.

After detection the system will be activated and running. The volume of the space will affect the efficiency of the system (because of the pressure that may be developed). The effect will be constant throughout the event for the volume being considered. (note that any change because of a door opening is a leakage problem).

$T(\text{perception}) - T(\text{safety})$. Yes.

Constant. Delphi group arithmetic mean 5/10 (medium). See diagram D85.

Does the **Wind** [308] impact on smoke control by containment at the following times ?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Wind is constant. Wind will be less important than it is for dilution. No impact before $T(\text{detection})$.

Delphi group arithmetic mean 5/10

Refer diagram D77.

Does the **Energy of Smoke** [315] impact on Smoke Control by containment at the following times?

$T(\text{ignition}) - T(\text{detection})$. No.

Smoke Control not yet activated. Energy of smoke will impact on smoke movement not on containment.

$T(\text{detection}) - T(\text{safety})$. Yes.

The energy of smoke will impact on Life Safety via containment because the smoke control system is overcoming the energy, thus the impact of energy of smoke (which is real) on Life Safety is counter-balanced against the smoke control. Delphi group arithmetic mean 7/10 (high). See diagram D86.

Does the **External Leakage** [309] impact on Smoke Control by containment at the following times?

$T(\text{ignition}) - T(\text{detection})$. Yes.

Smoke control not yet activated, but there may be a passive containment role.

$T(\text{detection}) - T(\text{safety})$. Yes.

Constant value because the equivalent orifice area is a constant. (ie; static) value throughout the event. If doors into a space used for containment are opened this will alter leakage but this will be due to an interaction and will result in a new static value. Delphi group arithmetic mean 6/10 (medium). Refer diagram D80.

Does **Internal Leakage** [310] have a potential impact on Smoke Control by containment at the following times ?

$T(\text{ignition}) - T(\text{detection})$. Yes.

Smoke control not yet activated, but there may be a passive containment role.

$T(\text{detection}) - T(\text{safety})$. Yes.

It is a vital factor in the functioning of smoke control by containment. The equivalent orifice area is constant. Delphi group arithmetic mean 6/10 (medium). See diagram D87.

Does **Reservoir Size and Design** [312] have a potential impact on Smoke Control by removal at the following times (natural) ?

$T(\text{ignition}) - T(\text{detection})$. No.

Venting is not yet activated, but there may be a requirement for the formation of a buoyant layer.

$T(\text{detection}) - T(\text{safety})$. Yes.

Static and having a constant and predictable value on smoke control and thus on Life Safety. Delphi group arithmetic mean 7/10 (high). See diagram D88.

Same comments as for natural apply to mechanical (forced) venting.

Does the **Inlet Area** [316] have a potential impact on Smoke Control by removal at the following times (natural)?

$T(\text{ignition}) - T(\text{detection})$. No.

Venting not yet initiated.

$T(\text{detection}) - T(\text{perception})$. Yes.

Inlet area is very important to the efficiency of venting. It must be balanced with extract area - there will be an interaction here and it is particularly critical with naturally powered venting where there is not so likely to be a significant imbalance. There is not the excess power available to overcome

imbalance with a wind induced ventilation.

$T(\text{perception}) - T(\text{safety})$. Yes.

Inlet area is constant and will be just as important to smoke control by removal (and through it to Life Safety) throughout the event. Delphi group arithmetic mean 8/10 (high).

Same comments as for natural apply to mechanical venting. See diagram D89.

Does **Exhaust Area** [317] have a potential impact on Smoke Control by removal at the following times (natural) ?

$T(\text{ignition}) - T(\text{detection})$. No.

Not yet activated.

$T(\text{detection}) - T(\text{safety})$. Yes.

The exhaust area will affect the smoke control (and thus Life Safety). The provision of exhaust area will have a constant potential input (the variation in wind - induced pressure differences across it, and quantity of smoke to remove may vary, but these are modifiers). The contribution of exhaust area to Life Safety through smoke control by removal is potentially constant. Actual value may be affected by whether there is or a number of vents. Delphi group arithmetic mean 8/10 (high).

Same comments as for natural apply to mechanical venting. See diagram D90.

Does **Ambient Temperature** [311] have a potential impact on Smoke Control by removal at the following times (natural) ?

$T(\text{ignition}) - T(\text{safety})$. Yes.

From $T(\text{ignition})$ on until $T(\text{safety})$ there is a constant potential

impact of ambient temperature on smoke control by removal (and thus to Life Safety). Delphi group arithmetic mean 5/10 (medium).

Same comments as for natural apply to mechanical venting, the Delphi arithmetic mean is 7/10 (high). See diagram D91.

Does Wind [308] have a potential impact on Smoke Control by removal at the following times?

$T_{(ignition)} - T_{(detection)}$. No.

No activation yet, based on Delphi group decision process. Note that External leakage and Internal leakage were considered by the Delphi group as having a potential impact. This factor should perhaps be included for $T_{(ignition)}$ to $T_{(detection)}$.

$T_{(detection)} - T_{(safety)}$. Yes.

The incident pressure across a removal vent will have a fundamental impact on the Life Safety aspect because of smoke control by removal. Delphi group arithmetic mean 5/10 (medium).

Same comments as for natural apply to mechanical venting. Refer diagram D77.

Does **Volume and Energy of Smoke** [307] have a potential impact on Smoke Control by removal at the following times (natural) ?

$T_{(ignition)} - T_{(detection)}$. Yes.

Formation of a buoyant layer prior to activation.

$T_{(detection)} - T_{(safety)}$. Yes.

The potential impact on Life Safety commences from $T_{(detection)}$ (or in actual fact, whenever the smoke control system is activated) until $T_{(safety)}$. The volume of smoke will vary

throughout the event, and unless it is sufficient to overload the system its importance will be constant (an actual aspect).
Arithmetic mean 9/10 (high).

Same comments as for natural apply to mechanical venting. See diagram D92.

Does **Air Pressure Developed** [313] have a potential impact on Smoke Control by removal (natural) ?

$T(\text{ignition}) - T(\text{detection})$. No.

Not yet activated.

$T(\text{detection}) - T(\text{safety})$. Yes.

Impact on the smoke control by removal is vital and of constant import throughout the event. Delphi group arithmetic mean 7/10 (high).

Same comments as for natural apply to mechanical venting. See diagram D93.

Does **External Leakage** [309] have a potential impact on Smoke Control by removal at the following times (natural) ?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Equivalent orifice area is constant and the impact on smoke control by removal will be constant. Delphi group arithmetic mean 5/10 (medium).

Same comments as for natural apply to mechanical venting. See diagram D94.

Does **Internal Leakage** [310] have a potential impact on Smoke Control by removal at the following times (natural) ?

T(ignition) - T(safety). Yes.

Constant equivalent orifice area throughout the event. Delphi group arithmetic mean 5/10 (medium).

Same comments as for natural apply to mechanical venting, Delphi group arithmetic mean 5/10. See diagram D95.

Does **Surface Characteristic** [318] have a potential impact on Fire Spread at the following times ?

T(ignition) - T(safety) Yes.

Surface characteristics are very important throughout the event for fire spread. Delphi group arithmetic mean 8/10 (high). See diagram D96.

Does **Fuel Supply and Distribution** [319] have a potential impact on Fire Spread at the following times ?

T(ignition) - T(safety). Yes.

Constantly throughout the event. Delphi group arithmetic mean 9/10 (high). See diagram D97.

Does **Passive Fire Stopping** [320] have a potential impact on Fire Spread at the following times ?

T(ignition) - T(detection). Yes.

But very low.

T(detection) - T(perception). Yes.

A bit more important. But intensity of fire not yet likely to be significant enough to present a threat.

T(perception) - T(action). Yes.

As decided by the Delphi group, it would not be of high importance.

$T(\text{action}) - T(\text{safety})$. Yes.

Increasingly important especially for $T(\text{relative safety}) - T(\text{safety})$ on protected routes. Note how the curve may alter if the growth is rapid. See diagram D98.

Does **Active Fire Stopping** [320] have a potential impact on fire spread at the following times ?

$T(\text{ignition}) - T(\text{detection})$. No.

Not yet activated.

$T(\text{detection}) - T(\text{safety})$. Yes.

Same as for pressure. Note the significance of fire growth rate for example if growth is considerable.

However, in Delphi consideration this is not very important because small at 1 minute (which is assumed $T(\text{perception}) - T(\text{action})$ stage). Note that in doing this the factor was considered in actual rather than potential terms. See diagram D99.

Does **Fire Suppression** [321] have a potential impact on Fire Spread at the following times?

$T(\text{ignition}) - T(\text{detection})$. No.

Whether automatic or manual, detection is required before suppression commences.

$T(\text{detection}) - T(\text{perception})$. Yes.

Very important impact of suppression in early stage to prevent fire spread and have an impact on Life Safety. Note how suppression may interact with smoke production and spread (cooling and logging).

$T(\text{perception}) - T(\text{action})$. Yes.

Very important to maintain control of the fire and thus maintain Life Safety.

No Delphi group arithmetic mean.

$T(\text{action}) - T(\text{safety})$. Yes.

Very important. No let off after entering protected route because concerned with fire spread throughout the event. See diagram D100.

Tertiary level

Does the **Existence of Aural Information** [237] have a potential impact on Communication at the following times?

$T(\text{ignition}) - T(\text{safety})$. Yes.

There will be a constant potential contribution of aural existence to communication. The actual importance of aural existent information will depend on interactions of existence and perception, but this is handled separately by the model. See later. The potential aural existent information may always be as significant for communication, although the actual value may alter. Delphi group arithmetic mean 8/10 (high). See diagram D101.

Does the **Existence of Visual Information** [238] have a potential impact on Communication at the following times ?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Throughout. It is of constant value potentially to communication (and through it to Life Safety).. Delphi group arithmetic mean 9/10 (high). See diagram D101.

Does the **Existence of Tactile Information** [239] have a potential impact on Communication at the following times ?

T(ignition) - T(safety). Yes.

Delphi group arithmetic mean 4/10 (low). See diagram D101.

Does the **Existence of Gustatory Information** [240] have a potential impact on Communication at the following times ?

T(ignition) - T(safety). Yes.

The potential impact of gustatory information onto Life Safety is low. Delphi group arithmetic mean 2/10 (low). See diagram D101.

Does the **Existence of Olfactory Information** [241] have a potential impact on Communication at the following times ?

T(ignition) - T(safety). Yes.

Olfactory information will have a potentially high impact on Life safety throughout the event. Delphi group arithmetic mean. 7/10 (high). See diagram D101.

For each sense, does the **Ability to Perceive** [242,243,244, 245,246] have a potential impact on communication at the following times?

T(ignition) - T(safety). Yes.

For each sense there is a potential impact onto communication at each stage of the event. See diagram D102.

Does **Psychological Capacity** [247] have a potential impact on Mobility at the following times?

$T(\text{ignition}) - T(\text{detection})$. Yes.

If mobility is concerned with the ability to effect escape (whether that includes egress or not) then the impact of psychological capacity the capacity to comprehend perceived information, and thus to formulate plans will be of crucial importance. Mobility only affects mode of escape at $T(\text{ignition}) - T(\text{detection})$ through detection implications, and psychological aspects are the main force behind detection. Mental alertness is required to detect a fire or a combination of alertness and movement itself - stumbling across it.

There is a potential impact at this stage.

$T(\text{detection}) - T(\text{perception})$. Yes.

Vital for the step from detection to perception.

$T(\text{perception}) - T(\text{safety})$. Yes.

Vital for information gathering and decision making, route usage and continued evaluation of the situation and decision making. See diagram D103.

Does **Physical Capability** [248] have a potential impact on Mobility at the following times?

$T(\text{ignition}) - T(\text{detection})$. Yes.

Improves the likelihood of detection.

$T(\text{detection}) - T(\text{perception})$. Yes.

Investigation of ambiguous cues may involve movement.

$T(\text{perception}) - T(\text{action})$. Yes.

Coping behaviour may involve movement.

$T(\text{action}) - T(\text{safety})$. Yes.

Important for the movement throughout the building. See diagram D104.

Does **Physiological Capability** [249] have a potential impact on Mobility at the following times?

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times the physiological capability may be important to mobility. In the later stages if escape involves movement the actual importance may be particularly high.

The preparation of the body for action (fight or flight!) involves changes in the physiology, and the potential contribution of this may be high, after $T(\text{perception})$. Physiological endurance may be significant in the latter stages of an event, and the potential contribution is high. See diagram D105.

Does **Building Knowledge** [250] have a potential impact on Training at the following times?

$T(\text{ignition}) - T(\text{detection})$. No.

At this stage of the event building knowledge does not contribute to Life Safety. (it is not being used specifically for the purpose of investigation or escape).

$T(\text{detection}) - T(\text{perception})$. Yes.

If movement is involved for the purpose of investigation or escape.

$T(\text{detection}) - T(\text{perception})$. Yes.

If movement is involved for investigation and this involves moving out of the space then a cognitive map of the building will be needed.

$T(\text{perception}) - T(\text{action})$. Yes.

As for $T(\text{detection}) - T(\text{perception})$, movement may be involved and so the impact of the knowledge of the spatial arrangement and a familiarity with routes to exit the building may be of potentially high importance. See diagram D106.

Does **Event Knowledge** [251] have a potential impact on Training at the following times?

$T(\text{ignition}) - T(\text{detection})$. Yes.

Event knowledge comes after and as a consequence of detection and perception. There can be no contribution until then.

$T(\text{detection}) - T(\text{perception})$. No.

Nothing yet perceived as a fire event and so there will not be any knowledge identified by the person as relevant to a fire event. (note that someone who stumbles across a fire will almost simultaneously detect and perceive it. The duration between the two points in time will be real even if short, and as such there is still a stage to go through.

$T(\text{perception}) - T(\text{action})$. Yes.

Any knowledge comes out of and after perception. This will result in an impact on training (and through this to Life safety). Event knowledge is important in decision making and tactics formation.

$T(\text{action}) - T(\text{relative safety})$. Yes.

Continued decision making. Event knowledge will impact on Life safety by eliminating possibility of wrong choice. Decisions are made on the basis of available knowledge (correct or incorrect).

$T(\text{relative safety}) - T(\text{safety})$. Yes.

Continued relevance of information about the event. See diagram D107.

Does a **General Fire Safety Knowledge** [252] have a potential impact on training (and through it to Life Safety) at the following times ?

$T(\text{ignition}) - T(\text{perception})$. No.

There is no contribution of knowledge of how to act in a fire until the person is aware of one.

$T(\text{perception}) - T(\text{action})$. Yes.

There is a relevance of general fire knowledge in decision making and activities such as fire fighting.

$T(\text{action}) - T(\text{safety})$. Yes.

In evacuating a building the use of the routes, signs and the awareness of procedures all contribute to Life Safety. All are aspects of general fire safety knowledge. See diagram D108.

Does a **Specific Fire Safety Knowledge** [253] have any impact on Training at the following times (and through it to Life Safety) ?

$T(\text{ignition}) - T(\text{detection})$. No.

$T(\text{detection}) - T(\text{perception})$. Yes.

Knowledge on coded information may increase speed of perception, and thus impacts onto Life Safety.

$T(\text{perception}) - T(\text{action})$. Yes.

Decision making based on route knowledge, and drill procedure.

$T(\text{action}) - T(\text{safety})$. Yes.

Knowledge of routes and specific procedures. See diagram D109.

Does **Location Identification** [254] have a potential impact on Ease of Use at the following times (and through it to Life Safety) ?

$T(\text{ignition}) - T(\text{perception})$. No.

$T(\text{perception}) - T(\text{action})$. Yes.

Decision making, plan formation and the relevance on details of evacuation procedure (e.g., phased evacuation instructions) will require identification of starting location.

$T(\text{action}) - T(\text{safety})$. Yes.

Continued identification of location significance throughout the rest of the event. See diagram D110.

Does **Route Choice Identification** [255] have a potential impact on Ease of Use at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{detection})$. No.

Unaware of event requirements .

$T(\text{perception}) - T(\text{action})$. Yes.

Route choice identification is important in decision making.

$T(\text{action}) - T(\text{safety})$. Yes.

Continued importance of route choice identification for ease of use throughout final stages. See diagram D111.

Do **Obstructions** [256] have a potential impact on Ease of Use at the following times?

$T(\text{ignition}) - T(\text{perception})$. No.

$T(\text{perception}) - T(\text{action})$. Yes.

The value of obstructions may be relevant in the preparation stage and during formation of plans.

$T(\text{action}) - T(\text{safety})$. Yes.

Blockages in the routes may make it difficult to use the routes and the capacity may be reduced consequently. Queuing and restrictions in carrying capacity will impose obstructions.

Obstructions are most important when movement occurs. See diagram D112.

Does **Choice of Alternative Routes** [257] have a potential impact on Ease of Use at the following times (and though it to Life Safety) ?

$T(\text{ignition}) - T(\text{action})$. No.

There is no potential contribution of routes to escape prior to action for escape.

$T(\text{action}) - T(\text{safety})$. Yes.

High potential contribution during the final stages of the event. 9/10 (high). See diagram D113.

Does **Width of Route** [258] have a potential impact on Exit Route Capacity (and through it to Life Safety at the following times)?

$T(\text{ignition}) - T(\text{action})$. No.

There is no movement during the first three stages. The width of the route is not relevant before it is used.

$T(\text{action}) - T(\text{relative safety})$. Yes.

Width is now relevant. It relates to flow and static capacities.

$T(\text{relative safety}) - T(\text{safety})$. Yes.

Life Safety is affected by the capacity for clearing people, and width is of continued relevance. Changes in width may have significance. See diagram D114.

Does **Length of Route** [259] have a potential impact on Exit Route Capacity (and through it to Life Safety at the following times)?

$T(\text{ignition}) - T(\text{action})$. No.

Length of route not relevant until it is used.

$T(\text{action}) - T(\text{relative safety})$. Yes.

The length of unprotected route that has to be travelled is significant to Life Safety. Continued potential relevance. See diagram D115.

Does **Rate of Heat Release** [260] have a potential impact on Rate of Burning at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

There will be a constant potential impact of rate of heat release

on rate of burning throughout the fire event. See diagram D116.

Does **Fuel Geometry and Orientation** [261] have a potential impact on rate of burning at the following times (and through it to Life safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times the fuel geometry and orientation will impact onto rate of burning. See diagram D117.

Does **Ignition Source** [262] have a potential impact on Rate of Burning at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{detection})$. Yes

There is obviously a requirement for the ignition source to have an impact on rate of burning in the first stage to ensure that ignition is maintained.

$T(\text{detection}) - T(\text{safety})$. Yes.

The impact is not continued through the event, although this was not fully decided until late on in the development of the model. It was considered realistic for a while to consider that spread of the fire within or between spaces required items to act as ignition sources for second item etc.,...

This was eventually decided to be eliminated, and the term applied only to the first ignition source. The duration and intensity of ignition sources may be that strictly speaking T_{ignition} occurs after the ignition source has acted.

Strict application would exclude ignition source from the model, and this would not always be applicable, nor would it be serving the purpose of analysis. See diagram D118.

Does **Bulk Density** [263] have a potential impact on Rate of Burning at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

The bulk density is a constant definitive factor and the a potential impact on rate of burning is thus constant. See diagram D119.

Does **Oxygen Supply** [264] have a potential impact on Rate of Burning (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$

Supply of oxygen is essential for the continued existence or growth of the fire. There is a constant potential impact on Life Safety throughout the event. See diagram D120.

Does **Mode of Burning** [265] have a potential impact on Smoke Yield (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

The a potential impact throughout will be constant. See D121.

Does **Type of Material** [266] have a potential impact at the following times ?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Throughout the event the impact of a material on yield will be potentially the same, although the material type may alter - differences in yield because of differences in materials will be represented by differences in actual value. Type of material may be expressed as wood equivalence. See diagram D122.

Does **Internal Temperature** [267] have a potential impact on Ambient Stack at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Internal temperature is a fundamental factor of ambient stack.. It is of constant impact and may affect ambient stack and thus Life Safety. Delphi group arithmetic mean 8/10 (high). See diagram D123.

Does **External Temperature** [268] have a potential impact on Ambient Stack at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

For same reasons as internal temperature. Delphi group arithmetic mean 8/10 (high). See diagram D124.

Does **Height** [269] have a potential impact on Ambient Stack at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Height affects the ambient stack, and may alter its significance to Life Safety. But the impact of height in ambient stack is of constant potential. Delphi arithmetic mean 9/10 (high). See diagram D125.

Does **Fire Temperature** [270] have a potential impact on the Fire Stack at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times there is a constant potential impact of fire temperature onto fire stack. Note that although the fire stack impact onto smoke movement was dependent on fire growth curve, the fire stack is of constant dependence on fire temperature. Remember also that the factors are being considered as discrete (at this stage).

Whether fire temperature is of less importance than ambient stack

(or vice versa) at any stage of the event depends on their relative importance, but there is a real potential at any time. See diagram D126.

Does **Ambient Temperature** [271] have a potential impact on Fire Stack (and through it to Life Safety) at the following times?

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times Ambient Temperature is potentially important - it is what the fire temperature acts against (similar to containment pressure needs smoke pressure to work against). Fire stack will depend on a combination of ambient and fire temperatures. Delphi group arithmetic mean. See diagram D127.

Does **Air Pressure Developed** [272] have a potential impact on induced flow (and through it to Life Safety) at the following times?

$T(\text{ignition}) - T(\text{safety})$. Yes.

A vital factor in flow. There will be an impact through onto Life Safety. Delphi group arithmetic mean 9/10 (high). See diagram D128.

Does **External Leakage** [273] have a potential impact on Mechanically Induced Flow at the following times (and through it to Life safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

For all time stages. The external leakage will be a constant equivalent orifice area. It will consequently have a constant impact on mechanically induced flow. Delphi group arithmetic mean 6/10 (medium). Diagrams D129, D130.

Does **Internal Leakage** [274] have a potential impact on induced flow at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

Constant equivalent orifice area. Delphi group arithmetic mean 7/10 (high). Diagrams D131,D132.

Does **Volume of Space and Design** [275] have a potential impact on induced flow at the following times (and through it to Life safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

The volume and design of the space will be constant, and so the potential impact will be constant. Delphi group arithmetic mean 7/10 (high). Diagrams D133,D134, and D135.

For the next section, factors are considered in terms of their impacts for the three different smoke control techniques (dilution, containment, and removal). The three smoke control techniques influence the Life Safety System differently. Hence, the model structure requires to be different, and it is necessary to split the model into three sub-models.

These models became referred to as the smoke control by dilution, containment, and removal models, since these are the distinguishing features.

The main body of each model (the mode of escape, escape route layout, smoke release and movement, and fire spread sections) is similar but not identical, because of systemic interactivity.

The contribution of a factor to the model may be different in each of the circumstances. The development of the model assumed only one smoke control technique is used in any scenario, and so the following sections on the smoke control aspects are discrete. The factors for the dilution technique are considered first, followed by the containment and removal models.

A factor that is relevant for each smoke control technique will

appear in each sub-model, but may have a different potential impact in each (the relative contributions, depending on interactions will also tend to be different). Where practical, factors common to more than one smoke control technique are discussed together.

This aspect of relative contributions becomes particularly relevant later on in the development of the model. The relative contribution of a factor to Life Safety depends on its interactions and its original impact. The impact of a factor in each of the three models may be different. Also, because there is a different set of factors in each of the three models, and any factor can be considered for interaction with any other factor in the system, it follows that each smoke control sub-model needs to be considered in the terms of a completely separate model.

Dilution model

Does **Smoke Mass Flow Rate** [276] have a potential impact on volume and energy of smoke at the following times, and through it to Life safety? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times, with a dilution system the smoke mass flow rate will have a potential impact on volume and energy of smoke. Delphi group arithmetic mean 9/10 (high).

See diagram D136.

Does **Nature of Smoke** [277] (ageing, etc.) have a potential impact on volume and energy of smoke at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

There will be a potential impact of the nature of smoke

(including such factors as ageing) from the time of ignition onto the volume and energy of the smoke. The actual value is most likely to be very low at the initial stages of the event, and only when the smoke has aged (by cooling, increasing volume on passing an obstacle, or the effect of sprinklers or gas flooding). Delphi group arithmetic mean 7/10 (high).

See diagram D137.

Do **Surroundings** [278] have a potential impact on wind at the following times (and through it to Life Safety)? Dilution model.

T(ignition) - T(safety). Yes.

The surroundings are constant - The only way the actual value of surroundings may change is if the wind direction changes and a different approach topography is experienced by the incoming air. The potential value for any given plot will be the most significant of the topographies. Delphi group arithmetic mean 6/10 (medium).

See diagram D138.

Does **Speed** [279] have a potential impact on wind at the following times (and through it to Life Safety)? Dilution model.

T(ignition) - T(safety). Yes.

At all times the pressure developed by the wind will depend on the speed. Delphi group arithmetic mean 9/10 (high).

See diagram D139.

Does **Direction** [280] have a potential impact on wind at the following times (and through it to Life Safety)? Dilution model.

T(ignition) - T(safety). Yes.

At all times the pressure developed by the wind on the building faces will relate to the angle of incidence of the wind onto the building. Delphi group arithmetic mean 9/10. (high).

See diagram D140.

Does the **Height** [281] have a potential impact on wind at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times the height of the building will impact onto the nature of the effect of the wind on the building.

See diagram D141.

Does **Integrity** [282] have a potential impact on external leakage at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times. In terms of the event duration concerned, even the correct levels of fire protection () hour from ignition?) will be sufficient and the intended integrity of the wall can be assumed to exist. Arithmetic mean of Delphi group 7/10 (high). Doors are a special case of permeability, windows also.

See diagram D142.

Does **Permeability** [283] have a potential impact on external leakage at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

The same principle applies as for integrity. It is assumed to be a constant aspect of the nature of the fabric and its fittings

and includes also cracks, doors, air conditioning vents. Delphi group arithmetic mean 6/10 (medium).

See diagram D143.

Does **Integrity** [282] have a potential impact on internal leakage at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times. In terms of the event duration concerned, even the correct levels of fire protection () hour from ignition?) will be sufficient and the intended integrity of the wall can be assumed to exist. Arithmetic mean of Delphi group 6/10 (high)> Doors are a special case of permeability, windows also.

See diagram D144.

Does **Permeability** [283] have a potential impact on internal leakage at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

The same principle applies as for integrity. It is a constant aspect of the nature of the fabric and includes also cracks, doors, air conditioning vents Delphi group arithmetic mean 6/10 (medium). See diagram D145.

Does **Air Conditioning** [284] impact onto ambient temperature at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{detection})$. Yes.

The air conditioning will be pre-existent.

$T_{\text{(detection)}} - T_{\text{(safety)}} \cdot \text{Yes.}$

Note that if the equipment is shut off automatically or manually then it will have no further potential contribution to make, Delphi group arithmetic mean 8/10 (high). See diagram D146.

Does **Heat Gain of Space** [285] have a potential impact on ambient temperature at the following times (and through it to Life safety)? Dilution model.

$T_{\text{(ignition)}} - T_{\text{(safety)}} \cdot \text{Yes.}$

At all times. The heat gain of the space may be unpredictable in occurrence. The potential impact of the factor is constant and may be relevant at any time in the event. See diagram D147.

Does **Space Shape** [287] have a potential impact on reservoir size and design at the following times (and through it to Life Safety)? Dilution model.

$T_{\text{(ignition)}} - T_{\text{(safety)}} \cdot \text{Yes.}$

At all times the space shape (which in most circumstances will be constant) will potentially impact onto the effectiveness of the reservoir. The effectiveness of the reservoir to allow the smoke to float around will depend on the shape.

Delphi group arithmetic mean 5/10 (medium). See diagram D148.

Does **Height of Reservoir** [288] have a potential impact on the reservoir size and design (and through it to Life Safety)? Dilution model.

$T_{\text{(ignition)}} - T_{\text{(safety)}} \cdot \text{Yes.}$

Static height, constant potential impact. Delphi group arithmetic mean 9/10. See diagram D149.

Does **Length of Space** [289] have a potential impact on reservoir size and design (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

A constant, and thus a constant impact at all times. Delphi group arithmetic mean 7/10 (high). See diagram D150.

Does **Breadth** [290] have a potential impact on reservoir size and design at the following times (and through it to Life Safety)? Dilution model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

Same as length. Delphi group arithmetic mean 7/10 (high). See diagram D151.

In the case of a smoke control system requiring activation, it is assumed that the earliest that this could occur would be just after $T(\text{detection})$ by automatic detection. Manual detection, or manual activation after automatic detection would both involve delays before activation. In the case of some factors this means that the factor has no contribution in the time stage 1.

Containment model

Does **Available Power** [291] have a potential impact on air pressure developed at the following time stages (and through it to Life safety)? Containment model.

$T(\text{ignition}) - T(\text{detection})$. No.

Not yet activated.

$T(\text{detection}) - T(\text{safety})$. Yes.

A vital factor in the development of pressure for the containment of smoke. Delphi group arithmetic mean 9/10 (high). See diagram

D152.

Does **Operating Philosophy** [292] have a potential impact on air pressure developed at the following time stages (and through it to Life safety)? Containment model.

$T(\text{ignition}) - T(\text{detection})$. No.

Not yet activated.

$T(\text{detection}) - T(\text{safety})$. Yes.

Operating philosophy refers to the adopted policy for use of power to control smoke by containment. It may involve selective positive and negative pressurisation and the air pressure developed (and where it is developed) will depend on the policy adopted. There is a high a potential impact on air pressure developed. Delphi group arithmetic mean 8/10 (high). See diagram D153.

Does **Space Shape** [287] have a potential impact on volume and design of space at the following times (and through it to Life Safety)? Containment model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

Delphi group arithmetic mean 6/10 (medium). See diagram D154.

Does **Height** [288] have a potential impact on volume and design of space at the following times (and through it to Life Safety)? Containment model.

$T(\text{ignition}) - T(\text{detection})$. No.

Passive containment relevance to an inactive smoke control system.

$T(\text{detection}) - T(\text{safety})$. Yes.

A static value, and of constant a potential impact on the volume and design of space and thus smoke control by containment. $T_{\text{(detection)}}$ is the earliest potential stage for active contribution. Delphi group arithmetic mean 9/10 (high). See diagram D155.

Does **Length of Space** [289] have a potential impact on reservoir size and design (and through it to Life Safety)? Containment model.

$T_{\text{(ignition)}} - T_{\text{(safety)}}$. Yes.

A constant, and thus a constant impact at all times. Delphi group arithmetic mean 7/10 (high). See diagram D156.

Does **Breadth** [290] have a potential impact on reservoir size and design at the following times (and through it to Life Safety)? Containment model.

$T_{\text{(ignition)}} - T_{\text{(safety)}}$. Yes.

Same as length. Delphi group arithmetic mean 7/10 (high). See diagram D157.

Do **Surroundings** [278] have any potential impact on Wind at the following times (and through it to Life Safety)? Containment model.

$T_{\text{(ignition)}} - T_{\text{(safety)}}$. Yes.

The surroundings are constant - The only way the actual value of surroundings may change is if the wind direction changes and a different approach topography is experienced by the incoming air. The potential value for any given plot will be the most significant of the topographies. Delphi group arithmetic mean 6/10 (medium).

See diagram D158.

Does **Speed** [279] have a potential impact on wind at the following times (and through it to Life Safety)? Containment model.

T(ignition) - T(safety). Yes.

At all times the pressure developed by the wind will depend on the speed. Delphi group arithmetic mean 9/10 (high). See diagram D159.

Does **Direction** [280] have a potential impact on wind at the following times (and through it to Life Safety)? Containment model.

T(ignition) - T(safety). Yes.

At all times the pressure developed by the wind on the building faces will relate to the angle of incidence of the wind onto the building. Delphi group arithmetic mean 9/10. (high).

See diagram D160.

Does the **Height** [281] have a potential impact on wind at the following times (and through it to Life Safety)? Containment model.

T(ignition) - T(safety). Yes.

At all times the height of the building will impact onto the wind as 'seen' by the building. Delphi group arithmetic mean 7/10. See diagram D161.

Does **Smoke Mass Flow Rate** [276] have a potential impact on volume and energy of smoke at the following times, and through it to Life safety? Containment model.

T(ignition) - T(safety). Yes.

At all times, with a containment system the smoke mass flow rate will have a potential impact on volume and energy of smoke. Delphi group arithmetic mean 9/10 (high).

See diagram D162.

Does **Nature of Smoke** [277] have a potential impact on volume and energy of smoke at the following times (and through it to Life Safety)? Containment model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

There will be a a potential impact of the nature of smoke (including such factors as ageing) from the time of ignition onto the volume and energy of the smoke. The actual value is most likely to be very low at the initial stages of the event, and only when the smoke has aged (by cooling, increasing volume on passing obstacle, or the effect of sprinklers or gas flooding). Delphi group arithmetic mean 7/10 (high). See diagram D163.

Does **Integrity** [282] have a potential impact on external leakage at the following times (and through it to Life Safety)? Containment model.

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times. In terms of the event duration concerned, even the correct levels of fire protection () hour from ignition?) will be sufficient and the intended integrity of of the wall can be assumed to exist. Arithmetic mean of Delphi group 7/10 (high). Doors are a special case of permeability, windows also. See diagram D164.

Does **Permeability** [283] have a potential impact on external leakage at the following times (and through it to Life Safety)? Containment model.

$T_{(ignition)} - T_{(safety)}$. Yes.

The same principle applies as for integrity. It is assumed to be a constant aspect of the nature of the fabric and its fittings and includes also cracks, doors, air conditioning vents Delphi group arithmetic mean 6/10 (medium). See diagram D165.

Does **Integrity** [282] have a potential impact on internal leakage at the following times (and through it to Life Safety)? Containment model.

$T_{(ignition)} - T_{(safety)}$. Yes.

At all times. In terms of the event duration concerned, satisfactory fire resistance of the structure is assumed sufficient and the intended integrity of the wall is assumed to exist. Arithmetic mean of Delphi group 7/10 (high). Doors are a special case of permeability, windows also. See diagram D166.

Does **Permeability** [283] have a potential impact on internal leakage at the following times (and through it to Life Safety)? Containment model.

$T_{(ignition)} - T_{(safety)}$. Yes.

See diagram D167.

The same principle applies as for integrity. It is assumed to be a constant aspect of the nature of the fabric and its fittings and includes also cracks, doors, air conditioning vents Delphi group arithmetic mean 6/10 (medium).

Removal model

Does **Space Shape** [286] have a potential impact on reservoir size and design at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

At all times the space shape will impact on the effectiveness of the reservoir. The effectiveness of the reservoir to allow the smoke to accumulate will depend on the shape

Delphi group arithmetic mean 5/10 (medium). See diagram D168.

Does **Height of Reservoir** [288] have a potential impact on the reservoir size and design (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

Static height, constant impact. Delphi group arithmetic mean ?.

See diagram D169.

Does **Length of Space** [289] have a potential impact on reservoir size and design (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

A constant, and thus a constant impact at all times. Delphi group arithmetic mean 7/10 (high). See diagram D170.

Does **Breadth** [290] have a potential impact on reservoir size and design at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

Same as length. Delphi group arithmetic mean 7/10 (high). See diagram D171.

Does **Air Conditioning** [284] impact onto ambient temperature at the following times (and through it to Life Safety)? Removal

model (mechanical and natural).

$T_{\text{(ignition)}} - T_{\text{(detection)}}$. Yes.

The air conditioning will be pre-existent.

$T_{\text{(detection)}} - T_{\text{(safety)}}$. Yes.

Note that if the equipment is shut off automatically or manually then it will have no further potential contribution to make, Delphi group arithmetic mean 8/10 (high). See diagram D172.

Does **Heat Gain of Space** [285] have a potential impact on ambient temperature at the following times (and through it to Life safety)? Removal model (mechanical and natural).

$T_{\text{(ignition)}} - T_{\text{(safety)}}$. Yes.

At all times. The heat gain of the space may be unpredictable in occurrence. The potential impact of the factor is constant and may be relevant at any time in the event. See diagram D173.

Do **Surroundings** [278] have a potential impact on wind at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{\text{(ignition)}} - T_{\text{(safety)}}$. Yes.

The surroundings are constant - The only way the actual value of surroundings may change is if the wind direction changes and a different approach topography is experienced by the incoming air. The potential value for any given plot will be the most significant of the topographies. Delphi group arithmetic mean 6/10 (medium).

See diagram D174.

Does **Speed** [279] have a potential impact on wind at the following

times (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

At all times the pressure developed by the wind will depend on the speed. Delphi group arithmetic mean 9/10 (high). See diagram D175.

Does **Direction** [280] have a potential impact on wind at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

At all times the pressure developed by the wind on the building faces will relate to the angle of incidence of the wind onto the building. Delphi group arithmetic mean 9/10. (high). See diagram D176.

Does the **Height** [281] have a potential impact on wind at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

At all times the height of the building will impact onto the wind as 'seen' by the building. Delphi group arithmetic mean 7/10. See diagram D177.

Does **Smoke Mass Flow Rate** [276] have a potential impact on volume and energy of smoke at the following times, and through it to Life safety? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

At all times, with a removal system the smoke mass flow rate will have a potential impact on volume and energy of smoke. Delphi

group arithmetic mean 9/10 (high). See diagram D178.

Does **Nature of Smoke** [277] have a potential impact on volume and energy of smoke at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(safety)}$. Yes.

There will be a a potential impact of the nature of smoke (including such factors as ageing) from the time of ignition onto the volume and energy of the smoke. The actual value is most likely to be very low at the initial stages of the event, and only when the smoke has aged (by cooling, increasing volume on passing obstacle, or the effect of sprinklers or gas flooding). Delphi group arithmetic mean 7/10 (high). See diagram D179.

Does **Available Power** [291] have a potential impact on air pressure developed at the following time stages (and through it to Life safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(detection)}$. No.

Not yet activated.

$T_{(detection)} - T_{(safety)}$. Yes.

A vital factor in the development of pressure for the removal of smoke. Delphi group arithmetic mean 9/10 (high). See diagram D180.

Does **Operating Philosophy** [292] have a potential impact on air pressure developed at the following time stages (and through it to Life safety)? Removal model (mechanical and natural).

$T_{(ignition)} - T_{(detection)}$. No.

Not yet activated.

$T(\text{detection}) - T(\text{safety})$. Yes.

Operating philosophy refers to the adopted policy for use of power to control smoke by removal. See diagram D181.

Does **Integrity** [282] have any impact on external leakage at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times. In terms of the event duration concerned, even the correct levels of fire protection () hour from ignition?) will be sufficient and the intended integrity of of the wall can be assumed to exist. Arithmetic mean of delphi group 7/10 (high). Doors are a special case of permeability, windows also. See diagram D182.

Does **Permeability** [283] have any impact on external leakage at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T(\text{ignition}) - T(\text{safety})$. Yes.

The same principle applies as for integrity. It is assumed to be a constant aspect of the nature of the fabric and its fittings and includes also cracks, doors, air conditioning vents. Delphi group arithmetic mean 6/10 (medium). See diagram D183.

Does **Integrity** [282] have any impact on internal leakage at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T(\text{ignition}) - T(\text{safety})$. Yes.

At all times. In terms of the event duration concerned, even the correct levels of fire protection () hour from ignition?) will be sufficient and the intended integrity of of the wall can be

assumed to exist. Arithmetic mean of delphi group 7/10 (high). Doors are a special case of permeability, windows also. See diagram D184.

Does **Permeability** [283] have any impact on external leakage at the following times (and through it to Life Safety)? Removal model (mechanical and natural).

$T(\text{ignition}) - T(\text{safety})$. Yes.

The same principle applies as for integrity. It is assumed to be a constant aspect of the nature of the fabric and its fittings and includes also cracks, doors, air conditioning vents. Delphi group arithmetic mean 6/10 (medium). See diagram D185.

Does **Geometry** [293] have any impact on surface characteristics at the following times (and through it to Life Safety)?

$T(\text{ignition}) - T(\text{detection})$. Yes.

Very important throughout the event. In the early stages as a component of a surface characteristic to allow fire growth.

$T(\text{detection}) - T(\text{safety})$. Yes.

This initial importance is continued throughout the event. There is a potential impact of geometry on surface characteristics through out the event. Delphi group arithmetic mean 8/10. See diagram D186.

Does **Flame Spread Characteristics** [294] have any impact on surface characteristics at the following times (and through it to Life safety)?

$T(\text{ignition}) - T(\text{safety})$. Yes.

It will have a potential impact for the whole event duration. Delphi group arithmetic mean 9/10 (high). See diagram D187.

Does **Compartmentation** [295] have any impact on passive fire stopping at the following times (and through it to Life Safety)?

$T_{\text{(ignition)}} - T_{\text{(safety)}}$. Yes.

Until failure of the structure or the fabric, there will be a potential impact of compartmentation on fire spread through passive fire stopping of the structure or the fabric. There will be a potential impact of compartmentation on fire spread through passive fire stopping.

Delphi group arithmetic mean 8/10 (high). See diagram D188.

(6) Derivation of 'Original Impact' vectors

Based on the original impact values derived by the Delphi group, a set of tables were drawn up as a summary tool. These were termed 'Original Impact Vectors'.

Tables to represent factors at each level of the hierarchy, for each smoke control technique, and for each of the time stages were created (45 total). Diagrams D189-D193 are examples of vectors for the secondary level factors included in the smoke control by containment model for the five time stages. Note the six columns representing the six primary level factors in the model. The secondary level factors impacting onto each primary level factor, and the potential values (expressed as a decimal) of these impacts can be identified easily. By time stage 4 all factors have a potential contribution.

Taking Exit Route Capacity as an example: Note there is no potential impact in stages 1 and 2, a potential impact of 0.80 in stage 3, and potential impacts of 0.90 in stages 4 and 5. Compare diagram D71.

(7) 'Interaction' values theory and derivation

Introduction

So far, the primary, secondary, and tertiary level factors in the model had been assumed to be discrete in their effect on Life Safety. The relationships considered had been limited to those links shown on diagrams D49-D56, for each of the five time stages. In reality, the contributions of factors to Life Safety are not simple enough to be described in terms of impacts only. Indeed, they are both complex and dynamic. The multi-faceted nature of factor contributions to Life Safety may only be represented by a complex set of statements about the operands. At this stage of the development, the unrealistic assumption was removed. The concept that occurrences during the event, and influences on Life Safety, are the result of **interactions** between factors, or groups of factors, was put forward.

Consider diagram D194 as an example. Factors have a potential contribution to Life Safety (the concept of impacts) (e.g., [300]). In addition, a factor may be influenced in some way by another factor (or factors) modifying the potential impact on Life Safety (e.g., [171,172]). A knock-on effect occurs. Further, since the subject factor may itself influence other factors, any modification of its potential impact may have implications for those other factors (e.g., [167,169]). A chaining effect may occur (e.g., Ease of Use [171,169]). These relationships are represented in the model as 'interactions'. Such modifications may reduce or increase the potential contribution of a factor to Life Safety, which in itself may be either of a safe or hazardous nature. See conceptual section for further discussion.

There are a number of limitations of interactions. For instance, a factor can only influence another whilst it has a potential contribution to Life Safety. Hence, a factor defined (earlier) as having no potential impact in, say, stages 1 and 2 of an event

cannot have any influence on other factors during stages 1 and 2 either (e.g., Exit Route Capacity). Neither can it be influenced by any other factors during this time stage.

A further conceptual restriction on factor interactions is concerned with branches. See diagram D195. Factors within a branch of the hierarchy are related by impacts, either directly (e.g., Communication and Mode of Escape) or indirectly (e.g., Existence of Aural Information and Mode of Escape). Such relationships prevent a factor interacting onto another factor in the same branch of the hierarchy.

Also if a factor (A) has a (potential) interaction onto a factor (B) in a branch of the hierarchy, then factor (A) cannot also have a (potential) interaction onto any other factor in that branch; neither can any other factor in the same branch as (A) have an impact on factor (B). Diagram D196 is an explanatory example of the above conceptual restrictions and assumptions. Otherwise there are no restrictions over interactions between levels in the hierarchy.

The term "interaction" requires careful definition, and a clear set of assumptions about its use. A summary of the term impact is also given.

Impact: An impact occurs between a lower and a higher factor in the hierarchy. The levels must be adjacent, and existence of an impact between two factors implies dependence of the higher on the lower.

Interaction: An interaction occurs between two factors in the model. It describes the potential knock-on effect between the two factors, but note that interactions are considered as being directional, ie; there may be an interaction of A on B whilst there is no interaction of B on A.

Refer diagram D194. Dictionary definitions of interactions discuss relationships of a reciprocal nature; an action or influence on each other. These sorts of relationships do occur

to a limited extent in the model (e.g., [171,169]).

The relationships modelled by the terms "Interactions" were intended to describe the network of influences, not necessarily reciprocal, which determine the real impact of factors on the objective during the event. The dictionary definition of the term was overlooked. Clearly, it is contradictory to use the term "interaction" to define relationships as being anything other than reciprocal - nevertheless, a great number of factors do influence other factors without themselves being influenced (e.g., [172,167]).

A more accurate terminology may be "Influence". The Delphi Group felt it would be less confusing to continue with the term interaction. For this reason it is kept in the thesis as defined.

Interactivity is defined for the purposes of this model as altering the importance of a potential contribution by modifying it. The contribution itself is assumed to be of a similar nature. For instance, the obstruction of an escape route by a queue modifies the potential contribution of that escape route to Life Safety. The increased time required for travel may be represented as a greater effective route length [103] or smaller effective route width [99]. The people waiting to enter the protected section of the route are suffering a reduced contribution of the route to their Life Safety (as are the escapees delayed in the protected route) - however, the nature of the contribution of the escape route to Life Safety remains similar. The queue, representing an obstruction modifies the escape route performance.

The qualitative and quantitative development of the potential interactions in the system are now discussed. Consideration will be given to each factor in the model in turn, for any interactions it has which influence other factors.

The Delphi group was presented with the following information, accompanied by diagrams to represent the interactions for the relevant time stages. Sample diagrams for the secondary factor

Exit Route Capacity are shown in diagram D197. These represent identified interactions onto Mobility and Ease of Use, both from time stage 4 onwards and of maximum potential importance.

A manual itemising the potential interactions for each of the time stages was developed and discussed by the Delphi group (8th and 15th January 1986). This comprised a set of standard sheets, each sheet dedicated to a particular subject factor and itemising its potential interactions onto other factors. Each standard sheet comprised information on the time stage definitions to which was added details of the magnitude of potential impacts and interactions of the subject factor, and the relevant time stages. Diagram D198 is a reproduction of the standard sheet dedicated to Exit Route Capacity. The information on it corresponds to that in diagram D197 ie; interactions onto Mobility and Ease of Use are identified.

In the following section a summary diagram is provided for each factor. This illustrates the interactions of and onto the factor; the time stages the interactions are relevant for; and the magnitude of the interacting factors and their potential interactions. The data in the diagrams corresponds to the information presented to the Delphi group (e.g., diagrams D197,D198), recast to save space. See diagram D199 (Exit Route Capacity) and diagrams D200,D201 (for Mobility and Ease of Use respectively).

To minimise interactions being assigned to the incorrect levels in the hierarchy (particularly too high a level) the tertiary level factors are considered first. For each of the factors, only those interactions thought to potentially exist will be detailed. Any interaction not listed is considered as not existing potentially for that time stage.

The text is based on information provided to the Delphi Group.

Tertiary Level

Do the **Existence of Information** factors have any potential interaction on any other factors in the model? Diagrams D202-

D206.

There will be no interaction of the Existence of Information factors onto other factors in the model.

The modelling concept of information handling by people is based on the idea that a stimulus does not 'exist' for a person or group unless it is perceived. For this reason the existence of information and the ability to perceive information factors are discrete. Communication occurs as a result of existence of information and the ability to perceive it. Any influence will occur indirectly, through an interaction of communication. (see later). See also diagrams D207-D211.

Does **Psychological Capacity** have any potential interaction on any other factors in the model? Diagram D212.

Psychological Capacity can not have any interaction onto existence of information factors, but will interact onto the ability to perceive factors [21,23,25,27,29]. The ability to perceive is defined for the purposes of the Delphi group as the ability to receive and interpret existent information, thus leading to the 'existence' of a stimulus (Radford (168)).

This will depend on the physical capability and the psychological capacity, modelled by an interaction between psychological capacity and the appropriate ability to perceive factor.

The interaction of psychological capacity on each of the five ability to perceive factors will be high. Also, since each of the ability to perceive factors can have an impact on communication at each of the time stages in the event, there may be an interaction at any time throughout the event. Note that the interaction of psychological capacity is of high importance in determining the ability to perceive regardless of how important that ability to perceive is to Communication or Life Safety.

There must be a link between psychological capacity and physical capability [38], in order that plans involving movement can be translated into action. This relates to post-T(action) stages of the event. Prior to action for escape, movement required for

investigation purposes will be dependent on physical capability and its impact on mobility. In turn, the interaction between psychological and physiological capabilities [45] will be potentially important (e.g., sleep as an immobilising state- this may have a crucial effect on time for detection). Once ambiguous cues become apparent there is a potential for interaction - this will be most significant after perception of the fire event, when mental activity is accompanied by physiological changes in the body (preparation).

For the purposes of the Delphi group, building knowledge has been defined as a cognitive map of the building spaces. Use of a cognitive map is influenced by psychological capacity [47]. There can be no impact of the Building Knowledge onto Life Safety until $T_{(detection)}$, and so there will be no interactive effect of Psychological Capacity and Building Knowledge prior to this either. The potential contribution of Location Identification is also influenced [64].

There is no interaction of psychological capacity with general or specific fire safety knowledge that will alter their impact on life safety. However there will be an element of feedback involving Communication and Psychological Capacity that correct or increase Event Knowledge [53]. This is potentially significant after $T_{(detection)}$ (when the person becomes aware of ambiguous information).

Does **Physical Capability** have any potential interaction on other factors in the Life Safety System? Diagram D213.

There is an interaction of physical capability onto the ability to perceive factors [22,24,26,28,30]. Tactile, gustatory, and olfactory factors have been assumed to be physical activities. They may be physiologically related, and in that case the interactions required to model the activity would be between physiological capability and ability to perceive.

There may be a small potential interaction of Physical Capability onto Psychological Capability [34]. It may be that knowledge of a limited personal physical capability will affect the psychological capacity contribution to the planning and re-

planning stages (ie; post-T(perception)).

There is no interaction of physical capability onto physiological capability, the effect will be the other way around. There is also no direct interaction of physical capability onto any knowledge factors - knowledge aspects are influenced by psychological capacity. Physical capability may interact with obstructions [81] to alter the impact on Life Safety, during the latter stages of the event. A weak individual may find an obstruction such as a fire door too much to overcome.

Does **Physiological Capability** have any potential interaction onto the other factors in the Life Safety System? Diagram D214.

This term relates to the functioning of the body. Similarly to the interaction of physical capability onto psychological capacity, physiological capability has a potential interaction on the psychological aspects of planning in the post-T(perception) stages of the event [35]. The effect will be limited.

Physiological capability will have a potential interaction onto physical capability of a large importance in the latter stages of an event involving egress. This is the effect of stamina on the continued ability to perform tasks. During early stages activities such as investigation of ambiguous cues, which rely on a degree of physical capability may also depend on physiological capability. Thus the potential of the interactive effect of physiological capability onto physical capability is high, throughout the event.

Physiological capability does not have any impact on any other factors directly. In conjunction with the effect on physical capability it may have indirect implications for any factors affected by physical capability or mobility (which depends upon it).

Does **Building Knowledge** have a potential interaction onto any other factors in the Life Safety System? Diagram D215.

Building knowledge may have a potential interaction onto Psychological Capacity [32]. There will also be a potential

interaction onto both General [59] and Specific Fire Safety Knowledge [61]. This is because of the high importance of building familiarity in the use of such knowledge. The factors will be closely linked and before the event it is likely an increase in specific fire safety knowledge may increase the building knowledge. The interaction of Building Knowledge onto General Fire Safety Knowledge does not occur until at least $T_{\text{(perception)}}$. The interaction onto Specific Fire Safety Knowledge may occur as early as $T_{\text{(detection)}}$. The step from $T_{\text{(detection)}}$ to $T_{\text{(perception)}}$ may be influenced by Specific Fire Safety Knowledge such as an understanding of the meaning of coded messages, and is modelled using this interaction.

The contribution of Location Identification to Life Safety may be significantly affected by Building Knowledge. Location identification does not become relevant until $T_{\text{(perception)}}$, so there can be no interaction until at least then either.

Does **Event Knowledge** have a potential interaction onto any other factors in the Life Safety System? Diagram D216.

There will be a strong potential interaction with psychological capacity [36]. This influence will be reciprocal, the Event Knowledge giving information to allow the reasoning required for planning and executing escape [36], the experience of which will feedback from Psychological Capacity to Event Knowledge [53].

There will also be a potential (reciprocal) interaction of event knowledge and Location Identification [54,66]. A person with knowledge about the event (e.g., fire location) may benefit more from information for Location Identification.

Similarly, Route Choice Identification may have more significance for someone with the relevant Event Knowledge [71]. This can be modelled by the interactive links between event knowledge and route choice identification [55,71].

There will be a potential interaction onto Choice of Alternative Routes during the $T_{\text{(perception)}}$ - $T_{\text{(safety)}}$ stages. Event knowledge on usability of route [87,56], or instructions on route usage may alter the importance of the options available.

Do the factors **General and Specific Fire Safety Knowledge** have any potential interaction onto other factors in the Life Safety model? Diagrams D217,D218.

The factors general and specific fire safety knowledge are similar enough in context to be considered together. Differences in relevance are noted. One of the elements of Specific Fire Safety Knowledge is the ability to interpret information presented in a way which the ordinary person would be inequipped to interpret. An example may be the use of coded messages.

Without the link between Specific Fire Safety Knowledge and Psychological Capacity the message may not be interpreted as significant [33]. Specific Fire Safety Knowledge allows correct interpretation.

There will be a potential interaction of General and Specific Fire Safety Knowledge onto Event Knowledge [52,51]. The interaction of Specific Fire Safety Knowledge could occur earlier and potential importance will be greater.

The two types of fire safety knowledge will complement each other. It is unlikely that someone with a Specific Knowledge will not have a General Knowledge, although the same cannot be said of the reverse. The use of Specific Knowledge could potentially be enhanced by this General Knowledge [62] and so an interaction may occur.

Location identification could potentially be altered significantly in its contribution to life safety by the interaction of both General and Specific Fire Safety Knowledge [67,68]. Similarly, General and Specific Fire Safety Knowledge is likely to improve the contribution of Route Choice Identification [72,73] and Choice of Alternative Routes [88,89] to Life Safety.

There are potential interactions between both General and Specific Fire Safety Knowledge and Fire Suppression [214,215].

The likelihood that people will tackle fires, and that actions will be effective will be improved by training, particularly of a specific nature.

Does the factor **Location Identification** have any potential

interaction onto other factors in the Life Safety model? Diagram D219.

There is a very strong potential interaction onto Building Knowledge [48]. The effectiveness of the use of an individuals cognitive map for escape depends on any identification of the location as a reference point about which plans for the movement for escape can be made.

There will be a potential effect of Location Identification on Event Knowledge [54].

There is no link of Location Identification onto General or Specific Fire Safety Knowledge, it is the reverse [67,68]. There will however be a potential interaction onto Route Choice Identification [74]. Although in an acceptable situation it would be expected that the contribution of Route Choice Identification would be sufficient, there exists the potential in real use for Location Identification to increase the understanding and acceptability of the Route Choice information, and this is modelled by an interaction of medium value occurring after $T(\text{perception})$. In addition, the potential impact of the Choice of Alternative Routes on Life Safety may be enhanced by knowledge of the location [90].

There may be a link between Location Identification and Operating Philosophy [150]. Operating decisions on variable air handling systems for the control of smoke spread will; require location identification.

Does **Route Choice Identification** have any potential interaction on other factors in the Life Safety System? Diagram D220.

The interactions of Route Choice Identification will of a similar context as those of location identification. There will be a potential interaction onto the existence of visual information [7].

Ease of route identification may make building knowledge more useful to life safety, this is modelled by an interaction onto Building Knowledge [49]. Event Knowledge may be enhanced significantly [55].

There will be a potentially strong link between the Identification of Route Choice Alternatives [91]. This is an important relationship. If alternatives can be identified the value to life safety may be enhanced considerably.

Do **Obstructions** have any potential interactions onto other factors in the Life Safety System? Diagram D221.

The factor Obstructions may interact with Mobility [165]. An Obstruction of duration longer than the event (e.g., a locked fire door), or of temporary duration will have a potentially detrimental effect on the usability of the routes, and this may also affect the contribution Mobility can make. The effect will be contextual, and is modelled by an interaction.

An Obstruction will potentially contribute to Event Knowledge [56]. Additionally, the impact of Route Choice Identification and particularly the Choice of Alternative Routes on life safety may be significantly altered by an interaction of Obstructions [75,92].

Width of Route is an obvious case for interaction of Obstructions [99], and the contribution of Length may be affected also [103] (generally less important).

Does the factor **Choice of Alternative Routes** have any potential interactions onto other factors in the Life Safety System? Diagram D222.

This may interact onto the contribution of Obstructions [79]. If there is an alternative route, the significance of an obstruction on the first may be reduced. This will be relevant only after $T(\text{perception})$.

Further, the significance of Choice of Alternative Routes may have an interaction on to the contribution of Exit Route Capacity [172]. Although in real scenarios the Choice of Alternative Routes may not always imply sufficient capacity (the design adequacy or otherwise may be modified by occupant load), in the acceptable situation the relationship relies on this and models an improved serviceability of the acceptable route.

Does the factor **Width of Route** have any potential interaction onto any other factors in the Life Safety System? Diagram D223.

There will be a potential interaction on to the factor Mobility [168]. Width restrictions will be contextual: an able bodied person may require less width for travel than a person with prosthetics. The availability of sufficient width for the person who's mobility requires it may be modelled as an enhancement of the contribution of Mobility to Life Safety. The balance is redressed. This relationship applies in general.

Width of Route will also have a potential interaction on Obstructions [82]. The relevance of a partial obstruction will depend on the width available (hence a reciprocal relationship - [99]). There is no potential impact of Width of Route on Life Safety until $T_{(action)}$, thus there can be no potential interaction until then either.

If escape is being considered from the space of origin of the fire, as may be the case with a shopping mall or atrium, there may be an interaction of width of route on to the sub-factors of smoke movement and control concerned with building spaces. Breadth of Route (smoke control by dilution model) may be affected by the influence of width of route. Breadth (smoke control by containment model) will also be affected as will Breadth (smoke control by removal model) [149]. Note that the interaction may have an influence on Life Safety before $T_{(action)}$. It may be from $T_{(ignition)}$ unless the smoke control system requires activation.

Volume and Design of Space (a Smoke Movement factor) may be affected for both wind and mechanically induced flow [138].

Does the factor **Length of Route** have any potential interaction onto any other factors in the Life Safety System? Diagram D224.

There will be a potential interaction on to the Physiological Capability [46] of the individual. The actual significance of the interaction of Length of Route on stamina (Physiological Capability) will depend on the individual concerned and the

effective length/difficulty of the route.

The significance of an obstruction may be increased if a great length has been travelled; the length of travel may be an obstacle in itself [83]. This is not a simple interaction and in reality will depend on the relationships between physical capability, physiological capability, and distance travelled (including the effective difficulty of that distance).

In a similar way to width of route, there will be an interaction of the factor Length of Route onto the Volume of Space and Design (Smoke movement and control) [139].

All these interactions are restricted to after $T_{(Action)}$.

Does the factor **Rate of Heat Release** have a potential interaction onto any other factors in the Life Safety System? Diagram 225.

The impact of Existence of Tactile Information on Life Safety may be influenced by the Rate of Heat Release (in the zone of origin only probably), so there will be an interaction effect [8]. The potential is high. In any space other than the origin of the fire (or a space that the fire has spread to) the potential value will be low. This interaction may exist at $T_{(ignition)}$ and for all subsequent times.

There may be a link between Rate of Heat Release and Physical Capability as excessive heat causes injury (see Victoria Nurses Home) [40]. This is a potentially critical interaction, which may result in serious injury or death. The interactive link for this reason is given a value of 10 (maximum).

Heat exhaustion or injury to lungs can incapacitate even if the rate of heat release is not sufficient to cause significant physical injury. This is because heat exhaustion is a cumulative effect. There will be a relationship between activity level and exhaustion which should be taken into account in a model at greater depth. The potential interaction of Rate of Heat Release on Physiological Capability could cause death. Again a potential value of 10 (maximum) [42].

Where the intensity of heat is such as to create a barrier to use of a route, this may be modelled again by an interaction. The interaction onto Obstructions [84] may be significant, but will

not be relevant until $T_{(action)}$ when people try to use the routes. Similarly, the contribution of Choice of Available Routes may be influenced by Rate of Heat Release [93]: routes become unusable because of heat and limit the choice.

There will be a potential interaction on to the factor Mode of Burning [119]. Whether the Mode of Burning of a fuel is flaming or smouldering depends in part on the available heat source for ignition/pre-heating. Pre-heating will depend on the Rate of Heat Release.

For the purposes of the Delphi discussions the factor Fire Temperature is related to Rate of Heat Release in a very strong manner [128]. This is reflected by a potential interaction value of 10 (maximum). The contribution of the Nature of Smoke is influenced by the Rate of Heat Release [141]. The buoyancy of the smoke depends on the amount of heat in the smoke.

There will be a potential interaction on to the factor Flame Spread Characteristics [152]. Note that the flame spread characteristics of a material itself may not be altered, it is the contribution of the Rate of Heat Release that alters its contribution to life safety.

The significance of Fuel Supply and Distribution to Life Safety may be influenced by Rate of Heat Release (a separation effect) [203]. Close distribution of fuel is more likely to allow spread of flame because of higher radiant heat levels for fuel ignition. There are implications for Compartmentation also [158].

Does the factor **Fuel Geometry and Orientation** have an potential interaction with any of the other factors in the Life Safety System? Diagram D226.

The contribution of Mode of Burning to Life Safety may be influenced by the Geometry (vertical or horizontal) of the surface [121].

To a small extent there may be an interaction between Fuel Geometry and Orientation and Fuel Supply and Distribution, reflecting the distribution [204].

Does the factor **Ignition Source** have any potential interaction on

any other factors in the Life Safety System? Diagram D227.

In the early stages of the event there will be a close link between Rate of Heat Release and Ignition Source [108]. The Ignition Source performs a similar function to Heat Release in pre-heating, and this is reflected by the potential interaction of Ignition Source onto Rate of Heat Release.

Does **Bulk Density** have any potential interactions with the other factors in the Life Safety System? Diagram D228.

There will be an interaction onto the factor Rate of Heat Release [109]. Dense material burns and releases heat differently to less dense material. The Bulk Density of a fuel will affect the Ease of Ignition. The Mode of Burning is related to the Bulk Density, and so may be affected by an interaction [120].

Does the factor **Oxygen Supply** have any potential interactions onto other factors in the Life Safety System? Diagram D229.

The Oxygen Supply will influence the nature of the fire, in terms of the Mode of Burning [329], and the effect of Type of Material on Smoke Yield [330]. There are potential consequences for occupants also (hypoxia) [328].

Does the factor **Mode of Burning** have any potential interactions onto other factors in the Life Safety System? Diagram D230.

Mode of Burning is related to the Rate of Heat Release [110]. If the Mode of Burning is smouldering, then the Flame Spread Characteristics of the fuel will contribute less to life safety (this is a reciprocal relationship) [153,122].

Does the factor **Type of Material** have any potential interactions onto any other factors in the Life Safety System? Diagram D231.

In a similar manner to Mode of Burning there may be interactions to represent a link between Type of Material and Rate of Heat

Release [111], and Flame Spread Characteristics [154].

Does the factor **Internal Temperature** have any potential interactions onto any other factors in the Life Safety System? Diagram D232.

There may be an interaction between the factors Internal Temperature and Existence of Tactile Information [9]. Perception of temperature changes is easier than perception of temperature itself. Nevertheless, a reference temperature will be necessary for comparison.

The motivating force of differential temperatures across leakages will be affected by the internal (as well as the external) temperature. This may be modelled by an interaction of internal temperature onto internal and external leakages [135,132].

Does the factor **External Temperature** have any potential interactions onto any other factors in the Life Safety System? Diagram D233.

External Temperature will interact onto and alter the impact of Internal and External Leakages [133,136].

Does the factor **Height** have any potential interactions onto any other factors in the Life Safety system?

The factor height is discrete and has no interactivity with system to tertiary level.

Does the factor **Fire Temperature** have any potential interactions onto any other factors in the Life Safety System? Diagram D234.

Similarly to Internal Temperature, Fire Temperature may interact to alter the impact of Existence of Tactile Information on to Life Safety [10]. If a comparison of temperature is to be made (or is what is perceived) this will be required. Fire temperature can also alter the contribution of Physiological [43] and Physical Capability [41] on Life Safety by interacting on to

them.

Fire temperature may also interact on to Nature of Smoke, influencing the smoke energy [142].

Does the factor **Ambient Temperature** have any potential interactions onto any other factors in the Life Safety System? Diagram D235.

This and Internal Temperature are common factors; the potential interactions will be similar (existence of Tactile Information [332], Internal [333] and External Leakages [334]).

Does the factor **Air Pressure Developed** have any potential interactions onto any other factors in the Life Safety System? Diagram D236.

Air Pressure Developed by Mechanical or Wind technique will influence the potential contribution of Internal and External Leakage onto Life Safety [137,133].

There may also be an influence on fire spread. This will be by a potential interaction that enhances the impact of Flame Spread Characteristics on Life Safety [155]. Also, the aspect of forced ventilation on fire growth may be significant. This will be modelled by a potential interaction onto the factor Oxygen Supply [116,117].

Does the factor **External Leakage** have any potential interactions onto any other factors in the Life Safety System? Diagram D237.

There will be an interaction of External Leakage onto Fire Stopping (active and passive) [210]. This will depend in actual cases on the scale of leakage that is being considered, and will be reflected by the relationship between the integrity and permeability of the structure. It is unlikely in the duration of the event that the contribution of external leakage will be as significant as internal leakage, but the potential is still there (cf; Summerland (1973)).

Does the factor **Internal Leakage** have any potential interactions onto any other factors in the Life Safety System? Diagram D238.

The same points apply to internal leakage as apply to external leakage. In addition to the interaction of Internal Leakage onto Fire Stopping [211] there will be a relationship of Internal Leakage and External Leakage [132].

Does the factor **Volume of Space and Design** have any potential interactions onto any other factors in the Life Safety System? Diagram D239.

This term relates to the spatial arrangement for air and smoke movement. However, the shape of that space at the level used by people for escape will have an impact on the use for escape. This can be modelled by interactions onto Width [98] and Length of Route [107]. In each case there will be no interaction until at least $T_{(perception)}$, when use of the route is planned.

The impact of Smoke Release on Life Safety may be altered by the Volume and Space of the Design [336]. The interaction to represent this link will be of high importance, and there is potential for it to exist throughout the event.

The Nature of Smoke may be altered by the Design of the Space [144]. Smoke moving up past obstructions may increase in volume, accompanied by an ageing effect. Note how the interaction occurs before $T_{(detection)}$ even for systems requiring activation, since the activation itself may in some way depend on the nature of the smoke.

The design of the space may affect the impact of Fuel Supply and Distribution on Life Safety by interacting on to it [209]. This interaction will be of medium import.

Now consider the sub-factors of smoke control. There will be a degree of overlap, and this may be reflected in similarity of factors. Also, the values of interactions of similar factors onto any given factor are expected to be similar also.

Does the factor **Smoke Mass Flow Rate** have any potential

interactions onto any other factors in the Life Safety System? Diagram D240.

This will interact with the factors Existence of Visual, Tactile, Olfactory, and Gustatory Information [4,11,15,18]. The potential interactions may occur from T(ignition) and are of high significance.

Location Identification [69], Route Choice Identification [76], and Choice of Alternative Routes [94] are all factors that may be interacted onto by the Smoke Mass Flow Rate. The potential contribution of each to Life Safety will be adversely affected. The potential contribution of the Reservoir Size and Design will be influenced by the Smoke Mass Flow Rate [182]. A small volume with a large Smoke Mass Flow Rate will not impact favourably on Life Safety.

Does the factor **Nature of Smoke** have any potential interactions onto any other factors in the Life Safety System? Diagram D241.

This will interact onto the factor Reservoir Size and Design [183]. This interaction will be of particular import for smoke control by removal (the efficiency of the removal depends on a buoyant layer, which in turn depends on the nature of the smoke), and of lesser import for dilution.

Do the factors **Surroundings, Speed, Direction, and Height** have any potential interactions onto any other factors in the Life Safety System? Diagrams D242,D243,D244,D245.

The factors relate to wind. The wind Direction may express itself on Life Safety through wind pressure. Note that where smoke and/or fire interface with the outer environment, there may be an interaction of wind direction onto the impact of Flame Spread Characteristics on Life Safety [156]. There will be no other interactions.

Do the factors **Internal and External Integrity** have any potential interactions onto any other factors in the Life Safety System?

Diagram D246.

There may be potential interactions onto Compartmentation [159,160], Fuel Supply and Distribution [207,208], and Choice of Alternative Routes [85,86]. A failure of the Integrity of an element may alter the impact on Life Safety of any/all of these factors.

Do the factors **Internal and External Permeability** have any potential interactions onto any other factors in the Life Safety System? Diagram D247.

The factor Permeability may include in its scope doors. The same space factors may be interacted onto as for integrity (Compartmentation [159,160], Fuel Supply and Distribution [207,208], and Choice of Alternative Routes [85,86]).

Does the factor **Air Conditioning** have any potential interactions onto any other factors in the Life Safety System? Diagram D248.

Changes in air conditioning may occur throughout the event. Prior to $T_{(detection)}$ (auto) or $T_{(perception)}$ (manual) stopping of air conditioning is the result of failure or intervention (without any knowledge of a fire). After these times alteration may be by failure or conscious decision. The interaction of any such alterations in the action of air conditioning may affect the Existence of Aural [1] or Tactile Information [12] (a form of ambiguous cue). Flame and smoke movement may also be interacted onto [145,146].

The factor Oxygen Supply may be interacted onto by air conditioning [118].

Does the factor **Heat Gain of Space** have any potential interactions onto any other factors in the Life Safety System? Diagram D249.

The term Heat Gain of Space is similar to the factors Ambient Temperature, and Internal Temperature [127].

Does the factor **Space Shape** have any potential interactions onto any other factors in the Life Safety System? Diagram D250.

This will interact onto ease of use sub-factor Route Choice Identification [78]. The potential impact of the factor Nature of Smoke may be altered by the influence Space Shape has on smoke movement [143]. The factors Ambient Stack and Fire Stack are related to Space Shape for their impact on Life Safety [337,338]. There may also be interactions onto the factors Width [102] and Length of Route [104]. In each case there will be no interaction until at least $T_{(perception)}$, when use of the route is planned.

Do the factors **Length** and **Breadth of Space** have any potential interactions onto any other factors in the Life Safety System? Diagram D251,D252.

The factors Length and Breadth may have similar types of potential interactions. The factors Breadth and Width [342], and Length of Space and Route [340] are similar. This is marked by common interactions.

There will be potential interactions of Length on Fuel Supply and Distribution [339,341], and on Compartmentation (effective separation) [161].

Does the factor **Height of Space** have any potential interactions onto any other factors in the Life Safety System?

This factor is discrete and has no interactions.

Does the factor **Geometry** have any potential interactions onto any other factors in the Life Safety System? Diagram D253.

This is similar to the factor Fuel Geometry and Orientation (a sub-factor of Rate of Burning) [343]. Potential interactions will be the same as for that factor (ie; Mode of Burning [121], Fuel Supply and Distribution [205]).

Does the factor **Flame Spread Characteristics** have any potential

interactions onto any other factors in the Life Safety System?
Diagram D254.

There may be an interaction that alters the impact of Ignition Source on Life Safety [114].

Does the factor **Compartmentation** have any potential interactions onto any other factors in the Life Safety System? Diagram D255.

Compartmentation will interact onto the factors Existence of Aural [2], Visual [5], Tactile [13], Olfactory [16] and Gustatory Information [19]. Remoteness from the fire will result in less direct information being available for reception:- A prime function of compartmentation is to allow safety for escape from the threat of the fire in areas other than the space of origin, such as protected routes. This is modelled as a potential interaction onto the factor Choice of Alternative Routes throughout the latter stages of the event [95].

Secondary factors

Does the factor **Communication** have any potential interactions onto any other factors in the Life Safety System? Diagram D256.

Communication will have a strong interaction onto Psychological Capacity [31]. This interaction may potentially occur throughout the event and is an important link in the assessment and re-assessment of the event; this is required to plan, and replan through a feedback process the escape from the threat.

Further, communication may interact onto Event Knowledge [57], which is updated throughout the event (post $T_{(\text{perception})}$).

General [60] and Specific Fire Safety Knowledge [63] may be enhanced by communication. Communication may assist in Location Identification [70], Route Choice Identification [77], and help minimise the problems of Obstructions [80]. This will occur post $T_{(\text{perception})}$.

Does the factor **Mobility** have any potential interactions onto any

other factors in the Life Safety System? Diagram D200.

During the event, Mobility may interact on to Building Knowledge [50], Event Knowledge [58]. There will also be interactions of Mobility on to Ease of Use [169] in general, and on Width [101] and Length of Route also [105].

Manual Fire Suppression [216] may be quite strongly influenced on to by Mobility.

Does the factor **Training** have any potential interactions onto any other factors in the Life Safety System? Diagram D257.

Training may influence Communication [164] at a general level.

Does the factor **Ease of Use** have any potential interactions onto any other factors in the Life Safety System? Diagram D201.

Ease of Use may interact onto Mobility [166]. The effectiveness of Mobility is contextual, and an easy to use route will enhance the impact of a given Mobility on Life Safety. This interaction will occur post $T_{(action)}$.

There will also be an interaction of Ease of Use on Exit Route Capacity [171] - an easy to use route may have a better handling capacity. This will also be post $T_{(action)}$.

Does the factor **Exit Route Capacity** have any potential interactions onto any other factors in the Life Safety System? Diagram D199.

Exit Route Capacity will affect Mobility [167]. If the route is overloaded then the impact of Mobility on Life Safety may be restricted, to the extent that movement for escape is nil.

Exit route capacity will also interact on the Ease of Use for similar reasons [169]. The blockage of a route by a crowd is an obstruction to each member of that population. See below:-

Does the factor **Rate of Burning** have any potential interactions onto any other factors in the Life Safety System? Diagram D258.

Rate of Burning may influence the Mode of Burning [123]. The impact of the factor Flame Spread Characteristics will also be influenced by the Rate of Burning [157]. There will be implications for the Energy of Smoke [193] and the Volume of Smoke [174].

Does the factor **Smoke Yield** have any potential interactions onto any other factors in the Life Safety System? Diagram D259.

Smoke Yield may influence the capability of people to escape. This is modelled by interactions onto the factors Visual [6], Olfactory [20], Gustatory Information [17], and also Physiological Capability [44]. In addition, the facilities for escape may be affected, Choice of Alternative Routes [96]. The factor Smoke Mass Flow Rate will also be interacted onto by Smoke Yield [140].

Does the factor **Ambient Stack** have any potential interactions onto any other factors in the Life Safety System? Diagram D260.

Ambient Stack does not influence any other factors. Relationships of smoke movement and smoke control are modelled by interactions of other more appropriate factors.

Does the factor **Fire Stack** have any potential interactions onto any other factors in the Life Safety System? Diagram D261.

Fire stack may affect the Energy of the Smoke [194], and the Volume produced [175].

Do the factors **Mechanically and Wind Induced Flow** have any potential interactions onto any other factors in the Life Safety System? Diagrams D262, D263.

Mechanical and Wind Induced Flows affecting smoke movement may potentially interact onto Smoke Control [344, 345, 346, 347]. However, it is normal in an event for Mechanical Induced Flows to be activated for control purposes (or ceased). Dedicated systems

would switch on, and variable systems would alter mode. Air flows and the equipment producing them provide tactile [14] and aural [3] information. Changes to this may provide ambiguous cues.

Does the factor **Volume and Energy of Smoke** have any potential interactions onto any other factors in the Life Safety System? Diagram D264.

Volume and Energy of Smoke occurs for dilution and removal models. There will be an interaction of Volume and Energy of Smoke onto Reservoir Size and Design [181]. If the Volume and Energy of the Smoke is excessive, the reservoir may be inadequate, and the potential impact of the reservoir on life safety would be affected.

The required Air Pressure Developed for Smoke Control by Removal will be influenced by the Volume of Smoke [188], and depth of the layer of smoke to extract, controlled by Reservoir Height [348].

Does the factor **Wind** have any potential interactions onto any other factors in the Life Safety System? Diagram D265.

Wind may create, enhance, or limit the Air Pressure Developed [185]. In each case this is the result of an influencing effect of the Wind, and is modelled by a potential interaction.

Wind acts through leakages to modify the internal environment. This is also modelled by interactions, onto Internal [179] and External Leakage [176].

The secondary factors External and Internal Leakage (Diagrams D266,D267), Ambient Temperature (Diagram D268), Reservoir Size and Design (dilution and removal models) (Diagram D269) were dealt with at tertiary level.

Does the factor **Air Pressure Developed** have any potential interactions onto any other factors in the Life Safety System? Diagram D270.

The Air Pressure Developed for smoke control purposes will interact onto the Volume and Energy of Smoke (Removal model) and the Energy of Smoke (Containment model), controlling it [195]. There will also be potential interactions of Air Pressure Developed onto Reservoir Size and Design (Removal model) [184] and Volume and Design of Space (Containment model) [191].

The design of removal systems must match the Inlet and Exhaust vent areas, and the Air Pressure Developed for an efficient and effective system [197,199].

Does the factor **Volume and Design of Space** have any potential interactions onto any other factors in the Life Safety System? Diagram D271.

The Volume and Design of Space will influence the Width and Length of the Escape Route through that space [98,1078]. Additionally, the Fuel Supply and Distribution [209] and the Smoke Release [351] will be affected. The spatial geometry will affect the Nature of Smoke (e.g., obstacles) [144].

Do the factors **Inlet Area and Exhaust Area** have any potential interactions onto any other factors in the Life Safety System? Diagrams D272,D273.

Inlet Area and Exhaust Area will interact for a balanced system [198,196]. Also each will interact onto Air Pressure Developed [187,352].

Does the factor **Surface Characteristics** have any potential interactions onto any other factors in the Life Safety System? Diagram D274.

Surface Characteristics will interact onto Rate and mode of Burning [173,124].

The effectiveness of Active and Passive Fire Stopping techniques, and Fire Suppression measures will be influenced by the Characteristics of the burning fuel [212,213].

Does the factor **Fuel Supply and Distribution** have any potential interactions onto any other factors in the Life Safety System? Diagram D275.

The Fuel Supply and Distribution will influence the nature of a fire growth, this is modelled by interactions onto Fuel Geometry and Orientation [113], Geometry [151], and Compartmentation [162].

Do the factors **Active and Passive Fire Stopping** have any potential interactions onto any other factors in the Life Safety System? Diagram D276,D277.

The factors Fire Stopping (Active and Passive) are intended to control the spread of fire. This may be done by influencing Supply and Distribution of available Fuel [201,202]. A practical method of limitation is Compartmentation [163].

Does the factor **Fire Suppression** have any potential interactions onto any other factors in the Life Safety System? Diagram D278.

Fire Suppression, depending on the technique employed, may interact onto Oxygen Supply [115], the Ignition Source [353], or the Rate of Heat Release of a developed fire [112].

Primary factors

Does the factor **Mode of Escape** have any potential interactions onto any other factors in the Life Safety System? Diagram D279.

After the perception of a threat, the ability of a person to effect their escape will alter the impact any given Route Layout has on Life Safety. Mode of Escape is modelled as interacting onto the factor Escape Route Layout [222].

Does the factor **Escape Route Layout** have any potential interactions onto any other factors in the Life Safety System? Diagram D280.

Escape Route Layout is an influential factor in the Life Safety System. It will influence the effectiveness of Mode of Escape [217], the Movement [227] and Control of Smoke [230], and the Spread of Fire [233].

Does the factor **Smoke Release** have any potential interactions onto any other factors in the Life Safety System? Diagram D281.

Smoke Release will interact onto Mode of Escape (affecting the occupant capability) [218], Smoke Movement [228] and Control [231], and Fire Spread [234].

Does the factor **Smoke Movement** have any potential interactions onto any other factors in the Life Safety System? Diagram D282.

Smoke Movement will influence the potential contribution of the Escape Route Layout [223], the Spread of Fire [235] and the effectiveness of Control techniques [232]. In addition it may influence the capability of the occupants to escape [219].

Does the factor **Smoke Control** have any potential interactions onto any other factors in the Life Safety System? Diagram D283.

Smoke Control will interact onto a number of factors to maintain safety: Mode of Escape [220] and Escape Route Layout [224], Smoke Movement [229], and Fire Spread [236].

Does the factor **Fire Spread** have any potential interactions onto any other factors in the Life Safety System? Diagram D284.

Fire Spread will interact onto Mode of Escape [221], Escape Route Layout [225], and Smoke Release [226].

(8) Derivation of interaction matrices

Following the development of an agreed set of potential interactions, and agreed potential values to represent the interactions, a set of tables were drawn up as a summary tool. These were termed "Interactivity Matrices".

Tables to represent interactions between factors at each level of the hierarchy, for each smoke control technique, and for each of the time stages were created (45 total). Diagrams D285-D289 are examples of matrices for the secondary level factors included in the smoke control by containment model for the five time stages. The values (expressed as a decimal) in the tables correspond to the potential interactions of the factors in the vertical column onto the factors across the top of the table.

Taking Exit Route Capacity as an example: Note it has no potential interactions in the first three time stages, and in time stages 4 and 5 there are potential interactions onto the factors Mobility and Ease of Use (value 1.00). Compare diagrams D197, D198, D199.

(The potential interactions of Ease of Use and Choice of Alternative Routes onto Exit Route Capacity can also be drawn off the matrices; by checking the column headed by the term Exit Route Capacity.)

(9) Manipulation technique for derivation of 'Modified Impact'
Values

The qualitative and quantitative interactions identified so far were approved by the Delphi group, following discussion in depth. Following this, the presentation of the values was reformatted to produce another series of standard sheets; illustrating the factors interacting onto a subject factor. A complete set of new standard sheets was produced for each smoke control model (275 total). The reason for this reformatting exercise was to simplify the calculation of the modified impact value of each factor, which depend on the original impact value and the factors interacting onto it.

Diagram D290 is a copy of the new standard sheet for Exit Route Capacity. It illustrates the factors identified and agreed as interacting onto Exit Route Capacity (ie; Ease of Use [171] and Choice of Alternative Routes [172]).

(Note that Ease of Use is a two-way interaction, and so appears on as a factor interacting onto Exit Route Capacity (diagram 456) [171] and interacted onto by Exit Route Capacity [169](refer diagram D291). Compare with diagram D199.

In contrast to the earlier standard sheets (e.g., diagram D198) this new sheet does not illustrate the factors Exit Route Capacity interacts onto (ie; Mobility [167] and Ease of Use [169]). This information is to be found on the new standard sheets for Mobility and Ease of Use respectively. See diagrams D292, D293.

The information recorded in the set of diagrams accompanying section (7) (e.g., diagram D199) provides the raw data necessary for the calculation of the 'Modified Impact Values' for each of the factors in each of the models, and for each time stage.

In turn the modified impact values will be used to calculate the

potential relative contributions of the factors to Life Safety.

The calculation of the 'Modified Impact Value' was done using a manipulative formula presented to the Delphi group (and agreed upon). See diagram D294. This was developed after studying the manipulative formulae used for a points scheme developed for hospital wards (Edinburgh, 1979)(325) (The formulae were used to manipulative considerably less relationships, of a different nature).

The scale of the calculation exercise was vast, and since it was felt that the objective of the research exercise was to establish the potential workability of a systems evaluation tool, rather than to identify the most suitable manipulative formulae at this stage, only one formula was used. There were time limitations also.

It was felt that if the formula produced results that appeared reasonable; and if these results could be interpreted by a user to produce meaningful and representative conclusions; on a repeatable basis; then the formula met the necessary current criteria for testing the potential workability of the model (A view is supported by Sugawara (326).

Diagram D290 is an example sheet for the calculation of the modified impact value for the factor Exit Route Capacity.

Note in stages 1 and 2 there is no potential impact of Exit Route Capacity onto Escape Route Layout. The modified impact value is nil also.

There is a potential impact in stage 3, but because the Exit Route Capacity is not being used yet (stage 3 is a planning stage prior to action for escape), and the extent of its contribution is in helping plan escape tactics, it was agreed by the Delphi group that there should be no potential interactions during this stage. Hence the original impact value (0.80) carries forward.

In stages 4 and 5 there are potential interactions of the factors Ease of Use (0.80) [171] and Choice of Alternative Routes (0.60) [172] onto Exit Route Capacity, which modify its potential contribution to Escape Route Layout (and thus Life Safety).

Each interacting factor makes a partial contribution to the modified impact value. Each partial contribution is calculated separately.

First, the potential impact values of the subject factor and the factor interacting onto it are averaged. This acts as a buffer against any unrepresentative distortion of values by a very strong factor interacting onto a weak factor (or vice versa).

Next, this is multiplied by the value of the interaction. Hence a powerful interaction has a more marked effect than a weak interaction.

This is repeated for each interacting factor.

These (partial) values are then summed and divided by the number of interactions occurring (in this case, two). Adding this value (0.60) to the original impact value (0.90) produces the modified impact value (1.50). The modification represents an enhancement of the potential contribution to Escape Route Layout (and Life Safety).

In this manner sets of modified impact values were derived for all the factors in each smoke control model, and for each time stage. These were tabulated, and are presented in diagrams D295 (primary level to objective modified impacts); D296-D298 (secondary level to primary level modified impacts); and D299-D301 (tertiary level to secondary level modified impacts).

(Note that the primary level factor smoke control does not distinguish between techniques, and so these values are common to each smoke control model).

(10) Derivation of matrices for modified impacts

Based on the tabulated modified impact values derived using the manipulative formula, and presented to the Delphi group for discussion, a set of tables were drawn up as a summary tool. These made access to the information clearer, and were termed 'Modified Impact Matrices'. Tables to represent factors at each level of the hierarchy, for each smoke control technique, and for each of the time stages were created (45 total).

To save space, only the vectors for the secondary level factors included in the smoke control by containment model, for the five time stages, are presented. See diagrams D294, D302-D305. Taking Exit Route Capacity as an example: Note there is no potential modified impact in stages 1 and 2, a potential modified impact of 0.80 in stage 3, and potential modified impacts of 1.50 in stages 4 and 5.

(11) Derivation of 'Relative Contributions' for each level

It was necessary for evaluation purposes that the relationship of each factor to the objective was established. This was straightforward with the primary level factors (which impact onto the objective); however, the modified impact values for the secondary and tertiary level factors represented the potential value of relationships to other factors in the hierarchy, rather than the objective.

The next step developed these modified impact values for the secondary and tertiary level factors into values directly representing their potential contribution to Life Safety.

The modified impact values were currently expressed in sets of matrices, representing:

- (1) Tertiary to Secondary modified impact values.
- (2) Secondary to Primary modified impact values.
- (3) Primary to Objective modified impact values.

Refer diagrams D294, D302-D305.

The interaction matrices represented the following relationships:

- (1) Tertiary onto Tertiary.
- (2) Secondary onto Secondary.
- (3) Primary onto Primary.

For example, diagrams D285-D289 (secondary level).

To derive a set of values for the modified impact values of the secondary and tertiary level factors to the Objective, it was necessary to carry out some matrix multiplication. See diagram D306.

If the vector representing the modified impact values of the

primary level factors on Life Safety was multiplied by the matrix representing the modified impacts of the secondary factors on the primary factors, the result would be a vector representing the modified impacts of the secondary factors to Life Safety. Diagrams D484-D488 tabulate the matrix multiplication to derive the modified impact values of the secondary level factors to the objective, for each of the time stages (smoke control by containment). Note no modified impact of Exit Route Capacity during time stages 1 and 2.

Multiplying this new vector by the matrix representing the modified impact values of the tertiary level factors on the secondary factors would produce a vector representing the modified impact values of the tertiary level factors to Life Safety. Diagram D312 is an example for the smoke control by dilution model.

Following the derivation of sets of values for the modified impacts of factors to Life Safety at the different hierarchical levels, it was necessary to derive relative potential contributions and rank these. This would give the relative potential contributions of factors to Life Safety in the different smoke control scenarios, and for the different time stages in events.

To derive these values, the modified impact vectors for the primary, secondary, and tertiary level factors were summed and expressed as a proportion of 1.0000. Diagram D313 presents these values for the secondary factors in the smoke control by containment model.

The factors were then put into order on the basis of the magnitude of the scale of potential contribution, allowing simple identification of the relative importance of each factor. This is expressed in tabular form, in the following diagrams:

D314-D318 (primary: all models)
D319-D323 (secondary: dilution)
D324-D328 (tertiary: dilution)

D329-D333 (secondary:containment)
D334-D338 (tertiary: containment)
D339-D343 (secondary: removal)
D344-D348 (tertiary: removal)

These new sets of values would allow evaluations to be done using any hierarchical level of the model, depending on the level of complexity and representivity required.

The hierarchical nature of the model led to each factor at any given level being determined by a group of factors at the adjacent lower level. This was a fundamental assumption. For example, Escape Route Layout is determined by Ease of Use and Exit Route Capacity. In turn, Exit Route Capacity is determined by Width and Length of Route. See diagram D349.

The values developed for the factors in the Life Safety System gave information about the relative potential contributions of factors in any given level of the hierarchy to Life Safety, and the time stages when potential contributions occur. It was also practical to analyse which factor in any group was potentially the most important. This is potentially useful when analysing a particular aspect of the Life Safety System. This information was gathered to produce a final set of tables of values developed using the Delphi group process. See diagrams D350-D372.

A number of observations may be made from considering such tables. For example, diagram D362:

Length of Route only makes 75% the potential contribution to Life Safety that Width of Route does.

Each factor determining the Ease of Route Use is of similar, high potential to Life Safety. Choice of Alternative Routes is potentially the most important factor, and with the exception of obstructions, all Ease of Use determinants are potentially more important than the physical dimensions of the route. This appears reasonable, but has implications for some methods of escape route evaluation.

However, there were still limitations in respect of (a) the **nature** of factor contributions to Life Safety (pro-safety or pro-threat) and (b) identification of those factors that were critical to the Life Safety System. These further developmental stages are now discussed.

(12) Listing and Discussion of +/- factors with respect to Life Safety

The wide range of factors identified and included in the model contribute either to the continued safety of occupants or to the imposed threat.

At this stage of the model development, factors were identified as being pro-safety (+) or pro-threat (-).

The nature of many factors is obvious (e.g., obstructions (-), mobility (+)). Some factors may contribute to safety or threat depending on context (e.g.; internal temperature [267,311]). To simplify the model at this stage the ambiguous factors are assumed to follow the implied nature of their contribution. For example, Internal Temperature [267] (a Smoke Movement factor) is assumed to make a negative contribution to Life Safety; Ambient Temperature [311] (a Smoke Control factor) is assumed to make a positive contribution to Life Safety.

Diagram D373 is a listing of the factors in the model, and their assumed contributory nature.

The nature of factors will influence the algebraic representation of factor performance. If a pro-safety (+) factor is assessed as being deficient then the value of the relative contribution to Life Safety will be less than the potential. For example;

<u>Exit Route Capacity</u>	(Smoke Control by Dilution model)
Potential Relative Contribution (Time stage 4)	+ 0.0787
Evaluated Deficiency	50%
Assessed Relative Contribution (Time stage 4)	<u>± 0.0394</u>

Consider a factor that poses a threat to Life Safety, such as Smoke Yield. A low Smoke Yield (relatively good) may be modelled by an actual value similar to the potential contribution value. A high Smoke Yield (not so good) may be modelled by an actual value that is algebraically greater. Hence:

Smoke Yield

Potential Relative Contribution (Time stage 4) - 0.0327
Evaluated Deficiency 50%
Assessed Relative Contribution (Time stage 4) = 0.0490

For each level in each model, and for each time stage, the nature of the potential contributions of the factors may be algebraically summed to give a net safety/threat balance. As a complete reference, see diagrams:

- D374-D378 (primary: all models)
- D379-D383 (secondary: dilution)
- D318-D388 (tertiary: dilution)
- D389-D393 (secondary: containment)
- D394-D398 (tertiary: containment)
- D399-D403 (secondary: removal)
- D404-D408 (tertiary: containment)

To clarify the nature of the potential contributions to Life Safety, the values for each of the factors for each smoke control model, were presented diagrammatically for each time stage. These are reproduced for reference as diagrams D409-D505.

(13) Net safety or threat diagram

The net safety/ threat diagram is a graphical representation of the aggregated contributions of the factors to Life Safety, taking their nature of contribution into account. The potential values indicate the datum line for acceptable overall performance. It may be used to compare evaluated levels against acceptable levels (see appendices 3 and 4). The value gives no indication of the contributions of individual factors, or the consequences of individual failures (not shown up by the aggregated value). See diagrams D506-D508.

(14) The concept of 'Criticality'

The total failure of a critical factor would be sufficient alone to cause the failure of the factor that directly depends on it. The failure of a non-critical factor would not be sufficient alone to cause such a failure.

The following list discusses the criticality of each of the tertiary level factors. The criticality of a factor may have implications for those factors it interacts onto. The potential interactions of such critical factors are listed. Note that implications may not apply for every time stage. This list refers only to the Dilution model.

Factor	Criticality	Implications for...
Existence: Aural	not critical	
Visual	not critical	
Tactile	not critical	
Gustatory	not critical	
Olfactory	not critical	
Perception: Aural	not critical	
Visual	not critical	
Tactile	not critical	
Gustatory	not critical	
Olfactory	not critical	
Psychological capacity	critical	Ability to perceive Physical capability Physiological capability Event knowledge Location identification Building knowledge
Physical capability	critical	Ability to perceive Psychological capacity Obstructions
Physiological capability	critical	Psychological capacity

		Physical capability
Building knowledge	not critical	
Event knowledge	critical	Psychological capacity Location identification Route choice identification Choice of alternative routes
General fire safety kn.	not critical	
Specific fire safety kn.	not critical	
Location identification	not critical	
Route choice identification	not critical	
Obstructions	critical	Mobility Event knowledge Choice of alternative routes Route choice identification Width Length
Choice of alternative routes	critical	Obstructions Exit route capacity
Width of route	critical	Mobility Obstructions Volume of space and design Breadth
Length of route	critical	Physiological capability Obstructions Volume of space and design
Rate of heat release	critical	Existence of information (tactile) Physical capability Physiological capability Obstructions Choice of alternative routes Mode of burning Fire temperature Nature of smoke Flame spread characteristics

		Fuel supply and distribution
		Compartmentation
Fuel geometry and orientation	critical	Mode of burning
		Fuel supply and distribution
Ignition source	critical	Rate of heat release
Bulk density	not critical	
Oxygen supply	critical	Physiological capability
		Mode of burning
		Type of material
Mode of burning	not critical	
Type of material	critical	Rate of heat release
		Flame spread characteristics
Internal temperature (SM)	not critical	
External temperature (SM)	not critical	
Height (SM)	critical	none
Fire temperature	critical	Existence of information (tactile)
		Physical capability
		Physiological capability
		Nature of smoke
Ambient temperature	not critical	
Air pressure developed (wind)	critical	Internal leakage
		External leakage
		Flame spread characteristics
		Oxygen supply
External leakage (wind)	critical	Fire stopping
Internal leakage (wind)	critical	Fire stopping
		External leakage
Volume of space and design (wind)	critical	Rate of burning
		Width
		Length
		Smoke release
		Nature of smoke
		Fuel supply and distribution
Smoke mass flow rate	critical	Existence of information

		(all except aural)
		Location identification
		Route choice identification
		Choice of alternative routes
		Reservoir size and design
Nature of smoke	critical	Reservoir size and design
Surroundings	not critical	
Speed	critical	none
Direction	critical	Flame spread characteristics
Height (of wind)	critical	none
Integrity (external)	critical	Compartmentation Fuel supply and distribution Choice of alternative routes
Permeability (external)	critical	
Integrity (internal)	critical	Compartmentation Fuel supply and distribution Choice of alternative routes
Permeability (internal)	critical	
Air conditioning	not critical	
Heat gain of space	critical	Internal temperature
Space shape	not critical	
Height of space	critical	none
Length of space	not critical	
Breadth of space	not critical	
Geometry	critical	Fuel geometry and orientation Mode of burning Fuel supply and distribution
Flame spread characteristics	critical	Ignition source Mode of burning
Compartmentation	critical	Existence of information (all types) Choice of alternative routes

(15) Discussion of factors

The following section discusses the potential relative contributions of some of the key tertiary factors. The secondary and primary level factors are dealt with in the discussion to the thesis.

Ranking the factors gives additional useful information, since there is a trend for the value of the relative contributions to drop throughout the event as more factors become potentially involved.

A large number of factors reduce in rank as the event progresses, many as a result of the occupants travelling away from the fire and smoke threat origin (a consequence of a single space model).

The phrase "basket" is used to refer to a group of factors which are all determinants of the same higher factor. For example width and length of route are the determinants of exit route capacity, and form a basket of factors.

Existence of Information

Consistently throughout the event, and for each of the three containment techniques, the existence of aural information was the third most important of the existence factors.

The trends for each of the "existence of information" factors is similar: time stage 1 is the least important with respect to Life Safety. Information is likely to be ambiguous.

The available information for making the step from detection to perception is of great potential importance. The potential contribution drops off throughout the event, as the reliance on dynamic information decreases. There is a continued relevance of information. The factors are not individually critical, however a failure of all sources of information is deemed to be critical.

Existence of Aural Information (not critical):- This factor is the third most important factor in the group of existence

factors. In the second stage it ranks high (7th/ 8th). Initially it is of medium potential importance, and the ranking drops towards this at the end of the event. Diagram D442.

Existence of Visual Information (not critical):- This is consistently the most important source of information. In the stages of the event following detection, it increases to a maximum during the step to perception, then dropping slightly (to 4th followed by 5th ranking) in the final stages of the event. Diagram D443.

Existence of Tactile Information (not critical):- This factor makes a medium/ low potential contribution to Life Safety compared with information available for the more commonly used senses. Diagram D444.

Existence of Gustatory Information (not critical):- Consistently throughout the event this is the least important factor in the basket of existence of information factors. It is a dynamic factor with a beneficial contribution to Life Safety. It is not critical in isolation. The potential contribution of this factor follows the same trend as for the other existence of information factors (see aural). It is unlikely that this will occur in isolation from olfactory information. Diagram D445.

Existence of Olfactory Information (not critical):- This factor is consistently and for each smoke control technique the second most important information source. Individually it is not critical. It is closely allied to Gustatory Information. Its ranking is at a maximum in the second stage (the step from detection to perception), dropping away throughout the event (retaining a medium ranking potential contribution). Diagram D446.

Perception of Information (not critical):- The means of perceiving information range in potential importance. Most important is visual perception (occupying the top place in the tertiary level in stages 2 and 3 and second place in stages 4 and

5). Additionally, aural and olfactory perception make high ranking potential contributions throughout the event. Gustatory is of low potential, tactile is of greater potential, particularly in the stages following perception (as with all the perception factors). Diagrams D447-D451.

Psychological Capacity (critical):- This factor is modelled as the least important mobility sub-factor. It rises throughout the event in potential importance, but only reaches a high/ medium value. It is critical to Life Safety, particularly in the stages following perception, when planning and use of the building requires alertness and manipulation of knowledge. Diagram D452.

Physical and Physiological Capability (critical):- This factor interchanges with physiological capability of the most important mobility sub-factor. In the early stages of the event the potential contribution is only of medium import. The potential of the factors rises dramatically following perception, to occupy 3rd ranking in the tertiary level as planning, and particularly movement for escape place a heavy requirement on individual capability and stamina. Diagrams D453,D454.

Building Knowledge (not critical):- In time stage 1, there is no potential contribution of Building Knowledge to Life Safety. The potential contribution in time stage 2 is the most important stage (investigation and interpretation of information). The ranking for the remaining time stages drops slightly (to 38th/40th) but remains a medium level. The factor is the third in the basket in stages 3, 4 and 5. In stage 2 it is second to Specific Fire Safety Knowledge (the only factors in the basket making a potential contribution). Diagram D455.

Event Knowledge (critical):- This factor has no potential contribution until time stage 3. Until perception occurs, which marks the end of time stage 2, there can be no event knowledge. However it is then the second most important factor in the basket (General Fire Safety Knowledge makes the highest potential

contribution). Event Knowledge is particularly important in time stage 3 (for planning), and this reflects the significance of full information. The ranking in the tertiary level is only of medium importance. As the event progresses the requirement for further event knowledge will decrease slightly (less information required for travel on protected routes or waiting in refuges). Refer diagram D456.

General Fire Safety Knowledge (not critical):- This factor has no potential contribution until stage 3. Then it is the most important in the basket of training sub-factors, indicating the importance of general knowledge compared with specific training, building knowledge, and even event knowledge, but is not critical. It has a medium ranking in the tier. The knowledge is static (gained prior to the event). Diagram D457.

Specific Fire Safety Knowledge (not critical):- This factor is of maximum importance in the second stage of the event (for early perception of ambiguous cues following detection). There is no potential contribution in the first stage. As the decisions required in the event become more conventional the potential contribution decreases (from medium to medium/ low). Diagram D458.

Location and Route Choice Identification (not critical):- There is no potential contribution in the first two time stages. In the third time stage it makes a high ranking potential contribution, as planning for escape requires information of starting location. In the final two stages it is at its most important (6th/7th/6th), particularly for occupants with no knowledge of the building. The factor is not critical, since it is possible for a person to escape using available route choice identification information.

Route Choice Identification makes a similar potential to Location Identification throughout the event, but ranks just higher. This factor is also not-critical. Diagrams D459, D460.

Obstructions (critical):- This is the least potentially important

Ease of Use sub-factor, however it is potentially critical to Life Safety, particularly in the latter stages when it makes its largest potential contribution (ranking 11th). Diagrams D461.

Choice of Alternative Routes (critical):- This is the most important factor in the basket of Ease of Use factors, and in the latter stages of the event is the most important factor in the tertiary level (underlining the importance of keeping routes available and unlocked). Diagram D462.

Width of Route, Length of Route (critical):- These two factors are associated with the Exit Route Capacity and have no potential contribution until stages 4/5. They are of reasonable potential importance and are both critical. Width of Route is of higher ranking (9th) than Length of Route (16th-18th, medium). Diagrams D463, D464.

Rate of Heat Release (critical):- There is a reduction in the potential relative contribution of this factor as the event progresses, as the number of pro-safety factors involved in the event respond (following the detection/ perception lag). The ranking and potential contribution is similar for each model, starting as a high ranking factor, and decreasing to medium importance. Diagram D465.

Fuel Geometry and Orientation (critical):- The potential contribution of this factor decreases through the event from initially high ranking to a medium level. It is one of the least important factors in the basket of Rate of Burning sub-factors (4th of 5 factors). Diagram D466.

Ignition Source (critical):- At the March 1986 Delphi meeting it was decided to limit the potential contribution of Ignition Source to the first stage. During this stage ignition source is one of the highest ranking factors (5th) although it is third most important in the basket, emphasising the importance of smoke release related factors in early stages. Diagram D467.

Bulk Density (not critical):- The ranking of Bulk Density declines within the level as a whole throughout the event (starting at medium high and becoming medium), although the relative importance within the basket of rate of burning sub-factors is constant. Diagram D468.

Oxygen Supply (critical):- Oxygen supply is critical to the growth of a fire and the nature of smoke released. The value of this factor is high in the early stages (3rd/ 4th in stage 1). As the event progresses the potential contribution to life Safety (via smoke release) decreases to a high medium level. Diagram D469.

Mode of Burning (not critical):- The factor decreases in relative potential contribution as the event progresses, but ranking medium throughout. It is more important to smoke yield than the type of material. Diagram D470.

Type of Material (critical):- This factor is the less important of the smoke yield sub-factors. The potential contribution decreases throughout the event (starting as a medium/ low rank and dropping to low rank by stage 5. Diagram D471.

Internal Temperature (Smoke Movement) (not critical):- This factor is initially very important (ranks 8) for the smoke control by dilution and removal scenarios. It is considerably less important for the containment scenario (less criticality of smoke buoyancy). Following activation of the smoke control systems the position drops (for each model) to a medium/ low ranking. Diagram D472.

External Temperature (Smoke Movement) (not critical):- The comments for this are similar to Internal Temperature, however there is no control over External Temperature. Maintaining a balance between the two temperatures will be difficult and related to the nature of the building. The factor is of lower potential contribution than Height (third factor in the basket of ambient stack sub-factors). See diagram D473.

Height (Ambient Stack) (critical):- This factor is generally of low potential contribution to Life Safety at all stages of the event. The contribution is just greater than external temperature, making it the second factor in the basket. Diagram D474.

Fire Temperature (critical):- This is the more important of the two fire stack sub-factors. It relates to the plume production effect of the fire. For each of the smoke control models there is a decay in relative importance with time stages. In each case it is more important than Ambient Temperature. Diagram D475.

External Leakage (Smoke Movement, Wind and Mechanically-Induced Flow) (critical):- There are differences in the values of the relative contributions of external leakage to a mechanical rather than a wind induced flow. External leakage is of lower potential contribution with mechanically induced flow (the Delphi group considered there was more likelihood of an overpressure with mechanically induced flow). In each case it is a medium ranking factor. Refer diagrams D479,D480.

Internal Leakage (Smoke Movement) (critical):- The potential contributions of the internal and external leakages is similar for the wind induced flow (both medium ranking in the early stages), dropping to medium/low. For mechanically-induced flow, an internally derived pressure, the potential contribution of internal leakage is significantly higher than that of external leakage, reflecting the importance of internal characteristics of a building for internal air flows. Diagrams D481,D482.

Volume of Space and Design (critical):- Similarly to internal leakage this factor is more important for mechanical induction of pressure than wind induction. It tends to be of low potential contribution (ranking 46 - 56), but in containment scenarios it is slightly more important. Diagrams D483,D484.

Smoke Mass Flow Rate (critical):- This factor makes the highest

potential contribution to Life Safety in the first time stage for each model. As control measures are activated the ranking of the factor decreases (control of smoke), but retains a high value. Diagram D485.

Nature of Smoke (critical):- This factor is initially very important. It ranks 2nd for removal and dilution, less for containment (6th) which smoke nature is less critical. The activation of smoke control and progression of the event (escape from the space initially occupied) reduces the ranking and potential contribution, nevertheless it retains a high/ medium ranking for dilution and containment. Diagram D486.

Height, Surroundings, Speed, Direction (Wind) (all critical except surroundings):- These factors are modelled as not having a potential contribution in the removal scenario during the first time stage. This is felt to be a limiting omission compared with the other scenarios, particularly containment for they are assumed to make a potential contribution to passive containment. Direction is the second most important factor in the group except in stage 3 (Removal) where it is first. The factor Speed has a similar relative contribution. The overall contribution is low, and the position within the order reflects this. (about 50 to 60). Diagrams D487-D490.

Internal and External Integrity (critical):- The factors rank highest for the containment scenario (integrity 2nd in tier for stage 1), which relies on internal leakages for effective control. Dilution and removal scenarios are both of high/ medium ranking. In all models permeability makes a lower potential contribution than integrity. Diagrams D491,D493.

Heat Gain of Space (critical):- This factor is important to dilution and removal smoke control techniques. Similar points arise with air conditioning. Diagram D496.

Space Shape (not critical):- The definition of this factor differs for removal (related to the reservoir). The factor is of

a medium/ low importance throughout the event, marginally higher for removal (to maintain a buoyant layer than dilution, and containment being the least important (smoke quality relatively un-important). Diagram D497.

Height of Space/ Reservoir (critical):- This factor is common to each smoke control model, but the context differs. For the containment and dilution models it refers to the height of the space, for the removal model to the depth of the smoke reservoir. The trend is similar to space shape and similar comments apply. Height is a potentially important factor, particularly in the early stages (high ranking in stage 1 for dilution and removal models, less important for containment). In the latter time stages it is replaced by the factors length and breadth of space as the most important factor in this basket. Diagram D498.

Length and Breadth of Space (not critical):- Similar comments apply to each. In the latter stages of the event the potential contribution (and ranking) of these factors decreases. The factors apply to the size of reservoir in the smoke control by removal model, and hold their position better in this model (reflecting the continued importance of reservoir capacity for extraction). Diagrams D499, D500.

Available Power (Smoke Control) (critical):- This factor applies only to smoke control by Containment and Removal and relates specifically to power for air movement for smoke control. In each model, the potential contribution in time stage 1 is nil. - There has been no detection. Time stage 2 is the earliest stage when a potential contribution may occur, although (depending on 'operating philosophy') this may not occur until later in actual case.

During this stage available power is slightly more important than operating philosophy - subsequently it is less important. The order within the level drops from 18/20th to 29/31st throughout stages 2 - 5 in a progressive manner. Diagram D501.

Operating Philosophy (critical):- This factor applies to the

active smoke control systems. It is potentially effective from stage 2 (assuming automatic operation). The potential contribution is of medium potential contribution. During and after stage 3 there may be manual activation or override. The potential contribution of this to Life Safety (in expert hands) is modelled as higher than automatic, and the ranking of the factor rises, particularly with the complex requirements of a containment system. Diagram D502.

Geometry (critical):- This factor applies to fire spread. It is a medium/ low ranking factor and the least important fire spread tertiary factor. Nevertheless it is critical. Diagram D503.

Flame Spread Characteristics (critical):- This factor is potentially the secondmost important within the tertiary level of fire spread factors (behind compartmentation). It is quite close in value to geometry and lies in the medium ranking bracket of the tertiary level. Diagram D504.

Compartmentation (critical):- This factor is potentially important for all stages of the event and for this reason it has a tight band of relative contributions and a shallow decay curve. Diagram D505.

General Comments

The derivation of a set of potential relative contributions requires checking for realism, representation, and repeatability. In using the model a particular scenario can be evaluated in terms of each of the factors in the model.

The user will consider the scenario and subjectively estimate the performance of each of the factors compared with the assumption implicit in acceptable level. For instance; If there is no aural alarm it may be that the user will attribute 100% deficiency to this model - A sounder rather than a tannoy gives ambiguous information of a low content, and so the user may decide that this represents a 20% deficiency compared with its acceptable

value.

It is possible that factors will be super-optimal. For instance, Building Knowledge [250], which represents the familiarity of the occupants with the building layout, may be estimated as being better than acceptable (e.g., in instances where the occupants live in the building). This would be represented by a super-optimal value.

A super optimal value of the factor may indicate to the user that a trade-off is possible against a related factor with a corresponding deficiency. It is important that the trade-off is balanced - The use of priority considerations for factors should allow the implications of the evaluated performance of each factor to be indicated. The complexity of the Life Safety System (reflected by the complexity of the model suggests that trade-offs must be considered systemically.

The interpretation of significance of deficiency, super-optimality, and any trade-off possibilities further limits the interpretation of the model and its usage to relative experts.

A super-optimal value for Building Knowledge [250] may balance up a deficiency in evaluated performance of ease of Location Identification [254], and the user considering such a scenario may consider that some deficiency in Location Identification is acceptable if Building Knowledge is super-optimal. Note however, that Location Identification interacts onto Building Knowledge [48] - the cognitive map is only use useful if you can identify where you are on it (such a problem arose in the Victoria Nurses Home incident - appendix 3).

There is a trend for factors making contributions throughout the event to reduce in the level of their contribution, and in some cases to take lower positions in the order for the level. The reason for this is that as people become aware of the fire and begin to participate so the factors required to potentially model this begin to make a contribution to the model. The greater the number of factors the smaller the average relative contributions

will be (for example the factor Choice of Alternative Routes is not represented until the third time stage, and then becomes the most important factor in the tertiary level in the final stages of the potential event.

As a consequence of this the level in the model of other factors will drop, and as more factors contribute factors below them will have their positions displaced. The high potential of threat factors in the early stages of the event before people are aware or automatic measures to limit the threat are applied, will reflect the high significance of the uncontrolled danger (and reinforces the common observation that the time to alert must be minimised).

In each model the smoke mass flow rate is the most important initial factor. It drops away in potential relative contribution throughout the event - more obviously so in the containment model. Similarly, nature of smoke, another very important factor in the early stages drops away in a markedly greater manner in the containment model. The smoke characteristics are less important when the mode of control is containment (provided the pressure balance is correct - an assumption of the model - all factors that are evaluated for potential are done so for acceptable levels of performance.) In dilution and removal scenarios the potential contribution of the smoke mass flow rate and nature of smoke are more important to the continued control in the space being used.

The energy and volume of smoke (a secondary factor) is the most important of the secondary factors in removal, and is very important throughout the model. It is also the most important to the Dilution model. In the smoke control by containment model this is so in the first (passive) stage. Once the pressurisation system is activated it is modelled as being of lesser potential than the air pressure developed (the control technique is assumed to work).

Appendix 3. Case Study (1) Victoria Nurses' Home.

Appendix 3. Case study (1): Victoria Nurses' Home, Kirkcaldy

This case study is based on information taken from official reports, witness statements, and newspaper cuttings. These formed the only information source available to the author. For this reason much of the description of the event relies heavily on the work of others. The reports used are included as appendix 5. Appendix 6 was made available after the evaluation. The abstraction of the appropriate information, interpretation for modelling purposes, and conclusions on the modelling of the event are the work of the author.

The main reasons for picking Victoria Nurses' Home as a case study were:-

- (1) A number of the members of the Delphi group were either familiar or had been directly involved with the inquiry set up into the event. This would allow a better appraisal of the evaluation tool.
- (2) It was a reasonably well documented incident.
- (3) It was a relatively simple building.
- (4) It gave the opportunity to test the model in assessing an existing building by abstracting the information objectively and then comparing this with the actual event occurrences and outcome.

Introduction

The fire at the Victoria Nurses' Home, Kirkcaldy, occurred on Friday the 13th of November 1981 at about 1 am. It resulted directly in one death, and there were a number of serious injuries caused to nurses who had to jump from their room windows on the fire floor (C floor) to avoid direct injury (rooms 2,3,4,7,8,9,10,12A).

A fatal accident inquiry was set up to investigate the fatality and the rapidity with which the fire spread through the (Crown) property.

The evaluation of the event was kept as objective as possible. Analysis of the scenario, made using the available information, was based just prior to the commencement of the fire. This included aspects of the building performance and the nature of the contribution of the occupants to their Life Safety.

Based on the evaluation of the scenario, a comparison was made of the predicted 'actual' performance, the potential performance, and the records of what actually occurred in the event.

The evaluated deficiencies in the performance of the factors, the influence this had on the overall level of safety, the nature of failure of factors, and their criticality were assessed.

The six storey, 87 bedroom Victoria Nurses' Home was erected in Kirkcaldy in 1959. It is approximately 38m x 11m and is constructed of a reinforced concrete frame with alternate bedroom walls continuous with the structure. Other internal walls are either brick or hollow block and the roof is asphalt. Floors B - F are similar in layout. The fire occurred on C floor. See diagrams A1-A3. There are two stairwells and the walls are plaster- covered with several layers of paint.

The floors of the building are reinforced concrete with hollow tile blocks set in the under-side. Conduit carrying the electrical wiring for the building appeared to be encased within the floor slab. The floor was covered with tiles, probably pvc, and was carpeted. The stairways giving access to the outside are each separated from the corridor by a self closing fire door and screen, this comprising a large area of wired glass. See diagram A4. The bedroom doors did not have self closers and were of a poor fit and poor construction; two leaves of eighth inch ply on framing with an 'eggbox' filling to provide some rigidity. See diagrams A5,A6.

The stud partitions in each of the rooms on C floor (excepting

C14) are timber faced on the window side with a plasterboard facing the door. Between the corridor door wall and the partition there is a wardrobe on the one side and a wash hand basin on the other. Beside this basin is a service duct that runs the height of the building. This juts into the room, and while one side is of brick, the other consists of 6mm ply on timber framing. This was significant in the fire.

There was a common room area on each floor situated at the west end of the corridor. See diagram A7. It is completely open on the corridor side although a rack of shelving and a low cupboard effectively separates the two areas. See diagram A8. There is some furniture comprising a television set, an electric fire and some easy chairs, and coffee tables.

Towards the east end of the corridor there is an alcove to the west of the bathrooms and cleaner's cupboard. See diagram A9. There is also a telephone booth. See diagram A10. There are curtains around the common room and alcove area.

There is nothing to suggest either from witnesses' statements or other notes that there were any other combustibles in the corridor area. The exception is one timber-lined wall in the ground floor lounge and the one side of timber partitions in the bedrooms. The exception to this was room C14 which had no partition and was maybe originally intended as a study room. This was nurse Goodall's room (the fatality).

The ceilings and linings in the bedrooms and one exit stairway were also plastered and covered with paint. The other exit stairway has a ceiling lining of acoustic tiles. The ceilings of the ground floor lounge and the corridors consisted of fibre-boarding, treated on the under-side with a fire retardant. These were fixed to a substantial timber frame so as to form a suspended ceiling with a 230mm deep ceiling cavity. Diagram A11 shows the corridor after the fire.

At the time of the fire the building was occupied by 51 of the 82 residents. As a result of the fire one died, eight were seriously injured when jumping, and twelve others were slightly injured. Seven occupants required rescuing.

Above the fire, most people used the west stairwell, the east

failing. See diagram A12. Below the fire both stairwells were used but the majority used the east.

A number of unusual features were reported about the fire. The time of ignition was not known accurately, but by the time the alarm was raised the fire had grown to such proportions that several of the occupants had to climb out of their windows to avoid injury, and some were compelled to jump for their lives.

The single fatality, nurse Goodall, was found in the corridor on C floor a considerable distance from her room and had appeared to have been caught in a flash fire and quickly perished, rather than succumbing to the toxicity of fire gases.

The alarm was activated at 00.57 on the morning of the 13th November. This was raised by some nurses who had been in the common room on B floor and had become aware of some banging noises coming from above (C floor). They initially assumed this to be some people "larking around" and, misinterpreting the cues, did nothing for a few minutes.

As these noises continued, two nurses decided to investigate. On the way up the west stair one of them said she heard a very loud thump. They discovered the corridor on C floor full of smoke and could only just see the common room area (a short distance from the doorway - refer diagram A3).

There are a series of anomalies in the witnesses statements concerning events preceding the alarm being raised, however, there was be assumed to be approximately five minutes delay between this and first hearing ambiguous cues (see reports, appendix 5). This was a significant amount of lost time to those who then had to escape. Assuming this, the time of ignition was approximately 00.50 to 00.52 (unless there was a smouldering stage of significant duration).

There were also reports from floors above (D) of smelling smoke faintly in the area of the bathroom.

There appeared to be some controversy surrounding the deceased, nurse Goodall. Reports suggest that she was conscious of the risk of a fire in the Nurses' Home and it is puzzling why she didn't raise the alarm. The post mortem result suggests she died as a result of being enveloped in flames and hot gases rather than in by inhalation of toxic gases. She was a heavy smoker,

and the blood carbon monoxide level of 11% is not very much more than could be expected normally. Either she was totally unaware of any danger and just happened to be on her way to or from the toilet when the fire suddenly erupted, or she was suspicious that something was wrong, the smell of smoke perhaps, and was investigating at the time.

The position of the deceased body, and report from the coroner suggest that the fire that engulfed her was more likely to have originated to the east of C18. Drysdale et al. (appendix 5), reporting on the fire: ' This is somewhat speculative, but a person suddenly engulfed in flames will not be capable of moving far.'

There is also a degree of confusion as to what the origins of the flame that engulfed the deceased could have been. The cleaner's room (diagram A9) has been proposed but there was an inconsistency with this and the amount of materials that were felt would be needed to cause such a build up of heat. Another source is the ceiling void, the fire being initiated by faulty wiring, and there were reports of a flood on F floor in the near past and subsequent problems with aspects of the power and light supplies. However, tests following the fire suggested no electrical fault was present. The void above the suspended ceiling may have housed a fire, but there were reasonably effective fire stops and it was felt that this may not have been the cause. The boarding was put up with round head nails, consequently there was very little force needed to bring the panels down, and it was suggested that this may have been a source of the out break that killed nurse Goodall.

Diagrams A13,A14 show the probable alternative locations of the fire, and the extent of damage on C floor.

The development of the evaluation tool meant that an evaluation could be made based on one level of the hierarchy. The tertiary level was chosen, to give maximum sensitivity.

The following notes are summaries of the relevant points arising from analysis of the event and individual factor performance. From this, the percentage deficiencies of the factors were

established.

Summing the relative contributions of the factors with respect to gave a net safety/threat balance, also reproduced graphically.

Existence of Information - Evaluation shows failure of all aspects of information existence during time stage 1. This is a serious deficiency. There is no guarantee of communication for stage 1. Note that individually the existence of information factors are not critical, but as a group they are and communication may fail.

Aural - The only information available in the aural sense is provided by the sounder. This gives information about threat only and of low content value. There is no automatic detection, the alarm is activated by either the two break glass points on each floor. The alarm sounded for only a short time (10 - 15s) and this would be in the $T_{(detection)} - T_{(perception)}$ stage (stage 2). With the benefit of hindsight, it is assumed that the alarm would have sounded for this length of time, and deficiency estimated on this basis. Note that in the event the contribution of aural information was greater. Ambiguous noises, and shouting and screaming contributed, particularly in the early stages. This cannot be included in an evaluation.

	1	2	3	4	5
Deficiency	100%	90%	100%	100%	100%
Acceptable Relative Contribution	0.0197	0.0324	0.0265	0.0245	0.0245
Evaluated Relative Contribution	0.0000	0.0032	0.0000	0.0000	0.0000

Diagram A15. Aural Existence (+).

Visual - In the context of visual information, this too was

unsatisfactory. There was no emergency lighting provision, and there is no mention of signage. The presence of any smoke will not help, except as provision of ambiguous cues [4,6]. In stage 1 there is no contribution; in all others the factor is evaluated as being 90% deficient. Note that in the real event the contribution of visual information was greater. The fire/ smoke provided information and also created problems by restricting information. This cannot be included in an evaluation.

	1	2	3	4	5
Deficiency	100%	90%	90%	90%	90%
Acceptable Relative Contribution	0.0261	0.0428	0.0346	0.0320	0.0320
Evaluated Relative Contribution	0.0000	0.0043	0.0035	0.0032	0.0032

Diagram A16. Visual Existence (+).

Tactile - At the evaluation stage of the event, there is no evidence that there will be any tactile information available for the benefit of Life Safety in the event. There can only be 100% deficiency estimated. Note that in the real event, heat from the fire will provide tactile information [8,10]. This cannot be included in an evaluation.

	1	2	3	4	5
Deficiency	100%	100%	100%	100	100%
Acceptable					
Relative	0.0124	0.0203	0.0166	0.0154	0.0154
Contribution					
Evaluated					
Relative	0.0000	0.0000	0.0000	0.0000	0.0000
Contribution					

Diagram A17. Tactile Existence (+).

Gustatory/ Olfactory - At the evaluation stage, no information in the gustatory/ olfactory sense can be relied on to exist. The deficiency is 100% throughout the event. Note that in the real event several of the nurses reported the smell of smoke as being the first ambiguous cue [17,20]. This cannot be included in an evaluation.

	1	2	3	4	5
Deficiency	100%	100%	100%	100%	100%
Acceptable					
Relative	(O) 0.0217	0.0357	0.0292	0.0270	0.0270
Contribution	(G) 0.0097	0.0161	0.0132	0.0121	0.0121
Evaluated					
Relative	(O) 0.0000	0.0000	0.0000	0.0000	0.0000
Contribution	(G) 0.0000	0.0000	0.0000	0.0000	0.0000

Diagram A18. Olfactory/ Gustatory Existence (+).

For all these factors, the inclusion in the evaluation of aspects of real contributions would have to be on a probabilistic basis. For this, statistics relating to people behaviour and the dynamic aspects of the environmental degradation would be needed. This limitation is data, not the model flexibility. The criticality

of the factors was mentioned above.

Each factor is not independently critical, but if all five were to fail then communication would fail, because of its dependency on information existence. In stage 1 the existence of information is evaluated as failing completely. See diagram A19 below:-

	1	2	3	4	5
Deficiency: Aural	100%	90%	100%	100%	100%
Deficiency: Visual	100%	90%	90%	90%	90%
Deficiency: Tactile	100%	100%	100%	100%	100%
Deficiency: Gustatory	100%	100%	100%	100%	100%
Deficiency: Olfactory	100%	100%	100%	100%	100%

Critical

Diagram A19. Showing predicted criticality of failure of information existence.

The existence of information is vital to alert people in an event. It is obvious from the evaluation that in stage 1 there may be no information available for detection. In the actual event, the fire was discovered by occupants (rather than automatically) as was to be expected. Although the ambiguous cues heard by those who first discovered the fire were ignored for some time, there was early detection.

For a fire at about 1.00 am this was fortunate. Automatic detection is strongly recommended, and would have gone a long way toward correcting the aural information deficiency. Provision of emergency lighting is also to be recommended.

Existence of Information. Further deficiencies as a result of knock-on effect.

Interactions onto existence of information that affect deficiency:-

Route Choice Identification (stages 3,4,5) [7]	25%
Smoke Mass Flow Rate (all stages) [4,11,15,18]	5%
Compartmentation (all stages) [2,5,13,16,19]	5%

Resulting in failure by all existence of information factors at all stages.

Ability to Perceive - No problems here. The population is able, and it is assumed that all the nurses have average abilities to perceive using the five senses. Deficiency = nil. Evaluated = Acceptable.

	1	2	3	4	5
Ability to Perceive:					
Aural	0.0253	0.0416	0.0341	0.0315	0.0315
Visual	0.0264	0.0435	0.0356	0.0329	0.0329
Tactile	0.0154	0.0253	0.0207	0.0191	0.0191
Gustatory	0.0098	0.0162	0.0132	0.0122	0.0122
Olfactory	0.0220	0.0361	0.0296	0.0274	0.0274

Diagram A20. Evaluated contributions of Ability to Perceive (+).

Ability to Perceive. Further deficiencies as a result of knock on effect.

Interactions onto ability to perceive that affect deficiency:-

Psychological Capacity (stages 1,2,3 only) [21,23,25,27,29] 50%

Resulting in a reduction of contribution to 50% deficient in stages 1, 2, and 3

Evaluation of **Psychological Capacity** - This applies in an evaluation sense to the general capacity of the population. It is assumed for this event that the occupants are slightly above average in terms of psychological capacity. Further, as nurses they could be expected to be reasonably familiar with acting in emergencies, and their ability to act fast and make balanced decisions under pressure is assumed to be above average. Offset against this is the timing of the event. At 1 '0' clock in the

morning, all can be expected to be tired or asleep [22,24,26,28,30]. Decreased efficiency is to be expected in relation to :-

- (1) awakening
- (2) perception of situation
- (3) planning

This will affect the early stages. In later stages (4,5) it is assumed that the drowsiness problem is overcome. In the early stages (1, 2, and 3) there is a knock on effect to other factors. This is because of the interactions of psychological capacity, and the factors affected are:-

Ability to Perceive [21,23,25,27,29]	50%
Physical Capability [38]	10%
Physiological Capability [45]	10%
Event Knowledge [53]	50%
Location Identification [64]	5%
Building Knowledge [47]	5%

Note that in the real event aspects of psychological capacity may vary. This cannot be included in the evaluation. There is little that can be done about the deficiency of psychological capacity in stages 1, 2, and 3. The deficiency results from the timing of the fire. A fire later may create worse problems, a fire earlier may be less problematic.

Psychological Capacity. Further deficiencies as a result of knock on effect.

Interactions onto Psychological Capacity that affect deficiency:-

Event Knowledge (stage 3 onwards) [36] - 30%
 Building Knowledge (stage 2 onwards) [32] + 5% (super-optimal)

	1	2	3	4	5
Deficiency	10%	5%	35%	20%	20%
	(1)	(2)	(3)	(4)	

- Notes.
- (1) Unchanged.
 - (2) 5% super-optimal Building Knowledge offsets 10% deficiency = 5%.
 - (3) Net deficiency knock on of 25%, +10% = 35%
 - (4) 5% super-optimal offset against 25% net deficiency knock on, = 20%

Diagram A21. Deficiencies in Psychological Capacity after knock on effects.

Evaluation of **Physical Capability** - The physical capability of each of the nurses is assumed to be average. There is no deficiency.

	1	2	3	4	5
Evaluated Relative Contribution	0.0186	0.0180	0.0350	0.0327	0.0327

Diagram A22. Evaluated Relative Contribution of Physical Capability (+).

Physical Capability. Deficiencies as a result of knock on effect. Interactions onto Physical capability that affect performance:-

Psychological Capacity [38]	10%
Rate of Heat Release [40]	100%
Fire Temperature [41]	100%
Total	210%

Total deficiency caused by interactions for all time stages.

	1	2	3	4	5
Deficiency	210%	210%	210%	210%	210%

Diagram A23. Deficiencies in Physical Capability after knock on effects.

Evaluation of **Physiological Capability** - The physiological Capability of each of the nurses is assumed to be average. there is thus no deficiency.

Physiological Capability. Deficiencies as a result of knock on effects. Interactions onto physiological capability that affect performance:-

Psychological Capacity [45]	10%
Rate of Heat Release [42]	100%
Fire Temperature [43]	100%
Total	210%

Total deficiency caused by interactions. Very high failure likelihood.

	1	2	3	4	5
Deficiency	210%	210%	210%	210%	210%

Diagram A24. Deficiencies of Physiological Capability after knock on effects.

Evaluation of **Building Knowledge** - The nurses will have a better than acceptable familiarity with the building. The value is considered as being super-optimal. Note that in the event there was an exception to this when one nurse forgot the west stairwell. This could not be included in an evaluation.

	1	2	3	4	5
Super-Optimal	-	110%	110%	110%	110%
Acceptable Relative Contribution	-	0.0145	0.0112	0.0104	0.0104
Evaluated Relative Contribution	-	0.0160	0.0123	0.0114	0.0114

Diagram A25. Evaluated contributions of Building Knowledge (+).

The value of Building Knowledge may interact onto other factors, and improve the relative contributions:

Psychological Capacity (after stage 1) [32]	+5%
General Fire Safety Knowledge [59]	+15%
Specific Fire Safety Knowledge [61]	N/A
Location Identification [49]	+30%

Building Knowledge. Deficiencies as a result of knock-on effect.

Interactions onto Building Knowledge that affect performance:

Psychological Capacity (all stages) [47]	5%
Location Identification (not stage 1) [49]	5%

	1	2	3	4	5	6
Deficiency	N/A	-	5%	10%	10%	10%

Diagram A26 - Deficiencies of Building Knowledge after knock on effects.

Evaluation of **Event Knowledge** - The amount of Event Knowledge available from an event depends on information available. This scenario is particularly poor in predictable Event Knowledge (considered in the evaluation). Aspects include sounders, Route Choice Identification [55], Location Identification [54]. There is a serious deficiency.

	1	2	3	4	5
Deficiency	-	-	85%	85%	85%
Acceptable Relative Contribution	-	-	0.0115	0.0106	0.0106
Evaluated Relative Contribution	-	-	0.0018	0.0016	0.0016

Diagram A27. Evaluated contributions of Event Knowledge (+).

The poor value of Event Knowledge may interact onto other factors:

Psychological Capacity [36]	30%
Location Identification [66]	5%
Route Choice Identification [71]	5%
Choice of Alternative Routes [87]	40%

It is suggested that the availability of information should be improved.

Event Knowledge. Deficiencies as a result of knock on effect. Interactions onto Event Knowledge that affect performance:

Psychological Capacity (stages 1,2 and 3 only) [53]	50%
General Fire Safety Knowledge (stages 3,4 and 5) [52]	5%
Location Identification (stages 3,4 and 5) [54]	5%
Route Choice Identification (stages 3,4 and 5) [55]	5%
Total	65%

	1	2	3	4	5
Deficiency	-	-	150%	150%	150%

Diagram A28. Deficiencies of Event Knowledge after knock on effects.

Evaluation of **General Fire Safety Knowledge** - The value of Fire Safety Knowledge is low in this case. This had implications during and before the event. Aspects including chocking open fire doors, poor drill technique from the points of procedure and experience, and poor understanding of the use of glass bolts on emergency exit doors. The deficiency is serious - 85%.

	1	2	3	4	5
Deficiency	-	-	85%	85%	85%
Acceptable Relative Contribution	-	-	0.0118	0.0110	0.0110
Evaluated Relative Contribution	-	-	0.0018	0.0016	0.0016

Diagram A29. Evaluated Contributions of General Fire Safety Knowledge (+).

The poor value of General Fire Safety Knowledge may interact onto other factors:

Event Knowledge [52]	-5%
Specific Fire Safety Knowledge [62]	N/A here
Location Identification [67]	-5%
Route Choice Identification [72]	-5%

Improvement in fire drills in the context of content, attitude, and thoroughness is suggested.

General Fire Safety Knowledge. Deficiencies as a result of knock on effects. Interactions onto General Fire Safety Knowledge that affect performance:

Building Knowledge (not stage 1) [59] +15% (super-optimal)

Evaluation of **Specific Fire Safety Knowledge** - Not applicable in this scenario.

Evaluation of **Location Identification** - At the evaluation stage the contribution of Location Identification was deficient. In the real event it was even more problematical for some of the

nurses, but this wouldn't be shown up in the evaluation. Generally, the nurses should be familiar with the building (this is modelled by the beneficial interaction of Building Knowledge onto Location Identification [65]). The consequence of the deficiency in the relative contribution of Location Identification is to affect (by its interactions onto) the following factors:

Route Choice Identification [74]	-5%
Choice of Alternative Routes [90]	-5%
Event Knowledge [54]	-5%
Building Knowledge [48]	-5%

Improved signage and indication of floor level is important generally. In the case of the nurses, the deficiency in this factor is unlikely to be as significant as for a population less familiar with the building. Note how this trade-off is modelled by the interaction of Building Knowledge onto Location Identification [65] (see below). A reduction in Smoke Mass Flow Rate would help.

Location Identification. Deficiencies as a result of knock on effect. Interactions onto Location Identification that affect performance:

Building Knowledge (not stage 1) [65]	+30%
Psychological Capacity (stages 1,2 and 3) [64]	-5%
Event Knowledge (stages 3,4 and 5) [66]	-5%
General Fire Safety Knowledge (stages 3,4 and 5) [67]	-5%
Smoke Mass Flow Rate (all stages) [69]	-60%

Evaluation of **Route Choice Identification** - There appeared to have been little information available about the route choices, but similarly to the factor Location Identification it would be probable that the nurses would be familiar with the route choices (against this must be laid the infrequent usage of the west stair at all, and use for exits only in drills). The factor is deficient. The consequence of this deficiency is also to

reduce the relative contributions of:

Existence of Information [7]	-25%
Building Knowledge [49]	-5%
Event Knowledge [55]	-5%
Choice of Alternative Routes [91]	-30%

Similarly to Location Identification, it is to be expected that the Smoke Mass Flow Rate in the real event would worsen the deficiency [76].

Route Choice Identification. Deficiencies as a result of knock on effects. Interactions onto Route Choice Identification that affect performance :

Event Knowledge (stages 3,4 and 5) [71]	-5%
General Fire Safety Knowledge (stages 3,4 and 5) [72]	-5%
Location Identification (stages 3,4 and 5) [74]	-5%
Smoke Mass Flow Rate (all stages) [76]	-60%

Route Choice Identification is about recognition of options, and the information provided for this. Routes which are not constantly used are not so likely to be recognised as options. In a building where occupant familiarity is likely, it is particularly important that routes are recognised as such, since signage is likely to play little part to a person who 'knows' the choices of routes (correctly or otherwise).

Evaluation of **Obstructions** - The only 'known' obstructions at the evaluation stage are the glass bolts on the exit doors. These were problematic in stage 5 only. In earlier stages the routes are sufficient to allow free movement. The contribution will be super-optimal. See diagram A30.

- In stages 1, 2 there is no contribution.
- In stages 3,4 the contribution is better than acceptable. Consequently, the relative contribution of the threat posed by obstructions is better than acceptable (with

respect to Life Safety) and the value will be algebraically smaller.

- In stage 5 the relative contribution is deficient (ie; worse than acceptable). The contribution is algebraically larger.

There is a difference in the contribution of the factor obstructions for the analysis of the bedroom and the corridor. There is one extra door to go through from the bedroom to reach safety, and so the obstruction will be more problematic.

Bedroom	50% (one extra door)
Corridor	40%

The consequence of the relative contributions of obstructions interacts onto the following factors (in stage 5 only):

Mobility [165]	25%
Event Knowledge [56]	5%
Choice of Alternative Routes [92]	5%
Route Choice Identification [75]	N/A
Width [99]	50%
Length [103]	20%

Obstructions. Further deficiencies as a result of knock on effects.

The Rate of Heat Release can also affect performance.

Rate of Heat Release [84]	100%
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An improvement in the deficiency of obstructions in stage 5 may be achieved by a less restrictive exit door system. Fire Safety should not be sacrificed to security, both must be considered for performance. More thorough training in the use of the glass bolts is apparently necessary from the witness statements.

Evaluation of **Choice of Alternative Routes** - From an evaluation point of view, this is satisfactory. In the event it was not,

but this would not be included in an evaluation. Deficiencies as a result of knock on effect.

Event Knowledge (stages 3,4 and 5) [87]	-40%
Location Identification (stages 3,4 and 5) [90]	-5%
Route Choice Identification (stages 3,4 and 5) [91]	-5%
Internal Integrity (all stages) [86]	-100%
Compartmentation (all stages) [95]	-100%
Obstructions (all stages) [92]	-5%
Smoke Mass Flow Rate (all stages) [94]	-100%

Obviously a very high likelihood of failure. Supposedly adequate Choice of Alternative Routes failure because of deficiencies as a result of interactions.

Evaluation of Width of Route - The widths of the routes are satisfactory (in relation to regulations).

Width of Route. Deficiencies as a result of knock on effects. The following factors affect the relative contribution of width by interacting onto it:

Obstructions (stages 3,4 and 5) [99]	-50%
Volume of Space and Design (all stages) [98]	-5%

Evaluation of Length of Route - The lengths of the routes when evaluated are satisfactory (in relation to the regulations).

Length of Route. Deficiencies as a result of knock on effects. The following factors affect the relative contribution of length by interacting onto it:

Obstructions (stages 3,4 and 5) [103]	-20%
Volume of Space and Design (all stages) [107]	-5%

Evaluation of Rate of Heat Release - This can be evaluated in terms of the probable rate of heat release of the relevant space. It has a severe deficiency because of:

Corridor:- Poor ceiling tiles, painted surfaces, doors, curtains, telephone hood - unacceptable,

Cupboard:- Unacceptable,

Bedroom:- Beds, partitions, interior fittings, doors - unacceptable.

The consequences of this deficiency affect the following factors:

Existence of Information [8]	N/A (at evaluation)
Physical Capability [40]	-100% *
Physiological Capability [42]	-100% *
Compartmentation [158]	-50%
Obstructions [84]	100% *
Mode of Burning [119]	50%
Fire Temperature [128]	50%
Nature of Smoke [141]	10%
Flame Spread Characteristics [152]	50%
Fuel Supply and Distribution [203]	50%

* Total failure as a result of interaction.

Control of ignition source would obviously stem the deficiency in this factor affecting Life Safety [108]. Other than that, material choice (for Bulk Density [109], Type of Material [111], Mode of Burning [110]) and Fire Suppression [112] (preferably automatic - in this case manual fire suppression equipment was inaccessible and of limited use when it could have first been used). The consequence was borne out by Goodall.

Rate of Heat Release. Deficiencies as a result of knock on effects.

The following factors affect the relative contribution of Rate of Heat Release by interacting onto it:

Mode of Burning (all stages) [110]	50%
Type of Material [111]	5%

Evaluation of **Fuel Geometry and Orientation** - In the corridor the geometry and orientation of the fuel is unacceptable. Horizontal unprotected (upper) surface of the fibre ceiling board allows spread. Vertical surfaces and fittings in both corridor and bedrooms allow for easy spread. The consequence for deficiency in Fuel Geometry and Orientation is an increased unacceptability of the threat factors:

Mode of Burning [121]	50%
Fuel Supply and Distribution [204]	20%

A change in the availability of fuels and continued availability (through both geometry and orientation) is desirable. Geometry cannot be changed in most cases, and where this is unavoidably unfavourable, adequate proofing should be made.

Fuel Geometry and Orientation. Deficiencies as a result of knock on effects.

There are no extra factor interactions to alter the deficiency.

Evaluation of **Ignition Source** - It could be said that the ignition source contribution was obviously unacceptable if a fire occurs - this is not consistent with the thinking applied to the other factors. There is no specific evidence of an identifiable ignition source, or for that matter universal agreement on a location, so, for any of the reasonable scenarios imagined (the model could be run for many scenarios similar except for the ignition source, for example) although fire occurred, the performance of materials may have been contributory. The ignition source is thus assumed to have been an 'acceptable' rather than unacceptable contribution (some theories on this event assume a slow start to the fire). Without a theory on ignition source it is difficult to make improvement suggestions - in general, ignition source can be avoided by good management - material performance under various ignition sources is an important parallel consideration [114]. There are no further interactions onto ignition source to alter its relative

contribution.

Evaluation of **Bulk Density** - This can only be given an acceptable value in the absence of further information on which material(s) to consider. In question may be the 'celotex' ceiling tiles. Under ordinary (test) ignition conditions no excessive smouldering was reported. Density is a factor in smouldering, so it would appear that density was not acceptable, and this is assumed. There are no other factors interacting onto Bulk Density to alter its relative contribution.

Evaluation of **Oxygen Supply** - This is concerned with oxygen supply for Smoke Release. In general, and for evaluative purposes, the oxygen supply can be assumed acceptable. Without excessive draughts there will be no excess of oxygen supply. (in the scenario of a fire in the cleaning cupboard or the ceiling void the value may be better than acceptable). In a real event with windows breaking the actual value may be unacceptable. At evaluation stage it is acceptable. There are no other factors interacting onto oxygen supply to alter its relative contribution.

Evaluation of **Mode of Burning** - In any assumed scenario, in both the bedroom and corridor, flaming combustion is unacceptable. From a smoke yield point of view so is smouldering.

Mode of Burning. Deficiencies as a result of knock on effects. The 50% deficiency of Mode of Burning is made worse by interactions of the following:

Rate of Heat Release (all stages) [119]	50%
Fuel Geometry and Orientation (all stages) [121]	50%
Flame Spread Characteristics (all stages) [122]	50%
Total	150%

Note also that the deficiency in Mode of Burning will interact onto the following factors:

Rate of Heat Release [110]	50%
Flame Spread Characteristics [153]	100%

Evaluation of **Type of Material** - The Types of Material are unacceptable with respect to smoke yield. Curtains, fibreboard, paints, create visibility and/or toxicity problems when they burn, but are not as serious as, say, some plastics. Deficiency of 50%. There are consequences of this deficiency for other factors:

Rate of Heat Release [111]	50%
Flame Spread Characteristics [154]	100%

Better material choice could improve smoke yield performance, but with implications for other functions (aesthetics, etc.). Usage and quality of materials is important. There are no other factors interacting onto Type of Material to alter the deficiency.

Evaluation of **Internal Temperature** - Although it is night time, it is assumed that the internal temperature would be kept within the range required for it to be acceptable.

Internal Temperature. Deficiencies as a result of knock on effects.

The interaction of unacceptable External Temperature at all stages in relation to Stack Effect creates a 10% deficiency in Internal Temperature [125].

Evaluation of **External Temperature** - It would be expected that an evaluation based on a November Night would give a colder than average temperature, and this is assumed in giving the factor a less than acceptable contribution. 20% deficiency. There are consequences for other factors:

Internal Temperature [125]	10%
External Leakage [133]	10%
Internal Leakage [136]	5%

External Temperature. Deficiencies as a result of knock on effects.

There is an interaction onto External Temperature of Internal Leakage which increases the deficiency to 25% (all Stages).

Evaluation of **Height** (for Ambient Stack) - For each floor above ground, the relative contribution will alter: the higher up the building, the greater the Stack Effect, (with respect to the whole building). For the top (F) floor, a fire here will be of lesser consequence than for a fire on the ground floor (A). For ordinary Stack Effect, the smoke will move upwards. Hence, the deficiency is greatest (with respect to Life Safety) for floor A, and least for floor F. It will change proportionally between them. See diagram A31. There is nothing that can be done to alter height. There are no increases in deficiency by knock on effect.

Evaluation of **Fire Temperature** - If a very severe fire develops, the relative contribution will be unacceptable. In this case it was unacceptable. Deficiency 100%.

The consequences of deficiency in this factor apply to the following:

Existence of (Tactile) Information [10]	N/A
Physical Capability [41]	(up to) 100%
Physiological Capability [43]	100%
Nature of Smoke [142]	10% (improvement)

Timely suppression may help here.

Fire Temperature. Deficiencies as a result of knock on effects. Rate of Heat Release further increases the deficiency of Fire Temperature (all stages) to 150% [128].

Evaluation of **Ambient Temperature** - Similar to Internal Temperature. No deficiency, or knock on effects.

Evaluation of **Air Pressure Developed (Wind)** - Note that Mechanical Air Pressure Developed is not included in this scenario. The Air Pressure Developed would be evaluated as within the range for acceptable contributions. There is no knock on effect.

Evaluation of **External Leakage (Wind)** - For evaluation purposes, the External Leakage of the building is acceptable with the windows closed. Opened or broken windows are aspects of the real fire, but difficult to include in an evaluation, without resort to a probabilistic approach.

External Leakage. Deficiencies as a result of knock on effects. The following factors affect External Leakage by knock on effects:

External Temperature (all stages) [133]	10%
Internal Temperature (all stages) [134]	5%
Total	15%

Evaluation of **Internal Leakage (Wind)** - This would be evaluated as acceptable for :

Bedrooms - If no doors were left open (doors opened during the event are difficult to include in an evaluation because this would require probabilistic modelling).

Corridor - If no doors were open, Smoke door to the east stairwell was open, and the factor is thus unacceptable.

Consequences of this deficiency for:

External Leakage [132]	5%
Compartmentation [211]	100% (corridor)

Keeping doors closed when not in use, and the installation of repeaters for telephones may have removed the reason for having door chocked open.

Internal Leakage. Deficiencies as a result of knock on effects. External Temperature increases the deficiency further (add 5%) [136].

Evaluation of **Volume of Space and Design (Wind)** - From the point of view of Smoke Movement, the bedroom is an unsuitable volume. It is deficient. The corridor is even less acceptable, the design of the space (narrow [138]) allowing the rapid spread of smoke along the route, a relatively small volume of smoke could spread over a large distance. An alternative technique of Smoke Control to Dilution may make the Volume of Space and Design less problematic - but with a fixed design of the building the scope of this would be limited. The poor performance is to be expected. The consequences of the low value of Volume of Space and Design are for the following factors:

Rate of Burning [335]	30%
Smoke Release [336]	100%
Fuel Supply and Distribution [209]	30%
Nature of Smoke [144]	20%
Width (of route) [98]	5%
Length (of route) [107]	10%

There are no further deficiencies (corridor or bedroom).

Evaluation of **Smoke Mass Flow Rate** - At an evaluation stage the amount of smoke that would be produced would be unacceptable - 50% deficient. This is similar for each space. In the event this factor becomes very important. At evaluation stage this is not reflected. The consequence of this deficiency applies to the following factors:

Existence of Information [4,11,15,18]	5%
Location Identification [69]	60%
Route Choice Identification [76]	60%
Choice of Alternative Routes [94]	100%
Reservoir Size and Design [182]	100%

Suggest minimisation of smoke potential in vital routes.

Evaluation of **Nature of Smoke** - This concerns the ageing of the smoke. In a small compartment with a low ceiling this may create a problem - However, this should be seen as an interaction between the smoke and the space, rather than the deficiency of the nature of the smoke alone. Hence, the evaluated contribution is left acceptable.

Nature of Smoke. Deficiency as a result of knock on effects:

Space Shape [143]	-10%
Rate of Heat Release [141]	+10%
Fire Temperature [142]	+10%

Evaluation of **Surroundings** (with respect to wind) - Evaluated performance with a SW wind would be acceptable in the context of the surroundings (little turbulence problem in the near vicinity).

Evaluation of **Speed** (with respect to wind) - An evaluated contribution of 25% deficiency for the 15 - 20 mph wind (Fire Brigade report).

Evaluation of **Direction** (with respect to wind) - At the evaluation stage this cannot be identified as problematic. In the actual event, with the other factor deficiencies, the direction was important.

Evaluation of **Height** (with respect to wind) - This relates to the velocity profile. At higher floors in the building the effect of

the wind becomes more marked than at low levels, and may disturb Dilution. At the low levels (including C floor) the velocity may be less unacceptable.

Evaluation of **External Integrity** - Whilst the windows are closed, this is no problem and will be acceptable. In an event where the windows are opened or break (as happened in this case) the contribution is deficient. This cannot be included in an evaluation without probabilistic data. External Permeability is similar.

Evaluation of **Internal Integrity** - This is poor. The door to the east stairway was open, and the ducts running through the bedrooms had a lack of integrity (for example smoke was reported on F floor). Also, in the real event, the opening of doors further affected each space detrimentally. Good design and workmanship are essential to provide a building with good integrity. Usage is important also. There are consequences for the following:

Compartmentation [159,160]	100%
Fuel Supply and Distribution [207,208]	50%
Choice of Alternative Routes [85,86]	100%

Evaluation of **Internal Permeability** - Gaps around doors are poor and this is modelled by a 50% deficiency (in the real event, this was worse as the doors failed, but 50% is picked up by the evaluation).

Evaluation of **Air Conditioning** - As for Internal Temperature the evaluation shows an acceptable value.

Evaluation of **Heat Gain of Space** - There will not be heat gain on a November night and it is assumed that the Internal Temperature was in reasonable equilibrium.

Evaluation of **Space Shape** - From the point of view of a Smoke Control by Dilution technique, the shape of the bedroom is not

unacceptable. The shape of the corridor is less useful for containing smoke, 10% deficient (note that this is distinct from the size). The 10% deficiency of the corridor has consequences for the following:

Route Choice Identification [78]	nil (no real problem because of shape)
Length of route [104]	nil
Width of route [102]	nil (not for route capacity)
Nature of Smoke [143]	10%

The consequences of this deficiency are not serious compared with other factors.

Evaluation of **Height of Space** - The height of the space is poor from the point of view of Smoke Control, 90% deficient. There are no consequences for other factors.

Evaluation of **Length of Space** and **Breadth of Space** - Length and Breadth analysis is similar. In the bedrooms, both are deficient. In the corridor, although the Breadth is deficient, the Length is considered acceptable. The consequences of these deficiencies apply to:

Fuel Supply and Distribution [339,341]	25%
Compartmentation [161]	30% (length)
	35% (breadth)

Evaluation of **Geometry** - In an evaluative sense this was unacceptable (borne out by problems of vertical and horizontal flame spread in corridor, 90% deficient, and vertical spread in the bedroom, 50% deficient). Relevance of ceiling tiles, paint, curtains, partitions. The consequence of this deficiency extends to the following factors:

Fuel Geometry and Orientation [343]	n/a (a similar factor)
Mode of Burning [121]	20%
Fuel Supply and Distribution [205]	20%

Suggest the correct proofing of materials, and correct usage (tiles).

Evaluation of **Flame Spread Characteristics** - Both the corridor and the bedrooms are unacceptable. Ceiling materials and wood allow for rapid flame spread. This is a greater problem in the corridor. Consequences of the deficiency for:

Mode of Burning [153]	50%
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Properly treated materials or choice of good materials and correct use may go a long way toward improving this. (similarly for the doors).

Flame Spread Characteristics. - Further deficiencies as a result of knock on effects. The following factors knock onto Flame Spread Characteristics:

Rate of Heat Release (all times) [152]	50%
Mode of Burning (all times) [153]	100%
Type of Material (all times) [154]	100%

Evaluation of **Compartmentation** - This is exceptionally poor. Doors are unacceptable and this has implications for both corridors and bedrooms. Consequences:

Existence of Information [2,5,13,16,19]	+ 5%
Choice of Alternative Routes [95]	100%

Suggestion:- All fire doors should be kept closed when not in use. This may be extended to cover the bedroom doors and self-closers may be useful. Doors should be adequately fire resistant.

Compartmentation. Further deficiencies as a result of knock on effects.

The following factors knock onto Compartmentation:

Rate of Heat Release (all stages) [158]	50%
Internal Leakage (all stages)	100%
Internal Integrity (all stages) [159]	100%
Length (of space) [161]	30%
Breadth (of space)	35%

The deficiencies of the factors may be summarised. This is presented in diagrams A32 and A33, separating those factors defined as being of a pro-safety or pro-threat nature.

These deficiencies may be applied to the potential relative contributions. This produces sets of evaluated relative contributions to Life Safety for the factors at each time stage. See diagrams A34,A35.

The totalled safety and threat contributions for each time stage are algebraically summed, to produce a net safety/threat value for each time stage. The performance of the corridor and bedrooms are differentiated. See diagram A36.

These results of the evaluation are displayed graphically on a net safety/threat diagram. See diagram A37. This shows an unsatisfactory performance: in stages 1 and 2 there is a net threat to Life Safety; in stages 3,4 and 5 the net level of safety is unsatisfactory. As would be expected the bedroom is evaluated as being less hazardous than the corridor.

In addition to the net safety/threat value it is useful to analyse the implications of individual deficiencies of factors on other factors in the system because of interactivity. A number of factors and interactions are identified - see diagram A38.

As a result of evaluated deficiency and knock-on effects fifteen factors were identified as failing using the model. These are shown in diagram A39. Note that the factors Rate of Heat Release, Fuel Geometry and Orientation, Fire Temperature, Internal Leakage, and Volume and Design of Space were evaluated as

completely deficient before considering knock-on effects.

Comparison of factors failing in the evaluation with reports and the event

A failed factor is one that has a deficiency when evaluated greater than or equal to 100%. The fifteen factors predicted as failing are discussed below in the context of their failure, deficiency, criticality, and the consequences of the failure. A criticality summary is reproduced in diagrams A40,A41. Where available information is from reports, this too is used. Diagrams A42-A45 provide a summary.

(1) **Existence of Information** - There is failure predicted for the provision of information in each of the five sense media. Although the Existence of Information in each sense is not critical in itself, the failure of all information is, and the result of this is predicted failure in communication. There is a reduction in safety indicated. In the actual event there was ambiguity of information. There was a delay in the alarm being activated, and for many of the occupants the first cues heard were not the alarm. The information was unpredictable and of low informative content.

(2) **Physical Capability** - The predicted failure of this factor indicates a reduction in safety. It is a critical factor to Mobility , consequently Mobility is predicted to fail also. In the early notional stages of the event the factor is of medium import only (Dilution/Removal 26th in stage 1 and 23rd in stage 2), but in the three last stages (after perception of the event) it is the third most important factor in the tertiary level (of 58 factors), and the prediction of failure must be seen as serious for Life Safety. In the actual event a number of occupants were injured, one fatally. There were a number of nurses who had to jump from their windows to avoid direct injury from the fire and smoke, and one nurse was injured in the corridor when trying to escape, and this impeded her escape (12A burned her hands).

(3) **Physiological Capability** - The failure of this second critical factor on which Mobility depends predicts a reduction in safety again. In the early stages the factor is only of medium importance (24th in each model). However, in the three stages after perception it is very important (2nd, 4th, and 4th of 58 respectively). Its predicted failure must be considered as serious. In the actual event the death and injuries were associated with physiological (and physically untenable) conditions. Goodall died as a result of inhaling hot fire gases, others reported having difficulty breathing.

(4) **Event Knowledge** - This critical factor is predicted as failing by the model with the result that training will also fail. There is no contribution in the first two stages of the event, but after perception it is of medium import to Life Safety. The predicted failure will give a reduction in safety and should be considered as serious. In the actual event there was a general ignorance of what was happening. This was exacerbated by misinterpretation of the event, and resulted in confusion and incorrect actions.

Note that the primary factor Mode of Escape depends on three secondary factors. These are Communication, Mobility and Training. The predicted failure of critical tertiary sub-factors which in turn gives rise to their failure of each of three factors must result in the predicted failure of the primary factor itself.

(4) **Route Choice Identification** - This factor is predicted as failing. It does not have a potential contribution in stages one and two, but is of fairly high importance in the three stages after perception. It is not critical to Ease of Use, and for a familiar population it may be of less than potential import in real circumstances. One nurse reported getting lost, and several forgot the option of the west stair (possible because of its infrequent use normally).

(5) **Obstructions** - This factor is critical to the Ease of Use of escape routes. The prediction of failure must be taken as being serious, and in turn jeopardises the performance of the factor Ease of Use. The failure is an increase in threat. The factor has no potential contribution in the event for the first two stages, but after perception it is of fairly high importance (16th, 11th, and 11th). In the actual event there was a significant problem of Obstructions. The glass bolts at the foot of the west stair, which many of the nurses noted unfamiliarity with, presented a less significant obstruction than they might have, (although one nurse reported returning upstairs to get a shoe to break the bolt).

Other source of Obstruction were the fire and smoke itself. This affected occupants in all the stages of escape:- T(perception) - T(action) - unable to leave rooms; T(action) - T(relative safety) - 12A unable to negotiate corridor; T(relative safety) - T(safety) - Nurses prevented from using the stairways, and Hopton et al. prevented from returning up the stairs.

(7) **Choice of Alternative Routes** - This is a critical factor to Ease of Use, and its failure must predict failure of Ease of Use also. There will be a reduction in safety, and because of the position of Choice of Alternative Routes in the tertiary level must be taken very seriously (it is -/-/6th, 1st, 1st). The failure is totally attributed to the interactions onto the factor. In the actual event the unusable the routes including the corridor limited the choices. The occupants above C floor had to use the west stairwell since the east was untenable, and on C floor the usability of the corridor meant that many of the occupants had no conventional routes available, and had to jump from the windows. The consequences for them of a similar fire but on D, E, or F floor would most probably have resulted in more deaths and much more serious injury.

Failure of the secondary factor Ease of Use as a result of the failure of critical sub-factors may be sufficient in itself to cause failure of the primary factor Escape Route Layout, and this

is borne out in the event. The failure of this primary factor and the primary factor Mode of Escape leaves the escape domain non-contributory.

(8) **Rate of Heat Release** - This is a critical factor to the secondary factor Rate of Burning. The failure of this factor results in the predicted failure of the secondary factor also. This gives an increase in threat. Failure of a pro-threat factor in the context of Life Safety means that the threat to Life Safety is greater than acceptable. In the early stages of the event the position of this factor in the tertiary level is fairly high (3rd, 10th in stages 1 and 2). In the actual event the fire grew very quickly, with an early build up of smoke and this can be seen as comparing well with the model prediction. The corridor becomes unusable quickly (Hopton reports thick smoke at the 'five minute' stage). The rooms and stairways also became untenable. There was early flashover in the corridor.

(9) **Fuel Geometry and Orientation** - This is a critical factor in the model. The importance of the factor is fairly high at the start of the event, and decreases to relatively medium import later (a function of increasing numbers of factors). Its failure would result in the failure (with respect to Life Safety) of Rate of Burning. In the actual event there was unacceptable Fuel Geometry aspects. The spread of fire across the ceiling tiles and other surfaces in the corridor and bedrooms (wood) allowed rapid growth of the fire size accompanied by unacceptable Smoke Release. The source of ignition and the origin of the fire is questionable, but the ceiling void or the cleaners cupboard may provide the necessary Fuel Geometry and Orientation for growth.

(10) **Mode of Burning** - This factor is of medium import in the model and is not critical. In the actual event the fire severity and the consequences of the early flashover on Smoke Yield caused significant problems in the building.

The evaluation concludes that the building was unsafe, and there was a high likelihood of death and/ or serious injury in a fire

scenario such as occurred. The likely severity of the incident outcome increased with height of the floor involved.

An evaluation just prior to the fire would have suggested improvements in the areas of communication, fire resistance (specifically doors and ducts), fire safety practice/training, route usage (west stairwell), and the locating of telephones (or repeater bells to avoid temptation to chock fire doors). Reductions recommended in the fuel availability, flame spread characteristics and potential smoke release of materials used in the corridor and lounge, of internal leakage (particularly around doors), and the occurrence of obstructions to rapid escape.

A number of factors performed worse in the event than evaluation suggested. These were:

- (1) Location Identification (Smoke)
- (2) Existence of Information (Alarm)
- (3) Physiological Capability (Death)
- (4) Route Choice Identification (Smoke)
- (5) Choice of Alternative Routes (Compartmentation, Smoke, Heat)
- (6) Obstructions (Smoke, Heat)
- (7) Oxygen Supply (Windows)
- (8) Mode of Burning (Flaming)
- (9) External Leakage (Windows)
- (10) External Integrity and Permeability (Windows)
- (11) Internal Leakage (Doors)
- (12) Internal Integrity and Permeability (Doors)
- (13) Compartmentation (Doors, Ducts)

The HSE report to HM Principal Inspector noted that the building would probably not meet current standards in respect of:-

- (1) Ceiling Lining
- (2) Unstopped service ducts with insufficient fire resistance.
- (3) Design of corridor outside rooms 12,12A,14 (fire resistance).
- (4) Lounge furnishings directly onto main corridor (now considered as protected routes) not considered to have played a part in death or injuries.

- (5) Bedroom doors poor.
- (6) Laxity in control of fire doors (influencing spread or escape from upper floors).
- (7) Alarm failure.
- (8) Fire Brigade access.

The predicted performance of factors from the evaluation exercise shows a good correlation with the event.

Appendix 4. Case Study (2) Standard Life Building.

Appendix 4. Case study (2): Standard Life Building

Evaluation Exercise

The Evaluation tool is intended for use on proposed as well as existing building scenarios.

A systemic approach to Building Performance requires incorporation of Life Safety criterion from the early stage of a building's life.

The objective of this exercise was to evaluate a proposed building in an early stage using the Life Safety Model. Data limitations imposed an increased reliance on assumptions and expert judgement in the use of the model. A number of specific points arose:

- (1) The input information was characteristically incomplete. The exercise should establish whether the tool can usefully assist with an analysis based on incomplete data.
- (2) It was important to establish whether the model could still highlight potential problem-factors? Also, could it indicate what implications this may have and what factors exacerbate or relieve the situation.
- (3) What information is needed to allow a performance-based (expert judgement) evaluation of each factor to be made?

The approach was to focus in turn on each factor; analyse the plans to assess the contribution to Life Safety, and the implications of inter-relationships. Factor criticality was also be appraised.

Introduction to The Proposed Standard Life Building

The information on the Standard Life Building available was limited to a design summary of the building (February 1986). This is reproduced as diagrams A46-A55.

See diagram A50. The building is bounded by Brandon Terrace,

Howard Place, Inverleith Terrace Lane, and the Water of Leith. The building should be mainly two-storey administration offices with 200,000 sq. ft. of space for 1,200 staff. A roof top garden and restaurant is proposed. The former wool warehouse on Howard Place will be retained and refurbished. There will be a basement car park combined with a sports facility, and the two storeys of open plan office area above it will combine with existing windows in the wool warehouse facade. There will be three external materials used - glass, natural stone, and slate, combined in a vernacular form. Refer diagrams A47,A53.

Diagrams A51,A52. Domed atria link the two open storeys, and four pillars run through the atria gaps. There are ten sets of stairs, each at the perimeter of the floor, all serve to the basement. In addition there is the main entrance affecting the ground floor only. Layout of pillars is based on a 13.5m grid. The envelope is based on a double-glazed curtain wall with a large gap between panes, which provides a circulation duct for the air conditioning. See diagrams A51,A56. The inner leaves of glass are full height, horizontally sliding. The stairs double as service zones. Vent louvres are at roof level around atria.

Services are housed under a raised floor void to a floor with exposed waffle structure on the under-side. Diagram A51.

It was assumed that in long term use the open plan format of the floors may be changed to a partially or totally compartmentalised format.

Evaluation of each of the factors

The building was considered unsuitable for smoke control by pressurisation (containment) technique in its proposed form. Evaluations were made assuming dilution or removal techniques of smoke control. Evaluation was based on the tertiary level factors.

There is insufficient information provided for the evaluation of

many factors. In these cases, evaluation is made on the basis of assumptions. Where an acceptable factor value is assumed, performance criteria are noted. In some cases sample evaluation questions are noted.

Many of the factors are related to the management aspects of in-use fire safety. This is a potential fire safety problem, and illustrates that Life Safety in Building Fires cannot be catered for solely by design, or by usage. The two must complement each other.

Existence of Aural Information (+) > Not Critical [237]

There is no information about proposals for this factor on the plans. Aural information provision at the design stage will be limited to the provision of alarm and information systems for use in the event of a fire. This is of relevance for all stages of the event. there may be problems in giving clear information to all 1,200 people that is applicable to all of them.

Confidence in information is a subjective, and depends on the history of alarm information (false alarms, etc.) and also on applicability to the individual and correctness. Aspects of an alarm system should include directionality (this is similar to applicability), comprehensibility, clarity, quality (correctness), and speed.

In a small to medium sized single space, it is possible that many people will know of a fire almost simultaneously. In a large space such as each of the main floors this may not be so, and work stations may localise information. A compartmentation effect is potentially relevant if the layout is changed subsequently from open-plan.

There are implications onto existence of information of the following:-

- (1) Air Conditioning (switching off or altering mode) [1].
- (2) Compartmentation, subject to changes to the internal format affecting sound attenuation [2].
- (3) Mechanically induced flow - Similar to Air Conditioning [3].

Assuming mechanically induced flow for air conditioning or a removal system there will be a switching effect that may alert people. Dilution model, switching off systems may alert people. An assumed acceptable alarm system to provide existence of information should be able to alert people at all locations of the building.

Different sounds may not be practicable in this situation and clarification of alarm is desirable - a tannoy system giving accurate information is desirable, and in a flexible workstation arrangement may be desirable for general day to day alerting, calls. Spacing of alarms and sound levels are important. Occupants are assumed awake, and sound level requirements normal.

The provision of an automatic alarm system of informative nature and adequate coverage whilst maintaining clarity, correctness and quality of information will be acceptable. Existence of Aural information would then not be a priority factor.*

Implications of changes to layout which cause significant sound attenuation (e.g., compartmentalisation, or partitioned work stations) must be noted. Additional stimuli of switching air handling equipment [1] may give information, but is not a reliable aspect of existence of aural information.

Sample questions arising:

- (1) Is there a reliable alarm system installed ?
- (2) Is it of a sounder or tannoy variety?
- (3) Is there adequate sound coverage?
- (4) Are staff regularly familiarised with the alarm?
- (5) Is it directional?
- (6) Is it automatically operated, with a relay to a Fire Station?
- (7) Is it adequately maintained, with a separate power supply?
- (8) Is the system regularly tested?

Assumed no deficiency.

Existence of Visual Information (+). Not Critical [238]

There is no information available from the plans concerning the provisions for existence of visual information.

Provision requirements as assessed in the model cover visual alarm (flashing lights) and also emergency/ continued provision of lighting. Signs are also significant but are covered by the factor Route Choice Identification [7] and are discussed there. In an open plan environment it may be less of a problem to ensure. However, should the space be compartmentalised [5] or partitioned at a later stage there are implications for Route Choice Identification (ie; provision of signs). Adequate lighting must be maintained across all spaces. The criteria of adequate illumination is affected by:-

Smoke Mass Flow Rate [4]

Smoke Yield [6]

Compartmentalisation [5]

Route Choice Identification [7]

There are no factors that visual existence interacts onto. There is a potential significance of subsequent changes in visual existence because of changes to any of the factors that interact onto it.

Sample questions arising:

- (1) Is there emergency lighting and secondary power supply?
- (2) Is switching automatic?
- (3) Is the switching delay acceptable and expected by occupants?
- (4) Is the lighting level in all areas of the building acceptable for escape?
- (5) Is emergency lighting regularly tested, maintained, and faults reporting encouraged?
- (6) Are any flashing alarm signals visible from all points in the spaces?

(7) Are any flashing alarm signals fully understood by occupants?

Assumed deficiency: nil

Existence of Tactile Information (+). Not Critical [239]

This is one of the factors that is going to be unacceptable. The type of occupancy will not have a requirement for special facilities for tactile information, and it is assumed they will not be provided. There may be information in an event [8,10,11] (cf; Victoria Nurse's Home), however such information (or threat) is not included in the evaluation. Any environmental changes caused by the switching or failure of the air conditioning [9,12,14] are unpredictable.

It is assumed that there is no special provision for tactile information.

Assumed deficiency: 100%

Existence of Gustatory/ Olfactory Information (+). Not Critical [240,241]

Similarly to the existence of tactile information, there is no predictable existence of gustatory or olfactory information at the design stage. Implications of compartmentalisation changes and the nature of the fire and its products may have consequences for existence of gustatory and olfactory information [15,16,17, 18,19,20].

Assumed deficiency: 100%

Ability to Perceive (+). Not Critical [242,243,24,245,246]

In general, the ability to perceive can be expected to be reasonable. A range of partial deficiencies will occur, which any employee, including the proportion of registered disabled may have. Locating those that have difficulty in perception in situations where their deficiency can be made up for by other

people should be considered. A minor deficiency is assumed.

Sample questions arising:

(1) What extent and nature of disability is expected?

Assumed deficiency: 5%

Psychological Capacity (+). Critical [247]

Again there is no information available about the psychological capacity of the occupants, nor could there be expected to be in detail. It is assumed though that in an office scenario the people could be relied upon to be reasonably alert (this may vary throughout the work session). The ability of people to cope in a fire is unlikely to be different to the normal. This is assumed to be acceptable.

Sample questions arising:

(1) Is there anything to suggest a population of less than average psychological capacity?

Assumed deficiency: nil

Physical Capability (+). Critical [248]

No information available. Bearing in mind the possibility of 3% registered disabled, and also the transiently disabled, there is likely to be a deficiency. Deficiencies in physical capability may be significant for the individual and the other members of the population (blockages, queues). Stairs may provide a problem for the disabled, provisions for the disabled are not apparent [81]. Thought about the location of workstations for the disabled will be necessary to minimise the effects of this deficiency.

Sample questions arising:

- (1) Could a fire scenario involve physically disabled occupants?
- (2) What implications are there for other escapees?
- (3) Are there any special facilities to minimise problems arising from restricted physical capability?
- (4) Where are the disabled located?

Assumed deficiency: 10%

Physiological Capability (+). Critical [249]

No information available. A 10% deficiency is assumed on the same basis as for physical capability. Travel distance may be significant [46], and there may be consequences of deficiencies for other occupants. Thought about the location of workstations will be required.

Sample questions arising:

- (1) Could a fire scenario involve physiologically disabled occupants?
- (2) What implications are there for other escapees?
- (3) Are there any special facilities to minimise problems arising from restricted physiological capability?
- (4) Where are the disabled located [46]?

Assumed deficiency: 10%

Building Knowledge (+). Not Critical [250]

In the absence of other information, it is assumed that the occupants of the building will be familiar with its layout. There are a number of potentially significant consequences of poor building knowledge [32,59,61], and changes affecting occupant familiarity should be noted.

Sample Questions arising:

- (1) Do occupants regularly use or have the opportunity to use all the building?
- (2) Is each person familiar with the layout of each floor?
- (3) Are there any escape routes not in general use?
- (4) Is the layout subject to change?
- (5) Are the disabled restricted in their use of the building [50]?

Assumed deficiency: nil

Event Knowledge (+). Critical [251]

Event Knowledge is influenced by the layout [54,55] and use [56] of the building. Problems of the size of the space may be offset by an ease of communication [57] between workstations for the transmission of knowledge.

Assumed deficiency: nil

General Fire Safety Knowledge (+). Not Critical [252]

No information available, and is assumed satisfactory as default. It is important that people are trained properly and are familiar with what should be done in fire events.

Sample questions arising:

- (1) Are all the occupants trained for the initiation, interpretation, and reaction to fire alarms?
- (2) Are occupants fire safety conscious?
- (3) Are people trained in fire procedure?
- (4) Is training updated regularly?

Specific Fire Safety Knowledge (+). Not Critical [253]

Similarly to general fire safety knowledge, this can be assumed only. There is no such information on the plans.

Similar requirements to general fire safety knowledge [62], but

extending to a greater practical depth. It must be ensured that there are sufficient people always present who are trained, that people know who the trained personnel are, that they are interested and given opportunity and encouragement to train. Feedback is necessary, and if anyone leaves there must be a person responsible for their replacement.

Assumed deficiency: nil

Location Identification (+). Not Critical [254]

No information available. It should be noted that in an open plan design for this type of building it may be difficult to provide obvious identification of location by signage. An imaginative layout and the view from the windows will aid orientation. The problem of location identification is likely to be less significant for those familiar with the building [65].

Sample questions arising:

- (1) Is it practical for a person unfamiliar with the building to locate himself in relation to the building at any location and reasonably effectively (signage requirements)?
- (2) Is orientation straightforward? Are stairs distinguishable in use?

Assumed deficiency: nil

Route Choice Identification (+). Not Critical [255]

There may be a deficiency with this factor if the layout of the open plan floor is muddled. In areas where there is a similarity in layout there may be ambiguity [78,74]. In some cases confusion as to direction of route has to be considered, but this is unlikely to be a problem here. Adequate signage and clarity of visual field may allow for ease of route choice identification. In the absence of other information this is assumed to be so and the factor evaluated as acceptable.

Note the implications of a change of internal layout such as partitioning or compartmentalising would have on this building with all routes at the perimeter.

Sample questions arising:

- (1) Can a person at any point in the building see at least two choices of routes [91]?
- (2) Can routes be easily identified and followed?
- (3) Is the space easily interpreted, or are there complications and obstructions [75]?

Assumed deficiency: nil

Obstructions (-). Critical [256]

This is a particularly worrying factor. There is a great potential for obstructions that could be built in, or arise in use in this building.

- (1) Stairs are an obstruction to the disabled [165,81].
- (2) Open plan long travel distances exacerbated by complexity of route and width allowance [82,83,99,103].
- (3) Possibility of zoned protection to allow sports or restaurant usage outside ordinary hours may involve restricted access implications for building (and egress) [92].
- (4) Security. Unless the car park is secure there will be a requirement to restrict entry to the stairwells from the building [92,79]. This may have implications for people trying to escape to or from the car park.
- (5) The travel distance requirements are excessive from the centre of the floors to the perimeter stairwells [83].

There is an excessive length and likely complexity of the routes across the floor, complicated further by the need to travel around the atria and the possibility of smoke travelling up as an obstruction. See diagrams A51,A52.

Evaluation produces a deficiency of 50%, mainly due to the unacceptable travel distance and complexity of route [83,75]. This may be overcome by reducing the required travel distance [83]. Compartments as refuges, or a central stairway may help. Dedicated aisles should be maintained for all travel. Location of the disabled at or near perimeter, on the ground floor should be aimed for [81]. The nature of the job function requiring an open plan office may require movement from post.

Sample questions arising:

- (1) Will all routes be available for escape use from any floor at all times the building is in use [92,79]?
- (2) Is there a foreseeable likelihood of stair usage being restricted?
- (3) Are there adequate choices of routes within an acceptable distance (the distance becomes an obstruction otherwise) [92]?
- (4) Is there a uniform distribution of people across the floor?
- (5) Will travel be restricted by the layout, or could it be [165]?
- (6) Can any change to the building be envisaged that will create or exacerbate the obstructions problem?
- (7) Are doors wide enough [82]?

Assumed deficiency: 50%

Choice of Alternative Routes (+). Critical [257]

This factor is reasonably good in terms of quantity of stairways [172], but the travel distance to the stairs is unacceptable. There are locations where a person could not be within acceptable travelling distance of any stairway.

It is assumed that the routes can be maintained in proper order throughout an event if fire doors are used (properly) at each floor. However, the routes are too far away from some locations for acceptability (certainly for the disabled). It should be considered contextually.

Sample questions arising:

- (1) Within a reasonable distance (the relevant travel distance) are there at least two stairwells, ie; protected routes?
- (2) Are the routes sufficiently protected to ensure continued availability of use ?
- (3) Is this acceptable as put forward, and are the consequences acceptable ?

Assumed deficiency: 50%

Suggestion - A central stairway or a protected central zone or corridor to bring choices for safety to within acceptable travel distances.

Width of Route (+). Critical [258]

The Width is evaluated as acceptable. Changes to the layout or usage of the building spaces may tend to alter the effective width of sections of the route [99].

Sample questions arising:

- (1) Is the width of every part of escape route (protected and unprotected) satisfactory for the occupancy load?
- (2) Is it ensured that all parts of the route will be wide enough?

Assumed deficiency: nil

Length of Route (+). Critical [259]

This appears excessive. Once inside the protected section of the route the distance required to be travelled in the stairways is acceptable. The length of the route to reach the protected section is not acceptable. There may be consequences for physiologically disabled occupants [46].

Sample questions arising:

- (1) Can a protected place be reached within an acceptable travelling distance from any location in the space?
- (2) Is this taking into account the complexity of the route [103]?
- (3) Is this the effective or actual length of travel?
- (4) Is this acceptable as it stands, and are the consequences acceptable?

Assumed deficiency: 50%

Suggestion - On the main floors, the inclusion of refuges or stairs within a suitable travel distance from any location (for example a central protected stairwell).

Rate of Heat Release (-). Critical [260]

The Rate of Heat Release and the fire size will be related. The quantity [152] and nature of fuel available [111,109], and effectiveness of any suppression techniques [112] will be important to the rate of heat release.

In an open space (such as in this building) a high rate of heat release will cause a very rapid fire growth unless swiftly and effectively suppressed. The alternative, and preferable option is to limit the rate of heat release that can be developed by material choice and management. Difficulty in controlling fuel availability is foreseen in an open plan scenario, and the factor is assumed 50% deficient.

Sample questions arising:

- (1) Is there material about of sufficient potential rate of heat release to be unacceptable - loose papers, carpets, office furnishings?
- (2) What amount of fuel is available and at what rate would it

burn?

- (3) What size fire (ie; Rate of Heat Release) is acceptable ?
- (4) Are materials fire retarded?

Assumed deficiency: 50%

Fuel Geometry and Orientation (-). Critical [261]

This refers to the proximity of adjacent fuels, and the orientation, and how this will impact on the rate of burning should a fire start.

The value of the contribution cannot be assumed to be satisfactory with the flexible layout opportunities afforded by the open plan scenario. Control of the fuel supply and its distribution cannot be guaranteed, and will also influence the contribution of this factor [113]. There are consequences of this deficiency for the mode of burning [121].

Little to be done directly concerned with this factor - it is a usage problem. Effective distribution of the potential fuels would help, and could be achieved by compartmentation techniques.

Sample questions arising:

- (1) Is material laid out, or likely to be laid out in such a way as to promote growth of fire or spread of flame, smoke production?
- (2) Is the material of the type to allow fire growth and/or smoke production?
- (3) Could the material be better orientated?

Assumed deficiency: 50%

Ignition Source (-). Critical [262]

This is a problematic factor to speculatively evaluate. It has been assumed for the purpose of this exercise that the ignition source will not be inordinate. What is assumed by this is that

abnormal ignition sources such as explosions, very high energy sources, are not likely to occur.

Measures should be taken in the ordinary use of the building to minimise the occurrence of ignition sources. Smoking is a particular example, particularly if taking place during ordinary usage.

Assumed deficiency: nil

Bulk Density (-). Not Critical [263]

This cannot be predicted from plans alone, and will also be affected by the live fuel load. The likely fuels that will be present in the space are papers, furniture and decor. None of these factors can be given an acceptable level of contribution of bulk density, and a deficiency of 10% is used in the evaluation. The consequences for the factors interacted onto by bulk density is a tendency to degrade the performance of the factors rate of heat release [109] and mode of burning [120].

Sample questions arising:

- (1) Can the bulk density properties of any of the materials used in the space be improved, or could an alternative choice of materials improve this?

Assumed deficiency: 10%

Oxygen Supply (-). Critical [264]

There is an excessive availability of oxygen for the development of a fire and the production of smoke. The assumed type of fire could be fuel controlled and liable to the production of an excess of smoke. The atria in conjunction with the large volume of the space will ensure a continued supply of oxygen. Before deactivation (or change of mode) the air conditioning system may also contribute [116,118]. The potential consequences of such problems, modelled as a deficiency of 70%, are to allow an

unacceptable mode of burning [329] and to affect the contribution of the type of material [330] to smoke yield in relation to the manner in which it burns. The characteristics of this will depend on the material properties.

The performance of this factor can be improved by the switching of the air conditioning to a more appropriate mode [116,118], and by ensuring that the fire can be effectively suppressed [115]. Direct measures to affect the availability itself would require compartmentation. Closing off the atria would also help (removal or replacement with a sterile tube).

Sample questions arising:

- (1) Can the size and design of the fire space be used to limit the oxygen supply?

Mode of Burning (-). Not Critical [265]

An assumption of a 5MW fire in the office and adequate oxygen supply, will give an unacceptable mode of burning.

Assumed deficiency: 50%

This may have implications for the Rate of Heat Release [110] and the Flame Spread Characteristics [153].

Type of Material (-). Critical [266]

This is an important factor in determining the potential release of smoke. It is a function of material that affects the type of smoke given off. Modern material usage associated with office function may contribute significantly to smoke yield and the fire nature [111,154]. It is assumed deficient.

Sample questions arising:

- (1) What materials choices in design or usage are likely to

create a potential problem, and can the use be limited?

Assumed deficiency: 10%

Internal Temperature (Smoke Movement) (-). Not Critical [267]

It is assumed that the functioning air conditioning unit will keep the building at a reasonably satisfactory and consistent temperature level. In winter the system will maintain a satisfactory internal temperature by heating the air, and in the summer it may have to perform a cooling duty.

In each circumstance there will be a temperature difference between the interior and exterior [125]. In addition, the heat gain of space will influence internal temperatures [127].

Assumed deficiency: nil

External Temperature (Smoke Movement) (-). Not Critical [268]

This factor is discrete. The climatic conditions of the city location are assumed satisfactory for the evaluation.

Assumed deficiency: nil

Height (Smoke Movement)-(-). Critical [269]

There is a deficiency in the evaluated performance of this factor because of the atria. The floor to ceiling heights of each main space are not unacceptable. The atria, stairways, and vertical spaces formed between the inner and outer leaves of the glazing (refer diagrams A56,A51,A52) all provide a significant height for the development of stack effect. The potential consequences for Life Safety will vary with the occupant location in relation to the neutral pressure plane. Level 3 space is assumed for the evaluation. This will be more deficient than level 2 and is assumed for the calculation. See diagram A57.

Limitation of vertical shafts in the building may help prevent the problems of a chimney effect on smoke movement being so

potentially significant in the main spaces (although the tendency for stack is not eliminated by this). Extraction at the roof level may may help lift the neutral pressure plane and reduce risk of smoke spread around level 3.

Sample questions arising:

- (1) Can the potential problems of tall spaces be avoided?
- (2) Alternatively, can the position of the neutral pressure be altered (using power).

Assumed deficiency: 60%

Fire Temperature (-). Critical [270]

The size of the fire assumed for such a space is 5MW (it is likened to a store rather than a conventional office). The smoke movement potential induced by that would be unacceptable [128]. There is no suppression (see later).

An unacceptable fire temperature will give rise to further problems, with tactile information [10], physical and physiological capability [41,43]. Further, it will produce a buoyant smoke, and the contribution of nature of smoke will be affected [142].

Sample questions arising:

- (1) Is the assumed fire size an acceptable design criterion?
- (2) Can the size of the fire be limited?

Assumed deficiency 50%

Ambient Temperature (Smoke Movement) (-). Not Critical [271]

Similar comments as for Internal Temperature - no deficiency.

Mechanically Induced Air Pressure (Smoke Movement) (-). Critical [272]

In this building type it is assumed that HVAC equipment is used for normal air handling - and this may produce the air pressure for smoke movement - This is designed to flow air along the ceiling level (325) on each floor, into the atrium space and away through ventilation louvres. There may be some natural assistance (325). The cut-away section suggests air inlets around building perimeter, extracts around the atrium (diagrams A51,A56).

This means a smoke movement potential across the whole of the space and then into the atria. A tendency of the air pressure developed to push any smoke across the floor plan may create significant problems for the environment.

Additional problems may arise with oxygen supply for the fire [116,117], lack of internal leakage [137] to limit spread and act as a buffer against external leakage [133], and encouragement of flame spread [155].

Sample questions arising:

- (1) Does the HVAC system switch automatically to a more suitable mode for fire conditions?
- (2) If a manual override facility is fitted, will trained personnel always be available?

Assumed deficiency: 50%

Wind Induced Air Pressure (Smoke Movement) (-). Critical [272]

Wind induced pressure should always create a scavenging effect and the top of the atria with appropriate venting controls. Alternatively, there could be counterpressure (to air conditioning) and smoke movement problems.

External Leakage (Smoke Movement) (-). Critical [273]

The effective external leakage is satisfactory if the outer

windows are closed. Openable internal leaves of the double glazing may present a problem in association with the vent louvres at roof level [133] (lack of internal buffer [132]) and HVAC [131]. Vent louvre will require to be fire damped to ensure no spread of fire/smoke through system [210]. Any residual leakage is assumed to be of an acceptable scale.

Assumed deficiency: nil

Internal Leakage (Smoke Movement) (-). Critical [274]

This is unsatisfactory. There is no internal resistance to smoke movement within the building. A fire or products of combustion within the occupied levels could spread throughout the whole building - there is limited fire stopping within and between floors [211].

There is no resistance to smoke movement throughout the building. Possible improvements in the internal leakage potential for smoke movement include omitting or sealing atria (sterile tube method); or use of internal partitioning.

Sample questions arising:

- (1) Is there any resistance to smoke propagation throughout room, floors or building?

Assumed deficiency: 100%

Volume of Space and Design (-). Critical

The volume of the space is certainly very large. However, it is too shallow and wide to create a safe, buoyant layer across its entirety and logging out will occur with all but the most serious fires - downward movement of smoke at the perimeter may be particularly serious because of stair location. Early loss of tenability is likely.

The design of the space has consequences for route effectiveness

[98,107], smoke release [336] and nature [144], rate of burning [335] (re-radiation from low roof!) and fuel supply and distribution [209]

Assumed deficiency: 100%

Introduction to Smoke Control

Considerations of potential smoke movement indicate the requirement for smoke control. Dilution or Removal are the options - spatial layout precludes smoke control by containment (total building pressurisation may be practical, but was not considered for the exercise).

Dilution will probably be unsuitable because of the space shape. Particularly, the floor to ceiling height, and problems of descending neutral pressure plane limit usefulness.

Problems of reservoir provision for smoke control by Removal may occur, because of floor to ceiling height and the distance across which smoke would have to be drawn if atria were used.

Wind leakage through the vents in atria will be problematic (see diagram A51. A positive pressure will drive smoke down onto the floor below; a negative pressure could cause a stagnant area between two removal points.

Practical solutions may be to put in extracts across each ceiling or create sterile tubes from the atria.

The following factors determine the effectiveness of smoke control, and are discussed for dilution and removal techniques only.

Smoke Mass Flow Rate (both models)(-). Critical [276]

Potential smoke mass flow rate is related to smoke yield [140], also related to fire size. The assumed fire size is 5MW, which will produce an unsatisfactory smoke mass flow rate.

The factor is unacceptable whether a dilution or removal system. Consequences for route usage [94] from the space and

identification [69,76] are potentially significant. Particular problems will arise with a dilution technique.

Assumed deficiency: 70% (Removal model)

80% (Dilution model)

Nature of Smoke (both models)(-). Critical [277]

An ageing effect will be caused by the shape of the space [143,144]. Factors include the entry to the atria, smoke travel past corbels (probably marginal because of boundary layer), the poor height, and the excessive travel distance.

The useful time provided by the reservoir in a removal or dilution smoke control technique will be limited by this [183].

Assumed deficiency: 30% (both models)

Surroundings (both models)(+). Not Critical [278]

The location of the building is generally built up (see diagrams A48,A54,A55). Wind passing across the roof is assumed to be turbulent. The roof finishings (garden) will affect the potential scavenging effect of the wind across the atria vents, particularly in the NE direction. A 20% deficiency is assumed because of the roof and the surrounding buildings.

Assumed deficiency: 20% (both models)

Speed (both models)(+). Critical [279]

There is no indication that this factor will be abnormal.

Assumed deficiency: nil (both models)

Direction (both models)(+). Critical [280]

There is no indication of the wind direction either. However the atria may be prone to less effective scavenging (roof ventilation

assistance across domes) in certain wind directions (e.g., NE). The restaurant facility may obstruct flow. A small deficiency is assumed.

Sample questions arising:

- (1) How effective will the scavenging effect of the wind be, and what are the marginal conditions?
- (2) Could a particular wind direction cause failure of the smoke control system?

Assumed deficiency: 10% (both models)

Height (Wind)(both models)-(+). Critical [281]

The building is deliberately set low (see diagram A47). The velocity profile may be disturbed by the adjacent buildings, and a deficiency is assumed. The surroundings are fairly open, and so the deficiency is minor.

Assumed deficiency: 10% (both models)

External Integrity (both models)(+). Critical [282]

The external integrity should be reasonably good. This has differential potential consequences for dilution and removal techniques (removal needs a fresh air inlet). Assuming adequate provisions for resupply of air, no deficiency.

Assumed deficiency: nil (both models)

External Permeability (both models)(+). Critical [283]

Similar comments to external integrity. This factor becomes unsatisfactory if the ventilation louvres and ducting around the perimeter are not damped, or if excessive leakage problems occur around windows and entrances.

Assumed deficiency: nil (both models)

Internal Integrity (both models)(+). Critical [282]

This is unsatisfactory (see also internal leakage). There is no internal integrity within or between the workspaces [159,207]. This will allow smoke to move away from the fire area, causing potential failure of a Dilution system, and severe problems for a removal system relying on the atria for removal. There are consequences of this poor integrity for compartmentation [159], effective choice of alternative routes [85], and limiting fuel supply [207]. Internal subdivisions would provide internal integrity, improving the consequences for other factors [159,85,207].

**Assumed deficiency: 100% (Dilution model)
80% (Removal model)**

Internal Permeability (both models)(+). Critical [283]

Similar comments as for internal integrity. Any poor sealing of vertical pipe runs, and power supplies may further exacerbate the large scale lack of integrity, throughout the building [159].

**Assumed deficiency: 100% (Dilution model)
80% (Removal model)**

Air Conditioning (+). Not Critical [284]

This may affect the efficiency of the smoke control systems - In each case if the air is too warm then a boundary layer at the ceiling of hot air will reduce the effective height, and affect normal buoyant layer formation (possible detection implications because of waffles also). Buoyant layers for removal may not perform properly.

It is assumed that (a) the HVAC system will function properly, and limit the potential problems and (b) that the vents for atria work properly.

Assumed deficiency: nil (both models)

Heat Gain of Space (+). Critical [285]

This may be a problem in the domes of the atria - glass domes in summer may build up excessive temperatures and depress the position of the neutral pressure plane. This will reduce the capacity of the dome to hold smoke, detectors to work, and will make extraction inefficient.

It is thus assumed that there is a 25% deficiency for the factor contribution to a dilution scenario because of loss of effective capacity, and 50% for the removal scenario - here the loss of capacity is compounded by the effect on extraction.

The area of glass in the envelope may cause general problems with the temperature of the workspaces - particularly since the gap between the double glazing leaves acts as the air-conditioning ductwork. See diagram A56.

The use of a sterile tube and extract system across the ceiling grid, and ventilation at the tops of the domes would provide a suitable smoke control which would largely eliminate the potential problems caused by heat gain of space.

**Assumed deficiency: 25% (Dilution model)
50% (Removal model)**

Space Shape (+). Not Critical [286,287]

Dilution [287] - The shape of the space is not particularly problematical, it does not restrict the smoke and so allows a free flow through the building for dilution. There may be a problem related to smoke expansion effects at the perimeter of the atria [143], and as a result of the height of the space. In the context of this factor, no deficiency.

Assumed deficiency: nil (Dilution model)

Removal [287] - Not unacceptable in this scenario either. The

waffles may let the factor contribution down a little, and the requirement to draw the consequently larger volume of smoke for removal [143].

Assumed deficiency: nil (Removal model)

Height of Space (+). Critical [288]

Dilution - There is no height available for a dilution system except in the atria. The smoke would log out on each floor otherwise and could create problems for escape and vision. This may be a particular problem at the perimeter of the floors where all the stairs are, and this is a weak point. The ceiling height is unacceptable (3.350m).

Assumed deficiency: 100% (Dilution model)

Removal - If downstands were used to create reservoirs this could be effective with a grid extract system.

Extraction via the atria, would involve smoke flow through the workspaces. A ceiling downstand at the perimeter of atria would be required to protect the upper floor against the neutral pressure plane dropping, which would prevent smoke control of a fire on the upper floor. Floor to ceiling height unacceptable.

Assumed deficiency: 100% (Removal model)

Length of Space (+). Removal: Critical; Dilution: Not Critical [289]

The performance of this factor appears to be unacceptable for smoke control by removal or dilution. The removal distance for smoke is excessive. There may be problems of maintaining a buoyant layer across such a distance, however the scale of the space is acceptable for dilution.

Assumed deficiency: nil (Dilution model)

50% (Removal model)

Breadth of Space (+). Removal: Critical; Dilution: Not Critical
[290]

In this type of building the breadth is of a similar scale to the length. The same assumptions about performance are made as for length. Minimising the length and breadth of the space by use of reservoir screens and grid extract for a removal system, may help the problem.

Assumed deficiency: nil (Dilution model)
50% (Removal model)

Available Power (+). (Removal model)-Critical [291]

There is mechanical power for air conditioning at the perimeter. If reliable, a variable mode may be used for smoke extraction to the outside. (Alternatively, smoke may be extracted from the workspaces to the atria, if further services were installed). Naturally powered smoke venting may fail because of reliability and effects of surroundings and structure (see earlier). A dedicated system installation in the dome may be a suitable alternative.

Assumed deficiency: nil

Operating Philosophy (+) (Removal model) Critical [292]

Assumptions - The operating philosophy is carried out as intended, and is an effective technique. Any different techniques required for different locations (a flexibility of system response) are implemented.

If extraction is through either the perimeter venting or the atria this will be a deficient technique, and flow problems may occur. A grid extract may provide a superior system.

Assumed deficiency: 50%

Geometry (-). Critical [293]

The geometry of the fuels which would be available for fire spread could be most unacceptable. The layout of office furniture and other associated combustibles to allow fire spread throughout the open-plan workspace. The geometry of the fuels could play a significant part in fire spread. The factor is unacceptable.

The consequences of this deficiency may make the contribution of the factors fuel geometry and orientation [343], mode of burning [121], and fuel supply and distribution [205] a more significant threat.

The geometry of the fuels is a function of usage in this scenario. Control of fire spread may be achieved by effective separation of the fuels [151], using compartmentation.

Assumed deficiency: 70%

Flame Spread Characteristics (-). Critical [294]

This is unknown at the stage of evaluation, and is assumed to satisfy current standards.

Assumed deficiency: nil

Compartmentation (+). Critical [295]

This factor is totally deficient for the workspaces under consideration. The stairways are assumed protected. Within each workspace (600 occupants), and between each floor (atria) there is totally unacceptable compartmentation. There is no (active or passive) fire stopping. There are implications of this deficiency for the choice of alternative routes [95] (cf; Summerland) and existence of information [2,5,13,16,19].

Assumed deficiency: 100%

The above evaluation of the performance of the tertiary level

factors may be summarised in a tabular form for each of the smoke control models, dilution and removal. See lists below; diagrams A58,A59,A60.

Diagrams A61,A62 represent the evaluated performance of the pro-safety factors, diagrams A63,A64 the pro-threat factors for each of the time stages.

Based on the potential contributions at each of the time stages the evaluated 'actual' contributions are derived. These are presented in tabular form - see diagrams A65,A66,A67,A68.

The algebraic summation of the evaluated contributions may be derived, and are presented in diagram A69.

Diagram A58. Factors assumed to be acceptable

Existence of Aural Information.	Psychological Capacity.
Existence of Visual Information.	Building Knowledge.
Event Knowledge.	Location Identification.
General Fire Safety Knowledge.	Width of Route.
Specific Fire Safety Knowledge.	Ignition Source.
Route Choice Identification.	Internal Temperature.
External Temperature.	Ambient Temperature.
External Leakage.	Speed.
External Integrity.	External Permeability.
Length of Space (Dilution).	Mode of Burning.
Breadth of Space (Dilution).	Space Shape.
Available Power (Removal).	Air Conditioning.
Flame Spread Characteristics.	

Diagram A59. Factors assumed to be 100% deficient

Existence of Tactile Information.
Existence of Gustatory Information.
Existence of Olfactory Information.
Volume of Space and Design.
Internal Integrity (Dilution).
Internal Permeability (Dilution).

Height of Space.
Compartmentation.
Internal Leakage.

Diagram A60. Summary of partially deficient factors

Values apply to both smoke control models unless otherwise stated.

Ability to Perceive: Aural (5%).
Ability to Perceive: Visual (5%).
Ability to Perceive: Tactile (5%).
Ability to Perceive: Gustatory (5%).
Ability to Perceive: Olfactory (5%).
Physical Capability (10%).
Physiological Capability (10%).
Obstructions (50%).
Choice of Alternative Routes (50%).
Length of Route (50%).
Fuel Geometry and Orientation (50%).
Rate of Heat Release (50%).
Oxygen Supply (70%).
Bulk Density (10%).
Type of Material (10%).
Height (Ambient Stack) (60%).
Fire Temperature (50%).
Air Pressure Developed (50%).
Smoke Mass Flow Rate (70% Removal; 80% Dilution).
Nature of Smoke (30%).
Surroundings (20%).
Direction (10%).
Height (of Wind) (10%).
Internal Integrity (80% Removal; 100% Dilution).
Internal Permeability (80% Removal; 100% Dilution).
Heat Gain of Space (50% Removal; 25% Dilution).
Length of Space (50% Removal).
Breadth of Space (50% Removal).
Operating Philosophy (50% Removal).

Geometry (70%).

The evaluated performance of factors can be summarised, and those factors that are critical identified. This is done for each smoke control technique. See diagrams A70 (Dilution), A71 (Removal).

Diagram A70. Listing of factors and deficiencies

Dilution model

		Deficiency	Critical Improvement
Existence of Information Tactile	100%	No	No
Existence of Information Gustatory	100%	No	No
Existence of Information Olfactory	100%	No	No
Ability to Perceive Aural	5%	No	No
Ability to Perceive Visual	5%	No	No
Ability to Perceive Tactile	5%	No	No
Ability to Perceive Gustatory	5%	No	No
Ability to Perceive Olfactory	5%	No	No
Physical Capability	10%	Yes	No
Physiological Capability	10%	Yes	No
Obstructions	50%	Yes	Yes
Choice of Alternative Routes	50%	Yes	Yes
Length of Routes	50%	Yes	Yes
Rate of Heat Release	50%	Yes	Yes
Fuel Geometry and Orientation	50%	Yes	Yes
Oxygen Supply	70%	Yes	Yes
Bulk Density	10%	No	No
Type of Materials	10%	Yes	No
Height (ambient stack)	60%	Yes	Yes
Fire Temperature	50%	Yes	Yes
Air Pressure Developed	50%	Yes	Yes
Internal Leakage	100%	Yes	Yes
Smoke Mass Flow Rate	80%	Yes	Yes
Nature of Smoke	30%	Yes	Yes
Surroundings	20%	No	No

Heat Gain of Space	25%	Yes	Yes
Height of Space	100%	Yes	Yes
Geometry	70%	Yes	Yes
Compartmentation	100%	Yes	Yes
Internal Integrity	100%	Yes	Yes
Internal Permeability	100%	Yes	Yes

Diagram A71. Listing of factors and deficiency

Removal model

		Deficiency	Critical Improvement
Existence of Information Tactile	100%	No	No
Existence of Information Gustatory	100%	No	No
Existence of Information Olfactory	100%	No	No
Ability to Perceive Aural	5%	No	No
Ability to Perceive Visual	5%	No	No
Ability to Perceive Tactile	5%	No	No
Ability to Perceive Gustatory	5%	No	No
Ability to Perceive Olfactory	5%	No	No
Physical Capability	10%	Yes	No
Physiological Capability	10%	Yes	No
Obstructions	50%	Yes	Yes
Choice of Alternative Routes	50%	Yes	Yes
Length of Routes	50%	Yes	Yes
Rate of Heat Release	50%	Yes	Yes
Fuel Geometry and Orientation	50%	Yes	Yes
Oxygen Supply	70%	Yes	Yes
Bulk Density	10%	No	No
Type of Materials	10%	Yes	No
Height (ambient stack)	60%	Yes	Yes
Fire Temperature	50%	Yes	Yes
Air Pressure Developed	50%	Yes	Yes
Internal Leakage	100%	Yes	Yes
Smoke Mass Flow Rate	70%	Yes	Yes
Nature of Smoke	30%	Yes	Yes
Surroundings	20%	No	No

Heat Gain of Space	50%	Yes	Yes
Height of Space	100%	Yes	Yes
Geometry	70%	Yes	Yes
Compartmentation	100%	Yes	Yes
Internal Integrity	80%	Yes	Yes
Internal Permeability	80%	Yes	Yes
Length of Space	50%	Yes	Yes
Operating Philosophy	50%	Yes	Yes

As a result of this, a number of factors emerge as failures as a result of inadequacies in design/ assumed usage, and are given suggestions for improvement:

Obstructions - Less travel distance, less likelihood of obstructions of layout (atria included) and less risk of fire affecting whole floor or floors.

Choice of Alternative Routes - Less travel distance, such as may be provided by a central stairway provision.

Length of Route - Lesser distance to a protected route. The protected routes appear to be of satisfactory length.

Rate of Heat Release - Reduce potential rate of heat release in respect of smoke release by more appropriate choice of materials.

Fuel Geometry and Orientation - A compartmentalisation of the space may lead to an improvement in this factor. Loose papers may be an unavoidable problem, and a long expanse of carpet or underfloor ductwork may be unacceptable.

Oxygen Supply - Subdividing the workspace, or closing off the atria (removal or creation of a sterile tube) may improve this.

Height (Ambient Stack) - Reducing the maximum height across which stack can occur (positive or negative stack) is an important factor in the reduction of potential smoke movement problems. Removal of atria or creation of a sterile tube are suitable

approaches.

Fire Temperature - Speed of application and effectiveness of Fire Suppression techniques will be important features in the reduction of the deficiency of this factor.

Air Pressure Developed - Design of HVAC may allow relatively easy smoke spread. Redesign of air circulation may reduce the deficiency of this factor and improve the potential for smoke control. The waffle ceiling may interfere with the nature of air movement near the ceilings of the workspaces.

Internal Leakage - There are no internal partitions, and consequently there are no passive restrictions on smoke movement. Subdividing the workspaces would ease protection against smoke spread.

Smoke Mass Flow Rate - Reduction of the available fuel load (e.g., compartmentalisation), or improved suppression could improve the evaluated performance of this factor.

Nature of Smoke - This is determined by the geometry of the building, and only a major redesign could alter the performs of this factor significantly. A sterile tube(s) and an improved ceiling surface may help.

Heat Gain of Space - This could be improved by altering the design of the domed atria (assumed to be glass). The creation of a sterile tube would largely eliminate the problems of heat gain in the atria. Some control of heat gain in the workspace may be achieved with sunshades.

Height of Space - The floor to ceiling height is too little in relation to the size of the space and the amount of smoke that could be produced. Redesign of the building may improve this - the potential problems of stack effect in the atria may be reduced by the creation of a sterile tube.

Geometry - Large open spaces allow potentially rapid spread of fire across the workspace. Control of materials in use is only practical with a subdivided space.

Compartmentation - Workspace subdivision, and integrity of floors will create compartmentalised spaces.

Internal Integrity and Internal Permeability - may be improved by subdivision.

Length of Space (Removal) - Length of individual spaces can be minimalised by subdivision of the workspace.

Operating Philosophy - Redesign of the space may allow for a practical smoke removal philosophy.

Other factors which fail are less practical to rectify, and are likely to remain weaknesses in the scenario. Design and usage of the building must cater for the deficiencies in these factors:

Existence of Tactile Information
Existence of Gustatory Information
Existence of Olfactory Information
Ability to Perceive
Physical Capability
Physiological Capability

There are implications for other factors in the model, because of the interactive nature of the system. An exercise to establish which factors would be affected by a knock-on effect of evaluated deficiencies was carried out. The results are presented in the listing below.

Diagram A72. Listing of interactions creating knock-on deficiencies

Values in square brackets are estimated knock-on effects.

- (1) **Existence of Tactile Information (100%).**
None
- (2) **Existence of Gustatory Information (100%).**
None
- (3) **Existence of Olfactory Information (100%).**
None
- (4) **Ability to Perceive: Aural (5%).**
None
- (5) **Ability to Perceive: Visual (5%).**
None
- (6) **Ability to Perceive: Tactile (5%).**
None
- (7) **Ability to Perceive: Gustatory (5%).**
None
- (8) **Ability to Perceive: Olfactory (5%).**
None
- (9) **Physical Capability (10%).**
Obstructions [25%]
Ability to Perceive [10%]
Psychological Capacity [5%]
- (10) **Physiological Capability (10%).**
Psychological Capability [5%]
Physical Capability [20%]
- (11) **Obstructions (50%).**
Mobility [50%]
Event Knowledge [5%]
Choice of Alternative Routes [50%]
Width of Route [30%]
Length of Route [50%]
- (12) **Choice of Alternative Routes (50%).**
Obstructions [20%]
Exit Route Capacity [5%]
- (13) **Length of Route (50%).**
Physiological Capability [80%]
Obstructions [80%]
Volume and Design of Space [25%]
- (14) **Rate of Heat Release (50%).**

- Existence of Tactile Information [5%]
- Physical Capability [100%]
- Physiological Capability [100%]
- Obstructions [100%]
- Choice of Alternative Routes [100%]
- Mode of Burning [25%]
- Fire Temperature [100%]
- Nature of Smoke [+10%]
- Flame Spread Characteristics [20%]
- Fuel Supply and Distribution [50%]
- Compartmentation [100%]
- (15) **Fuel Geometry and Orientation (50%).**
 - Mode of Burning [100%]
 - Fuel Supply and Distribution [60%]
- (16) **Oxygen Supply (70%).**
 - Physiological Capability [+5%]
 - Mode of Burning [100%]
- (17) **Bulk Density (10%).**
 - Rate of Heat Release [50%]
 - Mode of Burning [60%]
- (18) **Type of Material (10%).**
 - Rate of Heat Release [50%]
 - Flame Spread Characteristics [60%]
- (19) **Height (Ambient Stack) (60%).**
 - None
- (20) **Fire Temperature (50%).**
 - Existence of Tactile Information [+5%]
 - Physical Capability [100%]
 - Physiological Capability [100%]
 - Nature of Smoke [+10%]
- (21) **Air Pressure Developed (50%).**
 - Internal Leakage [100%]
 - External Leakage [20%]
 - Flame Spread Characteristics [50%]
 - Oxygen Supply [20%]
- (22) **Internal Leakage (100%).**
 - External Leakage [20%]
 - Fire Stopping [100%]

- (23) **Smoke Mass Flow Rate (70% Removal; 80% Dilution).**
 - Existence of Information (not Aural) [5%]
 - Location Identification [80%]
 - Route Choice Identification [80%]
 - Choice of Alternative Routes [100%]
 - Reservoir Size and Design (Removal) [20%]
- (24) **Nature of Smoke (30%).**
 - Reservoir Size and Design (Removal) [20%]
- (25) **Surroundings (20%).**
 - None
- (26) **Heat Gain of Space (50% Removal; 25% Dilution).**
 - None
- (27) **Length of Space (50% Removal).**
 - Fuel Supply and Distribution [20%]
 - Compartmentation [30%]
 - Length of Route [10%]
- (28) **Operating Philosophy (50% Removal).**
 - None
- (29) **Geometry (70%).**
 - Fuel Geometry and Orientation [50%]
 - Mode of Burning [60%]
 - Fuel Supply and Distribution [60%]
- (30) **Compartmentation (100%).**
 - Existence of Information (all) [+10%]
 - Choice of Alternative Routes [100%]
- (31) **Internal Integrity (100%).**
 - Compartmentation [100%]
 - Fuel Supply and Distribution [100%]
 - Choice of Alternative Routes [100%]
- (32) **Internal Permeability (100%).**
 - Compartmentation [100%]
 - Fuel Supply and Distribution [100%]
 - Choice of Alternative Routes [100%]

The factors affected by knock on effects may be summarised:

Diagram A73. Factors affected by knock-ons

(1) Obstructions:	
Physical Capability	25%
Choice of Alternative Routes	20%
Length of Route	80%
Rate of Heat Release	100%
(2) Ability to Perceive:	
Physical Capability	10%
(3) Psychological Capacity:	
Physical Capability	5%
Physiological Capability	5%
(4) Physical Capability:	
Physiological Capability	20%
Rate of Heat Release	100%
Fire Temperature	100%
(5) Mobility:	
Obstructions	50%
(6) Event Knowledge:	
Obstructions	5%
(7) Choice of Alternative Routes:	
Obstructions	50%
Rate of Heat Release	100%
Smoke Mass Flow Rate	100%
Compartmentation	100%
Internal Integrity	100%
Internal Permeability	100%
(8) Width of Route:	
Obstructions	50%
(9) Length of Route:	
Obstructions	50%
(10) Exit Route Capacity:	
Choice of Alternative Routes	5%
(11) Volume and Design of Space:	
Length of Route	25%
(12) Existence of Information:	
Rate of Heat Release (tactile)	+5%
Fire Temperature (tactile)	+5%
Smoke Mass Flow Rate (not aural)	+5%

	Compartmentation (all)	10%
(13)	Mode of Burning:	
	Rate of Heat Release	20%
	Fuel Geometry and Orientation	50%
	Bulk Density	60%
(14)	Fire Temperature:	
	Rate of Heat Release	100%
(15)	Nature of Smoke:	
	Rate of Heat Release	+10%
	Fire Temperature	+10%
(16)	Flame Spread Characteristics:	
	Rate of Heat Release	20%
	Type of Material	60%
	Air Pressure Developed	50%
(17)	Fuel Supply and Distribution:	
	Rate of Heat Release	50%
	Oxygen Supply	100%
	Fuel Geometry and Orientation	60%
	Length of Space (Removal only)	20%
	Internal Integrity	100%
	Internal Permeability	100%
(18)	Compartmentation:	
	Rate of Heat Release	100%
	Length of Space (Removal only)	30%
	Internal Integrity	100%
	Internal Permeability	100%
(19)	Air Pressure Developed:	
	Oxygen Supply	70%
(20)	Rate of Heat Release:	
	Bulk Density	50%
	Type of Material	50%
(21)	Internal Leakage:	
	Air Pressure Developed	100%
(22)	External Leakage:	
	Air Pressure Developed	20%
	Internal Leakage	20%
(23)	Oxygen Supply:	
	Air Pressure Developed	20%

(24) Fire Stopping:	
Internal Leakage	100%
(25) Location Identification:	
Smoke Mass Flow Rate	80%
(26) Route Choice Identification:	
Smoke Mass Flow Rate	80%
(27) Reservoir Size and Design:	
Smoke Mass Flow Rate (Removal only)	20%
Nature of Smoke	20%
(28) Internal Temperature:	
Heat Gain of Space	30%
(29) Fuel Geometry and Orientation:	
Geometry	50%

As a result of the (a) evaluated deficiencies of factors and (b) the extra problems identified as a result of knock-on effects the following factors fail (ie: greater than 100% deficiency):

- (a) Existence of Tactile Information
- Existence of Gustatory Information
- Existence of Olfactory Information
- Internal Leakage
- Height of Space
- Compartmentation
- Internal Integrity

(Existence of Information deficiency not considered unacceptable in this scenario)

- (b) Obstructions
- Physical Capability
- Choice of Alternative Routes
- Length of Route
- Mode of Burning
- Fire Temperature
- Flame Spread Characteristics
- Fuel Supply and Distribution

Air Pressure Developed
Rate of Heat Release
Fire Stopping
Fuel Geometry and Orientation

Net safety/threat values for Standard Life proposed building.

Improvements

The improvement values for the deficient factors are effectively used to provide a 'new' evaluated value on the basis of a 'new' building proposal.

Note how each successive increased package of improvements increases the performance of the building.

It was intended originally to produce two packages of improvements for the building. However, this is in effect already in implementation.

Improvements

(1) Sterile tube or remove atria

The Sterile Tube improvement is based on the (GLC) concept of a fire resisting glass tube that encloses the atria. The glass allows the functions of the atria (except air circulation) to take place, and thus prevents smoke movement. The problematic factors that this would improve:-

- (1) **Oxygen Supply** (to the fire) - A great improvement but still an excess available and still serious.

Residual deficiency: 30%

- (2) **Height** (ambient stack) - A vast improvement. There is now

no deficiency in respect of ambient stack and smoke movement.

Residual deficiency: nil

- (3) **Volume of Space and Design** - Improved, but large scale space means still not totally safe.

Residual deficiency: 80%

- (4) **Nature of Smoke** - Improved by removal of balcony effect.

Residual deficiency: 20%

- (5) **Surroundings** - The problem with surroundings may become less if the atria are not subject to natural ventilation. Still a problem for other high parts of the building.

Residual deficiency: 10%

- (6) **Heat Gain of Space** - May be better if the heat gain within the domes becomes irrelevant. There is still a great potential from the windows for heat gain.

Residual deficiency: 25%

- (7) **Compartmentation** - Vast improvement in respect of separation between floors, but still a problem within floors.

Residual deficiency: 90%

If in addition to the sterile tube, there is an automatic extract into the tube based on a balanced design, there may be additional improvements to :-

- (8) **Smoke Mass Flow Rate (Removal)** - There will be less of a problem with the smoke if the tube is used as a reservoir for removal. The problem of smoke mass flow rate on the

floor of origin is still potentially serious, although restricted to one floor.

Residual deficiency; 50%

(9) **Operating Philosophy** - There is now no deficiency, assuming that that smoke removal to the sterile tube is automatic and linked to the existing air conditioning system so as not to work in opposition. The existing air conditioning may be used as an inlet.

Residual deficiency: nil.

Deficient factors not improved by this measure

Existence of Tactile Information.	Ability to Perceive.
Existence of Gustatory Information.	Physical Capability.
Existence of Olfactory Information.	Physiological Capability.
Obstructions.	Rate of Heat Release.
Fuel Geometry and Orientation.	Bulk Density.
Type of Material.	Fire Temperature.
Air Pressure developed.	Geometry.
Choice of Alternative Routes.	Length of Routes.
Height of Space.	Internal Integrity.
Internal Permeability.	Length of Space.

(2) **Extract System for Removal**

The practicality of this is limited because of the floor to ceiling height. Ducting may be run through the floor void above and into the sterile tube (it is assumed that this option would be used in conjunction with the sterile tube). See diagram A74. The problematic factors this would improve:-

(1) **Air Pressure Developed** - a linked air conditioning and smoke removal system would eliminate the potential problem of conflicting air handling.

Residual deficiency: nil

- (2) **Volume and Design of Space** - Further improvements over sterile tube improvement if extraction used in conjunction.

Residual deficiency: 25%

- (3) **Nature of Smoke** - A residual deficiency related to the travel distance and disruptive effects of the waffle floor.

Residual deficiency: 10%

- (4) **Smoke Mass Flow Rate** - In conjunction with the improvement of the sterile tube, there is a further reduction in the residual deficiency.

Residual deficiency: 25%

- (5) **Length of Space** - A small residual deficiency as a result of the distance for smoke travel

Residual deficiency: 10%

- (6) **Height of Space** - The provision of reservoirs and frequent extraction vents is assumed to remove the residual deficiency.

Residual deficiency: nil

Deficient factors not improved by this measure

Existence of Tactile Information.	Ability to Perceive.
Existence of Gustatory Information.	Physical Capability.
Existence of Olfactory Information.	Physiological Capability.
Obstructions.	Rate of Heat Release.
Fuel Geometry and Orientation.	Bulk Density.
Type of Material.	Fire Temperature.
Internal Permeability	Geometry.

Choice of Alternative Routes.
Internal Integrity.

Length of Routes.

The two improvements have largely eliminated the smoke movement and smoke control problems (excepting internal integrity and permeability)

(3) Compartmentation

Each workspace is compartmentalised into three open plan spaces, each with a sterile tube. See diagram A75. Used in conjunction with improvements 1 and 2, the problematic factors this would improve are:-

- (1) **Fuel Geometry and Orientation** - this is reduced by the subdivision of the spaces.

Residual deficiency: 10%

- (2) **Oxygen Supply** - Deficiency assumed acceptable.

Residual deficiency: nil

- (3) **Rate of Heat Release and Fire Temperature** - The deficiencies of these factors are reduced significantly by the reduced size of space.

Residual deficiency: 25%

- (4) **Volume of Space and Design** - The reduced volume limits the deficiency.

Residual deficiency: 10%

- (5) **Internal Leakage** - Assumed satisfactory.

Residual deficiency: nil

(6) **Nature of Smoke** - A smaller space for smoke movement, however problems of waffle ceiling remain.

Residual deficiency: 5%

(7) **Smoke Mass Flow Rate** - Reduced because of the lower volume, the potential problem is limited to a smaller proportion of the building.

Residual deficiency: 10%

(8) **Geometry** - Improved because of a smaller space.

Residual deficiency: 10%

(9) **Internal Integrity and Internal Permeability** - assumed satisfactory.

Residual deficiency: nil

(10) **Length of Space** - Compartmentation removes problems of length to draw smoke over. Adequate inlets assumed.

Residual deficiency: nil

Deficient factors not improved by this measure

Existence of Tactile Information.	Ability to Perceive.
Existence of Gustatory Information.	Physical Capability.
Existence of Olfactory Information.	Physiological Capability.
Obstructions.	Bulk Density.
Choice of Alternative Routes.	Length of Routes.
Type of Materials.	

(4) **Central Stairway**

The inclusion of a central stairway used in conjunction with improvements 1,2 and 3. See diagram A76. This would improve the

following factors:-

- (1) **Volume of Space and Design** - Easier to evacuate.

Residual deficiency: nil

- (2) **Obstructions** - No length of travel obstruction.

Residual deficiency: nil

- (3) **Choice of Alternative Routes** - Now satisfactory because of increased access.

Residual deficiency: nil

- (4) **Smoke Mass Flow Rate** - Now almost acceptable.

Residual deficiency: 5%

- (5) **Length of Route** - now assumed satisfactory.

Residual deficiency: nil

- (6) **Physical and Physiological Capabilities** - Now assumed to be of acceptable performance.

Residual deficiency: nil

Deficient factors not improved by this measure

Existence of Tactile Information.	Ability to Perceive.
Existence of Gustatory Information.	Type of Materials.
Existence of Olfactory Information.	Bulk Density.
Rate of Heat Release	Fire Temperature.

(5) Life Safety Sprinklers

The installation of life safety sprinklers in each workspace.

The use of this improvement in conjunction with improvements 1,2,3, and 4 will improve the following factors:-

- (1) **Rate of Heat Release and Fire Temperature** - now assumed to be acceptable.

Residual deficiency: nil

- (2) **Fuel Geometry and Orientation** - a minimal deficiency remains.

Residual deficiency: 5%

- (3) **Bulk Density** - now controlled by the fire suppression effect.

Residual deficiency: nil

- (4) **Type of Materials** - a residual deficiency.

Residual deficiency: 5%

- (5) **Smoke Mass Flow Rate** - This becomes 'acceptable'.

Residual deficiency: nil

- (6) **Geometry** - this also is now assumed acceptable.

Residual deficiency: nil

The above improvements and the residual deficiencies can be converted into values for relative contributions. This is done for each factor affected by an added improvement measure. The revised deficiencies and relative contributions for factors affected by the improvements are presented in diagrams A77-A108. The net safety/threat values for each of the improvements can be calculated (diagrams A109-A113) and displayed graphically. See diagram A114. As the problems with deficient factors are

eliminated or minimised by the inclusion of improvements, so the net safety/threat level approaches the 'optimal' level. A number of residual deficient factors prevent optimal safety levels being attained. A net threat remains in stage 1 ('optimal' performance showed a small net threat value in stage 1 for removal (not activated at this stage)), however in the subsequent stages there is an increasing net safety level.

Suggestions and assumed performances required

Create sterile tubes or remove atria.

Smoke control by Dilution impractical, provide a variable extract system for smoke Removal.

Compartmentation and a central set of stairs.

Supply of inlets for air conditioning and smoke Removal system.

Assumed:

Fire suppression (e.g., life safety sprinklers)

Automatic fire detection and alarm (relayed).

Emergency lighting.

Effective dissemination of information.

General and Specific Fire Safety training.

Adequate location and route choice signage.

Maintenance of clear travel routes in workspaces.

Uniform population distribution.

Fire controlled at 5MW.

Satisfactory temperature control.

Ductwork damped.

Glass domes to atria.

Fire doors to stairs.

Satisfactory flame spread characteristic materials used throughout.

Under-floor void fitted with detectors and adequately fire stopped.

Switchable smoke control system.

Ventilation louvres in dome designed to prevent inflow.

No compromise of route facilities as a result of restaurant

(after hours usage); sports hall; car park.
Unannounced changes in layout limited.

Appendix 5. Reports on Victoria Nurses' Home.

REPORT ON THE FIRE AT THE NURSES' HOME, VICTORIA HOSPITAL,
KIRKCALDY, ON FRIDAY 13 NOVEMBER, 1981.

by

D D Drysdale, D J Rasbash and E W Marchant.

1. Introduction

The fire which broke out in the Nurses' Home of the Victoria Hospital, Kirkcaldy, on 13 November 1981, had many unusual features. The time of ignition is not known accurately, but when the alarm was sounded, the fire had already grown to such proportions that within a few minutes several of the occupants of the rooms on the fire floor had to climb out of their windows, some being compelled to jump for their lives. The single fatality, whose body was found in the corridor a considerable distance from her room, appeared to have been caught in a flash fire and had quickly perished, rather than succumbing to the toxic gases present in fire gases. This suggests that a confined fire suddenly burst out into the corridor, trapping the victim, and thereafter spreading rapidly to involve the corridor and threaten the individual rooms.

While the subsequent stages of the fire are of considerable interest from the point of view of fire spread within buildings, this report is concerned mainly with the early stages of the fire. Thus it is devoted to an analysis of the evidence relating to the fire, leading to a discussion of the location of the seat of the fire and the mechanism by which the fire could have developed so rapidly to involve the second floor corridor.

2. Level C and its contents

A plan of the Second (or "C") floor of the nurses' home is shown in Figure 1. The six floors are designated A - F, of which B - F are almost identical. The frame of the building, which incorporates some of the internal walls, is of reinforced concrete. Other walls are of either brick or hollow clay block. The floors are reinforced concrete with hollow tile blocks set in the underside. Conduit carrying the electrical wiring of the building appeared to be encased in the floor slabs.

On floor C, the walls were plastered and covered with several layers of paint. The bedroom ceilings were similar, but the corridor had a false ceiling consisting of a coarse fibreboard on a timber framing. The underside of the fibreboard was treated with a fire retardant paint. The floor was covered with tiles (probably PVC) and carpet, the nature of which is still to be identified.

Two stairways giving access to the outside exist, one at each end of the corridor, each separated from the corridor by a self-closing fire door and screen, comprising a large area of wired glass. The bedroom doors do not have self-closers and are of very flimsy construction, two leaves of 1/8 inch plywood on framing, with an internal "egg box" structure to provide some rigidity.

All bedrooms on level C (except C.14 which was perhaps originally intended as a study room) are partially divided by a timber stud partition, timber-faced on the window side, but with plasterboard facing the door. Between the corridor (door) wall and the partition there is a built-in wardrobe on one side and a wash hand basin on the other (see figure 1). Beside the basin is a service duct which runs the height of the building: this juts into the room and while one side is of brick, the other side consists of 6mm plywood on timber framing.

The commonroom area, situated at the west end of the corridor near the west stair, is completely open to the corridor, although a rack of shelving with a low level cupboard effectively divides this area from the corridor. It contains a television set, an electric fire, a number of easy chairs (upholstered with latex foam) and two or three low coffee tables (Plate 1).

Towards the east end of the corridor, to the west of the bathrooms and toilet, there is an alcove which contains a telephone booth and provides access to two self-contained bathrooms and a small cleaners' cupboard. The windows of the commonroom and alcove areas overlook Hayfield Road, and were provided with curtains.

Other than the items noted above, no other combustible materials should have been present in the corridor, the commonroom or the alcove. None of the witnesses' statements suggests otherwise.

along the entire length of F floor", She began to run east, shouting to alert the other girls, when the fire alarm sounded: by this time the smoke was thick enough to prevent her going beyond the 'midway' point in the corridor (telephone recess?). The fire door at the east end of F floor was open .

Clearly, it is not possible to pinpoint an exact time at which the fire started from these statements, particularly as estimates of time intervals by individuals under these circumstances are known to be unreliable. However, it would seem that the fire was well developed at least five minutes before the alarm was sounded (Hopton and colleagues) and was perhaps burning five minutes before noises were heard on B floor (Lawson (F.15)), although this is less certain.

A. B. W. F.?

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The fire was probably discovered by the deceased, Goodall (C.14). Reports suggest that she was conscious of the risk of fire in the nurses' home so that it is puzzling why she did not raise the alarm. The post-mortem report suggests that she died as a result of being enveloped in flames and hot gases (heat searing of the larynx and upper trachea) rather than by inhalation of toxic gases (blood carbon monoxide saturation 11 per cent, which is not much higher than that to be expected of a heavy smoker: Goodall was a "fairly heavy smoker" according to Hill (C.11)). Either Goodall was totally unaware of any danger and just happened to be on the way to or from the toilet when the fire suddenly erupted, or she was suspicious that something was wrong (a smell of smoke, perhaps) and was investigating at the time. The latter seems more likely as she was seen going to and from the toilet at about 2315 hrs (McNeil (C.16)). Moreover, her bedroom door was found open after the fire and there was evidence that she may already have been in bed (statement by Police Sergeant Kinnison). Whichever is the case, the fire must have been hidden from view when Goodall walked along the corridor, otherwise she would have raised the alarm.

From the position of the deceased's body (lying face downwards outside C.18 on the north side of the corridor with her head towards the west end of the corridor) the fire that engulfed her is more likely to have originated to

the east of C.18. This is somewhat speculative, but a person suddenly engulfed in flames will not be capable of moving far. This is a different situation from that in which a person's clothing catches fire. Under these circumstances, an individual could run a considerable distance before collapsing. * If the deceased had screamed for any length of time, she would have been heard. Only two nurses admit to being wakened by screaming before the alarm rang: Marini in C.4 and Thomson in C.15. (At the other end of the corridor, Taylor (C.12A) was also wakened by screaming but did not hear the alarm). Thomson's neighbour (McNeil (C.16)) was wakened by noises, found smoke coming under her door, and established that there were flames in the corridor. She admits to screaming to alert Thomson (C.15) and Duncan (C.17), which could account for Thomson's awakening. Duncan does not report hearing screams, although she was awake well before the alarm sounded. Rooms C.1, C.5, C.6 and C.18 (Hopton) were vacant at the time, so that if Goodall did scream, then one would expect the occupants of C.2 (Jamieson), C.3 (Russell) and C.4 (Marini) to have heard her. However, Jamieson was wakened by noises immediately before the alarm, and Russell (at the time her statement was taken) could remember nothing at all about the fire. Marini (C.4) recalled that the alarm sounded shortly after she heard "girls screaming". She too found flames in the corridor, and shortly afterwards the fire broke into her room. As the fire was apparently well established in the corridor when Marini woke, the screams are unlikely to have been those of the deceased (she may have heard Russell (C.3) although there is nothing to support this suggestion).

It would seem that no one heard Goodall at the time she was overcome: either she could not scream or could not scream effectively, both alternatives being compatible with her being engulfed in flame. The origin of this event must now be considered.

Possible origins of flame that may have engulfed the deceased
Except for the deceased, it would appear that the occupants of C level were aroused only when the fire was well-established in the corridor. Thomson (C.15) recalls the flames being to the east of her room when she investigated, but all others to the east of the commonroom area spoke of flames outside their rooms when they opened their doors slightly. It

3. Sequence of events

Table 1 gives the location of the residents at the time of the fire. From statements of these residents, it has been possible to build up a reasonable picture of everyone's movements. The fire alarm was activated at 0057 hrs on 13 November. Noises were heard during a period of about 5 minutes before this time. Working back, it would seem that the fire was already well established by 0050 hrs. All the occupants of floor C - with the exception of Hopton (C.18) - were in bed: two retired after midnight (C.9 and C.15) but reported nothing unusual.

It is necessary to examine the statements of eight nurses who were still up and about at the time the alarm was raised. Four nurses were in the commonroom area of level B, viz Quinn (B.2), Pearson (B.9), Brealey (B.12) and Hopton (C.18): two were in the toilet of level D (Petrie (D.6) and Connell (D.7)), one was in the commonroom at E level (Thorvaldsen (E.17)), and the eighth was in the corridor on F level (Lawson (F.15)).

The alarm was raised by Hopton and her companions who had been aware of banging noises coming from the floor above (i.e. C level). They assumed this to be some girls "larking about" and did nothing for a few minutes. As the noises were continuing, Hopton and Quinn decided to investigate. Quinn (B.12) stated that she heard a very loud thump as they were on their way. Hopton (C.18) went up to C level by the west stair (Quinn only climbed to the landing between B and C) and opened the door to look into C corridor. She states that the corridor was full of smoke and that she could only just see the commonroom area (4-5m). No flames or glow were noted. Hopton called to the others to sound the alarm, which was activated by Pearson (B.9). The call point was only 2m or so to the east of the exit on to the west stair. The statements by the four nurses involved are in general agreement, although Pearson states that on stepping back from the fire door to sound the alarm, she noticed smoke coming from the commonroom clock which is not visible from this part of the corridor. It may be that she had noticed smoke before moving to the fire escape door

with the others. Another contradiction is that Quinn states that from the half-landing she saw smoke and the glow of flames on C level through the fire door, although Hopton recalls seeing only smoke when she looked into the corridor. Brealey (B.12) states that she saw smoke entering the west stairwell from C level when Hopton opened the door to investigate, although Pearson (B.9) does not remember Brealey leaving the commonroom area.

Despite these anomalies, which could be attributed to the state of confusion that these witnesses must have experienced, they are all agreed that they began to hear noises from C level about 5 minutes before deciding to investigate. Given that the alarm was operated at 0057 hours, the noises must have started around 0050-0052 hours approximately.

On D level, the floor above the fire floor, Connell (D.7) reports smelling smoke faintly in the area of the bathroom, shortly after checking the time on the clock in the commonroom area. This would be about 0056. She commented to Petrie (D.6) who was also in the bathroom area. The fire alarm sounded shortly afterwards. Robertson (D.15) reported that she smelt smoke in her room immediately before the fire alarm sounded. These witnesses all recall seeing smoke coming from around the door of the lift, immediately to the east of the toilet/bathroom (the fire door at the east end of D corridor was closed, and remained closed throughout the fire). No noises were reported.

Torvaldsen (E.17) was sitting in the commonroom on E floor and heard noises like "someone running about", just before the fire alarm sounded. This could have been Lawson (F.15) already alerted to the fire (next paragraph). On leaving the commonroom area, she found that the east end of the corridor was full of black smoke (the fire door at the east end of E floor was open).

On the top floor (F), Lawson (F.15) states that she "smelt faint smoke in the area of the sittingroom" at about 0035 hours. She checked the kitchen (immediately to the west) and on satisfying herself that all was in order, she went to her room, leaving the door open. "About 10 minutes later", she smelt smoke again and this time found "dark grey smoke floating about,

would be unwise to place too much reliance on the individual statements but Thomson's statement was quite categorical, indicating a fire to the east of C.15. Jamieson (C.2) remembers seeing only smoke when she first peaked round her door, but reports flames when she looked again after a short interval. Jamieson and Thomson (C.15) probably looked out at about the same time (i.e. shortly after the alarm sounded). The initial fire would seem to have been confined to that stretch of the corridor between C.15 and C.2. Adding to this the observation made earlier regarding the position and location of the deceased's body, the area of interest can be reduced to the area between C.18 (or C.17) and C.2.

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The type of fire that we are proposing killed Goodall is that which is sometimes referred to as "flashback", when a fire in a room or enclosure has almost starved itself of oxygen, only to erupt with flame when fresh air is provided by the opening of a door, or the breaking of a window, or other barrier. The position of the deceased's body is quite compatible with the hypothesis that she opened a door on a dying fire and provided the ventilation necessary for flashback to occur. Examination of the evidence and the witness' statements effectively excludes any of the bedrooms as the seat of the fire. In the first place, if the room was occupied at the time, the occupant would have had to escape at an early stage or she would have died in the fire. No one died in a bedroom, and all those in their rooms at the time of the fire jumped or were rescued after the fire was known to be in the corridor: (in fact, the damage to the bedrooms suggests that only three are potential candidates for this scenario, viz C.4, C.7 and C.17; their occupants gave clear statements about the course of events). Secondly, the unoccupied rooms (C.1, C.5, C.8, C.17 and C.18) suffered relatively little damage in relation to their positions on the fire floor. With this scenario, the room of origin would have been burnt out.

The other rooms off the corridor are: (i) kitchen, (ii) cupboard containing fuse boxes, etc. (iii) two bathrooms off the telephone alcove, (iv) a cleaners' cupboard off the telephone alcove, (v) main bathroom with toilets. Of these, (i) and (ii) can be excluded as they suffered little damage. The bathrooms (iii) and the main bathroom/toilet (v) can be excluded for the same reason. However, the door of the cleaners' cupboard (iv) was wide open, 30-40° back on its hinges, and the interior had

suffered damage, although it was greatest just inside the door and diminished towards the rear. A low sink was intact and the shelf above still had intact jars and bottles on it. The evidence of the internal damage would make this an unlikely seat, but the position of the door is compatible with the slight overpressure that would be associated with a flashback and, moreover, the alcove ceiling was most severely damaged above the opening in the cupboard (see below). If the cupboard is excluded on the grounds that the internal damage is too slight, then the possibility that the fire started in the corridor must be considered. On the assumption that Goodall did not walk along a smoke-filled corridor (low blood carbon monoxide) we are still looking for a fire that was virtually undetected until she was close to it. Two situations that are compatible with this are: (a) a fire developed in the void above the false ceiling and burst out just as Goodall was underneath, bringing down several burning boards which burst into flame, or (b) the fire was malicious and Goodall was trapped in a pool of burning liquid. A third alternative is that the victim's clothing caught fire first, but this seems most unlikely for a number of reasons, viz (i) there is no obvious ignition source (although she was a smoker); (ii) it is likely that she was wearing little more than a nightdress or a dressing gown, which could have easily been removed if it had caught fire; (iii) there would have been time for her to cry for help and perhaps bang on a door; (iv) there seems no way for a clothing fire at floor level to spread to the ceiling (unless the paint on the walls happened to be particularly flammable).

The second of these alternatives ((b) above) can be dismissed as no evidence was found for flammable liquids being involved. Neither was there any indication that someone had left the building before the fire alarm was raised (the security devices on the exit doors had to be broken by the occupants as they left the building after the alarm).

The first alternative ((a) above) requires detailed consideration. The ceiling board comprised a coarse fibre insulating board treated on one side (the underside) with a fire retardant paint. This is being analysed in detail at the Fire Research Station, but tests carried out in the laboratory of the Fire Safety Engineering Department indicate that

the treated face of the board is resistant to flame spread, performing well in a small scale surface spread of flame test (BS 476 Part 7). It is likely that it would achieve "Class 1" status in the full scale test, although it is not possible to say if it would achieve "Class A", as would be required for escape routes under the present Scottish Building Regulations. The reverse (untreated) side of the board is almost certainly "Class 4", according to our tests. Normally a board of this type would be fixed directly onto a non-combustible substrate (e.g. brickwork or plaster), but in this particular building the ceilings of the corridors (and the commonroom areas) consisted of a timber stud framing to which the fibreboard was nailed at approximately 6-inch centres by oval nails with small heads. Consequently, there was a cavity above the untreated surface of the fibreboard which was about 10-inches deep, along most of the corridor. Transverse beams forming part of the reinforced concrete structure of the building provided (fortuitously) partial "fire-stopping" in the void, but there still remained gaps of about 1-inch between the fibreboard and the soffits of the beams.

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An upper limit to the volume of the cavity is about $23m^3$. If flaming combustion developed in the cavity, oxygen would become depleted in the vicinity of the fire and further combustion would probably proceed by smouldering, fed by oxygen diffusing from the rest of the void, or perhaps leaking into the void from the corridor. The combustion products would be confined within the cavity. It is not clear how ignition might occur (see below), but if it did, the development of the fire could be explained by a spreading smoulder, burning horizontally and downwards (towards the treated surface), releasing smoke which (in principle) could lead to the formation of a flammable atmosphere within the void. If this was ignited (by an electrical spark, or by the appearance of flame, however momentarily) then an explosion would occur which would bring down at least some of the ceiling boards. This need not have been a violent "explosion" causing a loud noise, but just sufficient to dislodge the boards. For Goodall to have been trapped, rendered incapable of screaming, and killed in a short period of time by this event, is just conceivable.

It would require fire to establish itself very quickly on the fibreboard sheets, some of which would be on the floor, others hanging from the ceiling. The main arguments against this scenario, which must be answered,

are as follows:

- (i) It seems very unlikely that Goodall would have been unable to raise the alarm. She would have been burnt by the burning premixed volatile/air mixture which brought the ceiling boards down, but the ensuing fire would have taken time to build up to its full intensity. (Of course, it is impossible to say how any individual would react in these circumstances. Shock, combined with a blow from a falling board, could have rendered her unconscious).
- (ii) The build-up of heat within the void prior to the explosion would have been very localised, and initial burning in the corridor would also be localised, particularly as the corridor itself was until that time quite unaffected by heat.
- (iii) There is no obvious ignition source in the void. The electrical wiring to the corridor lights was of good standard, and contained within metal conduits, leading to junction boxes set into (and flush with the lower side of) the fibreboard ceiling. The holes cut in the fibreboard to fit the circular junction boxes are not treated with fire retardant paint, but to establish burning here would require high local temperatures (certainly greater than $250^{\circ}C$). An overheat condition with the light bulb itself would not produce sufficiently high temperatures to initiate smouldering (or flaming) combustion. A report on the electrical fittings and connections will be available from the Health and Safety Executive. *Ad hoc* tests carried out at Edinburgh and Borehamwood indicate that the untreated parts of the fibreboard can be made to smoulder but that this is not self-sustaining. (In a cavity, with build up of heat, it may be self-sustaining. This should be investigated).
- (iv) A fire in the void cannot easily be reconciled with the early appearance of smoke on the top floor as there were no direct connections one with the other.

Thus, while we are still left with the conclusion that the fire must have started somewhere in the vicinity of the telephone alcove (certainly between rooms C.17 and C.2) it is not possible to locate the spot precisely. It may have started in the cleaners' cupboard or in the false ceiling of the corridor, but there are strong objections to both these scenarios. More information is required on (a) the contents of the cupboard, (b) the

properties of the ceiling board, and (c) the state of the electrical system and its behaviour under faulty conditions (the fact that previously there had been a flood on an upper floor may be significant (see statement by McLeod (F.17); also Jardine (C.6)). On balance, the cleaners' cupboard seems to be the more likely seat, particularly in view of the position of the door. We do not know if this door was normally closed, or what position it would adopt if left open. (In the position in which it was found, it would have hindered access to the bathroom at the end of the alcove). The damage pattern inside the cupboard would have to be explained.

Subsequent development of fire

In the subsequent development of the fire, three events can be pinpointed, approximately at least:

- (i) The moment at which flames broke out of the window at the telephone alcove at C level.
- (ii) The appearance of flames in the east stairwell and subsequent breaking of the windows, producing the "ball of flame" described by McIndoe (Patient in Ward 10).
- (iii) The time at which nurses began to jump from the bedroom windows of C floor. The consensus appears to be that the girl in C.4 (Marini) was the first to jump.

Of these three events, the first to occur was the emergence of flame at the north side of the building, from the telephone alcove. Thomson, McNeil and Duncan (C.15 to C.17) all describe this particular effect shortly after the alarm and it was also observed by Duthie (the normal occupant of B.7) who was returning to the Nurses' Home after a night at a disco. She heard the fire alarm sound and by the time she had reached the junction Dunnikier Road and Hayfield Road, she was aware of flames in a room on the south side of the C floor, but then observed flames to shoot out of the centre of C floor on the north side of the building. She assumed this to be the sitting room, but it must have been the telephone alcove. From this particular point she saw the girls beginning to appear at various windows on C and D floors, and at the same time the Fire Brigade arrived and began setting ladders up the north side of the wall. The Fire Brigade took approximately 2 minutes to reach the Nurses' Home from the fire station.

The second event - the emergence of flames from the east stairwell - took place shortly afterwards. It was observed by a number of the building occupants, although it is difficult to establish precisely the time interval between the first and second events. Many of the nurses from other levels who were able to escape from the building unaided observed the "ball of flame" and one girl states that flames came out of the east stairwell at about the same time as the Fire Brigade arrived. (Pearson (B.9)).

PC Kimmel (Police) stated that flames were emerging from the east stairwell as firemen were unloading equipment from an appliance on Hayfield Road. O'Donnell (D.17) saw the fire brigade coming up Dunnikier Road as she was leaving the building at the foot of the west stairwell. She subsequently went round the south of the building and ran along in front, observing the development of flames in the bedrooms. She saw Marini (C.4) climb out and jump as flames engulfed her room. This event almost certainly happened after flames had burst through the east stairwell.

However, the most vivid description of the events in the east stairwell is given by two nurses from B floor, namely Muir (B.16) and Laidlaw (B.1), both of whom escaped down the east stairwell and were going out the south door when they began to hear screams and decided to return to assist escape from the upper levels. The pair of them managed to get back to B level and perhaps to the landing between B and C when flames and smoke were seen at C level. Muir talks of flames swirling about behind the closed fire door at C level (she is the only witness to suggest that the fire door at the east end of C corridor was closed during the fire) and they retreated quickly to the ground floor. As they did so, there was a sound of shattering glass and fragments fell down beside them. This must have been the moment at which flames burst out of the east end of the building. It is difficult to put a time to this following the sounding of the fire alarm but both Muir and Laidlaw were only slightly behind Hopton who was opening the south fire door.

Hopton, as one of the group who first discovered the fire and raised the alarm, presumably managed to reach the door to the outside well within a minute, given that Laidlaw and Muir would have taken a little bit longer to get outside and decide to return to investigate the east staircase. Adding another minute to give the approximate time at which the glass of

of the east stairwell shattered, matches well with the time at which the Fire Brigade arrived on the north side of the building.

Several of the nurses escaping down the west stairwell, although delayed slightly while Thorvaldsen (E.17) was trying to break the glass bolt to open the fire door, succeeded in reaching the east end of the building in time to see flames burst out of the stairwell. The occupants of B.5, D.7, E.17, refer to flames appearing out of the east end of the building at roughly the same time as girls appeared at the windows of C floor. The conclusion is that flames broke out of the east stairwell at about two minutes after the fire alarm sounded, whereas the flames came out the north side of the building after about one minute, say between half and one and a half minutes. There is no way of being sure exactly when this particular event occurred, although the sequence is not in dispute. In view of the short time delay between the second and third events, it can be argued that the fire in the corridor broke out on the north side of the building very shortly after the alarm was sounded, particularly as Thompson in C.15 recalls seeing flames coming either from C.18 or the telephone recess when she first looked out of the window. (McNeil and Duncan in C.16 and C.17, recall that they were hanging out the window when flames erupted from the telephone alcove although McNeil may mean "leaning". Only Duncan was hanging out of her window when the Fire Brigade arrived).

The third event is the start of the short period of time during which the girls jumped from the windows. It is important to establish which girl had to jump first because this might give an indication of the point in the corridor at which the fire was most severe. There seems little doubt from the statements of the other witnesses that the girl in C.4 (Marini) jumped first. This is stated quite categorically by a number of witnesses (C.2, B.2, B.16, F.8, F.15, F.12 and D.17). It is also clear that she jumped without throwing a mattress as she had to get out quickly, although she dressed and began taking clothes from her wardrobe first. Most of the girls in the rest of the corridor succeeded in throwing mattresses out (all but C.12A who had burned her hands when trying to escape along the corridor).

It is difficult to establish the order in which the girls jumped from C floor but a rough order for at least five of the occupants is as follows: 4, 7, 10, 9, 8. It is not clear when exactly the occupants of rooms 2, 3 and 12A jumped although from one witness's statement, C.3 jumped at some considerable time after C.4 (O'Donnell assisted in carrying Marini from the paving onto the grass from where she observed Russell (C.3) jumping. C.3 and C.4 did not jump simultaneously, and a lapse of a minimum of 30 seconds would seem to be likely. It would appear that many of the girls jumped almost simultaneously. For example, McLeod (F.17) states that C.9 and C.7 jumped just a few seconds after C.4. Thorvaldsen (E.17) recalls that when she returned from the casualty department with a trolley she saw C.9 and one other jump almost simultaneously.

There is no statement to suggest that any occupant of C floor jumped before Marini (C.4) so that we can assume that she was the first to jump out of her window. She was awakened by undefined noises and then heard the fire alarm. On looking, she observed flames in the corridor and although she went straight to the window, she then dressed quickly and began taking clothes from her wardrobe. The smoke in her room began to get thicker and fire broke in rather suddenly. This would suggest that the fire was of considerable intensity in that part of the corridor outside her bedroom, which was opposite the telephone alcove. Once the windows of the alcove had broken, a very intense fire in the alcove would be expected, which could explain why the door of C.4 failed so rapidly.

The occupant of C.7 (Christie) who jumped next, commented that having heard the fire alarm and looked out from her door to see the corridor full of flames, she found that the fire was in the room by the time she managed to close the door. Consequently she must have jumped very shortly afterwards and it is likely that the through draught caused by her burnt door and open window would be sufficient to create a very substantial fire immediately outside her room, if one had not existed there before. Early involvement of C.17 cannot be accounted for quite so easily, unless the occupant, like Christie, had allowed the fire to enter the room when she opened the door. This, and the fact that the windows of C.7 and C.17 were opened by the occupants, would account for fire entering these rooms at an early stage, while the unoccupied rooms C.5, C.6 and C.18 suffered relatively minor damage.

When the first units of the Fire Brigade arrived, two minutes after the alarm was raised, Duncan (C.17) was hanging out of her window on the north side of the building, with flames coming out over her head. At about the same time, flames broke out of the east stairwell: it was shortly after this that nurses started to jump from their rooms on the south side of C corridor. Thus, fire appears to have broken into Duncan's room first. Of the three nurses in their rooms on the north side of the building, McNeil was probably the first awake, to hear noises which, as she lay in bed, seemed to get louder. She opened her door "fractionally" to see flames filling the corridor. Only after she went to the window did she hear the fire alarm. By this time, Duncan (C.17) was awake and realised something was wrong. She opened her door after the alarm had sounded. She states that "the heat was so bad that I had to shut the door quickly", which suggests that she was less cautious than McNeil (C.16) and her action may well have hastened failure of the door. The door to C.16 failed as McNeil was being rescued. Of these three rooms, C.17 suffered the greatest damage (Plates 2, 3 and 4) while C.16 did not quite reach the fully developed stage of burning (Plates 5 and 6) and C.15 was surprisingly lightly damaged (Plate 7). It seems that jets were brought to bear on the north side shortly after the rescue, which would account for the extent of damage compared, particularly, with C.7 (Plates 8, 9 and 10) which was the most heavily damaged room.

Of the three rooms which "flashed over" (C.4, C.7 and C.17), C.4 suffered the least damage because a jet was brought to bear on this room almost immediately after flashover as the external flames were threatening the fireman (Lumsden) who was ascending a ladder to rescue McGill (E.3) (see statements by Armit and Lumsden).

Subsequent behaviour of the fire can only be surmised. There was a south-west wind, speed 15-20 mpg (Fire Fire Brigade Report, p 15) which would have tended to move the fire towards the north and east of the building, particularly once windows had been opened or had broken. The areas of maximum damage in the corridor were outside the rooms which had flashed over, as judged by the fact that at these points the ceiling was most heavily damaged - the tiles were broken away, and outside C.4 and C.7

the underside of the reinforced concrete slab had spalled, exposing the reinforcing bars. One other area where the hollow block tiles were damaged under the ceiling was outside the cleaners' cupboard in the telephone alcove. This is curious as there had obviously been a very severe fire in the alcove as the walls are heavily damaged yet this is the only area of ceiling which is affected in this way. This may be a point to consider in trying to establish the seat of the fire, although as discussed earlier, the damage in the cupboard is not entirely consistent with the fire starting inside.

The plaster on the south side of the corridor was heavily damaged in the fire but nowhere was the damage greater than in C.7.

The internal firefighting was based on the east stairwell (Williamson, Fire Brigade). At 0115, two teams wearing breathing apparatus ascended the east stair to the floors above the fire floor, which suggests that the fire in the corridor had largely subsided by this time. Shortly afterwards a team of two entered C corridor with a branch and advanced along the corridor. The Fire Brigade report puts this at about 0120 hours, but there is no statement available from the firemen first involved. Scotland and Dyce (Firemen) state that they took a running hose line up the east stair at 0215 hrs to relieve two others. They found the body of the deceased and somehow informed S/O Williamson, who times this at 0220 hrs. The implication is that it took about 45 minutes to advance along the corridor to the telephone alcove. No further times are mentioned but Williamson recalls that the last area of fire to be extinguished was in the commonroom area. The fire could not have been burning in this area for very long as several of the latex foam cushions on the easy chairs survived.

Concluding remarks

Reviewing the evidence discussed in this report, the most likely sequence of fire development is that the fire origin was located in the cleaners' cupboard. This is the sequence most compatible with the various statements and the subsequent observation of the burnt and damaged parts of the building. The fact and location of the fatality may be explained by her leaving a bathroom, smelling smoke and then investigating by opening the door to the cupboard, which allowed the mixture of gases in the cupboard to mix with extra air and cause the "flash fire". Ignition of clothing would be almost instantaneous but there would be sufficient time before death for the girl to struggle part of the way to her room whilst still in air which was fairly clean. The subsequent pattern of destruction is supported by evidence discussed earlier, bearing in mind that volatile gases would evolve quickly from the painted wooden surfaces in the corridor (about 40 per cent of the wall area) as the flames came close to the surfaces.

The authors have insufficient information at the present time of the detailed contents of the cleaners' cupboard to allow any suggestions to be made as to how a fire may have started there.

The fact that the rear portion of the cleaners' cupboard was not seriously burned is difficult to explain if this cupboard was indeed the source of the fire. Another possibility is that the fire may have started in the void above the ceiling of C floor and broke through the fibreboard ceiling suddenly when the deceased was beneath. Such a break through may not have been the immediate source of extensive flames but it could have been preceded by a limited rise in pressure in the void which would have dislodged portions of the false ceiling so that they fell on the deceased. The upper surface of the fibreboard, so dislodged, would become fully enflamed in a short time if a portion of the fibreboard were burning when dislodged. This could then have spread fire to the rest of the corridor. However, if it is assumed that the electrical system was in good order, it is difficult to visualise a credible ignition source for a fire in the void.

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	B	C	D	E	F
1	0025*	-	2230	0000	a
2	CR(B)	2200	-	-	a
3	a	2230**	a	2200	0005
4	a	2230	2140	a	a
5	2200	a	a	2245	0045
6	a	a	Toilet(D)	a	a
7	a	2130	Toilet(D)	a	2200
8	a	2200	0000	a	0055
9	CR(B)	0000 [†]	0000	a	2345
10	0005	2330	-	0000	a
11	2215	2245	0045	0050	a
12	CR(B)	a	0010	0030	2345
12A	2300	2245	2315	a	~2300
14	(study)	in corridor(C)	a	a	-
15	a	0000	0057	2200	in corridor(F) [‡]
16	-	2345	a	a	a
17	0040	~2300	2315	CR(E)	0030
18	-	CR(B)	a	a	a

* Figures represent the times at which residents retired to their beds (or room)
CR = common room (letter in brackets refers to the floor).

a = absent from building at time of fire, "-" = not occupied.

** = Russell (C.3) cannot remember anything after "chatting with Tracy (C.18) and Jackie (B.9)". Hopton (C.18) states that Russell went to bed at about 10.30 pm.

† = Durie (C.9) cannot remember anything. However, Thompson (C.15) states that she, Durie and McNeil went to bed at about midnight from the common room (C level).

†† = Goodall (C.14)(deceased) told Hill (C.11) at 2245 that she was going for a bath. Duncan (C.17) thinks that she saw her in the commonroom (C level) at 2300 with her nightdress on. McNeil (C.16) "recalls" seeing Goodall go to and from the toilet at 2315. This is the last time anyone saw her alive.

‡ = Lawson (F.15) smelt "faint smoke in the area of the sittingroom" (F.level) at 0035. She checked the kitchen then returned to her room, leaving the door open. About 10 minutes later she smelt smoke again, and on investigation she saw "dark grey smoke floating about along the entire length of F floor". She began to alert others on the corridor, then she heard the fire alarm.

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29th March 1982

HM Principal Inspector
 Group 20/05

NURSES RESIDENTIAL HOME, VICTORIA HOSPITAL, KIRKCALDY
 FATALITY AND INJURIES RESULTING FROM FIRE

1. SECTION A - INTRODUCTION

The Nurses' Residential Home at Victoria Hospital, Kirkcaldy, is a separate six storey building within the hospital curtilage, adjacent to the main hospital entrance in Hayfield Road. Mr J Anderson, of this Field Consultant Group, has provided you with a Civil Engineer's Report of the building together with detailed drawings of one floor and other matters, to which I shall make reference, so I shall not further describe the building.

2. A fire occurred at the Residential Home during the night of Thursday 12 November and Friday 13 November 1981 and the Fire Brigade received a call at 00.57 am on 13 November. The result of this fire was that substantial damage occurred on Floor C (the second floor) in several bedrooms and the central corridor. More damage, principally smoke, occurred on the East stairway and on floors above. Several nurses were seriously injured when being forced to jump from windows on Floor C due to fire penetrating their bedrooms and one nurse was trapped by the fire, in the corridor, and found by the Fire Brigade after the fire was put out. That nurse died in the fire.

3. Because of certain aspects of the fire, principally the death of one of the nurses, the necessity for other nurses to jump and thereby sustaining serious injury before they could make safe escape or be rescued, the apparent extremely rapid spread of the fire in the main escape route on Floor C and the indetermination of the source of the fire, the Procurator Fiscal of Kirkcaldy requested help and advice from the Health & Safety Executive in preparation for the Fatal Accident Inquiry. Due to internal circumstances, that request was passed direct to the Field Consultant Group, but subsequent FCG operations and advice were channelled through Dr R Evans, HM Inspector of Factories of your Industry Group.

A preliminary visit was made to the Nurses Home by Mr J Anderson, Civil Engineering Inspector of this FCG and following his first visit, I made visits on Friday 20 November 1981 and Thursday 26 November 1981, the latter in company with Dr Evans. I also made a later visit, for clarification of certain points, on March 8th 1981. Following my first visit, I requested Dr Gunn, of the Fire and Explosion Section to visit and to report to myself and to you his views on the design of the building with respect to means of escape and related matters, with reference to such building standards as may have been applied in Kirkcaldy at the time of the construction and at present, as requested by the Procurator Fiscal. You have that report. The Home was also visited on several occasions by Mr J N Thomson and Mr R Laing, Electrical Inspectors of this FCG.

4. Dr Gunn, Mr Thomson, Dr Evans and myself attended a meeting with the Procurator Fiscal, in his office in Kirkcaldy, on December 3rd 1981, when also present were Mr R M Stewart, of the Strathclyde Police Forensic Laboratory, Mr P Hinkley of the Fire Research Station, Boreham Wood and Dr Drysdale of the Fire Engineering Department, Edinburgh University, together with Chief Inspector Nellis and Inspector Walker of the Kirkcaldy Police. The Fire Service were not present. The purpose of the meeting was to review the impressions at that time of the various people involved and to advise the Procurator Fiscal on future action. I later visited Mr Hinkley, at the Fire Research Station in Boreham Wood whilst in the London area on February 17th 1982 to discuss possible conclusions on the cause, seat and progression of the fire.

5. I am not clear as to the legal involvement of the Health & Safety Executive in this building and incident and take guidance from you. This type of fire is generally outwith the normal expertise of the Fire and Explosion Section of the Field Consultancy Group. Our normal duties involve fire in working places or due to chemical safety factors, including flammable liquids, gases and solids (such as plastic foams etc) and chemical reactions. Our experience includes considerations of ignition due to such causes as electrical etc. However, we have tried to respond to the request for assistance in the following fields in particular, where it could be that the Health & Safety Executive has some direct interest.

- (a) Seat of the fire
- (b) Cause, insofar as it could be due to faulty design or maintenance
- (c) Means of escape and warning (ie, why did the deceased become trapped and why did a number of nurses have to jump).

It will be realised that the latter question, in these premises, is probably more properly within the field of the local Fire Service.

SECTION B SEAT AND CAUSE OF FIRE

6. From time to time, during the investigations, attention has been focused on a number of possible causes of the fire including a hair-drier in bedroom C4, a light fitting in the corridor of floor outside room C7, the telephone booth on floor C and latterly the cleaners closet on floor C.

7. This section of my report attempts to re-examine the possible locations of the seat of the fire from evidence of damage, position of the deceased girl when found by the Fire Brigade, the behaviour of girls on floor C during the fire and knowledge to date of the results of work carried out on behalf of the Procurator Fiscal by the Fire Research Station, at Boreham Wood. Deduction of the location of the seat of the fire may have pointed to a possible cause or causes, indicating any possible involvement by Health & Safety Executive. In appendix A, I have given my impressions of the damage as noted at my early joint visit with Dr Evans on Thursday 26th November and clarified at my visit on March 8th 1982. I have also had opportunity to study the report prepared by the Fire Fire Brigade and statements by the resident nurses and observers, by courtesy of the Procurator Fiscal.

8. From the seriousness of damage it appears fairly certain that the fire started on floor C. The degree of damage points to the eastern end of the floor with apparent progress towards the west end and east end fire escapes. This assessment is also borne out by the progressive damage along the corridor to the bedroom doors, paintwork and carpet in particular. The corridor ceiling showed 3 places of apparent intense heat attack, one opposite the recess housing the telephone booth, a second between bedrooms C6 and 17 and, worst of all, from a position opposite the door of bedroom C7 to just beyond the further wall of bedroom C8. The intensity of these damaged areas has been given thorough consideration but I think that all parties consider that too much emphasis should not be placed directly on their positions, particularly that adjacent to rooms C4 and C8 as the intense heat could well have been caused or increased by ingress of air from the recesses by the telephone and lounge area and from broken or open windows. This consideration could also be applied to the space opposite bedroom C6 as the occupier of C17 opposite had opened her door, closed it and then been rescued through the window. As that bedroom door burned through there would have been a strong draught of air into the burning fire intensifying it in that position.

9. Examination of the statements of the nurses in residence on the floor C on 13 November may help to identify the seat of the fire.

Brenda Jamieson

Room C2

First saw black smoke and then fire outside the door

Dianne Russell

Room C3

Has no recollection

Louisa Marino

Room C4

Flames outside the door in the upper half

Brenda Christie

Room C7

Saw the corridor full of flame

Agnes Elder

Room C8

Saw the corridor full of flame particularly at high level

Christine Cluiness

Room C10

Saw flames all round the door

Sharon Hill

Room C11

Saw the corridor full of smoke orange and yellow flames coming from two windows to the east

Suzanne Taylor

Room C12A

Saw the corridor full of smoke

Frances Thomson

Room C15

Saw a bright orange glow to her left in the corridor with thick black smoke

Elizabeth McNeil

Room C16

Bright orange flames apparently filled the corridor

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Corridor full of flames possibly coming from the east

Elizabeth Hopton

This girl had been on floor B and approached floor C by the west staircase when she saw the corridor full of smoke. She could see no flames or glow.

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11. Possibly the most useful statements in this respect are those of Elizabeth Hopton, Room C18, Frances Thomson, Room C15 and Karina Duncan, Room C17. Whilst in the lounge on floor B, Elizabeth Hopton had heard banging noises from the floor above. When she went to floor C to investigate via the west staircase she saw a corridor full of smoke but not fire although she says she could not see beyond the lounge area. If the fire had been burning in the straight corridor one might have expected her to have seen some evidence unless the smoke was too dense at the eastern end or the fire had not then fully taken hold. The "bangs" according to work carried out by the Fire Research Station, could well have been ceiling tiles falling to the floor after being loosened from their holding tacks by the effect of heat drying out and shrinking the tiles. The evidence of Frances Thomson and Karina Duncan indicate the fire, particularly at a later stage, probably being to the east of bedroom C17.

12. It will be useful here to consider the behaviour of the Cellotex ceiling tiles as described to me during my visit to Boreham Wood on February 17th 1982. From that discussion it appears the tiles would have been difficult to ignite on the plain downward-facing surface possibly due to the treatment provided as indicated in correspondence with the Fire Service in 1959. The Fire Service had expressed considerable reservations about the efficiency of such treatment but from the tests at Boreham Wood it does appear that the performance of the flat surface of the tile under standard fire conditions had in fact been upgraded. This upgrading may not have applied to the tile edges but they were close butted together against a wooden joist and heat penetration between the tiles at an early stage leading to increased spread of fire along the upper unprotected surface would be delayed. I understand that the tiles were not so easily burned as would be expected without draught being applied. This same effect would not be, and I believe was not, observed if the tiles became detached by shrinkage from the fixing pins, under the effect of heat, and prevented a vertical surface to a fire below. The deduction from this observation and argument is that the ceiling would have required a fairly intense source of heat below to cause combustion. If fire penetrated to the upper side of the tiles it

would spread as far as the structural beams below which there would be some stopping due to the wooden batten to which the tiles were fixed. In fact this wooden batten may well have acted as a fire stop for a period until the tiles themselves became detached.

13. This leads to a consideration of the possible involvement of the light fitting outside bedroom C7, which has at times been attributed the cause of the fire. The report by Mr Thomson, HM Senior Electrical Inspector, with whom I have worked closely, casts considerable doubt on the validity of attributing the fire to this source. The statement of the resident nurses referred to above, would possibly place the light fitting in the wrong position in the corridor to be in the seat of the fire. The understanding I have from the Fire Research Station of the requirements for ignition of the Cellotex ceiling tiles indicates the need for a more intense source of heat than could be supplied by a fault in this light fitting and I am inclined to discard it as a possible source.

14. The position in which the deceased girl, Morag Ellen Goodall, should be important evidence in determining the seat of the fire. The Inquiry will determine the cause of death but I have had opportunity to study the Post Mortem report prepared by Dr Rushton and Dr Robertson of Dundee University and the statements of firemen Dice and Scotland and Station Officer Williamson who found the body. The deceased girl was lying in the north side of the corridor, face downwards with the head nearest the west door and said to be about 10 metres from the eastern staircase and, I understand, roughly outside bedrooms C18 or C17. The cause of death, according to the P.M. report was inhaled fire fumes. From the further description of the body it would appear that the deceased was attempting to make a hurried exit towards the fire door at the west end or her own room No C14, possibly away from the area of the telephone recess, bathrooms, etc, when she was overcome by the heat and smoke. However, one must bear in mind the possibility that in the intense smoke she may have become disorientated or even turned in falling.

15. Being led towards the eastern end of the corridor as the seat of fire, and finding no obvious source, I made my further visit on March 8th, together with Chief Inspector Nellies, partly to re-examine the cleaners closet, to which attention had now been drawn and which had had less previous examination and the bedroom door frames for a close re-check as to the possibility of progression of fire from any bedroom into the corridor.

16. The event had been postulated that the deceased girl had suspected fire at the eastern end of the corridor and gone to investigate, had opened the closet door, thus accounting for its being apparently opened during the fire, and had found a

(A)

fire and driven her back. In this closet I had previously noted on an upper shelf a broken 2 litre capacity brown glass bottle on a high shelf together with signs of heat damage, blistering paint, damaged plaster and woodwork, the door was outward opening, consumed in the fire with what remained indicating its position to be almost fully opened.

17. The Police arranged further investigation into the possible contents of the cleaners closet and into the question as to whether the door should have been open or closed, locked or unlocked for the benefit of myself and the Fire Research Station. The contents of a similar bottle to the 2 litre bottle, recovered from an upper floor, and labelled by hand K.P.5 were examined in the HSE laboratory in Edinburgh and found to have a flash point, if at all, well above 60°C. It appears that the material was probably a floor cleaning detergent/wax water emulsion. Of the other reported contents of the closet, such as polishing waxes, cleaning materials, dusters, etc there appeared to be no particular source of fire. On March 8th, I discovered on the shelf beside the broken 2 litre bottle referred to above, a folded paper bag similar in size to a domestic upright cleaner bag, charred on the upper surface only. Leaning on the bottle was a charred copy of rules for cleaners, inside a transparent plastic envelope, charred and partly melted. There were also toilet rolls, slightly charred on the shelf, a mop and other objects subjected to some fire but of limited intensity. We attempted to examine the floor of the telephone lobby for signs of local fire without success. I understand that since that date, a closer re-examination of that floor has been made by Divisional Officer Ritchie of the Fire Brigade. He points out that there was evidence of a tubular wooden chair in this recess and a waste paper basket, although neither would appear to be a source of intense fire although the greatest damage to floor tiles appears to be roughly central to this recess towards the window area.

18. The adjacent bathrooms were again examined. From the position of the detached bath-plug, shower-curtains, lack of evidence of clothing or shadow of clothing on the wall, and low intensity of damage, I think that these areas can be ruled out as seats of fire. The toilet area and third bathroom suffered little damage and can similarly be excluded.

19. Of the bedroom doors that I re-examined, that leading to room C2 indicated some possibility of fire spread from room to corridor due to the quality of charring on

both sides of the frame, excluding the rebated area where the door would have provided protection. The door to room C4 was also similarly equally charred on both sides and the rebate was completely burned away. This room could possibly be a more likely candidate than C2. Although this room was one of the most seriously damaged, the lobby is even more so and my opinion was that one could be more convinced that the fire had spread at least, from the lobby into the bedroom. The door to bedroom C7 was the most heavily damaged and in fact this whole room is the most seriously damaged in the building. The door-frame was very deeply charred on all sides from floor to ceiling and would possibly indicate the most likely candidate for an instance of fire passing from room to corridor. Examination of all other bedroom doors gave clear evidence of pregression of fire, where it had occurred, and from corridor to room.

21. It will be noted that Rooms C2, C4 and C7 were the only rooms occupied on that side on this floor in that section of the corridor. All three occupants reported seeing fire in the corridor and all occupants had had to jump to the pavement and suffered injury. The open windows in these three rooms could account for the intensity of damage to room and doors, once the fire had finally broken through.

22. During my visit to Boreham Wood I was able to see a video recording of fire tests carried out on two bedroom doors recovered the Home. One door had been hung each way and exposed to a standard fire ie simulating a fire on the outside and a fire on the inside of a bedroom door. Briefly my impression was that the doors behaved equally and that a fire could have first burned through the upper centre of the door after a period of approximately 7 minutes following a period of a 'photographic' development on the unexposed side of the door of the pattern of the inner framework, following fairly rapid destruction of the exposed surface. This was then followed by quite rapid destruction of the whole door with intense flame surging along what could be considered to be the ceiling of the inner room, or corridor, depending which way the fire progressed.

23. If one now postulates a sequence of events based on fire starting in an occupied room one is led to the following conclusions, if the fire started in the bedroom proper, the occupant would almost certainly have made escape via the corridor and presumably raised alarm before a corridor was fully involved. No occupant of the possible rooms involved made her escape in such a way. If the fire started in a bedroom lobby, the occupant's escape would have been cut off. Before her own door was involved, leading to passage of the fire into the corridor she would have been faced with no alternative but to have made her escape via the window. All occupants who made escape in such a manner from floor C, before the arrival of the Fire Brigade, suffered injury and had to be recovered from the pavement. In such an imagined event, the following intervals could be estimated:

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five minutes for the fire to develop in a lobby to high intensity,

ten minutes to burn through the door,

five minutes to attain high intensity in the corridor,

five minutes to incapacitate the fire alarm (see Section E),

thus it would be expected that such an occupant would have to have made escape by the window some 15-20 minutes before the alarm was raised. There is no evidence of such an escape.

24. The first evidence of a girl making escape by jumping appeared to be between the arrival of senior nursing officer McGregor from the dining hall and her re-exit from the burning nurses building. It is possible that the occupants of either C4 or C7 were the first to jump, both at the time of a congregation of observers outside the building during the intense stage of the fire.

25. From a consideration of the above, I am led to a confirmation of the early belief that the fire did not start in a bedroom. I believe that the fire started somewhere in the corridor in the area of the telephone recess or nearby. Some doubt must remain regarding the cleaner's closet, because of the open door and position of the deceased girl. My experience does not enable me to come to any more definite conclusion as to a source. (B)

SECTION C BUILDING DESIGN

26. In his early request for advice from HSE the Procurator Fiscal included a request for comment on aspects of building design relating to spread of fire and means of escape with a particular request to many room standards that may have been set to similar buildings in the private field by any legislation, local or national, at the time of the construction of the Nurses Home or at present.

27. Dr Gunn, Chemical Inspector of this FCG has presented you with a report on this topic and I have little to add to his report which presents the following conclusions.

27.1 Ceiling Void - Fire Stopping

The construction of the ceiling/floor membrane is such that the timber batten beneath the structural concrete beam comes very close

to, if not indeed fully complying with the appropriate standards for fire stopping. The Fire Research Station tests appeared to indicate that the first failure would have been the falling away of the ceiling tiles due to shrinking from the fixing pins, presenting large vertical services which would severely increase development of fire.

27.2 Fire Separation between Bedroom and Corridor

Such a building would normally be designed on the expectation that any fire would commence in a room leading off the corridor and that any corridor would be a "protected route" and that doors would remain intact long enough for people to make escape via a corridor. Two emergency stairs were provided, one at each end of the building, and the design would assume that given a fire in any particular room, other occupants would make their way to the appropriate end of the corridor without passing the burning room. As indicated in Part B of my report, it does appear that the fire in this instance started from an intense source in the corridor area itself, and the failure of the bedroom doors under the intense heat from the corridor was the main contributory factor in the injury of girls trapped in their rooms floor C being unable to await rescue by the Fire Service.

Dr Gunn indicated that there appears to be no minimum standard for fire resistance of these doors. Tests at the Fire Research Station indicate, I understand, a fire resistance of about 7 minutes when subjected to standard fire conditions. When fire resistance is specified, 30 minutes is usually the lowest standard called for. In that respect, Dr Gunn's interpretation of the 1971 Building (Scotland) Regulations in respect of the corridor between rooms 12, 12A and 14 and the western fire escape door is particularly relevant. It will be remembered that the occupant of room 12A found it impossible to locate the nearest fire door because of smoke. Senior Nursing Officer McGregor does say that because of smoke on floor D she was unable to find the west fire door and entered the kitchen by mistake.

The open lounge and telephone area leading directly off the main corridor are not, as Dr Gunn indicates, excluded by legislation though the furnishings of the lounge in these circumstances might give cause for disquiet. This aspect appears not to have paid any part in the death or sustained injuries.

27.4 Floor Compartmentation

The separation between floors, breached by the multitude of service ducts is a matter of disquiet, although again this appears to have played no part in the death or sustained injuries. It is known that fire travelled between floors via many of these ducts and their construction would not appear to meet present standards. Moreover burning material appears to have fallen down one of the ducts to the lower floors which may have caused further complications to the escape of the occupants.

27.4.1 British Standard CP 413 - 1973 Section 4.2.1 says "Where a duct conveys services to different fire compartments of a building, the separation between the compartments should be preserved by the duct enclosure which in normal circumstances should have fire resistance at least equal to the standard required for the structure of the fire compartment in which the duct is situated". ie, with care of the ducts connecting floors they should have fire resistance equal to the floor/ceiling, which would, I believe be 30 minutes standard. I interpret this clause as indicating that the surface closures of the vertical duct between bedrooms should have full 30 minutes fire resistance.

27.5 Ceiling Lining

The ceiling lining has been the subject of many tests at the Fire Research Station of which I have been made aware. Mr Anderson, Civil Engineering Inspector of this FCG has obtained details, sent to you, of the Celotex ceiling tiles, probably of the type used in this building, supplied by the manufacturer, which shows them to be of Class 4 with respect to fire resistance.

have seen copies of correspondence between the Regional Hospital Board and the Fire Service dated 1979, when the Fire Service expressed considerable disquiet about the ceiling tiles and the Authority indicated that the tiles were to be treated with a fire-retardant coating named 'Albi R'. It is my belief that the use of protective coating to up-grade the fire resistance rating would not be recognised by the appropriate legislation, partly because only the outward face would be coated and not the butted edge nor the upper face.

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tiles recovered from this building exhibit better fire resistance properties than would be expected of the Class 4 rating. The view, however, that the tiles probably failed by loosening from the fixing pins by heat shrinking, followed by the tiles swinging down and presenting vertical faces assisting rapid fire spread, indicates their unsuitability as ceiling lining for a corridor intended as a means of escape and is in reality indicative of their probable effective correct rating as Class 4. As Dr Gunn indicates, the 1971 Building (Scotland) Regulations require a Class 0 material, with much higher resistance, for corridor linings in these circumstances.

28. The summary is that this building would probably not meet current standards in respect of,

- (a) the ceiling lining
- (b) the unstopped service ducts with insufficient fire resistance
- (c) the design of the corridor outside rooms 12/12A/13
- (d) the furnishings for an open lounge area opening directly on to the main corridor.

(c)

29. Section D Fire Alarm

It was consistently reported by occupants of the building that the fire alarm gave an inadequate signal when first activated by, it is understood, Jacqueline Pearson, occupant room B9 on floor B. The consensus appears to have been that the alarm sounded for a period of from 15 seconds to 2 minutes. Jacqueline Pearson had actuated the alarm on instruction from Tracey (Elizabeth) Hopton who had discovered the fire on floor C after ascending the west staircase from floor B in order to investigate apparent disturbances. Elizabeth Hopton could see only smoke when looking along corridor C from the west fire door.

30. The hospital fire alarm system has been thoroughly investigated by Mr J N Thomson, Senior Electrical Inspector of this Field Consultant Group, whose report you have. After rejection of a number of hypotheses he reached the conclusion that the fire alarm had failed because of the involvement of the sounder on floor C in the fire and probably the effect of fire on the wiring where it emerged from the space behind the panel in the wall to which the sounder was mounted.

31. The sounders replaced bells, which had been behind the panels, in 1969 following discussion between the hospital authority and the fire brigade during an upgrading exercise on the fire alarm system throughout the hospital.

would continue sounding until reset, after the duration of the emergency, or until destroyed by fire. Mr Thomson has indicated that the wiring of the new sounders was to recognised standards and the failure of the alarm on floor C would appear to have been due to its position close to the main seat of the fire and would have been expected. The sounder was in a position in the escape route where it would normally be expected that a fire would be late to penetrate. In the peculiar circumstances of this fire, it appears to have started and rapidly developed in the corridor itself.

33. It appears to me that the question at issue would be, after destruction of the sounder or wire on floor C, would it be expected that all sounders in this building would become inoperative. It is assumed that the fire caused a short-circuit in the wire behind the sounder and Mr Thomson confirmed that with the reduced voltage which would ensue after damage by fire to the insulation, the sounder would behave roughly as reported.

34. British Standard 5839 part 1 of 1980, in Clause 9.1 says that, "The sounder circuits should be so arranged that a short-circuit or disconnection at a single point in the wiring does not result in the silencing of all sounders in the building". This British Standard superseded British Standard Code of Practice 1019 of 1972. I have found no such requirement in BS CP1019 1972.

35. The purpose of the clause would be to protect against the whole alarm system being unknowingly out of action during a non-fire situation, between tests. BS CP109 lays emphasis on regular testing. However, it could be that with an alarm system installed according to clause 91 of the new British Standard, destruction of the wiring on floor C might not have rendered inactive sounders on other floors.

36. Section E General Fire Precautions

Aspects of general fire precautions in the building to which I wish to refer relate to the condition of the fire doors and to the fire drills.

37. Fire drills appear to have been carried out from time to time. Some occupants have been involved in several unexpected drills during night periods. However, the practice seems to have been always to leave the building via the main eastern staircase and the front door. No one appears to have used lifts, but there was apparently no consideration that at some time the eastern route could have been blocked nor did any occupant appear to leave via the west exit, although this route could have been by far her nearest exit.

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There also appears to have been much lack of knowledge on how to open the emergency fastenings for the fire doors.

38. I note also the emphasis on the occupants gathering warm clothing when responding to a practice alarm. This may well be advisable during a practice at night and in cold weather but if there is a possibility that the alarm were to have been in earnest, valuable time could be lost in gathering clothing etc. In fire training, this cannot be too strongly emphasised.

39. The eastern staircase, particularly from the level of floor C upwards, had suffered considerable damage from heat and smoke. The smoke damage had progressed to the corridor in the upper floors. The fire sounder on floor F had suffered substantial heat damage and was considerably distorted. The fire door and frame at the eastern end of corridor C was also completely burned away so that the damage to the staircase is not surprising. Such a door would be expected to provide 30 minutes fire resistance under standard test conditions. That would be a guide to its performance but the fire in corridor C was probably of an intensity greater than standard fire conditions and a standard 30 minute fire door could well have burned through in less time under these conditions. However, such a door should still provide opportunity for higher floors to be evacuated.

40. On my visit to the home on March 8th, I found that the lower member, the only part remaining, of the eastern door of corridor C was still wedged in the fully open position by the floor tiles. When I investigated the hinge it suddenly released, the door moved rapidly to the quarter open position and then gradually fully closed.

41. There had been reports of a "bang" particularly by Senior Nursing Sister McGregor. That could have been caused by rapid ignition of a quantity of products of incomplete combustion from the heart of the fire, where oxygen supplies may there have been insufficient for complete combustion. If air were suddenly admitted by, eg a breaking or opening window, rapid combustion of the gaseous products would occur possibly giving an explosive effect. This could have suddenly thrown open the eastern door in corridor C, sufficiently for it then to be wedged against the floor tiles raised under the effect of the increasing temperature. On my visit on March 8th I tried the effect of a sudden push on the corresponding door of floor B, still intact, and found that a sudden blow of sufficient strength could cause it to fly wide open to the wall, from which position it returned to the closed position. Thus I do not consider it to be possible to determine whether the door on floor C was open or not.

42. However, on the upper floors there appears to have been evidence that doors were held open and there is constant reiteration in statements of residents that doors were often wedged open. The purpose seems to have been to enable telephones on alternate floors, including floor C, to be easily heard from intermediate floors rather than to remove obstructions to the normal entry and exit to and from the various floors during day to day purposes.

43. I am led to the conclusion that it must have been a common practice to wedge open fire doors and to leave them in that position thus defeating the very purpose of protecting the staircase from the immediate effects of fire on any one floor and delaying the spread of fire and smoke to upper floors. It is smoke that introduces difficulties into evacuation of buildings particularly in the early stages of a fire when occupants can become disorientated due to lack of visibility and choking effects.

44. However, it seems unlikely that in this case the fire doors played any part either in increasing the intensity or rapidity of spread of the fire developing on floor C or in delaying the escape of people from upper floors.

GENERAL CONCLUSIONS

45. I have not felt able to give an answer to the questions of where the fire started on Floor C or what would have been the cause of the fire. The distribution of fire damage is, I believe, of such a nature as to make answering those questions extremely difficult and possibly misleading.

46. There is strong indication that the deceased nurse Morag Goodall left her room in some hurry, as the bedroom door was left ajar, possibly to investigate something. If so she may have discovered the seat of the fire and then have been trapped by smoke and heat before she could make her escape. Her position when found outside bedroom C18 might indicate that she was running from the fire in a westward direction, but she may have turned in falling. A bedroom as a seat of the fire can probably be excluded and the other annexes, such as the cleaners closet off the telephone recess, do not appear to provide sufficient positive evidence.

47. The ceiling tiles probably contributed to the very rapid development of the fire once they became involved by heat and were loosened from their fixings after an already severe fire. Thereby they are shown to have been unsuitable for the lining of a means of escape route and any protective treatment given did not bring them to the appropriate standard of fire resistance.

48. The occupants of Floor C suffered severe injuries because the fire separation of the bedroom door did not provide sufficient time for rescue to be effected once the main escape route was severed. However, legislation does not appear to provide for any higher standard than was installed. Design would normally anticipate that a fire would start in a room off the corridor and not in the main means of escape.

49. Fire spread to upper floors via the service ducts which did not appear to be of the appropriate fire standard, although occupants appear to have made escape before the fire broke through and it was unable to take hold before the fire service had the situation under control.

50. There appears to have been some laxity in the control of fire doors adjoining the eastern stair well, although these doors do not appear to have influenced either the spread of fire or the difficulties of escape from upper floors.

51. The fire alarm appears to have failed at an early stage due to fire damage at the sounder at Floor C. This was partly a result of the fire occurring where it should not have been expected. Current British Standards appear to require that in the event of failure of the alarm on Floor C, the remainder of the sounders should have continued operating. That British Standard dates back only to 1980.

Kenneth Moss
K MOSS
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29 March 1982

APPENDIX 1

REPORT ON DAMAGE AS OBSERVED ON VARIOUS VISITS TO THE NURSES HOME, KIRKCALDY

Bedroom C1

There was fire damage to curtains, the carpet was charred. In the lobby paintwork on the walls was burned and peeling, a towel on the rail was scorched and the wardrobe door was charred particularly at the top. The door to the bedroom was burned away excluding part of the outer frame down two sides and along the top. The door frame was badly charred on the outside and less seriously charred on the inside.

Bedroom C2

The damage was similar to that in bedroom C1 but of a more serious nature. There were cosmetic bottles on a corner shelf of which the plastic had melted. The dressing table was severely charred on the top. Plastic cosmetic containers had melted, an anti-perspirant aerosol had a melted valve and probably discharged the contents. A second aerosol had softened plastic but had probably not discharged. There were charred books and paper in a corner by the window on the floor. In the lobby, the mirror was broken, the light above was broken and the plywood facing to the duct was completely burnt away. The framework of the duct was badly burnt but the fire had not penetrated through the duct into bedroom C1. The front of the wardrobe was burnt away and clothing on the shelves was partially burnt. The partition between the bedroom and lobby had suffered some damage on the lobby side. This partition was fixed on the lobby side with quarter inch plasterboard and on the bedroom side with thin tongued and grooved timber boarding. The gap between was about three inches. The main bedroom door was completely burned away excluding a very narrow remaining piece along the top on the hinged side which is extremely badly charred through. The door frame is badly charred equally on both sides excluding the rebate where the door would fit and the door was evidently closed during the fire. The damage was more severe at the higher parts than at the floor level.

Bedroom C3

The carpet was charred on the surface, the curtains were burned and the light shade was broken by heat. The bulb was intact but sooty. There was smoke and heat damage to paintwork of the ceiling and upper wall near the door but little other damage. In the lobby the mirror was cracked and the glass shade of the light above was cracked. The panelling of the duct was burned away at the top half and fire

had penetrated to the adjacent bedroom C4. Holes had burnt away in places in the lower half. The wardrobe door was charred, the upper cupboard and the door were badly charred and a suitcase in the upper cupboard was burnt. The lobby showed signs of heat and flame damage along the upper portion. The door rebate indicated that the door had been closed although the door had burned away excluding the edge timber supporting the locks which was lying on the floor and the edge timber holding the hinges which was very badly charred right through. The door frame was very badly charred on the corridor side possibly worse at the bottom than the top.

Bedroom C4

It is understood that this is the bedroom where the hairdryer was found. This bedroom showed considerable fire damage. The mattress was badly burned exposing springs, a table top was missing and the rest of the framework was badly charred apart from places where things were obviously standing on it and cooling the surface. The corner shelves were deeply charred. The panelling to the partition with the lobby was deeply charred and burned through from ceiling to half way down. The recess above the bed-head was completely burned away. Some of the timber panelling had shrunk and pulled out of the tongued and grooved joint. The hairdryer was lying on the floor, plugged into the socket and the wall switch was on. There were remains of a radio on the small wooden shelf above. On the shelf of the recess were two circles one about 2" in diameter and the other about 4" in diameter where heat shielding had been provided. Little remained of the easy chair apart from a portion of the portion of the wooden framework and some of the metal springs. The carpet appeared to be burned away in front of the dressing table for a rough area of about 2' x 1'. The rest of the carpet was substantially burned leaving the felt backing in contact with the floor scorched through. There were charred papers and books on the floor and the lower shelf of the corner shelf unit. The window ledge and frame were badly charred through. The plaster had suffered heat spalling, particularly on the wall adjacent to bedroom C5. The bed in C4 appeared to have been under the window. In the lobby the wardrobe was apparently completely burned away although the doors were propped against a wall above the pile of charred material. The doors were completely charred almost from both sides. The plasterboard of the partition with the bedroom had gone from top and was badly spalled in the lower half. The timber panelling was scorched and charred at the top. The framework of the recess entry showed bad charring from top to bottom. The plasterboard partition on the left hand side of the door was similarly affected. The mirror above the basin was cracked and the light fitting had suffered heat damage. The shade had gone and the bulb had broken away. The wash-basin was broken. The panelling to the duct had burned from ceiling level to within 12" of the floor below which it was badly charred.

The insulation on the adjacent pipes had burned away and the fire had penetrated through the duct to the adjacent room at the upper half. The plaster on the inside of the outer wall of the lobby had spalled away and a very small portion of the door frame was attached on the hinged side about 3' from the floor. The rest had completely gone. The facing of the door frame on the inside of the lobby wall had gone and the frame itself was completely charred particularly at the upper level. The rebate at the opening side had been burned away so that it was impossible to tell whether the door had been open or closed. On the outside the frame was probably more deeply damaged at the upper levels than the lower.

Bedroom C5

The curtains were burned but the rest of the damage was principally from smoke apart from the charred carpet. The bed was under the window. The light shade was missing and the ceiling was charred and the paint peeling. In the lobby the wardrobe door was scorched and one door was off the runners. The material behind suffered principally smoke damage. Some garments on the coat hooks on the bedroom partition wall were burned to charred fragments. The plasterboard was cracked and scorched and the paint peeled from the top half. There was much less damage at the bottom - principally from smoke. The frame was charred around the top particularly at ceiling level. The ceiling was charred, the paint was peeling and the wall to the corridor the plaster was peeling to some extent. The door was burnt through but the outer rim of the frame was substantially intact with the latch in the locked position. The frame was charred and scorched on the upper half, the lower half had suffered smoke damage. The outer frame on the corridor side was badly charred, very deeply, particularly on the upper level.

Bedroom C6

The damage in this room was similar to that in C5 but of a slightly worse nature. The curtains were burned, the carpet was charred. There was a box of matches on the dressing table, covered by a folding down lid. Three or four had not ignited. The lobby of bedroom C6 was similar to that of C5 but the damage was slightly worse. The wardrobe was empty and appears to have been empty at the time of the fire. A small portion of the door frame including the latch was in position but the latch was not locked. The state of the frame was similar to that of bedroom C5 and the damage on the outside was similar to C5 but more severe at the top level.

Bedroom C7

This room appeared to be the most severely damaged by the fire. The only item of furniture left in was one easy chair which itself had been substantially undamaged.

The brass union on the radiator beneath the window had been subjected to such heat that it had expanded and parted. The window sill was very deeply charred and the window frame similarly charred. The ceiling spalled down to tile level and the light had burned from the ceiling and was hanging by charred wire. The plaster was dislodged from both walls. The partition to the lobby had completely burned through apart from the wooden framework which was very deeply charred. What remained of the wardrobe frame was very deeply charred. It appeared that the remainder had been removed. There were in the floor of the wardrobe recess a number of gramophone records with charred paper sleeves. The small pile of nine 10-penny pieces lay on the charred remains of one of the horizontal members of the partition. The panelling to the duct to the adjacent room was completely burned away and most of the wooden framework for the panelling had charred almost completely through. The door frame was very deeply charred from floor to ceiling.

Bedroom C8

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The window sill was substantially undamaged although the curtains were burned away. The bed was beneath the window and the chair was badly burned. The dressing table lid had been up and a small book of matches on top of the dressing table was charred but had not fired. The rest of the material on the dressing table was badly charred and the plastic had melted. The light fitting had burned away but the metal part was in situ. The wooden panelling to the lobby was surface charred at the top half. The carpet was scorched but the pattern was visible when not covered with burnt debris. On removing a scorched blanket lying on the floor the protected ^{carpet} was exposed as if the blanket had been flung onto the floor when the occupant realised the fire had started but before it entered her room. In the lobby the panelling to the duct had completely burned away almost to floor level and the frame was badly charred. The mirror was cracked, the plaster had spalled away from the wall and was lying in the wash basin. The plasterboard on the adjacent partition had burned away at the top half although the lower half was substantially untouched. In the recess entry the framework was badly charred in the upper half. The plasterboard on the adjacent partition had burned away at the top half and suffered considerable damage at the lower half. The wardrobe had suffered severely. There was debris of very deeply charred wood on the floor. The frame of the doorway to the corridor was badly charred. The top hinge was in place on the frame in the closed position and substantially immovable. The door had completely burned away. In the position of the rebate, although the frame was very deeply charred, the surface opposite the edge of the door showed whiteness as of complete combustion. This also applied to the part of the top and the hingo side.

Apart from the floor which carried some charred debris a sheet on the floor adjacent to the dressing table and the easy chair protected the carpet and exposed undamaged carpet. The rest of the carpet had principally suffered slight surface scorching from the lobby inwards. There was very little other damage apart from smoke damage and condensed water dribbling down the wall. The windows and curtains were intact. In the lobby there was little damage apart from some slight heat effect and peeling paint but the door which was in position had burned through with a hole roughly 2' square. The remainder of the outer panel had almost completely burnt away exposing on the upper part of the door the charred honeycomb framework and on the lower half of the door, uncharred honeycomb framework. There was charred dust on the floor which may have been carried in later. The doorframe was very deeply charred on the upper half at the outside but less deeply charred towards floor level. There was blistered paint in the hinged rebate indicating that the door was probably closed throughout.

Bedroom C9

The lampshade had broken and broken glass was lying on the bed. The curtains had been torn down but did not appear to have suffered fire damage. A plant on the window sill was still living and the light still worked. The ceiling had suffered soot deposition and smoke damage. Heat had obviously been carried through the recess at ceiling level only where the framework was burned and peeling. On the wall there were undamaged posters. In the lobby the paintwork had blistered at ceiling level and there was soot deposition. The objects in the wardrobe were undamaged and the wardrobe doors were only slightly charred. Of the bedroom door which appeared to have been removed since the fire, the rebate on the hinged side was substantially undamaged although the upper half was charred. The remainder of the frame showed some charring including the rebate and the upper half. I suspect that this door had been closed and had just begun to burn through at the upper part.

Bedroom C11

The window was unbroken, the walls were substantially clean and there was debris on the carpet. In the lobby apart from some charred debris on the floor there was no other damage. There were signs of slight penetration of smoke across the top of the door which was almost certainly closed. The outer panel of the door was charred at the top half and just begun to burn through. The paint of the door frame was charred and peeling but was still in position.

Bedroom C12

The window was intact, the room was substantially undamaged and clean apart from debris on the floor probably trodden in and ^{partially} smoke above the door onto the frame.

The outer panel of the door was surface charred only at upper levels. The panel to the duct was missing.

Bedroom C12A

This bedroom was in similar condition to bedroom C12 but with less scorching on the floor.

Bedroom C14

The window was intact and a number of circles on the window sill indicate heat protection the rest being scorched. Similar remarks apply to the dressing table. The ceiling was scorched, the paint blistered and sooted. This room has no lobby. The carpet was dirty but undamaged, a suitcase on the floor by the dressing table showed heat damage and clothes in the wardrobe were undamaged but dirtied. Although the bedroom door frame was only blistered and sooted, examination of the rebate which was in identical condition with the adjacent woodwork, indicated that the door was probably open and allowed smoke to enter the room. The paint was peeling and hanging off the horizontal portion above.

Utility Kitchen

The window frame was slightly charred and the walls were sooted and the ceiling sooted and blistered. The door was charred at the top left hand corner above the hinge and the panel was peeling away from the frame. The indication was that this door was wide open. The frame was charred across the top and 2' down each side.

Bedroom C15

This bedroom had a conventional lobby and the bed was beneath the window. The ceiling paintwork was burned and peeling, the glass shade was broken and the walls were sooted at the upper level. There was debris on the carpet and the panelling to the lobby was slightly charred around the entry. In the lobby, the wardrobe doors were badly charred in the upper half and the plaster partition to the bedroom was falling away at the upper level. The panelling to the duct was burned through from ceiling level to about 2½' below that and the paint was peeling. There is an indication that this panelling had burned through bedroom C16. The bedroom door had burned away but the condition of the paint on the rebate on the latch side indicated that it was probably closed. The paint in the rebate was blistered and some of it had peeled. The damage was worse at the top than the bottom. The small portion of the remaining part of the door frame attached to the hinges is in position charred and in the closed position. The outer frame of the door was extremely badly charred on the corridor side with the facing substantially burned away.

This coincides with intense ceiling damage in the corridor.

Bedroom C16

The bed mattress was burned on the surface, the furniture had been disturbed. The curtains were burned. The ceiling showed considerable damage and the light had gone. The paint on the upper half of the walls had blistered and peeled and the plaster showed heat damage. The panelling to the lobby was charred on the upper half. The small recess panel in the corner had burned through to the lobby. There were melted hair brushes on the surface of the dressing table. The corner shelves were charred, the bottles had suffered heat damage. The carpet was charred and the pattern was no longer visible. In the lobby the plasterboard facing on the partition had almost disappeared and the wooden panelling was beginning to burn through. In the wardrobe much of the framework was lying on the floor as charred wood. The panelling to the duct had completely burned away and the wash basin was broken. There was an appearance of an intense fire in the wardrobe but the damage in the ceiling was very marked as opposed to the almost undamaged remainder of the lobby ceiling. On the small portion of the very badly burned framework of the wardrobe still in position in the wall the front was covered with the completely burned white ash but the adjacent plaster wall on the lobby side was only surface cracked with the emulsion paint peeling away. The top hinge of the outer door was fixed in the closed position, the door had completely burned away apart from the edge to which the locks were attached which was found on the floor. The door had evidently been closed. The same impression was gained from the rebate on the main frame on the latch side but the interior of that main frame was very badly charred. The fire was evidently burning in this lobby whilst the door was closed or after it had penetrated the main panelling. The framework to the ducting was very deeply charred and the outer part of the door-framework on the corridor side had substantially burned away.

Bedroom C17

This bedroom had suffered extremely severe damage. The bedframe lying on the floor beneath the window had almost completely burned away and the chair was in similar condition. A small coffee table in one corner and the hi-fi set were almost completely burned. Similar remarks apply to the dressing table and the corner shelving. The ceiling light fitting had burned away. The window sill ledge was badly charred apart from small areas of heat protection. The window frame was seriously charred. The floor power socket appeared not to have had a plug in and was switched off. Bottles on top of the dressing table had disintegrated and there was broken glass lying there. The interior panel to the lobby was charred all over and the small recess had burned through as well as the panelling below the recess. The reading lamp on the little wooden shelf had suffered severe damage

and spalled away to some extent. In the lobby the wardrobe had been almost completely burned away and a similar effect was evident in the wardrobe area to that in bedroom C16. The ceiling itself was quite black as was the interior of the brick wall to the corridor. The sliding doors to the wardrobe were propped up against the wall and were badly charred on the outside and distorted due to heat. The wash basin was broken and the light fitting above had substantially disappeared and the mirror was cracked. The framework to the entrance of the bedroom was charred particularly at high level, the panelling to the duct had burned right through from ceiling level for about 3' and below that was badly charred and bending away from the frame. The surrounding framework was charred particularly at ceiling level where it had burned away for 6". The main bedroom door was evidently closed. On the hinged side a small portion of the lower part of the frame was in position and behind it the paint was only blistered. Similar remarks applied to the latch side of the frame and elsewhere the frame suffered extreme damage.

Bedroom C18

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The ceiling was blackened and blistered, windows were out, window frame was sooted. The window sill was unharmed but the radiator was sooted. The bedding was unburned, the chair was unburned and the curtains were scorched and charred. One partly fire damaged suitcase was on the bed probably removed from the wardrobe. The dressing table was sooted on the surface. The panelling to the lobby was blistered and a plastic bend curtain probably hanging in the bedroom entry had melted and dropped to the floor. There was charred debris on the carpet. In the lobby the paint on the coat-hook had charred and burned. The ceiling had charred and blistered and the wardrobe door surface was charred. The panelling to the duct was charred and blistered at the upper level, the ceiling was blistered and the walls sooted and charred at upper levels. The plaster panel facing the partition to the bedroom was charred at upper levels. The outer portion of the door frame remained in position, the door itself had burned completely through. Inspection of the paintwork in the rebate for the door indicated that it had probably been fully closed during the fire. The main frame was badly charred from top to bottom.

Bathroom nearest Outer Wall

The door had burned through but the remains of the outer frame were still in position and the main supported frame was seriously charred. The window sill adjacent and the window frame were thoroughly charred, the radiator had been subjected to heat.

Bathroom nearer the Main Corridor

The paint was hanging from the ceiling, the tiles were dislodged at upper level above

the bath and had obviously been subjected to intense heat. The door was missing but a section of the frame indicated that it was probably closed in the early stage but thereafter completely burned away. Between the two bathrooms there appears to be a duct to which small windows lead from each bathroom. The windows were hinged at the bottom and open at the top for about 6", the whole window measuring about 8" square. The two windows evidently opened to a service duct with a pipe running through from ceiling level. At the ceiling level of this duct there was a sheet of hardboard through which the pipes passed to the upper floors, the hardboard did not appear to have suffered fire damage although it was not firmly in position and had sagged possibly due to dampness.

Cleaners Closet

This cleaners closet with a sink inside had suffered intense heat damage with blistering paint, damaged plaster and woodwork. The door opened outwards and appeared to be in the outward fully open position and almost completely burned away. On the shelf above the sink was the top half of a broken two litre quart bottle. A folder paper bag similar in size to a domestic upright cleaner bag, charred on the upper surface was lying on the shelf and leaning against the bottle was a charred copy of rules for cleaners, inside a transparent plastic envelope, charred and partly melted. There were slightly charred toilet rolls on the shelf, a mop and other objects on the floor subjected to some fire but of limited intensity at low level. An aerosol beside the sink had had the top burned out and was emptied and discharged.

Toilet Bathroom Area adjacent to Lift Shaft

The door had been burned through but would appear to have been closed at the time of the fire. It was fitted with self closing hinges and what was left of the door was still in the closed position, the door had been subjected to heat and buckled, the wooden frame surround was badly charred. Inside the area the paint was blistered and peeling.

Kitchen area off the Stairwell

The door appears to have been closed at the time of the fire from an inspection of the paint on the hinged side of the rebate. The hinges on the wooden part of the door were still in position but the rest was completely burned away. The rebate on the latch side was deeply charred as was the whole of the frame. The room inside was subjected to heating and blistering of the paint and the ceiling area. Just inside the door there may have been a small linen basket which had been burned out. A similar one inside the door had been burned out and a third one which was standing on

the floor inside the door appeared to be little more than water damaged.

The corridor (starting at the east end)

The fire door had completely burned away and all that remained was the outer frame which was very deeply charred together with the framework for the side panels, the upper one of which would have been glass and the lower one probably two sheets of plywood which had burned away. The timber members are charred almost completely through. On the ceiling above the tiles had disappeared, the wooden joist was charred overall quite deeply excluding the upper levels. The structural clay tiles above were substantially undamaged, plaster on the walls adjacent to bedrooms 1 and 2 had spalled away.

From the area by the toilets on the left hand side there were two planks lying on top of the ceiling tile support members and were obviously in that position from the evidence of the heat protection where they had lain on top of the joists. Outside bedroom door 2, the damage to the roof was such that the hollow clay tiles had spalled away on the lower surface, exposing the hollow channels. The interior of the hollow channels did not appear to be particularly discoloured by smoke. It appeared that the whole of this section of ceiling tiles may have disappeared late on in the fire, because the clay tiles in the opposite bedroom 1, opposite the lift were not very discoloured by smoke. Immediately over the fire hose there were two small pieces of charred Cellotex ceiling tile still fixed to the wooden frame. The timbers in this area were charred on the upper surface as well. One timber joist near to bedroom 2 was quite seriously burned away on the top side.

The first structural beam was in the wall between bedrooms 2 and 3, immediately on the eastern side of this beam the clay tiles were blackened but not broken. The timber beneath the beam was cut away to accept the beam and was charred in position. The timbers on the eastern side of the beam were charred but the upper surface appeared to be unburned. The timbers running lengthwise along the corridor for a distance of 2' between two cross members were simply surface charred. Passing towards the door of bedroom 3 the charring became much more intense. There was a light fitting between the lift door and the toilet door on timbers attached to the lengthwise member of the ceiling frame. There was a second light fitting almost in line with the doors to the bathroom leading off the open recess. The clay tiles opposite bedroom door 3 were blackened.

Opposite the telephone recess the clay tiles were badly broken away. This area was the most seriously damaged so far. Some of the concrete had spalled away in the lengthwise section between the roof tiles exposing the steel reinforcing bars.

The lengthwise timber members of the ceiling tiles supporting structure had completely burned through and the cross members were very badly charred. In the telephone recess area the telephone on the wall had suffered fire damage and the plaster had spalled from the wall as it had indeed in the corridor in this area. The window was out, the window frame was very badly charred and the radiators beneath had been subjected to heat damage. The ceiling tiles were missing and the supporting timbers were charred but only apparently on the sides and underside. The clay tiles were very black and showed signs of heat attack and surface spalling. The ceiling in this area rises slightly by possibly two courses of brick between the corridor and the window in the northern wall.

Between the recess and the bedroom 18 there is a second supporting structural concrete beam. The timbers beneath this beam were in place but completely charred through. The timbers beyond the beam were charred on the sides and lower surface only with the damage decreasing towards the western end. The clay tiles were badly blackened with some heat spalling. The plaster on the walls adjacent to bedroom 5 had spalled away, light fitting No 3 was between bedroom doors 5 and 6. Approaching bedroom 6 door, the ceiling had spalled away leaving the hollow sections which were not particularly blackened. The next structural beam was between the walls of bedrooms 6 and 7. Clay tiles to either side of this beam were not disturbed.

Between bedroom doors 7 and the structural beam between bedrooms 8 and 9 was the most serious damage to the ceiling where the clay tiles were very badly broken away exposing the reinforced concrete rod in the lengthwise concrete infill. Substantial quantity of the timbers supporting the structure for the Cellotex tiles had completely burned away. Opposite bedroom 8 the cross timbers were mostly remaining but the lengthwise timbers had gone. I understand that it was in this position that light fitting No 4, the suspect light fitting, would have been situated. Opposite the lounge area beyond the structural beam there was considerable combustion, the wooden framework reducing it in extent towards the western end. The clay tiles were substantially undamaged in this area. Opposite bedroom door 9 the roof timbers again appeared to be more heavily damaged.

From a point roughly 12" beyond the structural beam between bedrooms 9 and 10 the Cellotex tiles were still in place. They had suffered burning and the paint was peeling. Beyond bedroom door 12 the ceiling was little more than blackened. The residue of the plastic fittings for the fire exit signs opposite bedroom door 12 had melted and dropped away.

In the lounge area the room dividing unit between the lounge area and the corridor, being open shelving had suffering charring. Chairs set along the front of this shelving had the upholstery almost completely burned away and the framework was charred. Some of the foam was still present but charred and melted on the surface. The rest of the area of the lounge had been principally heat damaged at low level. The whole of the ceiling tiles apart from one small section on the western side near to the corridor had fallen away. The supporting timbers were merely scorched. Ceiling tiles in this area measured approximately 2' x 3' and were larger than those in the corridor area.

The corridor floor

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The corridor floor appeared to have been covered with vinyl tiles covered with a layer of carpet which did not extend into the telephone recess area. The carpet in the eastern half of the corridor had substantially burned away. In the area outside the bathroom toilet area the plastic tiles had lifted. To the western side of bedroom door 7 and in the doorway of the bedroom opposite there was a mound of material on the floor which looked to be burnt clothing etc, together with debris from ceiling tiles, slivers of glass. I later understood that this was probably material removed from the bedrooms by the Fire Brigade. From this area beyond there began to be remains of carpet first badly charred and then ultimately unburnt carpet.

The upper floors

Bedroom D8

The duct was just beginning to burn through at the base with smoke penetration at the top.

Bedroom D15

The ducting had burned through completely from the floor to within 1' of the base leaving a complete gap into bedroom D14 and heat damage in the lobby of bedroom D15 to ceiling and walls.

Bedroom D7

There were signs of the fire beginning to heat up the inside of the panelling at the foot of the duct and some smoke penetration.

Bedroom D16

There was fire penetration at the duct of the base.

Bedroom D17

There was smoke penetration at ceiling level and base.

Bedroom D18

The duct panelling had completely burned away. The interior of the duct had been subject to smoke and fire damage and the lagging of the pipework was fire damaged. The fire had blistered the paint on the wall and ceiling adjacent to the duct.

Bedroom D3

The duct panelling had completely burned through consuming a linen basket just inside the lobby. There was fire and heat damage to the ceiling and walls.

Bedroom E3

The panelling had been charred and had been removed, after the fire. There were signs that the lower end had burned through and the framework was charred. The curtains in this room were charred, possibly where the fire came back in the open window from outside.

Bedroom E4

The panel was missing, the wood was scorched and there were signs of smoke damage around the base of the opening.

Bedroom E17

The duct panelling had been removed but the woodwork showed signs of scorching and smoke deposition. There was smoke damage around the floor tiles etc.

Bedroom E15

The panelling had burned away and appeared to have been removed later.

The wooden framework was badly charred from ceiling to floor level. A linen basket adjacent to the duct was badly charred and burned through.

Bedroom F15

The duct panelling had been burned through and the wooden framework was charred.

The Eastern Stairwell

The elastic covering of the banister was severely damaged at level C, D up to E and again with some damage at the top at level F.

The fire door at level D had cracked glass with the panel still in place, and the woodwork was sooted and burned. Indications were that this fire door was probably closed. The fire sounder at level D was undamaged.

The fire door at floor E was open when I saw it and when touched, it swung into the closed position. When pushed open it remained in the open position. The indications were that this door was open during the fire. The fire sounder at level E had suffered damage from heat but there were no other signs of fire damage in the locality.

The fire door at level F had a cracked glass panel and the inside of the door was sooted and the paint beginning to blister. The outside of the door was also sooted. The walls of the corridor were smoke damaged and the fire sounder had suffered considerable heat damage and the plastic was severely distorted due to heat. The indications are that this fire door was probably functioned open during the fire.

S24

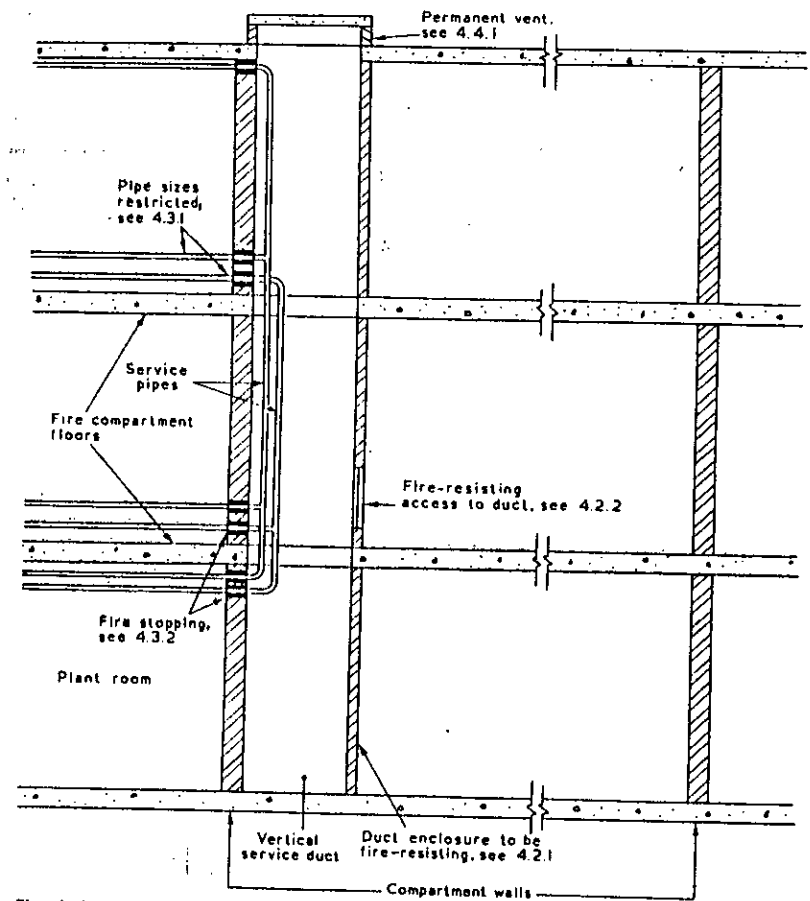
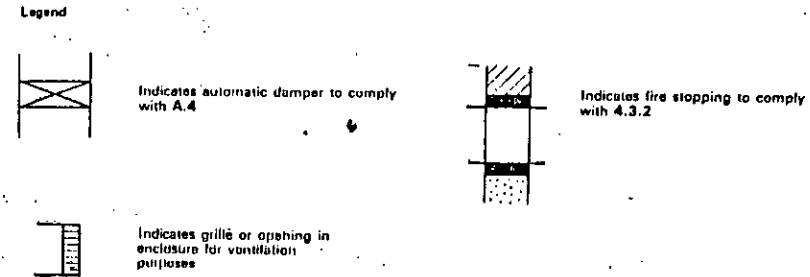


Fig. 1. Vertical duct

Appendix 6. Report on Victoria Nurses' Home. .



BUILDING CONTROL DIVISION

Scottish Development Department

New St Andrew's House Edinburgh EH1 3SZ

Telex 727301

Telephone 031-556 8400 ext 5092

Your reference

Our reference BC/8/30

Date 1 September 1982

Dear Chief Executive

FIRE AT NURSES' HOME: VICTORIA HOSPITAL, KIRKCALDY

1. The purpose of this letter is to bring to the attention of local authorities the findings of a fatal accident inquiry into a fire at the Nurses' Home, Victoria Hospital, Fife, in November 1981.
2. In his Determination of 25 May 1982, Sheriff Principal R R Taylor, while unable to establish the originating cause of the fire, listed in his Summary of Principal Findings reasonable precautions whereby death might have been avoided or the injurious effects of the spread of the fire on the occupants of the hostel might have been alleviated.
3. A copy of the Sheriff Principal's Summary of the Principal Findings has been sent by the Scottish Home and Health Department to the Secretaries of all the Scottish Health Boards. As local authorities may also wish to take account of the Sheriff Principal's findings, a copy of the Summary is attached for your information. At the request of Scottish Education Department, copies of this letter are also being issued to Directors of Education and Social Work of Regional and Islands Councils.
4. It will be noted that the Sheriff Principal places considerable emphasis on the use of combustible ceiling linings having resulted in the fire spreading rapidly and trapping the occupants of the Nurses' Home and on the chimney effect of vertical pipe ducts which did not have fire resistant qualities. He also draws attention to the lack of protection of the wiring of the fire alarm system.
5. It is stressed that the defects in the Nurses' Home arose from a failure to comply with the local byelaws in force when the building was erected (and, of course with the building standards regulations which superseded them). The building standards regulations clearly prescribe the standards to be used in the lining of escape corridors and also prescribe the standards for fire-damping, service ducts and pipes.
6. Local authority buildings are, of course, required by statute to conform to the building standards regulations and consequently one would not expect any defective construction or materials in buildings within local authority ownership. However, as this can only be established by means of a check, authorities may wish to consider whether it would be appropriate for them to undertake a check of the buildings within their estate, either specifically or in the course of routine maintenance.

Yours sincerely

Richard Bott

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A R H BOTT

SUMMARY OF PRINCIPAL FINDINGS

1. The fire started somewhere in the corridor between C15 and the telephone area or in the telephone area, of C (second) floor. It progressed along the corridor and cut off most of the occupants of that floor from escape by the fire exits at either end of the corridor.
2. The originating cause of the fire has not been established.
3. When alerted to the fire, all the occupants of C corridor retreated to their rooms and closed their doors, except the deceased.
4. It is inferred that the deceased probably came out of her room at the west end of the corridor, in order to escape from the fire, but forgot and passed the west fire exit which was next to her room, and made for the exit at the east end, thus going into the fire.
5. The deceased, Morag Ellen Goodall, student nurse, Pathcondie Farm, Letham, Fife, who was residing in C14 The Nurses Home, Victoria Hospital, Kirkcaldy, died between a few minutes to 1.00 am and 1.00 am on 13 November 1981 in Corridor C of the Nurses Home outside room C18, from inhalation of fire fumes.
6. Three occupants of rooms on the north side of C floor were rescued at their windows by firemen as fire invaded their rooms.
7. At about the same time seven occupants of rooms on the south side of C floor had no option but to jump or drop from their windows. ^{In addition} One occupant jumped unnecessarily. All who dropped or jumped suffered serious fractures. One occupant of a room on the south side of C floor was rescued by a fireman on a ladder.

Smoke passed through the open fire door at the east end of floor C, up east stair, and through the open fire door of floor E, trapping three patients, who were rescued from outside by firemen.

The fire alarm in the Nurses Home sounded for about 10 to 20 seconds and then ceased on all floors, because of the effect of fire on the wires or cables under on the second floor.

The principal cause of the fire spreading and resulting in occupants of the Nurses Home being trapped was the improper use of combustible ceiling linings in a corridor which was an essential part of the escape route from both exits in the event of fire.

The use of such linings in that situation was contrary to the Building Bye-Laws of the Royal Burgh of Kirkcaldy, made in terms of model bye-laws drafted by the Scottish Department of Health. The Regional Hospital Board was not bound to comply with these Bye-Laws. In 1959, before the Nurses Home was occupied, the Firemaster warned the Chief Architect of the Regional Hospital Board about the dangers of similar materials and construction in the Nurses Home, and the Architect was aware that the danger apprehended by the Firemaster was also present in the Nurses Home.

2. Subsidiary causes of the spread of the fire and of smoke, were (i) the fact that fire doors at the east end of corridors C, E and F were open at the time of the fire, and (ii) the chimney effect of vertical pipe ducts which did not have the fire resistant qualities required by the Building Bye-Laws of the Royal Burgh of Kirkcaldy, made in terms of model bye-laws drafted by the Scottish Department of Health, so that when fire penetrated through the poly-wood panels covering them, fire and smoke was carried to upper storeys.

the/

The dangers of similar ducts in the Hospital had been brought to the notice of the Chief Architect of the Regional Hospital Board in 1959, and to official of Fife Health Board in 1978 by fire officers.

13. Causes of the death in terms of the Fatal Accidents and Sudden Deaths (Scotland) Act 1976, Section 6(1)(b), included (i) the improper use of combustible ceiling linings ^{in the corridor,} and (ii) the failure of the deceased to use the fire exit door which was immediately next to her room.

14. Reasonable precautions whereby the death might have been avoided (in terms of Section 6(1)(c) of the Fatal Accidents and Sudden Deaths Inquiry (Scotland) Act 1976) were:

- (i) The use of ceiling linings ^{in the corridor} which were either (a) non-combustible; or (b) Class I as specified in clause 7 of British Standard 476: 1953, obtained without impregnation or surface treatment of a combustible material, as required by § 79 of the Building Bye-Laws of the Royal Burgh of Kirkcaldy at the time of construction of the Nurses Home.
- (ii) The use by the deceased of the fire exit door immediately adjacent to her room when she became alerted to the fire.
- (iii) On the premise that the precaution in (i) was not observed, (a) the use of fire retardant paint on each occasion when the ceiling of the corridors was redecorated, (b) a fire alarm system set off by smoke detectors in the corridors

15. Other reasonable precautions whereby the spread of the fire or the injurious effects of its spread on the occupants, might have been alleviated were:

- (i) Keeping the fire doors closed at all times, and avoiding the issue of wooden wedges whereby they might be kept open.

- (ii) The provision of either fire resistant panels to enclose the vertical pipe ducts, or dampers at each floor level, so as to secure that every storey above the lowest storey should have a fire resistance of one hour, as required by § 38 of the Building Bye-Laws of the Royal Burgh of Kirkcaldy in force at the time of construction of the Nurses Home.
- (iii) On the premise that the precaution of using linings which were non-combustible or Class I BS 476, was not observed, (a) the protection of the wiring of the fire alarm system in conduits throughout its length and the provision of fire resistant sounders, (b) the provision of vehicular access to the south side of the building so that fire appliances could be used to rescue persons from outside the building.

16. The following did not cause or contribute to the death of the deceased, or contribute to the difficulties which those who were trapped experienced:

- (i) The break-glass locks on the main doors on the ground floor. However the break-glass protection for these locks serves no useful purpose, and might be a danger in different circumstances:
- (ii) The advice or instruction given by Chief Nursing Officer McGregor that nurses should put on some outdoor clothing when an alarm sounded.

512 May 1982

J.R.R. Taylor

Appendix 7. Other Work Arising from the Project

Publication of material included in this appendix before submission of the thesis was done with the approval of the Supervisor.

• Following an in-depth study on developing a heuristic structure for escape potential during fires in large buildings, A. J. HINKS of the Unit of Fire Safety, University of Edinburgh, has prepared this article on the subject.

Predicting danger levels to life — the deciding factors

IN any fire emergency involving people the attainment of complete life safety is the most important objective. It requires the escape of the threatened population from a degrading building environment by exiting from the building, or by using refuge facilities. Alternatively, control of the degrading environment can be achieved throughout the set of spaces affected by the fire.

The effectiveness of attainment of the life safety objective may be described in terms of the escape potential of the threatened population. The exact level of escape potential will depend on the choice of the degree of injury that can be tolerated and appropriate levels of life safety still be attained. Therefore the level of safety to be attained is regarded as a variable.

With this assumption for safety, the factors that determine the level of escape potential will vary with the plan form, type of construction and performance of the building; the spatial distribution and the physiological and psychological characteristics of the occupants; and the expected fire scenario which includes aspects of the location of the fire, fuel loading, smoke release, smoke movement and smoke control.

Escape path network

Moving the threatened population to safety will depend on the design of the escape system including the number, location and capacity of the escape path network, and the continuing ease with which the pathways can be used throughout the duration of the fire event. In addition the size and distribution of the threatened population, together with the capability of those affected to escape, are important factors.

This capability is influenced by a number of components, including mobility and sensory perception, and a level of prior knowledge of the escape pathway through training. The inter-relationships between the population and

the building may be best handled by considering people in spaces and movement within and between spaces. The scale of this consideration is likely to vary with building type, as the number of people in a space may be the whole population (eg a stadium), a group or groups of people (eg offices), or individuals.

The degradation of the environment within a building will be contributed to by the fire directly — if and when the fire spreads — and by the products of combustion. These may be hazardous by their toxicity, singly or in a synergistic combination, and/or by impairing the visibility of escape routes. Various aspects of the release of toxic gases and smokes, their subsequent movement within and between building spaces (as influenced by the effect of smoke-control systems) are important factors in the attainment of safety for the threatened population.

A high level of safety is described by a high escape potential and can be assumed only when the time required for the threatened population to reach an acceptable location and standard of safety is less than, or equal to, the time available as the environment in the building degrades progressively. These times may be described as T(REQ), which may be defined as the time required from detection to the escaping population reaching safety, and T(AVAIL), which may be defined as the time available between ignition and when the local environment becomes untenable to the threatened population. This may be represented by the following inequality:

$$T(REQ) \leq T(AVAIL).$$

It should be noted that this approach is similar to that considered by a number of other workers (eg Sime(1)) and reflects an increasing complexity of fire events, indicating a need for a detailed model for T(REQ).

It is clear that there are a great number of factors which are relevant to successful escape, each having different degrees of influence for all, or part, of the duration of the fire event, in

some, or all scenarios, but not necessarily for all members of the threatened population. The study of these factors, their interrelationships and dependencies within the fire event system is a worthwhile exercise, and part of the initial work on this study is reported in this paper.

Overview of structure

Figure 1 shows the primary components that directly determine T(REQ) and T(AVAIL). They are: mode of escape and escape route layout; and the release, movement, and control of smoke and spread of fire. Each primary component will depend on secondary and tertiary sub-components and also on other components lower in the hierarchy. Using this approach, a hierarchical structure of all components of escape potential can be formed.

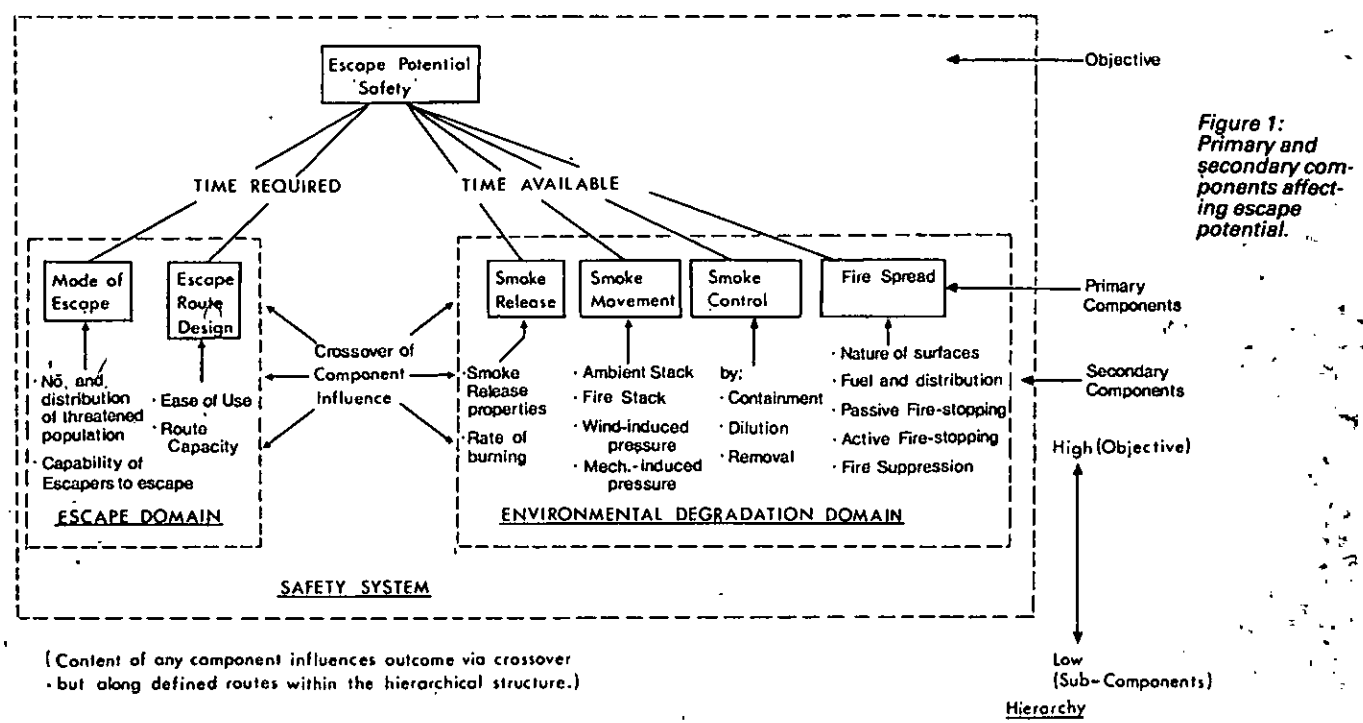
Two separate domains

Many of the components lower in the hierarchy will not belong exclusively to a single primary component; although the whole system is formed into two separate domains, escape and environmental degradation, there is a degree of cross-over giving rise to a complex inter-active network that exists within the hierarchical structure and in real fires.

For the evaluation of life safety, each primary component and its sub-components would be considered as having a variable impact on escape potential for different escape scenarios and for different times in the duration of the fire event. Accordingly, each will be assigned notional values (which may be zero) to reflect this variation. A "freeze-frame" approach can be used; for each time segment, of the total fire threat duration, changes in the relative importance of each variable for each threatened population (total, group or individual) are assessed, and applied using the logistics within the model and as many components as are realistically significant.

There are obvious problems in the practical

Continued overleaf



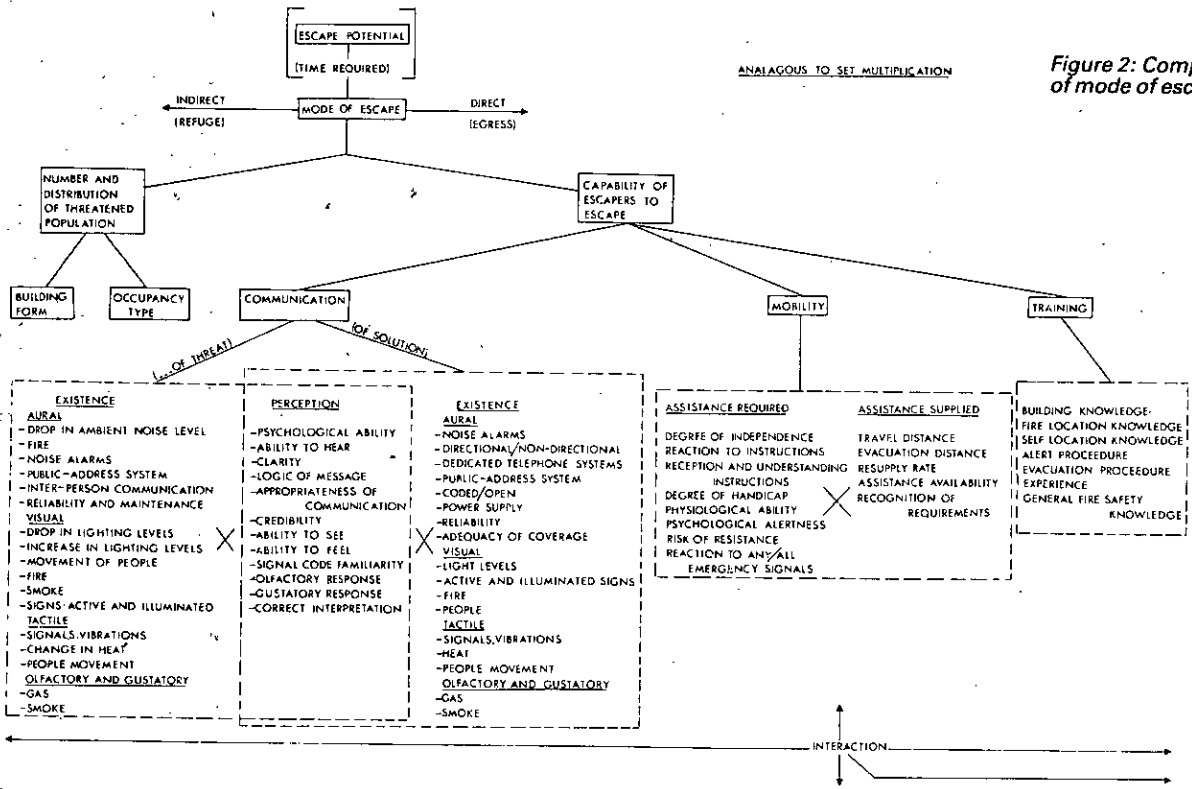


Figure 2: Components of mode of escape.

implementation of such a theoretical model, particularly as data of a reliable nature for use in deciding the values for the contribution of a component at a particular stage in the developing threat-safety situation are not available generally (2, 3).

However, it may be noted that the model is a heuristic concept to approach a systemic understanding of fire safety. This broad approach is a necessity if detailed research on fragments of the whole subject are to be amalgamated.

The complexity and scale of such a framework to depict the system are indicated in Figure 1, which illustrates the framework to secondary level only (of the 13 or so levels defined elsewhere).

Secondary components

Escape route design depends directly on the secondary components ease of use and route capacity. Smoke release is determined by the rate of burning (rate of weight loss) and the smoke release properties of the burning fuel(s); smoke movements depends on air pressure which will be determined by four mechanisms — ambient stack effect, fire stack effect, wind induced pressure, and any mechanically induced pressure; the secondary factors affecting smoke control will vary with the mode(s) chosen from containment, dilution, and removal of smoke; however, they may include the volume and energy of the smoke, the influence of internal and external leakage, spatial size and geometry, ambient temperature, and wind or mechanically induced pressure. Fire spread will depend on the fuel and its distribution, the nature of the surfaces with respect to fire spread, passive or active fire stopping, and any fire suppression activity.

There is potential for component interactions within and between domains, and secondary factors will depend on input from tertiary and lower level components.

Because of the scale of the framework only one component and its sub-components is described, and that is the component of mode of escape, indicated in Figure 2.

Mode of escape

Mode of escape is an essential primary component of escape potential. It describes the

technique(s) employed to safeguard the threatened population. The threat may be the fire itself or the products of combustion, or a combination of effects. These products may be hazardous because of their toxicity and/or reduction of visibility. There are several methods of escape that may be employed and involve either egress (phased or simultaneous) or the use of a refuge facility within the building. It is possible in many buildings that more than one mode will be employed in any fire event.

The adoption of one or other escape method will be influenced by a number of factors. For example: Design stage provisions — such as refuge and protection-in-place facilities and the provision of adequate route capacity — come within the primary component of escape route layout; however, they also have a significant interaction with mode of escape.

The nature of the fire event will influence the rate of degradation of the environment and may be important also to the choice of mode of escape, forcing changes from the initial design intentions.

The initial choice of the mode of escape depends directly upon the nature of the threatened population.

Potential interaction

The components of mode of escape are illustrated in Figure 2, and the potential interaction between components is indicated. Any of the components or any set of components determining perception of information may, or may not, be influenced by any of the components or any of the sets of components determining the existence of information about the threat or solution. The impact and influence of components will depend on the escape scenario and changes during the event. Values can be assigned to components to reflect particular escape scenarios. Values and relative values for sets of components may be achieved using set multiplication.

Factors in choosing the mode of escape

Within the range of possible influences on the choice of mode of escape lie aspects of the following factors:

Building form (including spatial arrangement, construction type, location, number of floors);

Occupancy type (hospital, factory, dwelling);
Threatened fraction of total population (individuals, groups, crowd);
Distribution of the threatened fraction of population (around floors and within spaces).

A factor lower in the list indicates an increase in the likelihood of short-term variations and thus a reduction in predictability. As the factors are related spatially and temporally they can be described in terms of occupied points within a three-dimensional spatial matrix. This type of description could describe easily changes in location of the threat and of the threatened population with time. This approach is similar to that adopted by Stahl (4) for two-dimensional horizontal movement.

Interdependent

Building form and occupancy types, especially for new designs, are interdependent and will affect the size and distribution of the threatened fraction of the population. The location of different groups within the population may be dependent also on mobility. This will be reflected as an interaction between number and distribution of threatened population and mobility.

The capability of escapees to escape depends on complex, and dynamic, combinations of the communication, mobility and training factors. This has been discussed in terms of the phases of a fire event (1).

Communication of information about a fire — a vital pre-requisite to the action of commencing escape — takes place in the recognition phase of escape. This is the time from being alerted by a cue to knowing there is a fire. A delay will occur between ignition and detection, which may be of minimal or significant duration. Information may take the form of actual discovery of the fire by a threatened population member (either by "stumbling" across it, or by following up ambiguous cues). It may be presented also as information from another member of a group in a given space when the status and credibility of the member may be significant; or by means of either an alarm or other information system.

Alarms do not give information about the location, severity and relevance of the fire or any other event serious enough to warrant use

Danger levels

Continued from page 22

of alarms, or suitable solutions to achieve safety, nor do they ensure authenticity. Information systems may give details of the actual threat and solution, although the usefulness of this information depends on at least the following factors: perceptibility, coded/open, directionality, clarity, logic, credibility, accuracy, and coverage.

Alarm and information systems depend on location and reliability of the systems' sensory components for effectiveness. It is clear that communication is vital and any deficiencies in reception of information that could be attributable to lack of coverage, faulty equipment, perceptible deficiencies in the population, or the lack of clarity or logic in the signal, will have a significant influence on escape potential.

There is an interaction between *communication* and *training*. Coded or targeted information is only of use to those who can perceive and utilise it. Withholding information from sections of the population, for whatever reasons, may have implications for escape potential.

Depending on the type, reliability and extent of information initially available, and on the role of the person threatened, a period of delay before action towards safety may occur.

Warning others

During the next stage of escape, coping behaviour such as warning others and fire-fighting may occur. This will depend on the role of the threatened population member(s), but a shift occurs in the relative importance of communication, mobility and training. Any such coping behaviour would require a degree of mobility.

The evacuation phase again depends on the components of communication, mobility and training. Mobility is clearly important, but so is training to gain a familiarity with all available routes; this is particularly important if routes to be used normally are blocked temporarily or permanently. Communication is necessary for a continual appraisal of the situation's development and to provide information feedback.

Variations in the relative importance of communication, mobility and training factors, and delay in response to changes to fire scenario occur with individuals and groups (5). Generally, group reactions will exhibit a greater inertia, and escape potential may be reduced, assuming that all other parts of the escape system are operating optimally. These variations would be reflected in values assigned to the components in these various situations.

Mobility during evacuation is a complex area worthy of consideration in itself. It covers the wide range of ambulatory (6) from mobile to totally immobile. This will obviously affect choice of mode-of-escape between the extremes of rapid direct egress and "protect-in-place".

Important factor

The design, number and location of escape routes are significant interactive components, as ambulant members of the population, capable of self-starting, may find it impossible to maintain the action of escape along complex pathways. This is a factor that would become more important as the severity of the threat increases through the continual degradation of the environment.

Escape route design is also inter-actively significant with building layout (ie the location of the systems with respect to the need for assistance). The supply and re-supply of assistance could well be affected by excessive travel distances, and the complexity of pathways. This will reduce the number of the threatened frac-

tion of the population that can be assisted in the time available.

Throughout evacuation a constant updating of information about the degradation of the environment, remaining route options and the activities of other fractions of the total population may be important. As degradation of the environment proceeds so the choice of routes will diminish. The effect of reduced choice of route will be different for each fraction of the escaping population. For example, it would be irrelevant for the fraction that have made safe escape, or who are assured of safe escape because of their location in the total geometry of the building.

However, continuing degradation and reduction in choice of route could change the mode of escape necessary for other fractions of the population that need to be evacuated. The effectiveness of communicating current information may influence the ability of the remaining fraction of the population to re-adapt to these changes.

Discussion

The two most valuable objectives behind the adoption of a systemic modelling approach to fire safety are: (a) to arrive at a more thorough understanding of the fire safety system; and (b) to evaluate the inter-relationships of the results of other research and investigatory work.

During the initial stages in the assembly of the heuristic framework it became clear that a vast number of componential factors of variable importance determine the life safety of the system. The arrangement of these factors into a hierarchical inter-active structure indicates that the number of levels of dependency in some areas (eg, escape route layout) is considerable.

The definition and assessment of changes in the relative values of components at a level in the hierarchical structure will be important also. These values are essential input as it is necessary to ascertain if all components at a particular level in the structure are of equal importance to the assessment of escape potential.

Investigated

Many components of the escape potential model have been researched or investigated and the results range from quantitative sequela of experimental investigations, through observational studies to theoretical and conceptual studies. Each of these approaches is likely to use variables that are part of an interactive hierarchical structure and, therefore, the results should contribute to the assessment of relative values of the components at some level in the structure.

The implicit or explicit assumptions, or proven dependencies and inter-relationships in the studies of parts of the escape potential system need examination and should form part of the total pattern of interactive crossovers in the structure. It should be possible to overlay the part-models that exist on to the developing structure, provided that the input parameters and output results can be identified closely with components of the structure.

Attempts to overlay part-models of different, but similar, sets of components upon the escape potential network may generate some problems. For example, the set of components considered in evacuation studies, including some studies using observational information on occupant behaviour (1), some using a mechanical approach to the carrying capacity of exitways (3), and some using network flow systems (7), may not be compatible directly. An analysis of the part-models will indicate areas of overlap, in terms of components considered, thereby strengthening the data available for that set of components.

Areas in the structure and interactions and crossovers not overlain may be indicators of topics in which further research is required. Individual models may deal with a vertical section of components in the hierarchical structure — ie, penetrate the components in one limb to a great depth — or may deal with an

horizontal section of components at one level in the structure — ie, a part-model from which positive crossovers can be identified.

Preliminary studies of relevant concepts and componential relationships, such as those discussed for *mode-of-escape*, yield a concentration of information represented by the middle to lower levels of the hierarchy. There appears to be a need for research into the higher-level relationships, between components of primary and secondary importance in the structure, to consolidate understanding of component contribution at the top end of the hierarchy.

The use of the structure as a tool to highlight these points, and to encourage their resolution, may test both individual models and concepts of a systemic structure equally.

Conclusion

Assessment of escape potential in buildings requires a full complement of factors, and a correct model to evaluate level of importance, interactions and relative values, including changes in relative values of components. This is a distant goal but work in this direction may be useful to pull together detailed research of fragments of the system and allow a more comprehensive view of fire safety to be achieved. A tool, such as this structure, for bringing fragments together will be required, as will estimates of values, and relative values; problems of data collection, handling, and meaningfulness (3) must not be underestimated.

The use of a systemic approach will allow a more thorough understanding of the safety system to be attained, an amalgamation of work done so far, and an identification of areas where further research is needed.

ACKNOWLEDGEMENTS

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Greece offers reward for arsonists' arrest

REWARDS of up to 30 million drachmas (£164,000) were offered recently by the Greek Government for assistance leading to the arrest of arsonists, who were thought to be responsible for an 11-day series of forest fires.

The announcement said Prime Minister Andreas Papandreu believed the fires were part of a planned attempt to destabilise Greece. He decided on the reward offer during a meeting with defence chiefs on the problem.

THE APPLICATION OF EXPERT SYSTEMS TO THE EVALUATION OF LIFE SAFETY IN FIRES.

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Summary

Fire Safety is a wide and inter-disciplinary field in which experts are few, and knowledge is relatively ill co-ordinated. There is a need for an expert in Fire Safety matters from the conceptual stage of a building's life cycle. A shortage of knowledge for the design or evaluation of a building may arise either because the necessary expertise is unavailable or is ill-defined. Developments in computerised Expert Systems may open up an extensive area of expertise.

Expert Systems are a style of computer program derived for the manipulation of relational knowledge to produce decision making tools of a similar nature to an expert. For a number of reasons this similarity to the expert is variable and limited.

A model has been developed based on a series of identified relationships and their relative contributions to Life Safety. This is considered to be a suitable application for an Expert System.

Some initial thoughts are presented on the applicability of Expert Systems to the evaluation of Life Safety in Fires, based on a systems model developed by the author. Further research in this area is planned.

Keywords..Life Safety, Fires, Expert Systems,

Introduction

Fire Safety is an integral part of successful building design and usage. It is inter-related to all other aspects of building performance, however, it may not be evident in the normal daily use of a building. See diagram 1. This may lead to it being overlooked.

If the factors that constitute Fire Safety Performance are identified, together with their inter-relationships with the other aspects of Whole Building Performance, a model for the contributory relationship of Fire Safety to Whole Building Performance may be created. Integration becomes more feasible.

Such an exercise to identify and model the inter-related factors determining Life Safety in Fires has been undertaken, and an introduction to the concept is presented elsewhere (1). The basis of the model is general, so it may be applied to any specific building-fire scenario. This is done by modelling the building, its occupants, and the internal environment as a series of sub-components of the Life Safety System, dynamically inter-related.

Fire events may be broken down into a number of notional time stages common to all occupants (2). See diagram 2. The potential relationships between factors and their relative contributions to Life Safety may vary throughout the event stages. A model for the evaluation of Life Safety must reflect this.

The Building Regulations have been criticised in the past on the basis of overcomplexity and over-provision, resulting mostly from the manner of development. The Building Regulations (1985) reflect a move toward an improved, performance-orientated approach. They contain the concept of equivalency, together with encouragement to attain the required performance levels by a flexible approach.

There is evidently much scope for flexibility in design. This, and any changes to the design of proposed buildings, or use of existing buildings will have implications for Fire Safety (because of the inter-relationship with all other aspects of building performance). It is important that this is recognised. The continuing Fire Safety implications are recognised by the designation of some building usages for compliance with minimum Fire Safety Standards (Fire Precautions Act, 1971). Review of the Fire Precautions Act suggests placing the onus for Fire Safety on the owner/occupier (similar to the Health and Safety at Work Act, 1974), and the possible extension of designation to all building types. The adequacy of Fire Safety provisions for the premises would be evaluated by the local Fire Brigade.

The concept of equivalent safety may be interpreted as its attainment in a particular instance by different means, or between building types and usages (for example sports grounds and hospitals).

In order that the Fire Safety aspects of design, or usage, of all buildings in the UK, and its review at each of the stages in the building life cycle by the appropriate bodies (Architects, Services Consultants, Building Control Officers or Approved Inspectors, Owner/Occupiers, the Fire Brigade, and also Insurance) may be achieved effectively and efficiently; all must have access to a means of assessment that is both comprehensive and consistent.

The model developed recently by the author (1) can be used to analyse the relationships between, and the relative contributions of, factors determining Life Safety. This involves the building, its occupancy, and the internal environment throughout any fire scenario. It is applicable to proposed or existing buildings; as in reality the extent of assumptions varies. Implications of changes in design or usage may also be modelled. The model forms a base from which the comprehensive and consistent means of assessment required by all those associated with Life Safety in buildings may be developed.

A particular problem with the evaluation of Fire Safety is the paucity of data. The development of the model was made using a structured group technique; to verify the concepts behind the model and provide a congruent set of values for the inter-relationships and relative contributions of each factor to Life Safety. The group consisted of eight members selected from the interested professions such as Building Control, the Fire

Brigade, and Academics including Fire Safety Engineers and an Architect. The result is a systems model that consists of a set of relational statements about the factors affecting Life Safety in Fires; and a set of data concerning the inter-relationships and relative contributions of these factors to Life Safety. The model was developed to the tertiary level only, and involves approximately one hundred and fifty inter-related factors. Each sub-factor of the Life Safety System is clearly defined, and described by its potential relationships with other factors in the system at any notional time stage. Evaluation of deficiencies convert these potential relative contributions to actual contributions. Life Safety is evaluated on the basis of a consistent manipulation technique developed by the group. Diagram 3 illustrates typical relationships and relative contributions to Life Safety for one factor. This approach, replicated for each factor in the system produces a set of rules and a consistent subjective knowledge base. The Life Safety systems model allows the evaluation of any scenario based on the judgement of factor performances. The model provides a measure of safety which may be compared with minimum acceptable levels. The performance of individual factors of the system is recognised and the output will provide an analysis of the factors failing to meet specified standards, the criticality of these factors to Life Safety and any implications this may have. In this way, consequences of design or change in use can be evaluated using this information. The complexity of the Fire Safety problem is enormous and the model is consequently vast and its use laborious. See diagrams 4,5,6. This poses a restriction on its general application as an evaluative tool that can be overcome only by simplification or computerisation. The former would be a return to the unsatisfactory approach to Fire Safety, and not in the spirit now adopted for the Building Regulations and Fire Precautions Act.

Application Aspects

Expert Systems already exist or are being developed in a wide range of disciplines. An Expert System has been defined as: "...an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used can be thought of as a model of the expertise of the best practitioners in the field." (3,4). See diagram 7. A limited study of the applicability of aspects of the Building Regulations to Expert System modelling was made at the Fire Research Station (6). Such an approach may not be a true Expert System, but more akin to a database. An attempt to apply Expert Systems to Fire Safety has been made in the USA, and is encouraging. This is an elementary model and so far applied to models of lesser systemic representivity (7). The Life Safety model and the nature of its structure makes it suitable for the application of an Expert Systems approach. The relationships and relative contributions required can be abstracted (see diagram 3).

There are number of aspects of the development of an Expert System for Life Safety in Fires that require consideration:-

The tool must be relatively straightforward to use.

The tool must be able to handle data ranging from a relatively hard nature (e.g.; fire test data) to a relatively soft nature (e.g.; people behaviour). It should also be capable of justifying decisions made, and presenting the input data and the implications of the decision. These are features of Expert Systems. Knowledge shortages in the Life Safety field will require a combination of further research, distillation from experts and knowledge rationalisation (1); there is also a well recognised need for data in a wide range of fire related subject areas.

If the Expert System is to be widely used it must be capable of running on a micro-computer. There is evidence from a number of sources (6) that the nature of the micro-computer is currently a major restriction on the scale of Expert System that can be accommodated. This is supported by a seminar held by the Open University Systems Group and the RIBA, concluding that the concepts involved in Fire Safety were suitable for Expert Systems representation (8).

The developmental restriction posed by the handling capacity of a single micro-computer, and the often restricted focal area required for consideration by an evaluator, suggests that a modular and hierarchical approach to the handling of the information may be an appropriate approach. See diagram 8.

In this case the interactivity of the Life Safety System could be administered by a managerial Expert System. This would co-ordinate the information and inference rules developed to represent the knowledge sub-sets. It will be the direct interface with the user. This is the equivalent of the expert using a traditional library. The main strategic Expert System will draw on any or all of the (expert) Sub-Systems for information and data on the subject being considered. Use of Sub-Systems in isolation would limit the systemic representivity. There may be further extensions; - some Expert System shells (e.g.; Savoir) can address databases and interface with other programs. The implication of this for the Life Safety System is broad because of the range of accepted (computerised) sub-systems models (e.g.; Evacnet+, BFires, Aset, Harvard). See diagram 9. Model assumptions and input/output requirements will need examination.

Comments

The development of the model described, and the philosophy behind the Building Regulations and the Fire Precautions Act make an Expert Systems application aimed at the interested professions timely. Research to develop the Expert System for the Evaluation of Life Safety in Fires is scheduled to commence late 1987.

The growth in power and flexibility expected in the micro-computer field in the near future should make the manipulation of larger Expert Systems practicable, and is encouraging for the

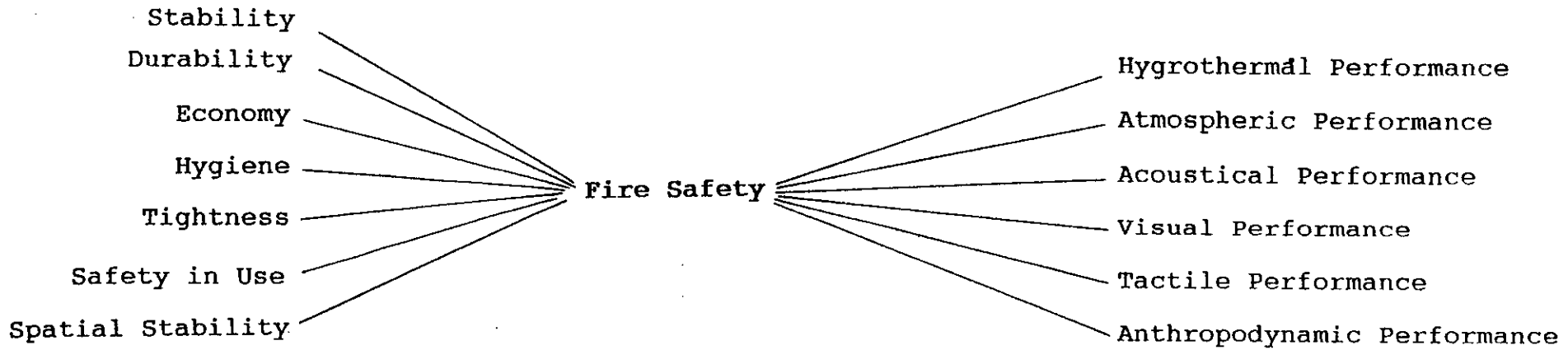
research and development exercise.

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Potential relationships between Fire Safety and other identified factors of Whole Building Performance.

Diagram 1.

Stage 5: The time stage for travel in a protected route or waiting in a protected zone until safety is achieved (egressing building or rescue).

Stage 4: The time stage between commencing escape from the threatened space until achieving relative safety, eg; a protected route or a refuge.

Stage 3: The time stage between perception and action.

Stage 2: The time stage between detection and perception.

Stage 1: The time stage between ignition and detection.

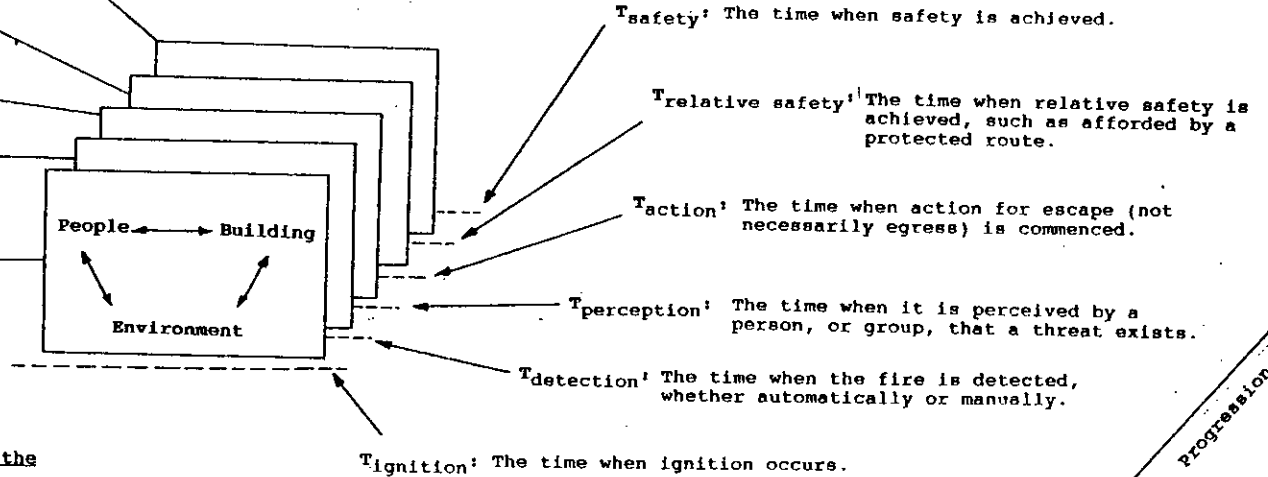


Diagram 2.

The relationship of People, Building, and Environment during the notional stages of a Fire Event.

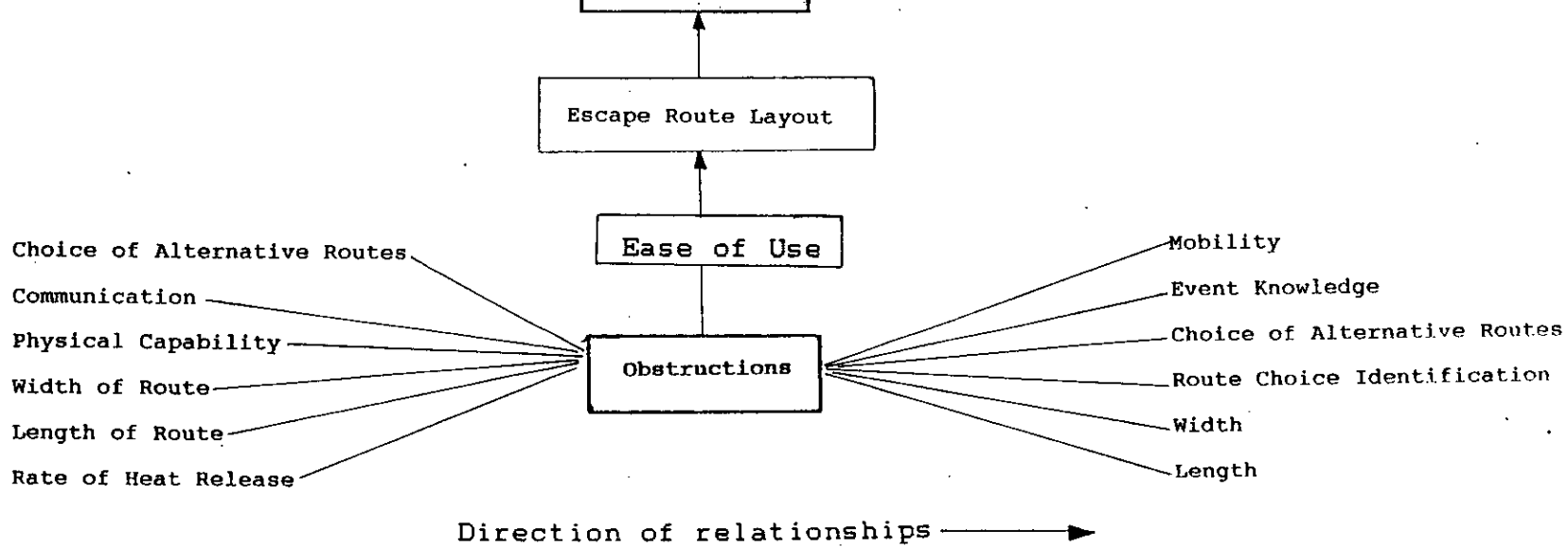
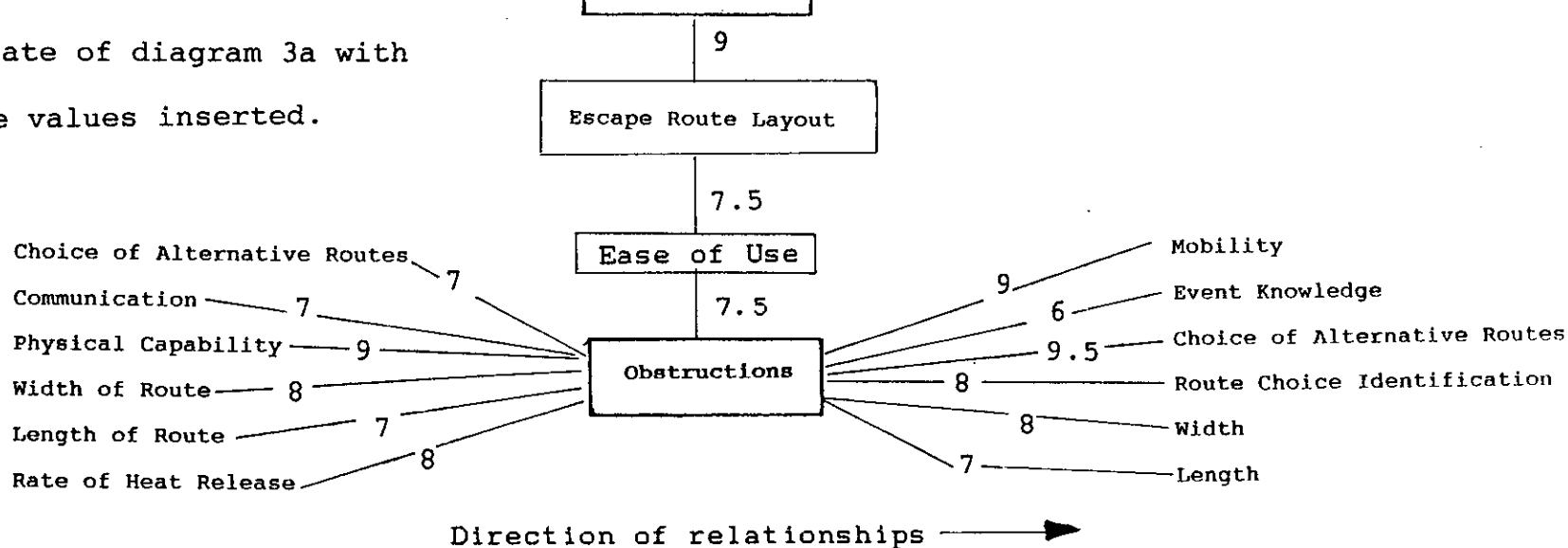


Diagram of Typical Relationships. RULES.

Factor: Obstructions.

Diagram 3a.

A duplicate of diagram 3a with relative values inserted.



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Diagram of Typical Relationships. (SUBJECTIVE) KNOWLEDGE BASE.

Factor: Obstructions.

Typical notional time stage 4: The time stage between commencing escape from the threatened space until achieving relative safety, eg; a protected route or a refuge.

The values on this diagram are taken from structured group decisions. They represent the potential relative contribution of the factors to Life Safety during time stage 4.

The values on this diagram are for a Life Safety System involving Smoke Control by Removal. The alternative techniques of Smoke Control: Dilution or Containment, may produce different relative values.

Scale: 0 - 4 : a low potential relative contribution.
 4.5 - 6.5 : a medium potential relative contribution.
 7 - 10 : a high potential relative contribution.

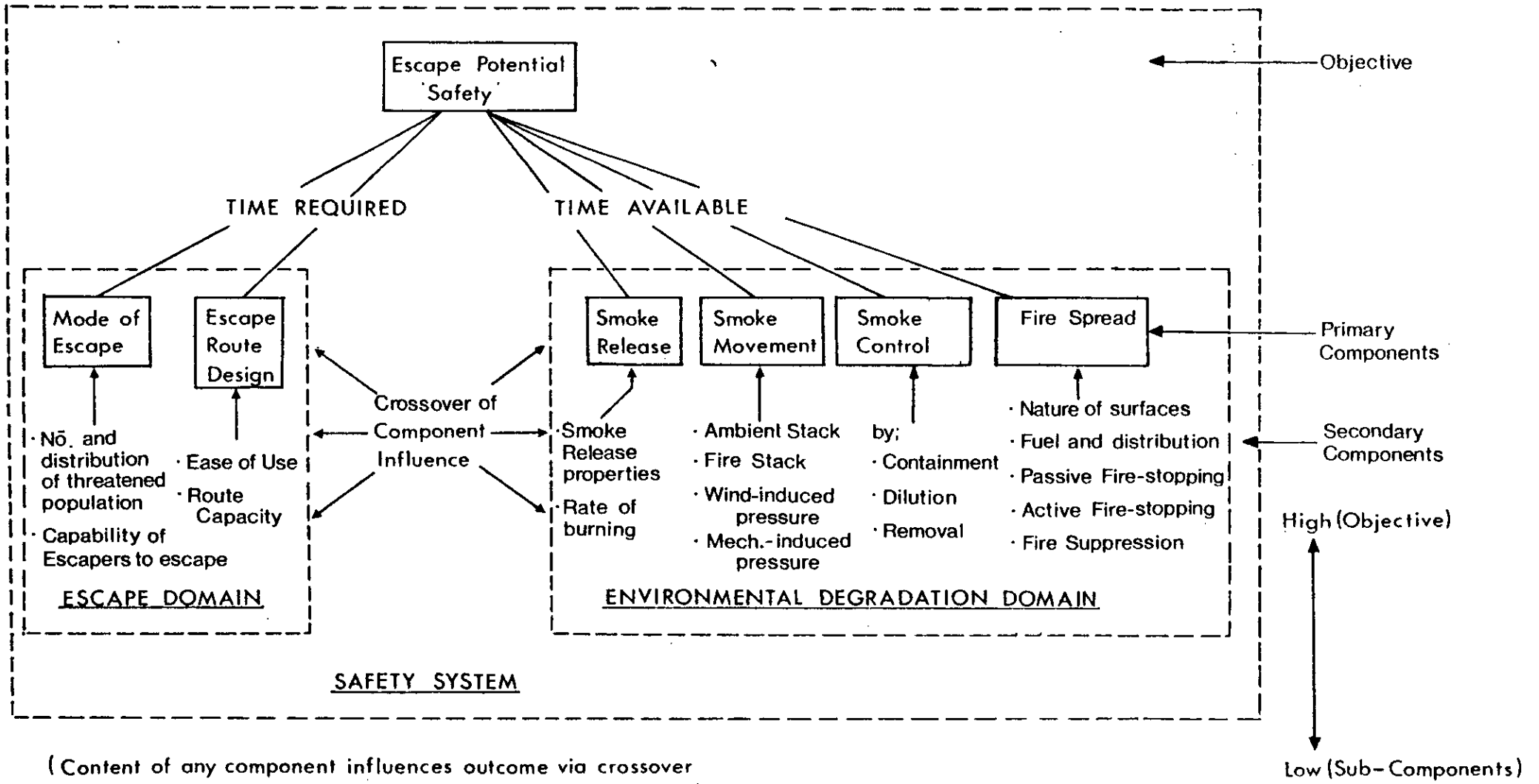
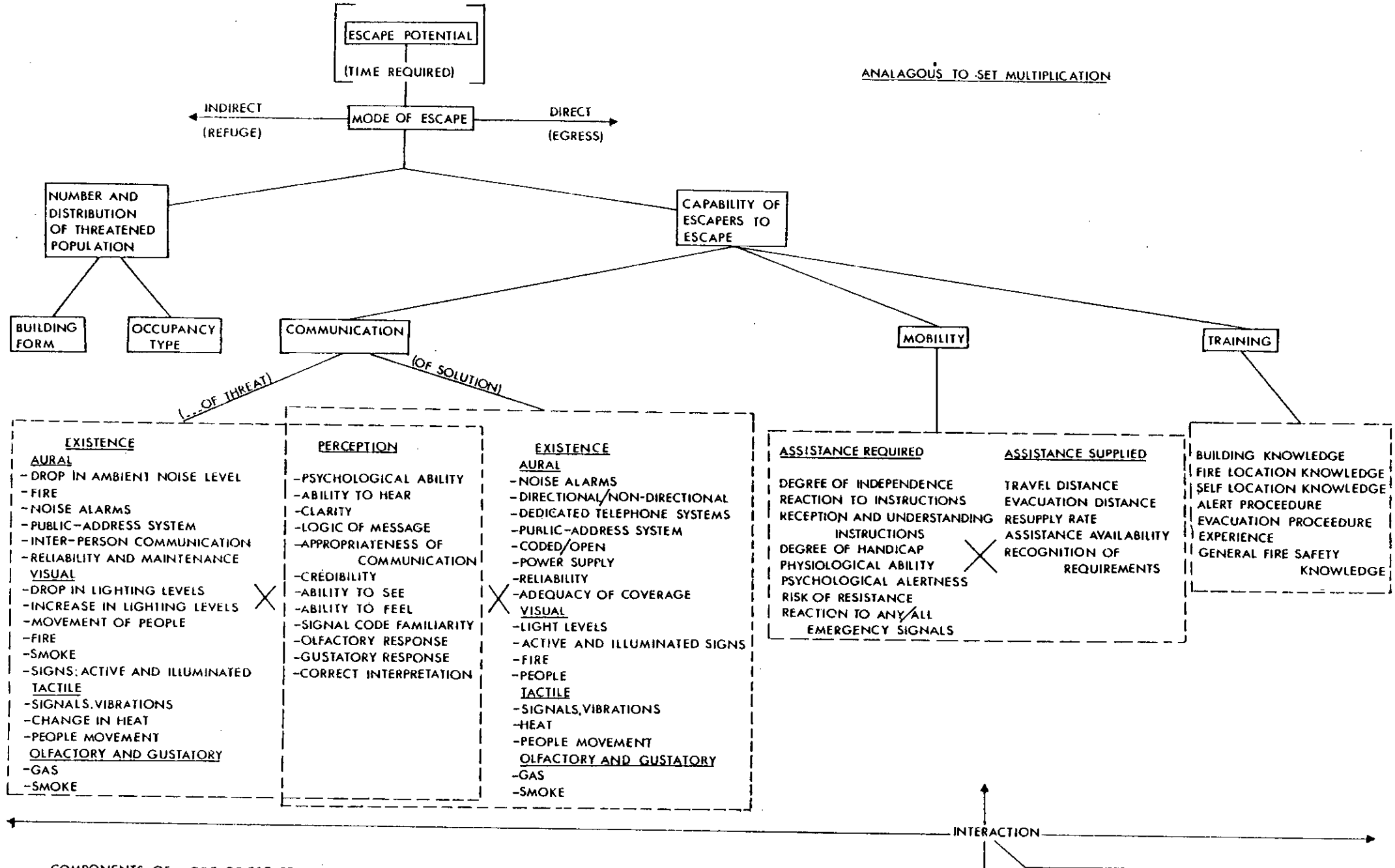


Diagram 4.

Primary and Secondary Components affecting Escape Potential

Source: Fig 1 in "Predicting Danger Levels to Life - The Deciding Factors" A.J. Hinks (1)

Diagram 5a



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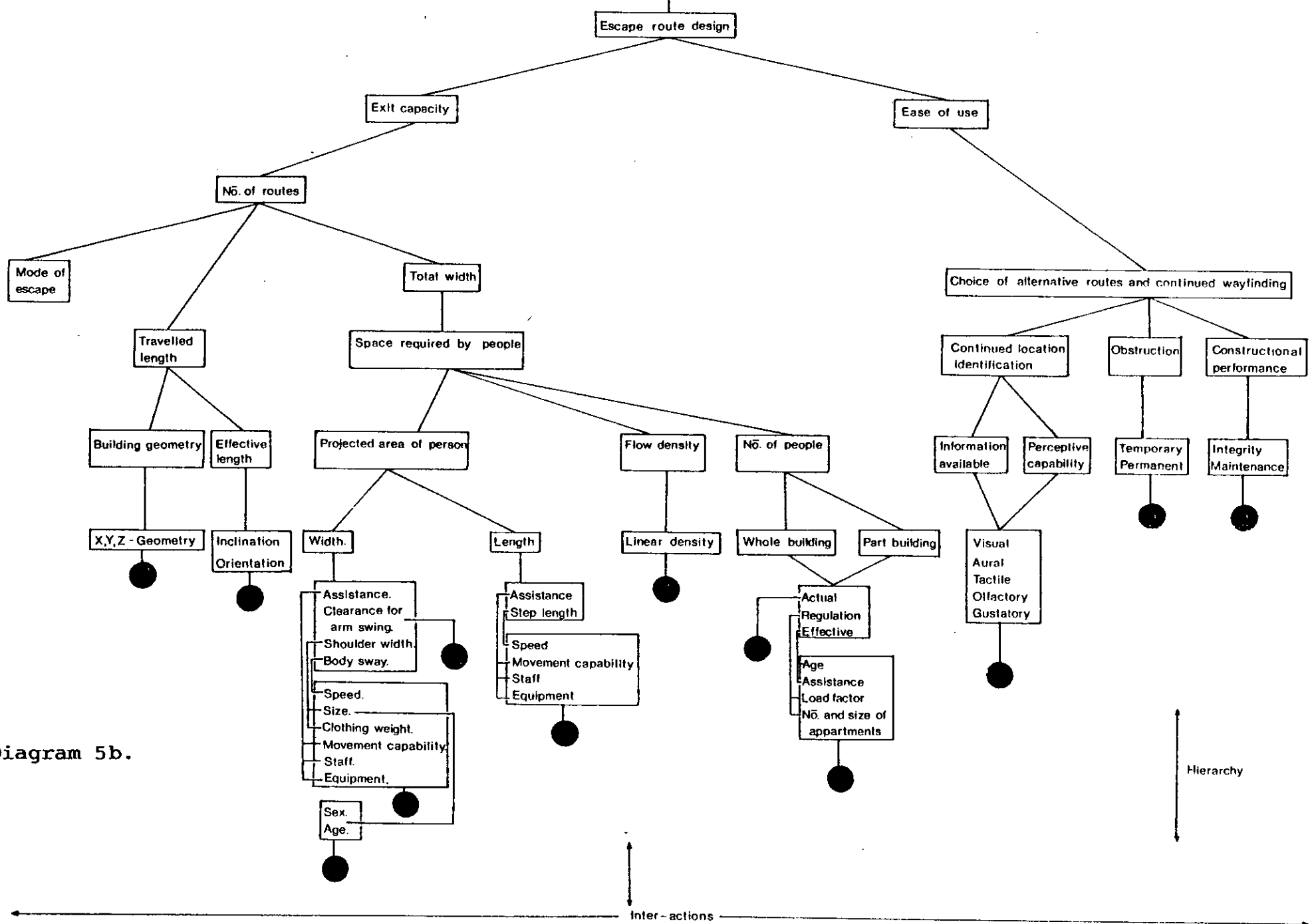


Diagram 5b.

Inter-actions

Hierarchy

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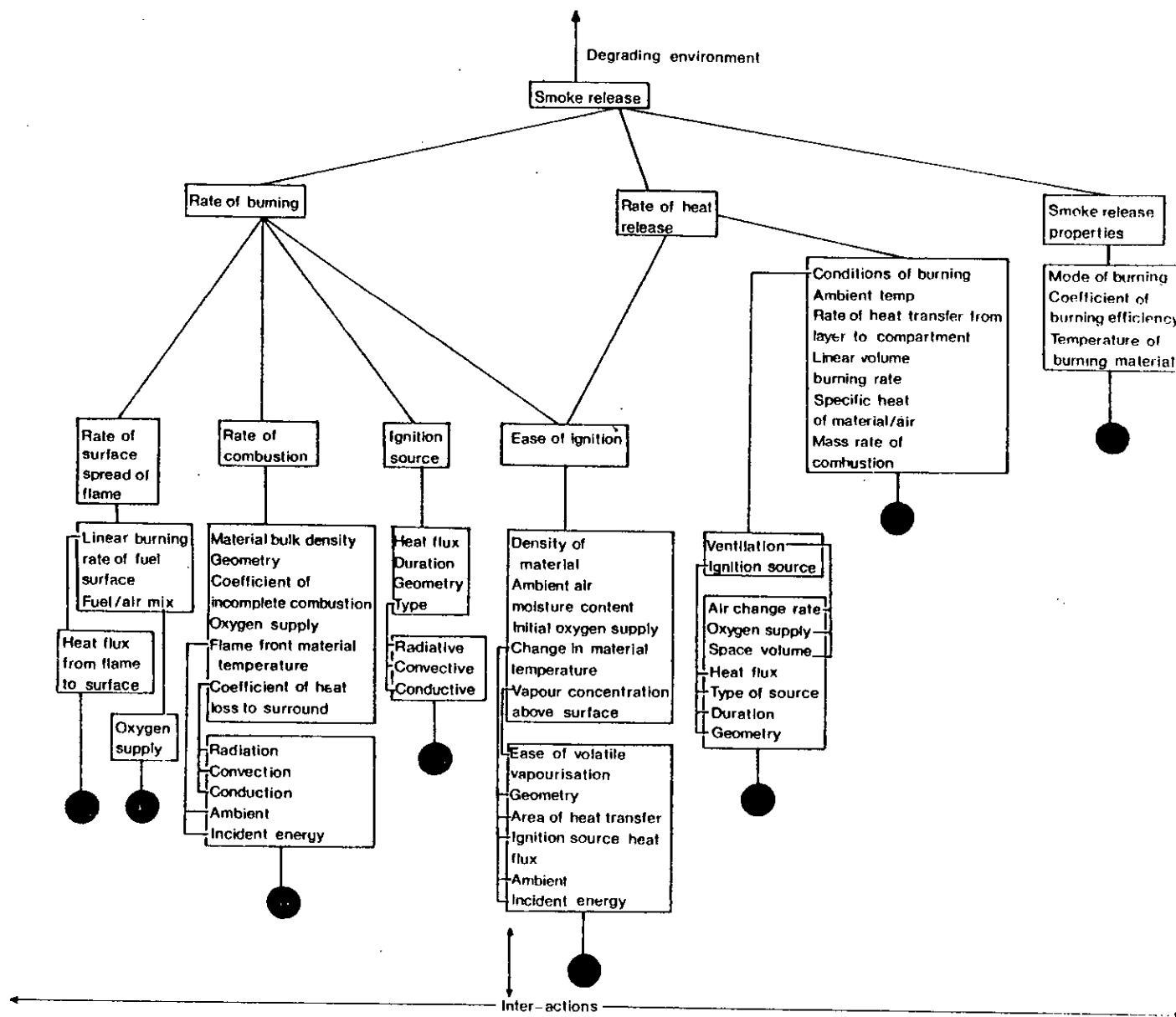


Diagram 6a. Smoke Release factors.

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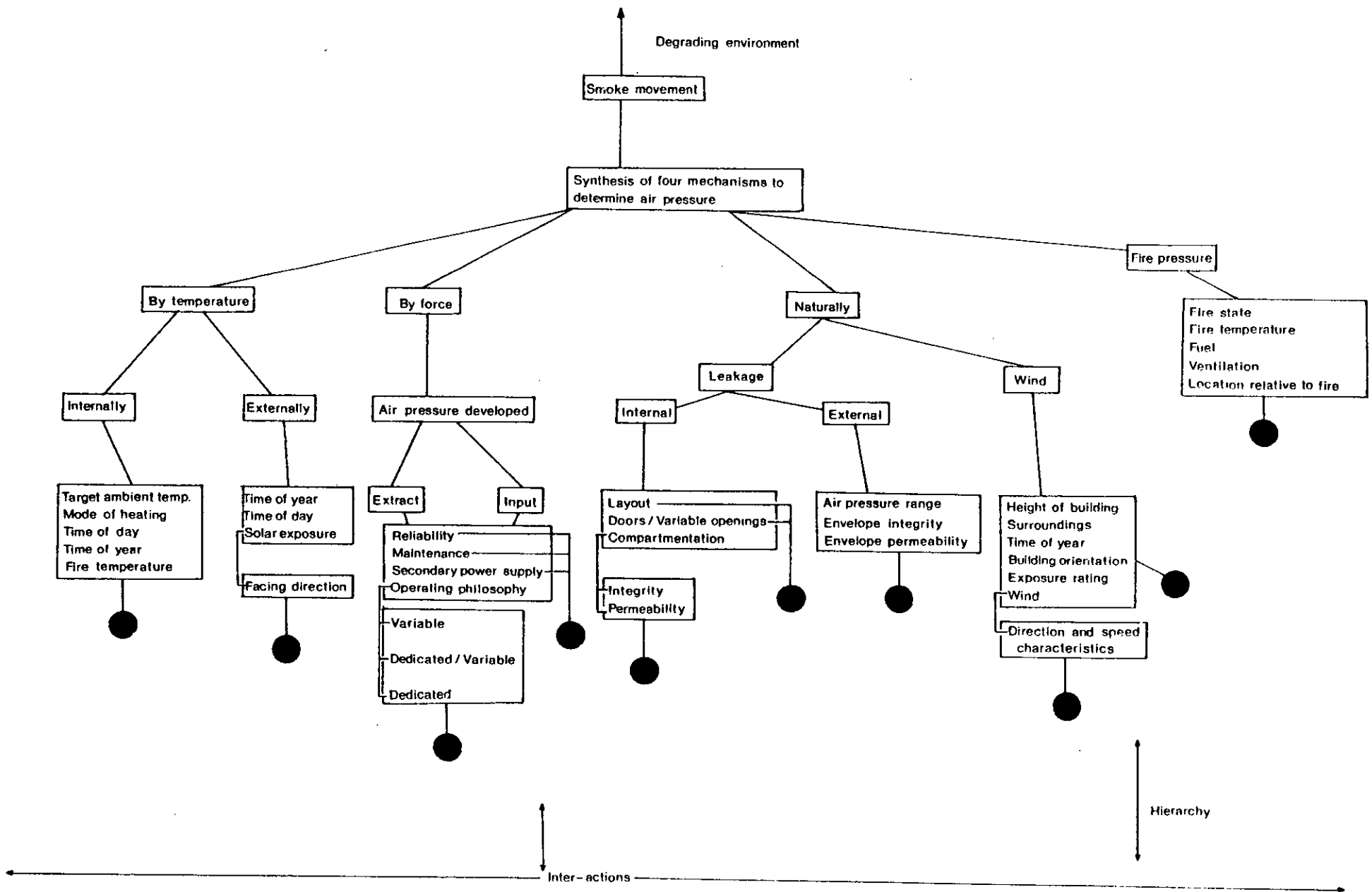
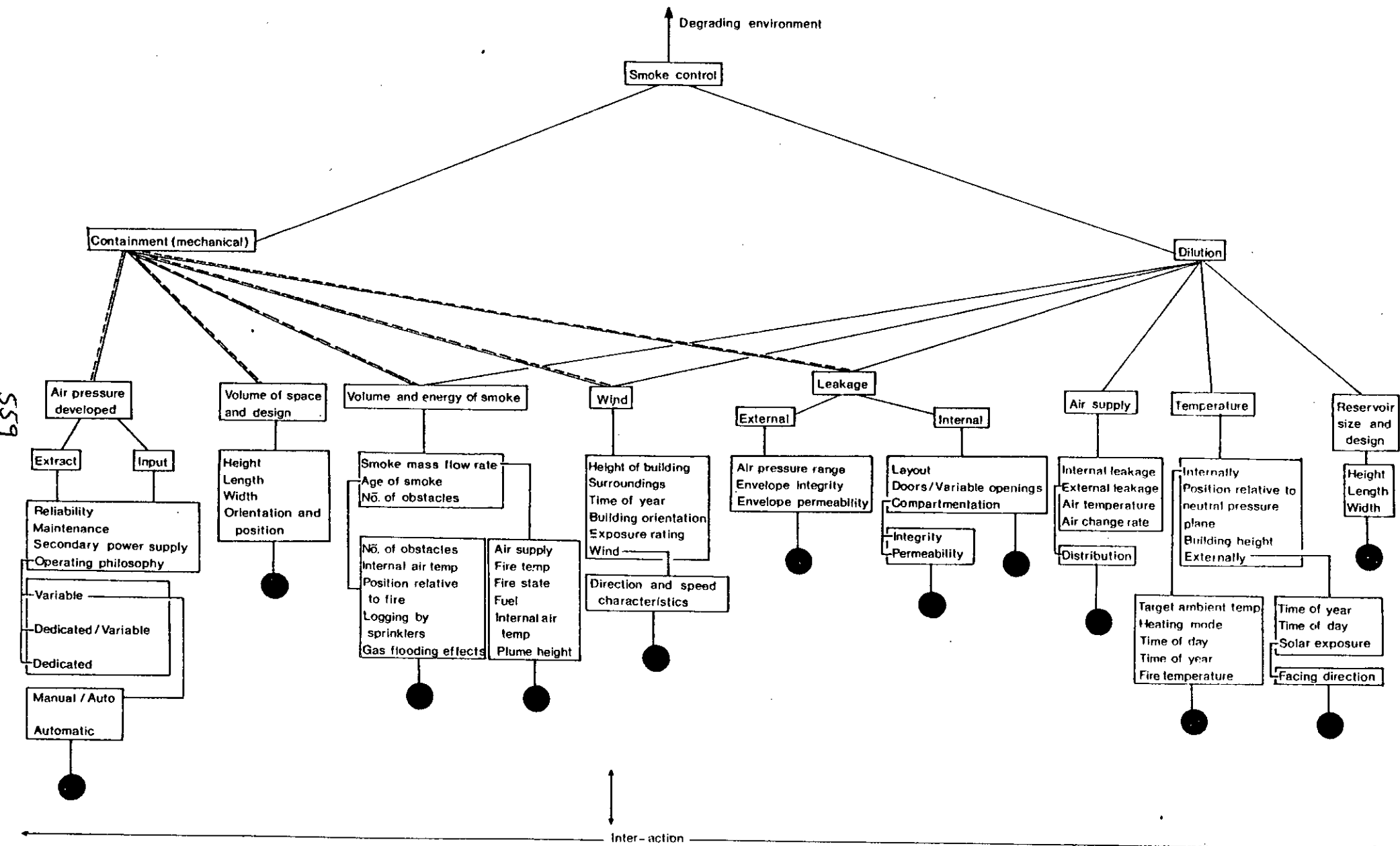


Diagram 6b. Smoke Movement factors.



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Diagram 6c. Smoke Control factors - Containment and Dilution.

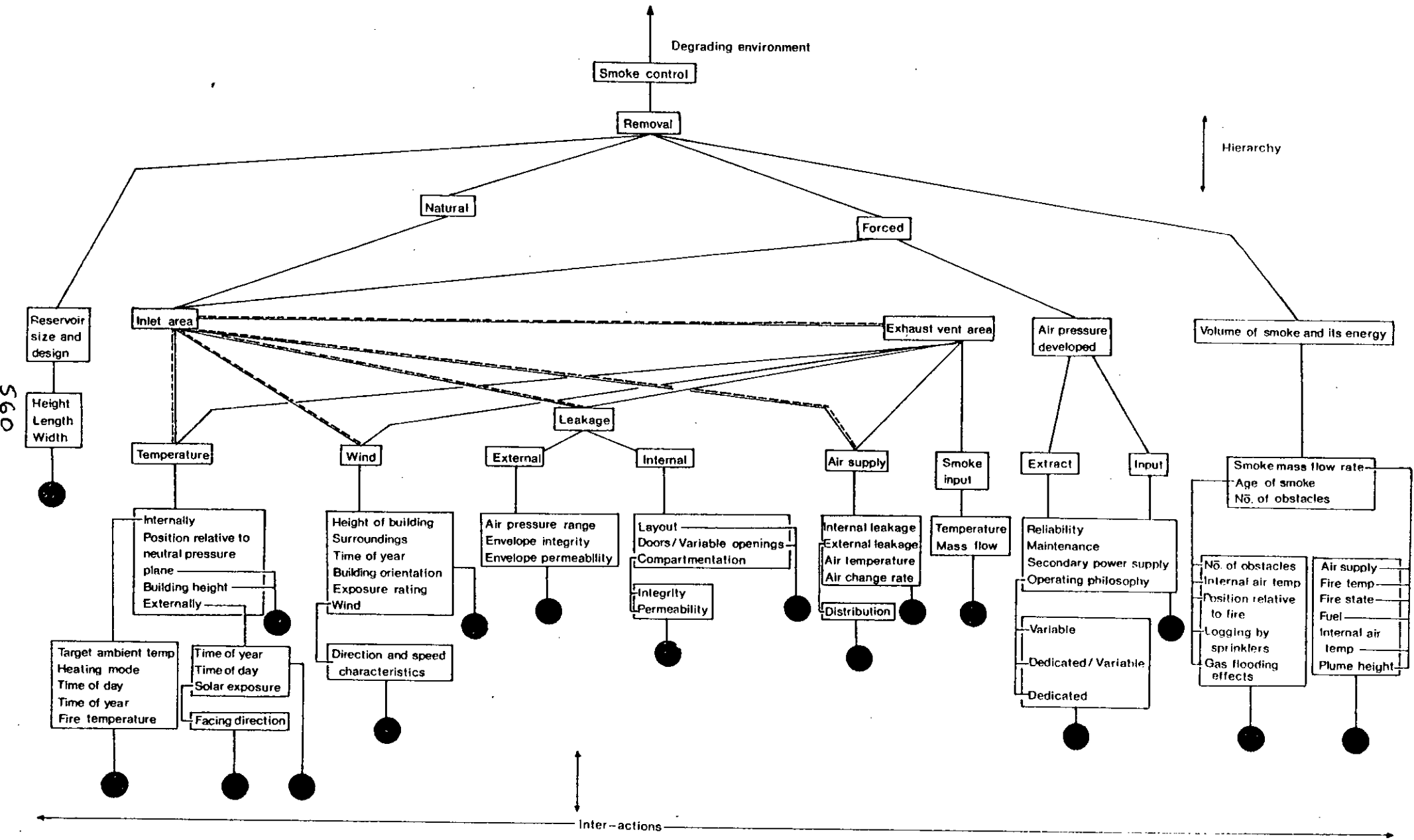


Diagram 6d. Smoke Control factors - Removal.

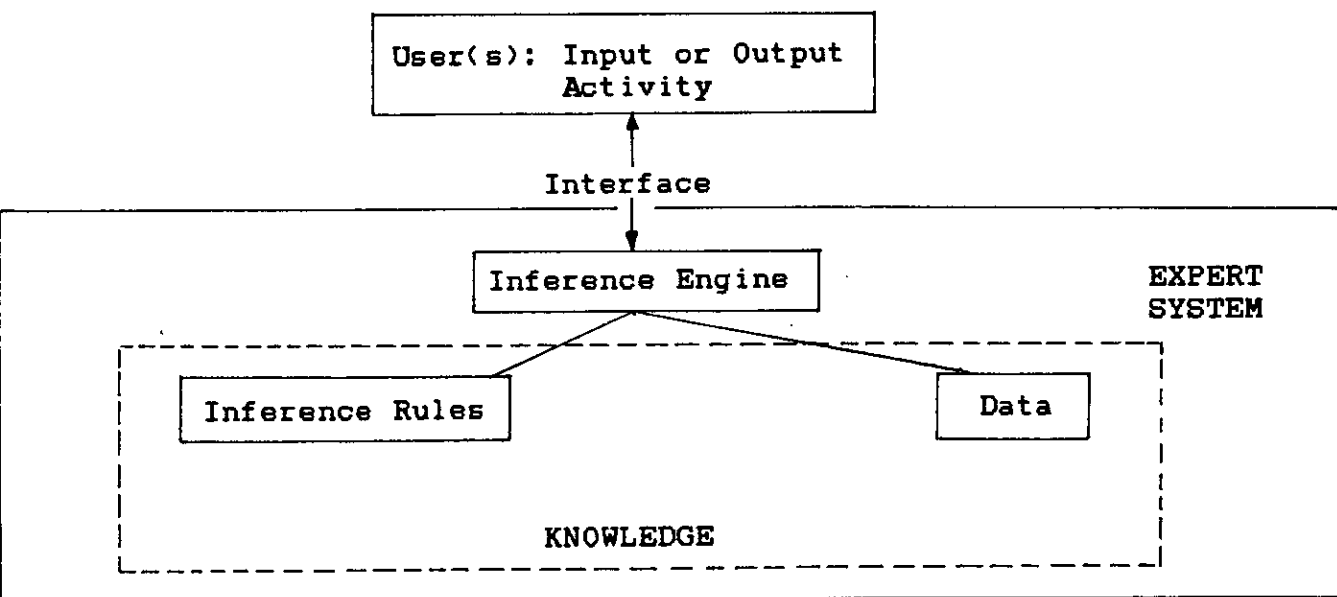
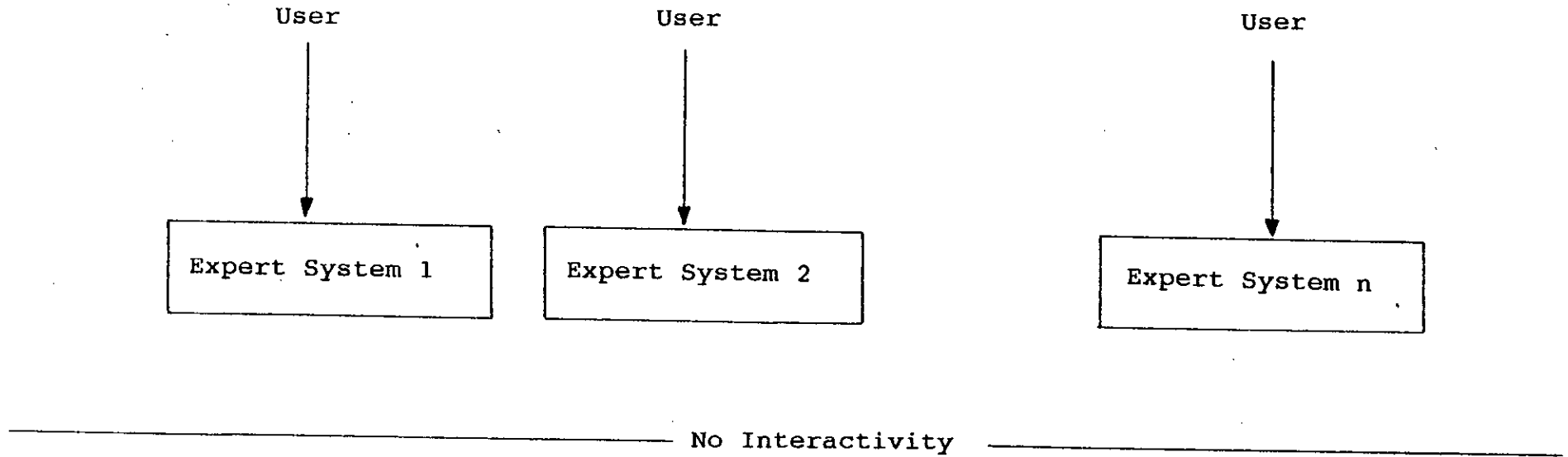


Diagram 7. Anatomy of an Expert System.

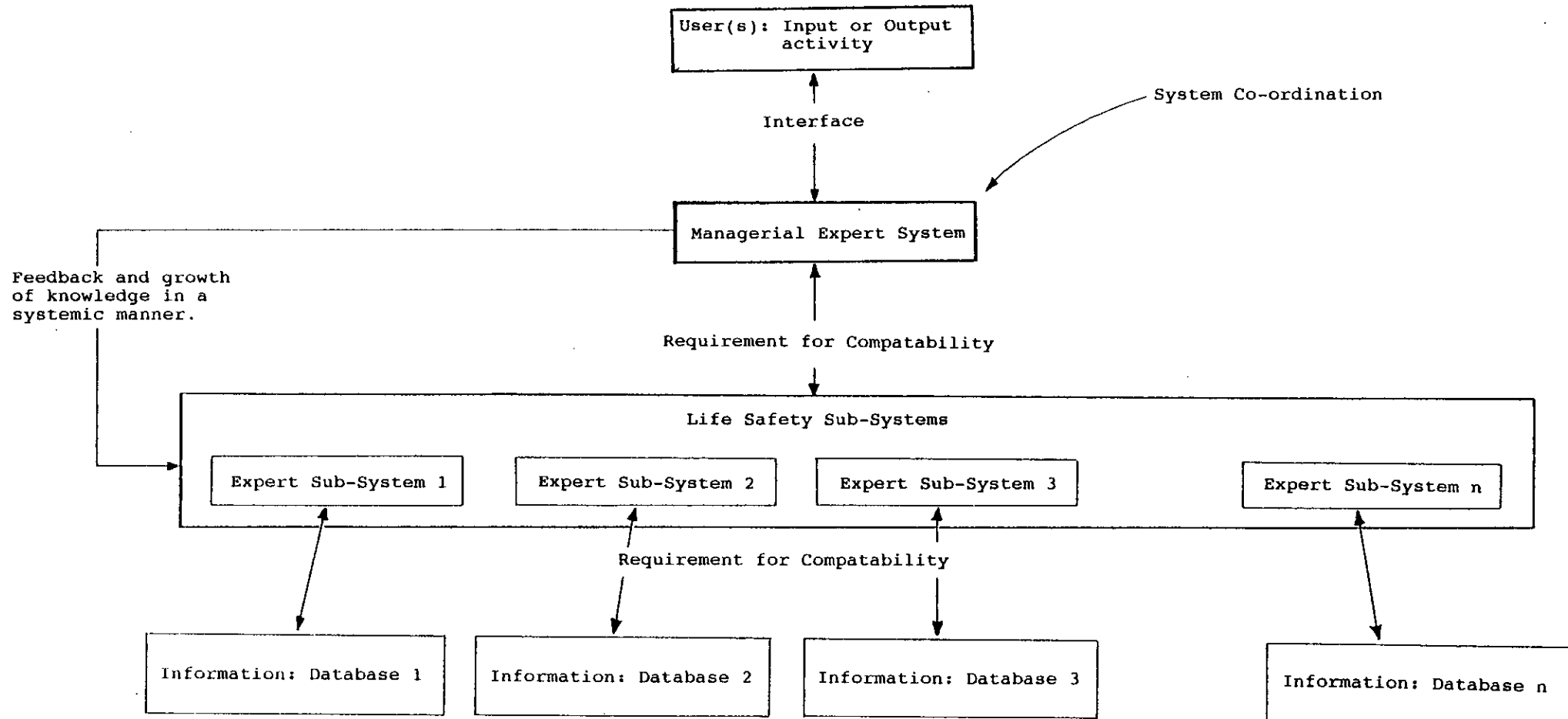
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The use of closed micro-computer systems limit scope, and interactivity is not recognised.

Diagram 8a.

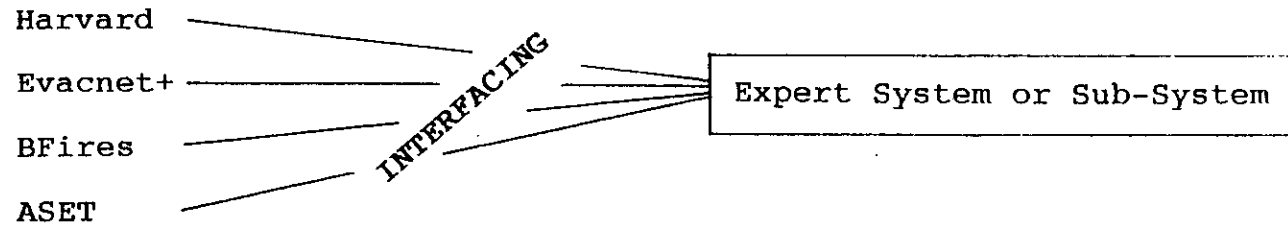
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An alternative to closed micro-computer systems.

Diagram 8b.

Examples:



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Inter-relationship between Expert System and existing models for sub-aspects of Life Safety System.

Diagram 9.