Previous studies and reports

- Preparing Australians For a Future with Technology Project Report 1988
- Preparing Australians For a Future with Technology Technical Papers 1988
- Advanced Process Control Project Report 1987
- Advanced Process Control Technical Papers 1987
- Winning By Design Project Report 1987
- Winning By Design Technical Papers 1987
- Major Industrial Hazards Project Report 1986
- Major Industrial Hazards Technical Papers 1986
- Advanced Surface Mining Technology Project Report 1985 (out of print)
- Macroprojects Project Report 1985
- Computer Aided Design Project Report 1984
- Local Area Networks Project Report 1983
- Marine Works for Bulk Loading Project Report 1983

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# Table of Contents

THE WARREN CENTRE

THE VISITING FELLOW

EXECUTIVE SUMMARY

PROJECT REPORT

1 BACKGROUND TO THE PROJECT

2 FIRE RISKS AND COSTS IN AUSTRALIA

3 CURRENT SITUATION AND NEED FOR CHANGE

4 DESIGN OBJECTIVES

5 RISK ASSESSMENT MODELS

6 DESIGN CRITERIA

7 BUILDING DESIGN OPTIONS CONSIDERED

8 PRELIMINARY RESULTS

9 RISK ASSESSMENT MODELS AND DECISION MAKING

10 REVIEW OF FIRE TECHNOLOGY

11 FIRE SAFETY SOLUTIONS FOR THE 1990's

12 CONCLUSIONS

13 RECOMMENDATIONS

APPENDICES

1 DEMONSTRATION RISK ASSESSMENT MODEL TERMINOLOGY AND LOGIC DIAGRAM

2 PROJECT ORGANISATION

3 PROJECT STEERING COMMITTEE

4 TASK GROUP MEMBERSHIP

5 PROJECT FELLOWS

6 ACKNOWLEDGEMENTS

7 PUBLICATIONS STRUCTURE
The Warren Centre

ORIGIN

The Warren Centre for Advanced Engineering was established in 1983 to mark the Centenary of Engineering education at the University of Sydney.

In 1883 Mr William Henry Warren delivered, to ten students, the first engineering lecture at the University. His popular leadership of Engineering extended to 42 years. During Professor Warren's reign, substantial endowments, notably the Challis bequest and that of Sir Peter Nicol Russell, enabled the Faculty of Engineering to grow. Professor Warren was the first President of the Institution of Engineers Australia on its establishment in 1919. He died a year after his retirement.

The Warren Centre is similarly supported by donations. While the University provides and maintains the facilities used by the Centre, substantial donations by over 90 companies and 350 individuals provide investment earnings for the Centre to operate.

GOAL

The general object of the Centre is technological transfer of advanced engineering by co-operating with industry to promote excellence and innovation in all fields of engineering in Australia.

FUNCTION

The Warren Centre is controlled by a Board comprising representatives from industry and from the University, industry representation predominating. A small full-time staff operate through an Executive Officer administering, typically, two projects each year.

As part of the Faculty of Engineering, the Warren Centre provides facilities and basic funding for groups of senior engineers and a Visiting Fellow to come together for an intensive period of several months. Such a period is central in Warren Centre projects which usually involve:

- Selection of an engineering subject of national importance with scope for advancement of engineering skills.
- Appointment of a Visiting Fellow, recognised to be a stimulating authority in the subject, for leadership of the team of engineers and to influence engineering design, practice, organisation and management in Australia.
- Establishment of a Steering Committee to provide policy guidance and general support for the project.
- Recruitment of the engineering team from industry, government, research and teaching to work with the Visiting Fellow.
- Work by the Visiting Fellow and the team for an intensive period of usually three months in progressing the subject. A period of preparatory work is often included, with a preliminary visit by the Visiting Fellow.
- Lectures, seminars and presentations by the Visiting Fellow and team members to the public and by selected local experts to the team.
- Documentation of the project for distribution.

The projects of the Centre range over all fields of engineering. It is understandable, therefore, that there is no permanent or continuing commitment to any one topic or area. The Centre does, however, support efforts for a period to establish bodies that might provide such continuity.

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Visiting Fellow

Dr Vaughan Beck

The Visiting Fellow, Dr Vaughan Beck, is Principal Lecturer Department of Civil & Building Engineering at the Footscray Institute of Technology, Melbourne. Besides lecturing in fire engineering and related subjects, he is responsible for the building courses at FIT and also provides consulting advice to industry and government. The major focus of his research has been into a cost-risk assessment model for the provision of fire safety in buildings. He is also collaborating with the National Research Council of Canada in this field. In 1987 he worked for a period at the Canadian Institute for Research and delivered a number of lectures on fire safety engineering in major Canadian cities.

Before moving to Footscray in 1982, Dr Beck was with the Commonwealth Department of Housing and Construction where he conducted research into the effects of fire and investigations into modern construction techniques including roof cladding failures caused by Cyclone Tracy.

Dr Beck gained his PhD at the University of NSW in Fire Engineering following a Masters degree in Structural Engineering and a Mechanical Engineering degree at the University of Melbourne and a Diploma in Mechanical Engineering at Footscray. His early experience was with ICI Australia and at the BHP Melbourne Research Laboratories.

His publications include many papers on cold-formed steel structures, wind engineering and fire engineering. He was awarded the WH Warren Medal by the IEAust in 1976 and the Fred Wilson Memorial Prize by the Australian Institute of Building in 1988.
Executive Summary

CURRENT SITUATION

Australia has achieved an excellent fire safety record compared with other countries. The vast majority of fire deaths in buildings occur in dwellings. A very small percentage of fire deaths occur in non-residential buildings, yet there is very significant expenditure on fire safety and protection.

There is evidence that substantial cost savings are possible while maintaining our current fire safety record.

The design for fire safety in buildings is controlled and administered in a highly legalistic, regulatory environment.

There are numerous factors which affect the fire safety of a building. Traditional approaches cannot readily quantify the integrated effect of such factors on life safety. Building regulations, for example, clearly do not take account of all the possible interactions between physical fire safety features, provisions for maintenance, and the nature of the people and activities in the building.

There is a need to introduce design flexibility to consider a wide range of possible fire-safety systems.

THE WARREN CENTRE PROJECT

This project has addressed this problem in a comprehensive manner and has shown that a 'model' can be created which gives a rational assessment of:

(a) the effectiveness of the various inter-relating fire safety and protection facilities,
(b) the cost of fire protection and losses resulting from a fire, and
(c) the risk to life safety from fire.

The project has shown that a risk assessment approach is feasible. This project has developed a risk assessment 'model' which, with further refinement, will assist in:

(a) developing more economical building regulations, and
(b) comparing the cost-effectiveness of various combinations of fire safety measures for a particular building.

RECOMMENDATIONS

It is recommended that:

(a) the current levels of fire safety in Australia should be maintained,
(b) design for fire safety be treated as an engineering responsibility rather than a matter for detailed regulatory control,
(c) that the risk assessment models and the associated sub-models and input data be further developed to improve their reliability before they are used for design purposes,
(d) adequate financial resources be provided to enable this development to be progressed in the short-term,
(c) risk assessment models be used as a basis for identifying cost-effective combinations of fire-safety sub-systems for building design,

(f) appropriate statistical information on actual fires be collated and form input data to the risk assessment models,

(g) designers develop a greater understanding of fire phenomena and human behaviour and adopt appropriate engineering techniques for the design of fire-safety sub-systems in buildings,

(h) fire engineering design courses and training strategies be developed and implemented (up to and including post graduate level),

(i) national strategy be developed for research, development, application and education on fire-engineering design.
1 BACKGROUND TO THE PROJECT

Fire safety and protection facilities to satisfy current Australian regulatory requirements are a significant component of the cost of many buildings in this country. Substantial cost savings can be made while maintaining the current levels of safety.

Australian fire protection requirements were established many years ago and are defined and administered in a highly legalistic, regulatory environment. Buildings are required to be designed in accordance with various regulations and codes and be approved by building code officials who are not necessarily familiar with the underlying science and engineering involved in building fire safety. The building is designed for fire safety using several design disciplines, the task often coordinated by an architect untrained in the area. The potential for needless cost to the community is high.

The objectives of this Warren Centre project were to develop an engineering basis for cost-effective design for fire safety, in multi-storey and other buildings.

Such aspects as community attitudes to risk, fire load and contents, fire behaviour and its containment, occupant behaviour and safety, and building design and integrity were examined with reference being made to overseas experience and practice.

The aim of the project was to recommend the most appropriate philosophy and a systematic approach to engineering design for building fire safety in Australia. These recommendations should form the basis for the development of a new generation of regulations, codes and standards designed to ensure the economical achievement of satisfactory levels of fire safety in buildings.

Some relevant details of the project are contained in the appendices.

2 FIRE RISKS AND COSTS IN AUSTRALIA

2.1 THE RISKS

The community faces a wide range of risks every day. Some of these risks are accepted voluntarily, while others are imposed on people without much choice. Involuntary risk levels are expected to be much lower than those entered into voluntarily, or they will arouse opposition.

Table 1 lists examples of some everyday risks in Australia calculated using data for the period 1981 - 1986. It can be seen that the risk of deaths from fire and flames, while small, is still significant (although it has fallen by half during the last twenty years).
TABLE 1  EVERYDAY RISKS IN AUSTRALIA

<table>
<thead>
<tr>
<th>SOURCE OF RISK</th>
<th>NUMBER OF DEATHS PER MILLION PERSON-YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancers from all causes</td>
<td>1740</td>
</tr>
<tr>
<td>Motor vehicle traffic accidents</td>
<td>183</td>
</tr>
<tr>
<td>Accidental poisoning</td>
<td>13</td>
</tr>
<tr>
<td>Fire and Flames</td>
<td>8</td>
</tr>
<tr>
<td>Falling objects</td>
<td>4</td>
</tr>
<tr>
<td>Travelling by aeroplane</td>
<td>2.8</td>
</tr>
<tr>
<td>Therapeutic use of drugs</td>
<td>1.6</td>
</tr>
<tr>
<td>Travelling by rail</td>
<td>1.0</td>
</tr>
<tr>
<td>Lightning Strikes</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 2 lists the causes of the 5495 yearly average accidental deaths in Australia from 1985-1987 on a percentage basis.

TABLE 2  CAUSES OF ACCIDENTAL DEATH IN AUSTRALIA 1985-87

<table>
<thead>
<tr>
<th>CAUSE OF DEATH</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Vehicle</td>
<td>55.1</td>
</tr>
<tr>
<td>Accidental fall</td>
<td>17.0</td>
</tr>
<tr>
<td>Submersion, suffocation</td>
<td>8.2</td>
</tr>
<tr>
<td>Other transport</td>
<td>3.7</td>
</tr>
<tr>
<td>Fire and flames</td>
<td>2.4</td>
</tr>
<tr>
<td>Others</td>
<td>13.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.0</td>
</tr>
</tbody>
</table>

On the basis of statistics from New South Wales, approximately half of the fire and flame deaths occurred in buildings. Thus the number of fatalities per million-person-years from building fires in Australia is about 4. This compares very favourably with the American figure of over 20 and the British figure of around 15.

Analysis of the New South Wales fire statistics reveals that 47% of building fires were in one and two family dwellings. These fires accounted for 69% of all fire deaths, and 53% of fire-related injuries in buildings. Private accommodation, other than one and two family dwellings, accounted for 10% of all fires, 7% of deaths and 16% of injuries. Commercial accommodation (hotels and boarding houses) had 2% of all fires, 3% of deaths and 3.2% of injuries. Thus, some 80% of all fire deaths occur in residential-type buildings.

Shops accounted for 7% of all building fires, no deaths, and 5% of injuries. Manufacturing and storage occupancies together accounted for 13% of building fires, 10% of fire-related deaths, and 12% of injuries. Office-type occupancies accounted for only 2% of building fires with an average of less than 1% of both deaths and injuries.
2.2 THE CAUSES

A study of fire deaths (mostly in dwellings) in the United Kingdom during 1976-1982 found burn injuries in 79% of cases, respiratory injury in 72% of cases, and soot deposition in the respiratory tract in 96% of the deaths. Carbon monoxide was the cause of death in 51% of the cases, and a contributing factor in a further 37% of cases. Cyanide gas was a significant factor in 33% of the deaths.

The high percentage of fire deaths which occur in domestic buildings is thought to be a reflection of:

a) age - the young and the elderly are most often the victims;
b) condition of occupants - asleep or incapacitated;
c) relatively high number of ignition sources - cooking and heating appliances, - and smokers material

2.3 THE COSTS

Reliable data on the cost associated with building fires in Australia is difficult to obtain. For countries with a similar technological development to Australia, the following are typical figures:

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage of GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Fire Loss Claims</td>
<td>0.23%</td>
</tr>
<tr>
<td>Indirect Fire Loss Claims</td>
<td>0.03%</td>
</tr>
<tr>
<td>Expenditure on Fire Fighting</td>
<td>0.20%</td>
</tr>
<tr>
<td>Expenditure on Fire Protection</td>
<td>0.26%</td>
</tr>
<tr>
<td><strong>Total Cost of Fire in Buildings</strong></td>
<td><strong>0.72%</strong></td>
</tr>
</tbody>
</table>

This indicates that the annual cost associated with fires in buildings is some 0.72% of GDP, which is equivalent to $2,000 million per year for Australia.

The cost of fire safety and protection in buildings can be attributed to the costs of materials and labour, as well as costs for design and construction time. Delays associated with obtaining regulatory approvals are very expensive.

2.4 IMPLICATIONS

Currently most fire deaths (69%) occur in one and two family dwellings where there is little or no expenditure on fire safety. Conversely, in high-rise and other buildings, a relatively small proportion of deaths occur, yet there is substantial expenditure on fire safety and protection facilities.

For example, a 10% reduction in the costs associated with fire in buildings would represent a saving of $200 million per year for Australia. This saving can be achieved while maintaining the current levels of safety in high-rise and other buildings.

3 CURRENT SITUATION AND NEED FOR CHANGE

Society has responded to the threat of fire in buildings in many ways including: fire brigades, insurance, education on fire hazards, controls on the use of materials and products in buildings, and the design of buildings to resist the effects of fire. The level of safety reflects the general economic, social and cultural features of society. The control mechanisms and organisational arrangements used in Australia have obviously been successful as Australia has one of the lowest death rates from building fires in the world.

Currently building regulations are an important component in design for fire safety in buildings. The design requirements of building regulations were introduced many years ago and are applicable to the technology and practices then in vogue. Many of these provisions were empirically derived but they
have assumed great authority with the passage of time, although perhaps lacking technical substantiation.

The prescriptive requirements in building regulations are a reflection of the low level of technology previously available for the design of fire protection and safety in buildings.

There has been substantial recent progress in the development of building regulations in Australia with the Building Code of Australia being introduced progressively throughout the country. However the current design for fire safety and protection is unscientific, being largely based on empirical rules. The building regulations do not contain any explicit statements of the fire-safety design objectives to be achieved.

It is acknowledged that the current design approach has resulted in the achievement of safety levels the community appears to accept. However, the current design approach is unlikely to result in the most cost-effective design solutions, nor in designs which maintain a consistent level of safety.

The complexity of the regulations, the number of disciplines involved (none of which is primarily responsible for fire safety), and the fragmentation of the process is a central problem for the design of fire safety in buildings. It appears that the situation is essentially no different in most other countries, ie the procedure involves observance of regulations which are considered inflexible and inefficient.

Furthermore, the current regulatory approach restricts the range of choices available, inhibiting and restricting innovation. The recycling of existing buildings, often historic, demands that there be a more systematic approach to the design for fire safety and protection in buildings.

The fields of fire dynamics and fire protection engineering are rapidly advancing. This brings opportunities for reducing the overall cost of safety and protection measures while maintaining current safety levels.

4 DESIGN OBJECTIVES

The major objective of design for the effects of fire in buildings is to achieve satisfactory levels of life safety for:

(a) occupants of the building of fire origin,
(b) occupants of adjoining buildings, and
(c) fire brigade personnel.

The level of fire safety in buildings is a reflection of the complex interaction between fire growth and spread, and human behaviour. This depends on many features of the building including active and passive protection facilities, provision for egress, occupant mobility and familiarity, and building management. Thus, fire safety in buildings is a system consisting of many interacting sub-systems.

Alternative building designs must obtain satisfactory levels of life safety. The level of property protection in buildings should not be subject to community regulation, but be a matter for building owners and their insurers.

5 RISK ASSESSMENT MODELS

Risk assessment models can be used to help identify those combinations of building sub-system which provide the requisite level of safety in a cost-effective manner. Once a building system has been chosen, it is then appropriate to use deterministic models to undertake the detailed design and specification of the individual fire-safety and protection sub-systems.
In the Risk Assessment Model developed during the project, deterministic models were used to estimate the effects of particular fires within the enclosure of fire origin, as well as the spread of fire to a few adjoining enclosures. Deterministic models and risk assessment models are complementary to one another in the design process.

To model the risk from fire in buildings it is necessary to estimate the likelihood of harmful consequences to people and property by taking a global, or systems view, of fire safety and protection. This is a radical change from the traditional approach. In developing a systematic approach to building fire safety and protection, a number of sub-systems were considered:

(a) Nature of Occupancy
(b) Fire Growth and Development
(c) Active Systems
(d) Passive Systems
(e) Occupant Avoidance
(f) Fire Fighting

A brief description and appraisal of current and emerging technologies applicable to each of these sub-systems is given in Chapter 10 of this Project Report.

A fundamental risk assessment model (FRAM), is described in the Technical Papers. This model is applicable to any enclosure where fire starts. The model can be applied to each enclosure throughout a building. It is only required to estimate the time of fire and smoke spread from the enclosure of fire origin to an adjacent enclosure, and to apply the same fundamental model to that enclosure. The application of the fundamental model enables the effect of a variety of design factors on the life safety of occupants to be assessed.

A demonstration risk assessment model (DRAM), is described and was implemented for two case studies. The DRAM is based on the FRAM, but is a simplification of it. The object of the DRAM, is to demonstrate the capability of risk modelling techniques for design of fire safety and protection features in buildings. The demonstration model is not intended for immediate use for the design of fire safety systems in buildings. Rather, it is conceived as laying the foundation for the further development of such models. The Demonstration Risk Assessment Model retains the essential features of a more comprehensive risk model. Thus, it is expected that the DRAM will correctly rank the importance of building design features and sub-systems in terms of their influence on the life safety performance associated with fire in buildings. The DRAM was applied to two case studies: multi-storey apartment and office buildings.

A brief introduction to the DRAM, an explanation of terminology and a DRAM logic diagram are given in Appendix 1.

6 DESIGN CRITERIA

In design it is appropriate that consideration be given to the level of safety afforded to occupants of buildings, and to the costs associated with such provision. When applied to alternative designs, such an approach enables designers to select the most appropriate cost-effective solution. Accordingly, the risk assessment models developed during the project characterise building design performance in terms of two parameters, namely:

(a) expected risk-to-life, and
(b) fire-cost expectation.

No attempt was made to assign monetary values to either the loss of life or the value of lives saved. This avoids serious moral, ethical and economic difficulties which arise when attempting to assign monetary value to human life or suffering. The risk-to-life parameter provides an explicit estimate of the expected number of deaths resulting from fire in buildings.
The fire-cost expectation parameter incorporates the following direct costs and losses:

(a) capital cost of active and passive fire safety and protection facilities,
(b) maintenance and inspection costs associated with active fire safety and protection facilities, and
(c) expected monetary losses resulting from fire growth and spread,

but does not take into account any costs associated with:

(a) fire brigade services,
(b) insurance, and
(c) fatal and non-fatal fire casualties.

To identify alternative designs which are considered equivalent to, and more cost-effective than, designs conforming with current regulatory provisions, the decision criterion was: "For an alternative design to be considered acceptable, the expected risk-to-life value shall be equal to, or less than, the risk to life value of a building conforming with the regulations and the fire-cost expectation for the alternative design shall be less than the value for the conforming building".

With such a comparative approach it is not required to directly compare estimated risk-to-life values, derived from a risk assessment model, with an acceptable level of risk derived from independent sources.

The expected risk-to-life values for designs conforming with current regulatory requirements provide an estimate of current levels of risk to life safety. These risk levels are assumed to be acceptable to the community. However, reduced or higher levels of risk may be justified or sought for a variety of reasons. The expected risk-to-life values for designs conforming with current regulatory requirements provide a convenient reference, or benchmark, to compare the performance of other designs.

7 BUILDING DESIGN OPTIONS CONSIDERED

The DRAM was structured so that various sub-systems could all be excluded or be included in any combination. The several fire safety and protection sub-systems considered were:

- Automatic Alarm System in Building
  - Emergency Warning and Intercommunication System
  - Bells (Office Building only)
- Automatic Door Closers
- Corridor Smoke Management System (Apartment Building only)
- Detectors for Automatic Alarm
  - Smoke Detectors
  - Detection by a Sprinkler System (Office Building only)
  - Thermal Detectors
Fire Brigade Intervention
Fuel Characteristics
Fire Resistance Levels
Floor-zone Smoke Management System
Foyer Smoke Management System (Office Building only)
Local Alarm in Apartment of Fire Origin (Apartment Building only)
Sprinkler System
Stair Pressurisation System

Substantial input data is required for the DRAM. While the initial development of this data represents a significant task, once established and validated for a generic type of occupancy, much of the data remains unchanged and appropriate for use in future applications.

8 PRELIMINARY RESULTS

The DRAM was applied to an apartment building and an office building.

A deliberate policy was adopted of invoking conservative assumptions for the DRAM and the input data. This resulted in estimates of risk-to-life safety that are clearly very conservative (i.e., higher than expected in reality).

Accordingly,

(a) It is not appropriate to draw definite conclusions from the results obtained from the DRAM for both the apartment building and the office building.

(b) It will be necessary (as was always expected) to undertake further development of the DRAM to make it more accurate for design purposes.

9 RISK ASSESSMENT MODELS AND DECISION MAKING

While the results to be developed subsequently will assist in the identification of cost-effective alternative design strategies, the results must be regarded only as an aid to the decision-making process. It is expected that designers and regulatory officials will employ the results generated by risk assessment models to assist them to make more rationally-informed decisions and thereby achieve cost-effective solutions for building fire safety and protection.

It is preferable that results from risk assessment models be used to guide, but not replace, the decision-making process.

It must be recognised also that there will be progressive refinement to the risk assessment models. This situation is analogous to other areas of engineering design, where there is continual refinement and development of codes and standards.
10 REVIEW OF FIRE TECHNOLOGY

The project was conducted using eight task groups (Appendix 4). A brief review of fire technology undertaken by several of the task groups follows.

10.1 NATURE OF OCCUPANCY

Modern building codes categorise all occupancies into a limited number of generic classifications, which in turn forms a primary determinant for the type of construction and the extent of fire and safety facilities to be provided. The assumption that similar hazard characteristics apply to all occupancies within each occupancy classification is often not valid.

A systematic approach to fire safety in buildings requires the specific needs and characteristics of particular occupancies to be quantified so that related construction and fire and safety facilities can be designed appropriately.

Task Group 3 identified the fundamental characteristics of various types of building use. However, more work is necessary to quantify data for future fire safety risk assessments.

10.2 FIRE INITIATION AND DEVELOPMENT

The prevention of fire initiation and development plays a central role in fire safety in buildings. Control of ignition sources and fuel could provide a general means of improving fire safety in buildings.

The effects of design factors such as ignition sources, fuel and enclosure, on events related to fire initiation, growth, obscuration, lethality and damage were analysed. The effects were characterised in terms of the probability of the events occurring, the time at which the events occurred and the magnitude of the damage to the contents and boundary elements of the enclosure. These analyses were carried out 'from first principles' to provide an input to the fundamental risk assessment model.

"Design fires" appropriate to typical fire scenarios in each of two occupancies (high-rise office and apartment buildings) were used as input to mathematical sub-models to estimate fire conditions. These fire conditions were used to determine event times, which formed input to the demonstration risk assessment model. The design fire approach was used to overcome the problems inherent in the current capability of predicting fire initiation and growth from potential ignition sources and the various materials comprising the fuel.

10.3 ACTIVE SYSTEMS

The range of active systems which can be installed in buildings to assist or provide fire safety was reviewed. The review of these detection, alarm, suppression, smoke management and fire management support systems resulted in characterisation of their performance in a manner suitable for use in the risk assessment models. Further development of the characterisation of performance of these systems is necessary, both for future use in the model and to lead to improved application of individual systems in the field.

It is evident from the study that performance-based design has rarely been available in the past due to lack of clear objectives in the field of life safety, and lack of analytical models for many of the active systems and their components. Feedback on field performance of active systems and equipment is extremely limited. This situation identifies a need for the increased collection of relevant statistics as an aid to the development and confirmation of analytical models.

Developments in modelling of sprinkler and smoke management systems (principally in the U.S.A.), have provided valuable insight and assistance to the work undertaken in the study. This work has shown that active systems can be modelled as an aid to design and operation. Such models are expected to form a basis for future input to risk assessment models and to assist in reaching conclusions regarding the relative effectiveness of active and passive fire safety measures.
10.4 PASSIVE SYSTEMS

Passive fire safety systems may be defined as those systems which do not react to a fire situation. They may play three major roles in building fire safety by:

(a) directly influencing the development of fire (by providing fuel or controlling ventilation);
(b) inhibiting the growth or spread of fire itself, or the spread of the products of fire; and
(c) assisting the people affected or potentially affected by the fire to remove themselves from a hazardous location, or to gain access to fight the fire.

Much is known about passive system behaviour during post-flashover fires due to extensive testing using the standard fire-resistance test (rather than in real fire situations). A review of this information and translation of its applicability to other stages of fire growth, real fire scenarios and aspects associated with people movement was undertaken. Techniques for the design of passive systems were assessed and recommendations for research presented.

Classification of the characteristics of passive systems which influence their performance in fire was attempted, and as a simplification, four basic types of passive systems and eight characteristics were defined and examined. This included a qualitative assessment of the influence of various passive system design characteristics on fire growth and development, in the form of a matrix of characteristics versus fire events.

A comprehensive compilation of methods for the assessment of the effectiveness of passive systems as barriers to the spread of fire, together with a critical assessment of those methods, was then carried out.

The presence of openings is the dominant performance characteristic for most passive systems. The possible presence of openings in a barrier has a significant effect on its likely effectiveness. Opening treatments such as doors or penetration sealants may restore effectiveness provided that their performance is adequate, and provided they are closed or in place. Maintenance of passive systems thus requires close attention.

10.5 OCCUPANT AVOIDANCE

Occupant avoidance in fire-related emergencies means the responses and likely actions available to occupants during a fire to ensure their safety. These actions generally involve responding to a cue (smoke, heat, unfamiliar sounds or alarms), making a decision to evacuate, preparing for evacuation and then travelling to and through an exit route to a place of safety.

Occupant avoidance (or means of egress) was previously modelled assuming that upon activation of an alarm or detection of fire by other means, occupants of a building would immediately proceed (by the most direct means) to travel the exit route to an open space or a safe haven. Another generally accepted view was that people would panic in the event of a fire and that steps should be taken to alleviate this problem. People were thus regarded as “ball bearings”, and the “hydraulic” egress model was considered to be the best available approach to predict the evacuation times for building occupants. It has been demonstrated that this approach is quite inadequate and fails to understand, or account for, human behaviour.

The time taken for occupants to decide that they are going to evacuate, can exceed the time to travel to and through the exit route. This time is generally taken up with occupants investigating the fire and may mean that occupants move towards the fire. They may also seek information from other people. The design and installation of emergency warning systems is therefore critical to ensure that people receive the appropriate level of information. The importance of education and training in improving the preparedness of occupants to respond quickly, and take effective avoidance action, should be recognized.
The current and emerging technologies in human behaviour, egress movement (including way finding) and cue response were reviewed, and a qualitative assessment of the control factors that would affect occupant avoidance was prepared. A further issue examined was exit choice; this is a function of an occupant's familiarity with the building.

For the DRAM input, a quantitative assessment of the number of persons exposed to untenable conditions in an eight-storey apartment building and a twelve-storey office building, together with their spatial location at that time was undertaken. This involved the development of a sequential model which was analysed and the evacuation sequences depicted graphically. Probabilities were then able to be assigned to estimate the likelihood of response under certain given cue/alarm conditions.

10.6 FIRE FIGHTING

The fire brigade is an emergency service whose role is proclaimed by legislation. This legislation requires the brigades to save lives and property in the case of fire.

Fire services attempt to provide a level of service commensurate with the presumed hazard. This level of service reflects the deployment of stations and staff in order that rescue and fire fighting can be provided.

Fire brigades have adopted advanced technology to enhance fire suppression activities. However, it is recognised that a major influence on the fire-loss performance is the ability of the building fire safety and protection system to limit fire growth and spread, to limit the number of people exposed, and to allow better assessibility for fire suppression resources.

Successful fire fighting may be achieved with early alarm and rapidity of response, and the provision of sufficient equipment and labour to respond to the hazard presented by the occupancy.

11 FIRE SAFETY SOLUTIONS FOR THE 1990's

11.1 WHAT HAVE WE LEARNED?

What have we learned from the Fire Safety and Engineering project?

The first thing we have learned is that the opportunity to gather representatives of the wide range of people involved in fire safety and fire engineering was extremely valuable in developing a broad and systematic approach to fire safety in buildings. Much has been done. Much more remains to be done.

Secondly whilst the problems of fire safety and engineering are complicated and difficult, they are not intractable. The fire safety issue combines elements of all engineering disciplines, a knowledge of areas of physics (and chemistry) not normally used in building design, and people response and management.

Thirdly in this country we have some deficiencies in the knowledge, skills and experience necessary to handle these matters on an engineering basis. This presents great opportunities to improve our grasp of these areas and to contribute new knowledge and ideas. This also demands effort be put into the education of current practitioners and undergraduates.

Fourthly in terms of our deficiencies, much of the knowledge and many of the skills and experience are available elsewhere. We just have to have the need and will to obtain and use them.

Fifthly there are still large gaps in the knowledge base, and that much research, development and practical application needs to be undertaken to fill those gaps.

11.2 WHAT HAVE WE ACHIEVED?

We have achieved:

(a) the development of a systematic characterisation of the important factors influencing the effectiveness of most fire safety sub-systems;

(b) the means to design and assess fire-safety systems based on those sub-systems;
increased the knowledge and awareness of risk assessment in the Australian engineering and building regulations community;

recognition of the factors of greatest importance in real fire risks:-

. the overwhelming proportion of deaths and injury occurring in dwellings of all kinds (including hotels); and

. the high proportion of property loss occurring in commercial and industrial buildings; and

. the importance of smoke;

the development of the FRAM and DRAMs, and computer programs for DRAMs.

11.3 PROJECT REVIEW

At this stage few conclusions can be drawn from the demonstration risk assessment models developed and, to a limited extent, used in this project. The information gathered and analysed leads to several observations:

(a) very considerable variations exist in the levels of safety achieved within the current regulations;

(b) in modelling fire development and occupant response and in evaluating the level of risk, "time" is of the utmost importance;

(c) while many alternative fire-safety systems can provide perfectly satisfactory performance, they are not even considered by the regulations;

(d) many issues involved in fire safety in buildings are not dealt with by regulations or addressed in current design;

(e) in the engineering design of buildings for fire safety the approach needs to be very systematic, with detailed assessment of alternative strategies;

(f) the development of the DRAM showed the practicality and effectiveness of risk assessment models;

(g) design for fire safety clearly must be treated as an engineering responsibility rather than a matter for detailed regulatory control.

11.4 IMPLICATIONS OF A SYSTEMATIC APPROACH

The systematic approach used in this project demonstrated flexibility in the choice of the elements in a fire safety system, discrimination in assessing the suitability of various elements and to enable the evaluation of new or improved products, and the means to ensure satisfactory fire safety systems are achieved with economy.

11.4.1 Flexibility

The systematic approach to fire safety in buildings demonstrated that many elements may contribute to a fire safety system. The interaction of these elements is complex and requires detailed analysis to assess the system’s effectiveness.

So many combinations of elements may be available that automated and systematic analysis is necessary for comprehensive comparisons to be made.

The systematic approach will give much greater flexibility in designing an appropriate and economical fire safety system.
11.4.2 Suitability

The systematic approach has shown that the elements of a fire-safety system may have different levels of effectiveness depending on the nature of occupancy (the type, condition and normal activities of the occupants) being considered.

Thus the suitability of elements of a fire-safety system can vary greatly depending on the occupancy and other characteristics of a building.

11.4.3 Economy

The systematic approach enables the identification of the most economical system to achieve a satisfactory level of safety.

11.5 IMPLICATIONS OF THE DRAMS

A most exciting aspect of the development and use of the DRAMS has been the large number of alternative fire safety systems analysed. More exciting is that we have not even begun to ask the questions which might lead to new systems, new developments and new approaches to fire safety systems.

Some interesting questions are given below:

(a) for example, what happens if we reduce the response times of the sprinklers by half? By an order of magnitude?

(b) what would be the effect of more sensitive (but reliable) smoke alarms?

(c) how is safety effected if we change the heat-release rate of fuel in the building?

(d) what is the effect of changed spread characteristics of the materials used in the building? Of the contents?

(e) what is the effect of combustible linings? Of combustible exterior walls?

(f) what effect does decreasing the FRL’s have?

There are literally hundreds of questions which may now be asked with the hope of getting a reasonably quick and reliable answer.

Additional development of the DRAM is required to remove some of the overly restrictive assumptions, and to employ more advanced technology for both the development of the risk model and data, including more reliable modelling of time-dependent smoke and flame growth and spread through buildings.

11.6 FUTURE DIRECTIONS

11.6.1 Research

All areas of fire safety require further research and development. The requirement to obtain input data for the DRAM has shown severe limitations in the sub-system models available to estimate the development and spread of fires.

Difficulty in assembling the input data required has shown some limitations in our ability to model the response, reliability and effectiveness of passive and active sub-systems when confronted with a developing fire.

Similarly, more reliable data is required for human response aspects.

Verification and calibration of the DRAMs is required.
11.6.2 Model development

The risk assessment models developed and used are limited in ability and range of application. The development of more sophisticated models and general models is worthwhile.

The risk assessment model used requires input data from a range of fire development models and sub-system response models. Incorporation of these models into the risk model is required to give us a more user friendly and efficient tool.

The DRAMs are limited in their application to particular building configurations and occupancies, thus generalisation of the models is required for efficient analysis and design of a wide range of buildings.

11.6.3 Analytical techniques

Comparative risk assessment:

More work is required before the reliability and accuracy of the model can be assessed. Until then caution must be exercised in comparative risk assessments.

Nevertheless, this kind of model will provide a most useful technique to assess the effectiveness of many different elements of fire safety systems, and thus provide the basis for more rational, effective and economical fire safety systems.

11.6.4 Expertise

The need for, and value of, increased expertise in many areas concerned with fire safety has become obvious during the course of this project. A continuing effort to upgrade our knowledge and skills is required as is a regulatory environment which will encourage and reward those who make the effort to do so.

12 CONCLUSIONS

12.1 CURRENT SITUATION

Australia has achieved an excellent fire safety record compared with other countries. It is essential that this record be maintained.

The vast majority of fire deaths in buildings occur in dwellings. A very small percentage of fire deaths occur in high-rise and other non-residential buildings, yet there is very significant expenditure of fire safety and protection.

There is evidence that substantial cost savings are possible while maintaining our current fire safety record.

The design for fire safety in buildings is controlled and administered in a highly legalistic regulatory environment.

There is a need to introduce design flexibility to consider a wide range of possible fire-safety systems.

12.2 DESIGN FOR FIRE SAFETY

An examination was made of the most appropriate philosophy for a systematic approach to engineering design for fire safety in Australia.

Risk assessment models were developed to identify cost-effective fire safety systems for particular buildings and occupancies.
The risk assessment approach is used to model the effect of fire growth and spread and the possible intervention of fire-safety sub-systems on the expected number occupant fatalities.

Alternative designs will be selected on the basis of maintaining existing safety levels.

12.3 DESIGN FLEXIBILITY

This project has provided the basis of assessing the cost-effectiveness of a wide range of possible fire safety systems in particular buildings and occupancies. A risk assessment approach can:

(a) appraise existing code requirements for a particular building occupancy, and investigate whether consistent and equivalent cost-effective performance is provided for other occupancy types,

(b) provide a performance-based approach to the design for fire safety and protection in buildings.

12.4 LIMITATIONS

The risk assessment models, the associated sub-models and data that were used for the case studies of a apartment building and an office building contain a number of conservative and simplifying assumptions. It is not appropriate at this stage to draw any conclusions from the results obtained.

12.5 FUTURE DEVELOPMENT

There is need for further development of the risk assessment models, sub-models and input data before any reliance can be placed on the results from risk assessment models. This development is feasible, and can be achieved in the short term.

The risk assessment approach can guide future research efforts into those areas which are identified as having a significant impact on the cost-effective provision of fire safety and protection in buildings.

12.6 APPLICATION TO DESIGN

There will be a progressive refinement to risk assessment models. This situation is analogous to other areas of engineering design. This should not prevent the application of risk assessment techniques for design in the short term once further development of the models has occurred.

Results from risk assessment models will assist in the decision-making process to select appropriate cost-effective combinations of fire safety sub-systems for buildings.

There has been rapid growth of fire engineering technology in recent years. There is a need to apply fire engineering techniques for the design of both the:

(a) overall building fire safety system (risk assessment techniques), and

(b) detailed design of the individual fire safety sub-systems within a building.

12.7 OTHER IMPLICATIONS

There is urgent need for a greater understanding by designers and regulatory officials of fire phenomenon, human behaviour and fire engineering techniques. This has important educational and technology transfer implications for such groups.

Professional, research, educational, and regulatory organisations must continue the spirit of co-operation developed during the Warren Centre Project, to ensure the further development and application of fire engineering techniques for the benefit of the Australian community.
12.8 STATISTICAL DATA

To apply fire risk assessments it is essential that reliable data from actual fire situations be available to define important parameters such as:

(a) the rate of fire starts for various types of occupancy, and
(b) the type of fires in each occupancy such as smouldering, flaming or fully-developed.

13 RECOMMENDATIONS

It is recommended that:

(a) the current levels of fire safety in Australia should be maintained,
(b) design for fire safety be treated as an engineering responsibility rather than a matter for detailed regulatory control,
(c) that the risk assessment models and the associated sub-models and input data be further developed to improve their reliability before they are used for design purposes,
(d) adequate financial resources be provided to enable this development to be progressed in the short-term,
(e) risk assessment models be used as a basis for identifying cost-effective combinations of fire-safety sub-systems for building design,
(f) appropriate statistical information on actual fires be collated and form input data to the risk assessment models,
(g) designers develop a greater understanding of fire phenomena and human behaviour, and adopt appropriate engineering techniques for the design of fire-safety sub-systems in buildings,
(h) fire engineering design courses and training strategies be developed and implemented (up to and including post-graduate level),
(i) a national strategy be developed for research, development, application and education on fire-engineering design.
A demonstration risk assessment model (DRAM) was developed and implemented during the project. The model was applied to an office building and an apartment building.

The risk assessment model is used to compare alternative designs. Cost-effective design solutions are those that:

(i) at least maintain existing levels of risk to life safety, and

(ii) have a lower fire-cost expectation than the value applicable to buildings designed in accordance with the current regulatory requirements.

The diagram overleaf illustrates the logic by which the DRAM estimates the expected risk-to-life for an apartment building.

**TERMINOLOGY**

Expected Risk to Life, ERL

\[
ERL = \frac{\text{Expected Number of Deaths over Design Life of Building}}{\text{Building Population} \times \text{Design Life of Building}}
\]

Fire Cost Expectation (present value), FCE

\[
FCE = \text{Capital cost associated with active and passive fire protection} + \text{Annual costs for inspection and maintenance of fire equipment} + \text{Expected cost of building and contents fire losses}
\]
DEMONSTRATION RISK ASSESSMENT MODEL (DRAM) LOGIC DIAGRAM

Expected Risk to Life = \( \frac{\text{Expected Number of Deaths in Building during Design Life of Building}}{\text{Building Population} \times \text{Building Life}} \)

(Slightly simplified - refer Part 1, Chapter 10)

First Assume fire starts in one particular room, then calculate

\[ \text{Expected number of deaths in Room} + \text{Rest of apartment of fire origin} + \text{Adjacent apartments} + \text{Apartments above and below} + \text{Corridor} + \text{Stairs} \]

(expected example)

- Expected number of deaths = Term A x Term B x Term C x Term D

Term A = Probability that the fire which occurs in the bedroom is a 'Smouldering' fire.

Term B = Probability that untenable X conditions occur in adjacent apartment

Term C = Combined probability that:
  i) smoke capable of being smelled, enters adjacent apartment; and
  ii) that occupants respond.

Term D = Number of people still in adjacent apartment when untenable conditions occur.

\[=\text{Initial Population - Number of people who exit room during the duration available for egress}\]

Duration = Time of occurrence of untenable conditions - Time of occurrence available for egress (Toxic or Thermal) condition

Repeat with each possible combination of the following:

Term A = Fire scenarios ('Design fires')
  - Smouldering
  - Non-flashover
  - Flashover

Term B = Untenable conditions; X - Toxic, and
  - Thermal conditions

Term C = Cue and response
  - Audible alarm activates and is audible
  - Audible evidence of fire
  - Visible evidence of fire
  - Smell evidence of fire available to occupants
  - occupants respond
  - occupants do not respond

Term D = Population remaining

Then Re-calculate for each possible enclosure of fire origin, and sum all possibilities appropriately
APPENDIX 2
PROJECT ORGANISATION

TASK GROUPS

In order to undertake this project it was decided to form eight (8) task groups (TG) which are listed below:

TG1  Systematic Approach  
This task group provided technical direction for the project under guidance from the Steering Committee. Additionally, the group developed procedures to identify those designs which provide acceptable designs in a cost-effective manner.

TG2  Analysis of Fire Risk
TG3  Nature of Occupancy
TG4  Fire Ignition and Development
TG5  Active Systems
TG6  Passive Systems
TG7  Occupant Avoidance
TG8  Fire Fighting

INTER-RELATIONSHIP OF TASK GROUPS

The inter-relationship of the Task Groups and the Steering Committee is shown below:
APPENDIX 3

PROJECT STEERING COMMITTEE

CHAIRMAN
Paul Jeans - BHP Engineering

VISITING FELLOW
Dr Vaughan Beck - Footscray Institute of Technology

PROJECT COORDINATOR
Ted Merewether - Wormald International

MEMBERS
John Anderson - Construction and Housing Association Aust
Ron Alexander - Civil & Civic
Mr Stephen Barratt - Aust Institute of Building Surveyors
Prof Bob Bilger - Uni of Sydney - Mechanical Engineering
Prof Denison Campbell-Allen - University of Sydney
Ashley Colley - WT Partnership
Claude Eaton - Building Owners & Managers Association
Supt Ross Freeman - Board of Fire Commissioners
Assoc Prof John Glastonbury - Uni of Sydney - Faculty of Engineering
Stephen Grubits - CSIRO Div of Building, Const. and Engineering
Liz Hurst - The Warren Centre
Ray Lacey - Lincolne Scott Australia
Barry Lee - Wormald International
Chris Levy - Concrete Constructions
Ray Loveridge - AUBRCC Fire Committee
Corb Macfarlane - The Warren Centre
John Peyton - John Connell & Associates
Dr Caird Ramsey - CSIRO Div of Building, Const. and Engineering
Lawrence Reddaway - Irwin Johnston & Partners
John Richardson - Philip Cox Richardson Taylor & Ptnrs
Mick Ryan - W G Ryan & Associates
Eoin Shearer - Insurance Council of Australia
Ron Swane - R A Swane & Associates
Dr Ian R Thomas - BHP Research
Prof Mark Tweeddale - Uni of Sydney - Risk Management
Prof Peter Webber - Uni of Sydney - Architecture
APPENDIX 4

TASK GROUP MEMBERSHIP

TASK GROUP 1  SYSTEMATIC APPROACH
Vaughan Beck (Chairman)
Ashley Colley
Ken Copeland
John Anderson
Claude Eaton
Bruce Forwood
Ross Freeman
Stephen Grubits
Peter Johnson
Ray Lacey
Ray Loveridge
Ted Merewether
Caird Ramsay
Lawrence Reddaway
John Richardson
Ian Thomas
Hamish MacLennan

TASK GROUP 2  ANALYSIS OF FIRE RISK
Vaughan Beck (Chairman)
Norm Bowen
Andrew Brown
Claude Eaton
Mark Jarman
Peter Johnson
Bob Leicester
Ted Merewether
Lawrence Reddaway
Stuart Reid
Mark Tweeddale
Len Lamothe

TASK GROUP 3  NATURE OF OCCUPANCY
Claude Eaton (Chairman)
Len Carter
Ken Copeland
Peter Loomes
Peter de Verdic
Don Williamson
Wal Mursa
Charles Miller

TASK GROUP 4  FIRE IGNITION/DEPARTMENT
Caird Ramsay (Chairman)
Vince Dowling
Ross Freeman
David Gardner
Stephen Grubits
Peter Johnson
Jack Keogh
Ross Thomson
John Anderson
Tony Green

TASK GROUP 5  ACTIVE SYSTEMS
Ray Lacey (Chairman)
Ian Bennetts
Andrew Brown
Warwick Barnett
Tony Hatton
Jack Hamilton
Peter Johnson
Barry Lee
Graham Timms
Ian Thomas

TASK GROUP 6  PASSIVE SYSTEMS
Ian Thomas (Chairman)
Kathleen Almand
Ken Bernie
David Carne
Rick Dahey
Trevor House
Ian Hogbin
Daryl Knight
Bob Potter
John Rayner
Ron Swane
Eoin Shearer
Ross Thomson

TASK GROUP 7  AVOIDANCE STRATEGIES
John Richardson (Chairman)
Barry Eadie
Tony Jacques
Hamish MacLennan
John McNulty
Charles Miller
Robert Turner
Peter de Verdic

TASK GROUP 8  FIRE FIGHTING
Ross Freeman (Chairman)
Michael Clarke
Ken Copeland
Barry Eadie
Mick Holland
Phil Robeson
Ron Davies

PREPARATION OF DRAM COMPUTER PROGRAM
Leong Poon
Alfred Lee Kam On
APPENDIX 5

PROJECT FELLOWS

Members of the eight Task Groups involved in the Fire Safety Project have been drawn from a broad spectrum of Australia's Fire, Building, Regulatory and Research communities. These Project Fellows have made a significant contribution to the project in terms of time and resources, and their support is acknowledged.

Kathleen Almand - BHP Melbourne Research Laboratories
John Anderson - NSW Fire Brigades
Warwick Barnett - Insurance Council of Australia
Dr Vaughan Beck - Footscray Institute of Technology
Dr Ian Bennet - BHP Melbourne Research Laboratories
Ken Bernie - Bells Thermalag Pty Ltd
Norm Bowen - Melbourne City Council
Andrew Brown - Melbourne Metropolitan Fire Brigade
David Carne - CSR Gyprock
Len Carter - Telecom Australia
Dr Michael Clarke - T.A.F.E.
Ashley Colley - WT Partnership
Ken Copeland - Melbourne Metropolitan Fire Brigade
Ron Davies - State Rail Authority
Rick Daysh - CSIRO Div of Building Construction and Engineering
Peter de Verdic - Commonwealth Bank
Vince Dowling - CSIRO Div of Building Construction and Engineering
Barry Edie - NSW Board of Fire Commissioners
Claude Eaton - Building Owners & Managers Association
Bruce Forwood - University of Sydney
Supt Ross Freeman - NSW Board of Fire Commissioners
David Gardner - Forestry Commission NSW
Stephen Grubits - CSIRO Div of Building Construction and Engineering
John Hamilton - Leroy Fire Protection
Tony Hatton - WA Fire Brigades
Ian Hogbin - Fire Research Pty Ltd
Mick Holland - QLD State Fire Services
Trevor Howse - Howse & Associates
Tony Jacques - SARMC Security Consultants
Mark Jarman - Viner Robinson Jarman Pty Ltd
Peter Johnson - Australian Construction Services
Jack Keough - Consultant
Daryl Knight - Daryl Knight Pty Ltd
Ray Lacey - Lincolne Scott Aust Pty Ltd
Brian Lacey - Melbourne City Council
Alfred Lee Kam On - Monash University
Barry Lee - Wormald International
Dr Bob Leicester - CSIRO Div of Building Construction and Engineering
Michael Lewin - W T Partnership
Peter Loomes - AMP Fire & General Insurance Pty Ltd
Ray Loveridge - AUBRCC Fire Committee
Assoc Prof Hamish MacLennan - University of Technology, Sydney
John McNulty - NSW Public Works Department
Ted Merewether - Wormald International
Charles Miller - Charles Miller & Associates
Wal Mursa - NSW Public Works Department
Leong Poon - BHP Melbourne Research Laboratories
Bob Potter - Cement & Concrete Association
Dr Caird Ramsay - CSIRO Div of Building Construction and Engineering
Lawrence Reddaway - Irwin Johnson & Partners
Dr Stuart Reid - University of Sydney
John Richardson - Philip Cox Richardson & Taylor
Phil Robeson - Australian Fire Protection Association
Eoin Shearer - Insurance Council of Australia
Ron Swane - R.A. Swane & Associates
Dr Ian Thomas - BHP Melbourne Research Laboratories
Ross Thomson - National Association of Forest Industries
Robert Turner - Rankine Hill Pty Ltd
Professor Mark Tweeddale - University of Sydney
Don Williamson - Fire Control Pty Ltd
APPENDIX 6

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- Building Owners and Managers Association Australia (BOMA) NSW, ACT, Qld and National
- Colonial Mutual Life
- Comrealty
- Concrete Constructions (NSW)
- CSR Gyprock
- Dino Burattini & Associates
- The Hammerson Group
- Lincole Scott Australia
- National Association of Forest Industries
- National Mutual Life Association of Australia
- Public Works Department of NSW
- The Regent, Sydney
- SGIO Western Australia
- Westfield Shopping Centre Management Co
- Westgarth Middletons, Solicitors
- Westpac Banking Corporation

FOR PROVISION OF PROJECT COORDINATOR

- Wormald International

FOR PROVISION OF TRAVEL ASSISTANCE

- Ansett Airlines of Australia
- Qantas Airways Ltd

FOR PRODUCTION OF PROJECT BROCHURES

- Civil and Civic

FOR DILIGENT TYPING OF PUBLICATIONS

- Lorda Alam
- Teresa Pizzinga
- Robin Macleod
APPENDIX 7

PUBLICATIONS STRUCTURE

This documentation on the project entitled "Fire Safety and Engineering", is structured into a Project Report and accompanying Technical Papers, consisting of nine parts. These parts are listed below, together with the task group having responsibility for the preparation of that particular part of the report. A third volume, Fire Safety and Engineering International Symposium Papers, completes the documentation.

<table>
<thead>
<tr>
<th>TITLE</th>
<th>PREPARED BY</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLUME 1  PROJECT REPORT</td>
<td>Task Group 1</td>
</tr>
<tr>
<td>VOLUME 2  TECHNICAL PAPERS</td>
<td></td>
</tr>
<tr>
<td>Part 1 Systematic Approach</td>
<td>Task Group 1</td>
</tr>
<tr>
<td>Part 2 Analysis of Fire Risk</td>
<td>Task Group 2</td>
</tr>
<tr>
<td>Part 3 Nature of Occupancy</td>
<td>Task Group 3</td>
</tr>
<tr>
<td>Part 4 Fire Inition and Development</td>
<td>Task Group 4</td>
</tr>
<tr>
<td>Part 5 Active Systems</td>
<td>Task Group 5</td>
</tr>
<tr>
<td>Part 6 Passive Systems</td>
<td>Task Group 6</td>
</tr>
<tr>
<td>Part 7 Avoidance Strategies</td>
<td>Task Group 7</td>
</tr>
<tr>
<td>Part 8 Fire Fighting</td>
<td>Task Group 8</td>
</tr>
<tr>
<td>Part 9 Case Studies</td>
<td>Task Group 1</td>
</tr>
<tr>
<td>VOLUME 3  FIRE SAFETY AND ENGINEERING INTERNATIONAL SYMPOSIUM PAPERS</td>
<td></td>
</tr>
</tbody>
</table>

FURTHER READING. References and related documents for further reading are available at the Warren Centre.